NUI MAYNOOTH

Ollscoil na hÉireann Má Nuad

Integrating Haptic Feedback into Mobile Location Based Services

A dissertation submitted for the degree of

Doctor of Philosophy

by

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Declaration

I hereby certify that this material which I now submit for assessment on the program of study leading to the award of Doctor of Philosophy in Computer Science is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed: - - - - - - - - - - - - - - -

Ricky Jacob

Dated: - - - - - - - - - - - - - - -

Abstract

Haptics is a feedback technology that takes advantage of the human sense of touch by applying forces, vibrations, and/or motions to a haptic-enabled device such as a mobile phone. Historically, human-computer interaction has been visual - text and images on the screen. Haptic feedback can be an important additional method especially in Mobile Location Based Services such as knowledge discovery, pedestrian navigation and notification systems. A knowledge discovery system called the *Haptic GeoWand* is a low interaction system that allows users to query geo-tagged data around them by using a point-and-scan technique with their mobile device. *Haptic Pedestrian* is a navigation system for walkers. Four prototypes have been developed classified according to the user's guidance requirements, the user type (based on spatial skills), and overall system complexity. *Haptic Transit* is a notification system that provides spatial information to the users of public transport. In all these systems, haptic feedback is used to convey information about location, orientation, density and distance by use of the vibration alarm with varying frequencies and patterns to help understand the physical environment. Trials elicited positive responses from the users who see benefit in being provided with a "heads up" approach to mobile navigation. Results from a memory recall test show that the users of haptic feedback for navigation had better memory recall of the region traversed than the users of landmark images. Haptics integrated into a multi-modal navigation system provides more usable, less distracting but more effective interaction than conventional systems. Enhancements to the current work could include integration of contextual information, detailed large-scale user trials and the exploration of using haptics within confined indoor spaces.

I dedicate this dissertation to my late grandmother, Accamma Abraham.

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Contributing Publications

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- **R. Jacob**, P. Mooney, P. Corcoran, A.C. Winstanley (2010) *Haptic-GIS: exploring the possibilities*, SIGSPATIAL Special, Volume 2, Issue 3, November 2010, ACM, New York. pp 13-19.

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- **R. Jacob**, A.C. Winstanley, N. Togher, R. Roche, and P. Mooney (2012), *Pedestrian navigation using haptic feedback: Results from a field study to test spatial abilities and memory recall*, In Proceedings of the GIS Research UK 20th Annual Conference, Volume 2, pp 195-201, Lancaster, England, 2012.

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1 Introduction

1.1 Mobile Location Based Services

A *Mobile location based service* (MLBS) can be defined as an information service that uses the current location as one of the contexts for providing useful information to the user. This information therefore will be more pertinent as it will be local to (within a short walking distance) the user's position. To provide a MLBS service, a device needs a method for obtaining an accurate location, a data connection to a service provider and a user-interface allowing the user to interact with the service.

From the late 1990s MLBS has found the interest of researchers and businesses throughout the world. In the early years localisation (finding the physical geographic location) was usually performed using proximity to cellphone towers and the services were not accurate and efficient. With the availability of newer technologies that integrated sensors like accelerometer and magnetometers along with a Global Positioning System (GPS) receiver into light-weight mobile devices, more accurate localisation of the user was possible. Mobile location based services provide services such as on-street pedestrian navigation in real-time, city tourist guides, public transport information about bus stop locations and real-time arrival data, and dynamic data like weather conditions and pollution levels at a particular place.

Research shows that there is a great increase in people searching for information via mobile devices and 1 billion people will use a mobile phone as their primary internet point. Google found that in the UK, 84% of smartphone owners seek local (offline) information via their devices (GoogleMobileResearch, 2012). 78% of those people took some form of action (calling or visiting the shop and/or purchase goods) after such a lookup. This shows a growing trend towards usage of mobile location based services. People use mobile location based services for assistance for searching points-of-interest (POI), and also for obtaining navigation assistance to find that place.

The various types of data that can be delivered by MLBS are:

- location (current place where the user is/inform the user when they reach a particular place),
- distance (how far it is to the nearest POI/how much more to walk),

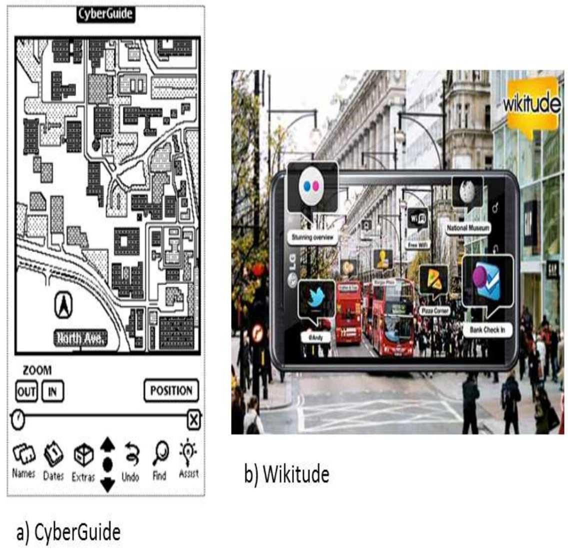


Figure 1: a) *CyberGuide*, one of the early (1996) prototypes of mobile navigation assistant systems and b) *Wikitude*, one of the latest (2012) augmented reality browsers.

- orientation (direction in which the POI/place is located) and
- density (number of features/POIs in their proximity).

There has been much research into mobile location based services. One of the earliest adaptations of such a mobile guide and navigation assistant tool was CyberGuide (Abowd et al., 1997). Figure 1a represents the visual interface of the outdoor navigation component of *CyberGuide* and Figure 1b represents one of the latest augmented reality browsers called *Wikitude* (Wikitude, 2012).

The most popular interaction methods used in MLBS is the use of overlays of information on maps for navigation assistance and spatial query responses (Reichenbacher, 2001b; Ernst and Ostrovskii, 2007; Nurminen and Oulasvirta, 2008; Wenig and Malaka, 2010). Some systems provided textual feedback with turn-by-turn directions and some integrated landmark information and photographs (Raubal and Winter, 2002; Caduff and Timpf, 2005; Dale and Geldof, 2005; Schöning et al., 2009). Researchers have also integrated panoramic images or other geo-tagged images of places along with information overlay to provide feedback to the user (Beeharee and Steed, 2006; Hile et al., 2008; Walther-Franks et al., 2009; Wenig and Malaka, 2010). We also see a shift from pure location-based to orientation-aware systems with the availability of low cost on-board digital compasses. Thus bearing based mobile spatial interaction has gained popularity (Simon et al., 2007, 2008; Robinson et al., 2008; Strachan and Murray-Smith, 2009; Jacob et al., 2012a). Most recent works show that there is great interest in the use of augmented reality in mobile spatial interaction systems (King et al., 2005; Wither et al., 2006; Kim and Dey, 2010; Rahajaniaina and Jessel, 2010; Wu and Ren, 2010; Gee et al., 2011; Wikitude, 2012). In augmented reality based systems, the location and orientation of the mobile device is used along with the camera of the device to provide spatial information to the user overlaid on real-time images.

We can classify mobile location based services into the following broad application types:

- knowledge discovery,
- pedestrian navigation and wayfinding, and
- notification/alert systems.

1.2 Issues with mobile location based services

According to Carroll, *Human Computer Interaction* (HCI) is "concerned with understanding how people make use of systems that embed computation, and how such systems can be more useful and usable" (Carroll, 2003). Chittaro believes that in order to have users (especially novice ones) enthusiastically adopt mobile computing devices, we will need to prevent the pains and complexities of interacting through very limited input and output facilities (Chittaro, 2004). He also adds that mobile services will not be successful if we do not understand mobile users and design for their contexts, which are very different from the ones traditionally studied in HCI. Thus emphasis on the need to keep the end user in the centre of design/development stage for services involving mobile interaction is important.

Most applications providing mobile location based services are designed with the belief that the user will devote their full attention to the interaction. However, in many situations in the real world, the use of mobile spatial interaction is more often than not the secondary task. The primary task, like driving a car or avoiding other pedestrians and obstacles, should not be directly affected while using assistive technologies. Mobile Spatial Interaction techniques and presentation of such information on mobile terminals with small screen size has always been a big challenge. While the benefits of visual interfaces and maps in general can be seen, the need for modelling various other user-related contexts is also important. The need to ensure that the user can also attend to other tasks while on the move and using such location based services is also important. All these factors need to be considered at the system design phase to ensure the optimal usability of such interfaces.

Further research is needed to evaluate which type of information presentation is appropriate for which tasks and in what contexts. Despite the ubiquitousness of visual interfaces, they can be highly distractive. Some of the key issues of MLBS can be summarised as follows:

- the visual cues as feedback requires the user's complete attention to the mobile device at all times
- the MLBS assumes that using the service and other assistive technologies are the primary tasks of the user
- the MLBS assumes that the physical conditions/social contexts of the user is always ideal to obtain visual feedback from the system

There is thus a need for low interaction, and that easy-to-use techniques for mobile spatial interaction are important. The potential non-visual, eye-free interaction techniques use audio (speech and non-speech) and haptic feedback (using the sense of touch).

1.3 Non-visual feedback for MLBS

While there has been research into many techniques (Loomis et al., 1998; Nemirovsky and Davenport, 1999; Holland et al., 2002b; Strachan et al., 2005; Bartie and Mackaness, 2006; Mcgookin et al., 2009; Tsuruoka and Arikawa, 2008; Baldauf et al., 2010; Mackaness et al., 2011) using hearing to deliver information, they often require complete attention by the user and so would not be always be suitable for users with visual impairment or people moving around in a busy/noisy street.

Effective communication of spatial information to the user in an easy to understand manner is one of the fundamental requirements for any mobile location based service. One of the goals listed by Reichenbacher is taking into account the user's cognition of space; delivering and presenting spatial information in a mode easily perceivable for the user (Reichenbacher, 2001a).

Any mobile location-based service ideally needs to provide the following:

- the fast, complete, clear delivery of information
- easy to use while mobile or performing other tasks (multitasking)
- non-obtrusive
- have simple interfaces and interaction techniques suitable for all physical conditions

A purely visual interface for interaction with the device would mean a lack of balance in attention distribution between the primary task (walking) and the secondary task (using the device for assistance). On a bright sunny day or during rain/snow, it will not be possible to use the visual interface effectively and thus there is a need to provide low-interaction/low-attention non-visual modes of feedback to the user.

Therefore we propose *haptics* or using the sense of touch may be an effective way to communicate with the user. The word *haptics* is derived from the Greek word *haptesthai*, which means 'of or related to the sense of touch'. In the psychology and neuroscience literature, haptics is the study of human touch sensing, specifically via kinesthetic (force/position) and cutaneous (tactile) receptors, associated with perception and manipulation. Haptics should be able to provide subtle feedback about information such as distance to a particular Point of Interest (POI) or the direction in which the user needs to walk.

The benefit of using the human sense of touch is that it is faster (reaction time) than vision (Welford, 1980; Robinson, 1934), it is the first sense one develops when born and the last sense to fade at death (Gottlieb, 1971; Barnett, 1972). Another important feature of this kind of communication is that unlike visual or audio based interaction, it overcomes the language barrier and can thus be extended to other countries with different languages/cultures with ease. Human hand gestures have been used for non-verbal communication. When someone within a group of people point the hand in a direction, others tend to look in that direction. When someone asks another person for directions to a place, a hand pointing gesture would mean the direction in which they

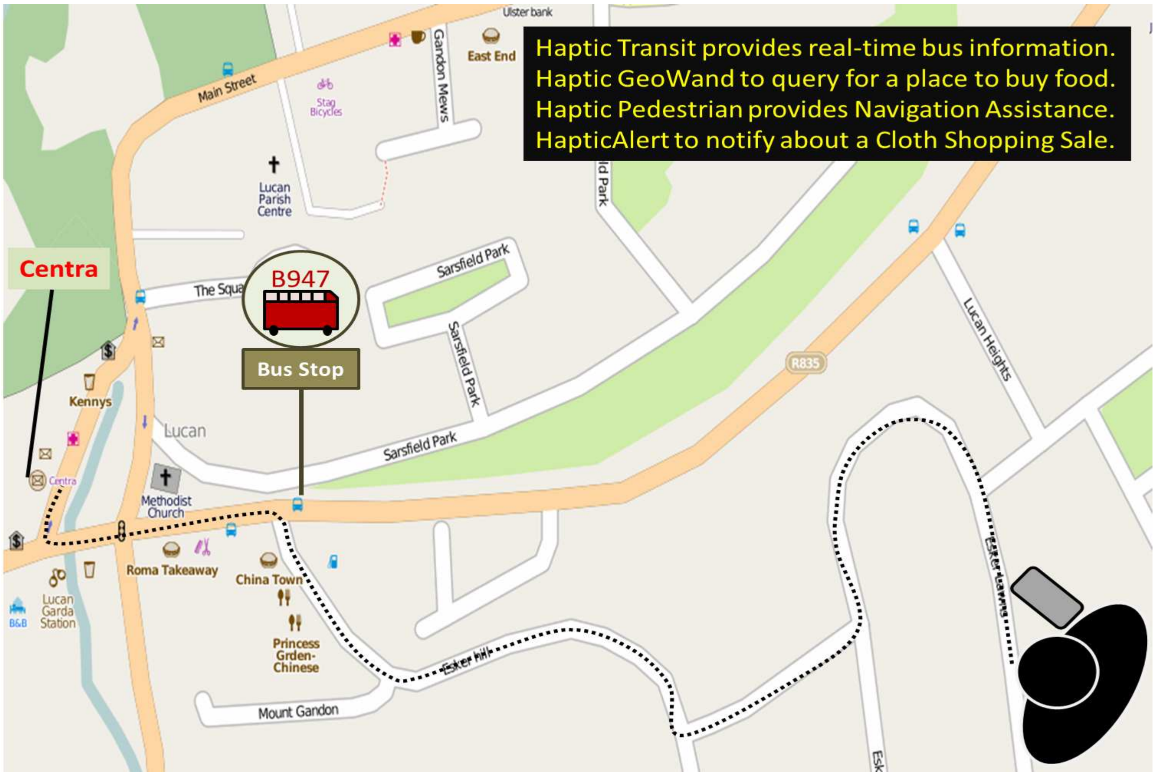


Figure 2: Haptic feedback for mobile location based services.

need to head to get to that destination. The use of a non-visual system that integrates haptics means that the user can query features by performing such pointing and/or scanning gestures without having to look into the mobile device. Thus such operations can be performed privately by having the phone in the jacket/loose pant pocket and by pointing and waiting for feedback.

Integration of haptic feedback is possible in pedestrian navigation and way finding tasks, notification systems alerting about a location specific information and querying and discovering knowledge about places or spatial objects around the user (Figure 2). In the example shown in Figure 2, the user plans to take a bus to get to the city centre. From the current location, the user first queries for bus arrival time information and the Haptic Transit system provides real-time data. The information about the location of the bus stop and the walking time to get to the bus stop is calculated. Walking directions to the bus stop is provided by Haptic Pedestrian using the pointing gesture based scanning functionality. Since the next bus arrives only after 20 minutes, the user looks for a place to get a sandwich using the Haptic GeoWand. The user gets the food and then catches the bus a few minutes later. The HapticAlert system notifies the user via vibration feedback about the bus stop where he ought to get off in order to get to the cloth sale.

1.4 Objectives of this thesis

This thesis investigates how haptic feedback can be integrated into mobile location based services based on the ideas outlined above. In doing so we try to address the following questions:

- **Question 1: Can haptic feedback be used to deliver spatial information like location, direction, distance, density of features?** The aim here is to understand if spatial information can be delivered using haptic feedback using simple interfaces and user interaction.
- **Question 2: Can haptic feedback help the user understand information about their physical environment?** Here we try to exploit the use of haptic feedback as a way for delivery of knowledge discovery about surrounding POIs.
- **Question 3: Can haptic feedback be effectively used to direct the user towards their destination with low/no visual feedback and with minimal mobile interaction?** Here we explore various ways in which haptic feedback can be used to help provide low interaction pedestrian navigation cues to the user.
- **Question 4: Can haptic feedback be used to assist public transit users to get information about location and navigation to a stop and be notified when they reach a destination stop?** The aim here is to understand how haptic feedback can be used by public transport users as a location-based notification system.
- **Question 5: Can haptic feedback ensure better division of cognitive workload while multi-tasking (walking and using such systems simultaneously) as compared to visual interaction?** Evaluation by tests and experiments carried out by user trials helps us draw remarks about the usefulness of such haptic feedback based systems. The objective here is to carry out tests to evaluate and understand the performance of haptic feedback based system while

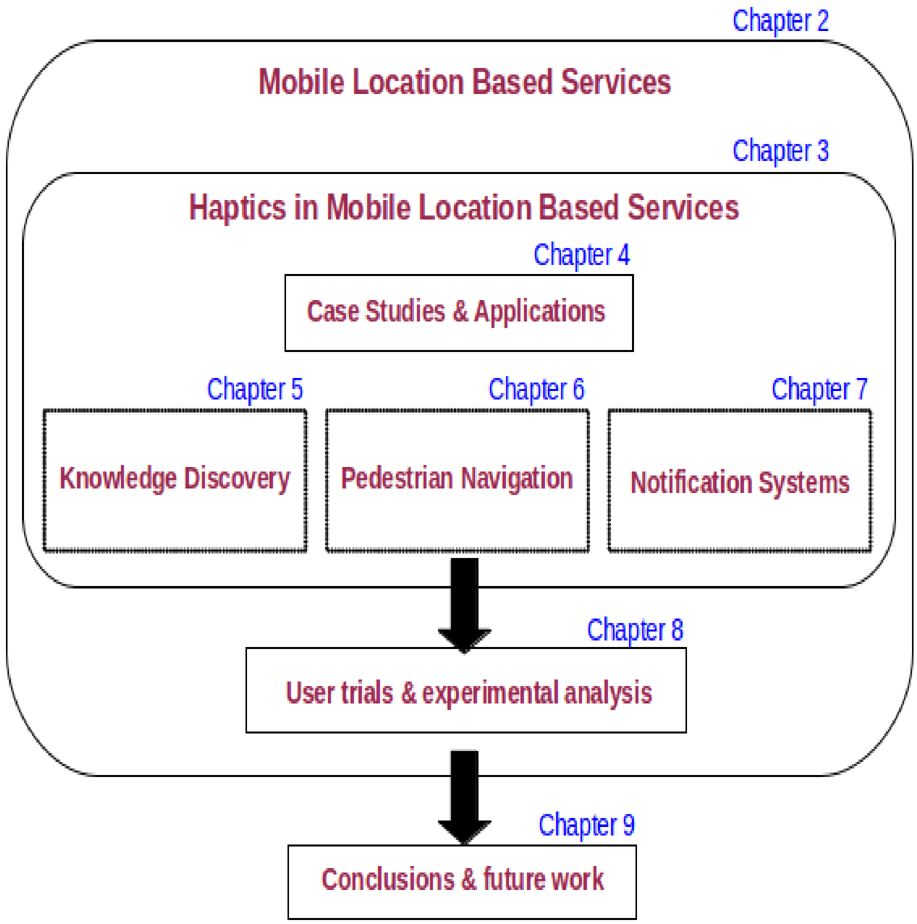


Figure 3: Structure of the thesis.

the user navigates while performing other primary tasks (For example, talking to a friend, avoiding obstacles) on the move.

1.5 Thesis outline

In this thesis we describe the integration of haptics into mobile location based services to ensure easy mobile spatial interaction. The main components of the thesis are shown in Figure 3 which indicates the chapters in which various components of the work are described.

Chapter 2 reviews literature about the various visualisation techniques in mobile location based services. It highlights the need for a non-visual modality like audio and haptic feedback. The importance of considering spatial cognition and reducing information overload to allow mobile spatial interaction as the secondary task is also discussed. Then in **Chapter 3**, we define haptics and its current applications and use. Review of literature and previous work integrating haptics into location based services is discussed in detail. A few case-studies where the use of haptics as a modality for mobile spatial interaction can be integrated are highlighted in **Chapter 4**. The easy, low interaction use of the system is highlighted here. Haptics can be integrated to knowledge discovery using a mobile device and is outlined in **Chapter 5** with the use of mobile as a GeoWand. The spatial interaction involves pointing and scanning of the area using a mobile device to gather information from the surroundings. Haptic feedback is used to provide spatial information like 'distance to' and the 'density of' available features that are selected by the user. The integration of haptic feedback into wayfinding tasks and pedestrian navigation applications is described in **Chapter 6**. 4 prototypes were developed to integrate four different ways in which a user would like to interact with the device for feedback while on the move in the real-world. **Chapter 7** provides an overview about the integration of haptics into mobile based public transport systems to notify passengers about their destination stops and/or alert them about other features of interest as an in-bus service for public transport users especially tourists. The integration of haptics into a Location Based Notification System is discussed in detail here with the description of a system for public transport users. **Chapter 8** describes the user trials and experimental analysis carried out to validate the use of a haptics-based system in a physical environment and points out the key features and benefits of such an approach for information delivery through mobile devices with small screens. The thesis finally closes with **Chapter 9** where we revisit the research questions addressed in the thesis, outline some of the possible directions for further research and concludes with a summary of the main contribution of this thesis.

In chapter 2, we discuss the various visual interfaces available and those that are in use currently in mobile location based services. The benefits and shortfalls of such visual interfaces are described by highlighting the key requirements of such mobile location based services for use by a user. The need for non-visual feedback which compliments the visual interfaces to help users navigate in the physical world is also addressed.

2 Mobile Location Based Services

2.1 Introduction

Mobile location based services (MLBS) are used by people on the move to get information about the physical space around them. A map based representation is the most popular form of delivering spatial information such as location, distance to features, direction to a destination and density of features in mobile location based services. While in an indoor computer desktop environment one can easily focus on the main task of interacting with a visual interface on the screen, the interaction with mobile devices on the move comes with various challenges. The various contexts of use of mobile devices vary a lot and could even change while in use. Raubal and Panov felt that by automatic map simplification and generalisation for visualisation of geographic information on mobile devices where only essential aspects of the map that is important for the user can be displayed (Raubal and Panov, 2009). This can ensure that only the relevant data that is required by the user on the move is displayed. Research by various authors in the field of Human-Computer Interaction (HCI) on small mobile devices highlight the fact that simplicity in design of the user interface and presentation of data in an easy to use manner is most important (Holland et al., 2002a; Pospischil et al., 2002; Reichenbacher, 2001b).

Mobile location based services can be classified into the following, based on the kinds of spatial interaction features. They can

- facilitate navigation and wayfinding,
- create (contribute to information about that location) information about physical places or objects, and
- access information and services about physical places or objects.

Based on the application type of such services, we broadly classify mobile location based services into the following:

- knowledge discovery,
- pedestrian navigation and wayfinding, and

- notification/alert systems.

We discuss these three categories of MLBS in detail in Chapters 5, 6, and 7. In this chapter we look at the various visual and non-visual techniques to represent spatial information in mobile location based services. We then describe the key requirements and challenges in the use of MLBS. We also discuss the various shortfalls of such visual interfaces based on the challenges of using them in the real-world. We then conclude the chapter by highlighting the need of non-visual techniques for representing spatial data to users of mobile location based services.

2.2 Delivery of spatial information in MLBS

Delivery of spatial information in mobile location based services are through visual and non-visual techniques. Based on the kinds of spatial interaction techniques and information representations, they can be classified into visual or non-visual MLBS. They are:

1. Mobile Cartography - Maps,
2. Landmark information using geo-tagged photos,
3. Textual description,
4. Mobile augmented reality applications,
5. Audio feedback by speech and non-speech, and
6. Haptic feedback

Some of the visual techniques to represent information in a visual mobile interfaces are - maps, landmark images, augmented reality and textual description. The most popular interaction methods used in MLBS is the use of overlays on maps for navigation assistance and spatial query responses (Reichenbacher, 2001b; Ernst and Ostrovskii, 2007; Nurminen and Oulasvirta, 2008; Wenig and Malaka, 2010; GoogleMaps, 2012). Some systems provided textual feedback with turn-by-turn directions and some integrated landmark information and photographs (Raubal and Winter, 2002; Caduff and Timpf, 2005; Dale and Geldof, 2005; Schöning et al., 2009). Researchers have also integrated panoramic images or other geo-tagged images of places along with information overlay to provide feedback to the user (Beeharee and Steed, 2006; Hile et al., 2008; Walther-Franks et al., 2009; Wenig and Malaka, 2010). We also see a shift from pure location-based to orientation-aware systems with the availability of low cost on-board digital compasses on mobile devices. Thus bearing based mobile spatial interaction gained popularity (Simon et al., 2007, 2008; Robinson et al., 2008; Strachan and Murray-Smith, 2009; Jacob et al., 2012a). Most recent works show that there is great interest in the use of augmented reality in mobile spatial interaction systems (King et al., 2005; Wither et al., 2006; Kim and Dey, 2010; Rahajaniaina and Jessel, 2010; Wu and Ren, 2010; Gee et al., 2011; Wikitude, 2012). In augmented reality based systems, the location and orientation of the mobile device is used along with the camera of the device to provide spatial information to the user.

The non-visual techniques involve audio feedback which includes both speech and non-speech technique and also by using haptic feedback by the sense of touch. Before understanding the non-visual techniques in detail, we first discuss the most common ways of visual representation of spatial information in mobile location based services.

2.2.1 Mobile Cartography - Maps

Maps are the most conventional way of representing spatial information visually to the user in mobile location based services. Maps add great value when it comes to representing location information about points of interests in a new area or navigation cues for getting to a particular destination in an unfamiliar environment. These mobile maps need to support real-time interaction that is intuitive and responsive.

LOL@ (Pospischil et al., 2002) was one of the earlier developments with respect to mobile tourist guides with icons representing landmarks (Figure 4). The system dynamically generates maps and annotates them with labels and icons. The common techniques for map interaction on mobile devices like zooming and panning are also possible.

TellMaris (Laakso and Kray, 2003) was one of the first mobile systems that combine three-dimensional graphics with two-dimensional maps and that runs on a mobile device (Figure 5). Taher and Cheverst use a combination of mobile and fixed displays along with a range of navigation content such as digital 2D maps, 3D route and graphical directional arrows for indoor navigation assistance for users (Taher and Cheverst, 2011).

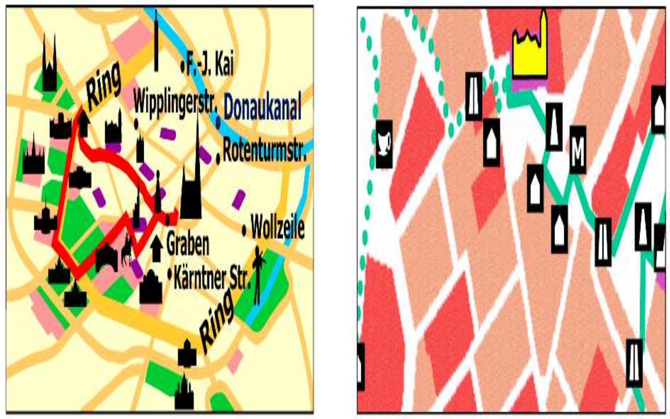


Figure 4: Mobile map interface of LOL@ (Pospischil et al., 2002)

Figure 5: *TellMaris* Guide by Nokia (Laakso and Kray, 2003)

Figure 6: Google Maps for mobile (GoogleMaps, 2012)

Map based interfaces like GoogleMaps for Mobile (GoogleMaps, 2012) still remain the popular mode for geographic information representation on mobile devices (Figure 6).

When visual map interfaces are used, spatial information to the user must be represented is a simple and easy to understand way without burdening the user with a lot of data. This is done via generalisation and simplification. Setlur et al. highlights the need for system optimizations to help user interact efficiently with the mobile map interfaces by various cartographic techniques (Setlur et al., 2010). They are:

- exaggeration (increase spatial detail and visibility of map object for important information like routes),
- elimination (selectively removes regions that are too small to be represented),
- typication (reduction of feature density and level of detail) and
- outline simplication (reduces vertices of boundary lines).

The designer of mobile maps on small display devices has to find trade-offs between the maximally allowed visual load on a mobile display device and the minimum amount of information required by the user for a certain moment (Meng, 2005). Tiina Sarjakoski et al. on evaluating map interfaces find the importance of having user-centric topographic maps on mobile devices (Tiina Sarjakoski et al., 2007). Zhang and Adipat notes that although usability engineering is a good design approach for checking the use of a mobile map, a user-centric design which considers all possible dynamic use contexts need to be considered during design (Zhang and Adipat, 2005).

2.2.2 Landmark information using geo-tagged photos and/or textual description

Landmarks are seen as important element for describing a route. They have been incorporated into route descriptions in order to make representations more user-friendly (Raubal and Winter, 2002; Elias, 2003; Hile et al., 2008). Caduff and Timpf propose the landmark spider model where a subset of prominent or important landmarks along the way is used to provide the user with navigation assistance (Caduff and Timpf, 2005). Snowdon and Kray study how landmark based information can be used to help users in natural environments (Snowdon and Kray, 2009). Goodman et al. finds that landmarks based cues help older people derive substantially more benefits from navigation aids than younger people (Goodman et al., 2005).

Beeharee and Steed integrated geo-tagged photographs to assist in giving routing directions (Beeharee and Steed, 2006). Here the user is provided with a route in the form of text and a map that refers to a series of photographs. The reassurance about the navigation decision provided by such a system to the user increases the confidence of the user to use such systems. Walther-Franks et al. uses photographs alongside text and iconic direction instructions (Walther-Franks et al., 2009) (Figure 7).

Schöning et al. discusses PhotoMap that uses images of 'You are here' maps taken with a GPS-enhanced mobile camera phone as background maps for on-the-fly navigation tasks (Schöning et al., 2009). The *pitchMap* prototype by (Wenig and Malaka, 2011) which shows photographs on top of a map of the University of Bremen (Figure 8).

Ishikawa and Yamazaki study the effectiveness of different methods of presenting route information on a mobile navigation system, for accurate and effortless orientation at subway exits (Ishikawa and Yamazaki, 2009). Here they test and compare spatial orientation performance with pictures and maps, in relation to the levels of their spatial

Figure 7: Photographs along with text and iconic direction instruction (Walther-Franks et al., 2009)

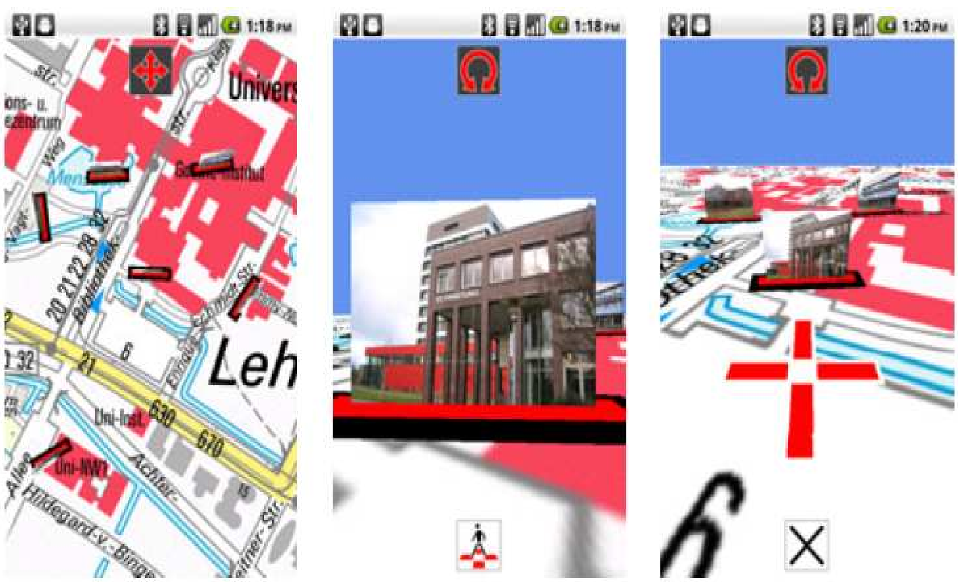


Figure 8: pitchMap: map plus image overlay (Wenig and Malaka, 2011)

Figure 9: One of the early Augmented Reality based Campus Information System Prototype (Feiner et al., 1997)

ability. The authors find that for those with poor spatial orientation ability, a pictorial representation was more effective than maps when exiting subways.

2.2.3 Augmented reality

Augmented reality (AR) is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data. One of the earliest (year 1997) implementations of augmented reality for a mobile user was the campus information system prototype (Feiner et al., 1997). Here the user wears a backpack and headworn display, and holds a handheld display and its stylus (Figure 9). Kim et al. developed a bird's-eye view system look at virtual buildings within real environments and navigate in this environment with the system (Kim et al., 1999).

Gee et al. developed a 'Topometric System' where they integrated localised mapping and tracking based on real-time visual Simultaneous Localization And Mapping (SLAM) with global positioning from both GPS and indoor ultra-wide band (UWB) technology (Gee et al., 2011). The former allows accurate and repeatable creation and visualisation of AR annotations within local metric maps, whilst the latter provides a coarse global

Figure 10: Augmented Reality browser - Layar (Layar, 2012)

representation of the topology of the maps. Mulloni et al. developed an augmented reality interface to support indoor navigation where they combine activity-based instructions with sparse 3D localisation at selected info points (important nodes within the building) in the building (Mulloni et al., 2011).

Figure 10 shows *Layar*, one of the most popular augmented reality browsers with over 10 million installs (Layar, 2012). One of the latest developments in augmented reality is the work by Luley et al. on a *Mobile Augmented Reality for Tourists* (MARFT) (Luley et al., 2012). This system is targeted at people visiting mountainous rural regions. The user can choose between the two features/functionalities: (i) an augmented photo superimposed with tourist information like hiking tours or lookout points or (ii) a rendered 3D virtual reality view showing the same view as the real photo also augmented with tourist objects.

We have looked at the various visual interfaces providing different kinds of feedback to the user using different techniques. We now look at the non-visual modes of feedback which can ensure low attention and interaction with the device and more real-world interactions.

Figure 11: *gpsTunes* Non-speech audio feedback (Strachan et al., 2005)

2.3 Non-visual feedback using Audio

Researchers have looked at the use of audio to provide users with feedback about spatial information. For audio based systems, researchers have looked at both speech based feedback (similar to the GPS devices in car navigation systems) and also non-speech based techniques (using sounds/music by varying frequency and amplitude). One of the early adaptation of using audio feedback was *GuideShoes* (Nemirovsky and Davenport, 1999). Here background awareness principles are incorporated into a wearable tangible interface, providing users with information regarding their travel. They have defined a term *emons* which is the process of incorporating emotional cues by a refined system of aesthetic information fragments. This is the first tool to utilize music as an information medium and musical patterns as a means for navigation in an open space, such as a street. Loomis et al. developed audio based navigation assistance for visually impaired users (Loomis et al., 1998). The users were able to navigate using the system along a predefined route. Virtual acoustic display, and verbal commands issued by a synthetic speech display were tested and the virtual acoustic display fared best in terms of both guidance performance and user preferences.

Holland et al. used a simple form of non-speech audio and built the *AudioGPS* prototype (Holland et al., 2002b). It is an audio user interface for a Global Positioning System

Figure 12: *maPodWalks* synchronises map with audio feedback (Tsuruoka and Arikawa, 2008)

(GPS) that is designed to allow mobile computer users to carry out a location task while their eyes, hands or attention are otherwise engaged. On the other hand, Strachan et al. describe the rst prototypical implementation of a system, *gpsTunes* which adapts the music currently playing, in order to guide a user to a desired physical location (Strachan et al., 2005). Here volume adaptation and panning is used to provide navigation and direction cues to help the user reach the destination (Figure 11). Warren et al. developed a similar prototype, *Ontrack*, continuously adapts audio, modifying the spatial balance and volume to lead listeners to their target destination (Warren et al., 2005; Jones et al., 2008). The notifications to guide users to a destination here are continuous and are embedded within the audio stream. *Audio Bubbles* is an audio based feedback system to inform the user of a nearby, non-obvious point of interest, that he or she might be interested in (Mcgookin et al., 2009). The audio pulses repeat at a faster rate the closer the user is to the point of interest. Tsuruoka and Arikawa describe a prototype called *maPodWalks* which provides egocentric mappings synchronized with narrations on mobile media player Tsuruoka and Arikawa (2008) (Figure 12).

Stahl introduces *The roaring navigator*, which is a group guide for the zoo with shared auditory landmark display (Stahl, 2007). Spatial audio manipulates the volume and stereo balance of the sound clips, so that the listener can identify their distance and direction to the animal enclosures. The system also proactively presents audio clips with detailed information about each animal. Vazquez-alvarez et al. proposes an *urban sound garden* design featuring both overlapping proximity zones and 'spatialised' animal sounds to attract the user's attention to particular landmarks in a non-guided exploratory environment (Vazquez-alvarez et al., 2010).

KIBITZER, a lightweight wearable system that enables the browsing of urban surroundings for annotated digital information. KIBITZER exploits its user's eye-gaze as natural indicator of attention to identify objects-of-interest and offers speech- and non-speech auditory feedback (Baldauf et al., 2010). The *SpaceBook* project by (Mackaness et al., 2011) is a mobile, hands-free and eyes-free guide device that facilitates pedestrian exploration of the city (Mackaness et al., 2011). It provides a voice only presentation and a voice only interaction via a Bluetooth headset. Here speech based feedback like 'look right', 'slightly to the left' are used to convey information to the user. Bartie and Mackaness highlights some of the key advantages and disadvantages of using a non-visual feedback system like speech-based audio as listed in Table 1 (Bartie and Mackaness, 2006).

Rehrl et al. compares two different kinds of verbal turn instructions in the context of GPS-based pedestrian navigation (Rehrl et al., 2010). The first one was enhanced with metric distance information and the second one was enhanced with landmark-anchored directions. Although the users performance was similar in both tasks, results showed that users are able to walk in unfamiliar environments without stopping the walk and with lower error rate.

In section 2.2 we discussed the various visual feedback techniques and in section 2.3 we discussed the audio based feedback techniques for delivery of spatial information in MLBS. We now describe the key requirements in MLBS and discuss the shortfalls in existing systems.

2.4 Key requirements in MLBS

One of the goals listed by Reichenbacher is taking into account the user's cognition of space; delivering and presenting spatial information in a mode easily perceivable for the user (Reichenbacher, 2001a). The mobile location-based service needs to provide the following:

- the fast, complete, clear delivery of information
- easy to use while mobile or performing other tasks (multitasking)
- non-obtrusive
- have simple interfaces and interaction techniques suitable for all physical conditions

The main purpose of a mobile device is to be able use the device while doing other things on the move. Pascoe et al. uses the term "*Using while moving*" to describe this activity (Pascoe et al., 2000). On mobile devices, factors like limited attention capacity and high speed interaction are important and needs to be considered for user interface and data delivery design. Minimal Attention User Interfaces (MAUIs) and context awareness needs to be integrated into mobile interface design to ensure effective use of such services. The goal of such systems should be to take up as little a portion of the user's attention as possible.

Further research has to be done to evaluate which type of information presentation is appropriate for which tasks and in what contexts. We now look at the shortfalls of most mobile location based services.

2.5 Shortfalls in MLBS

During the initial stages of integration of map applications on mobile devices, the use of map visualisation for the desktop applications was put into mobile devices. For many centuries, maps have been used as representational media representing knowledge regarding geographic information (Bagrow, 1985). The fundamental processes involved in map use had been discussed by Keates (1996) are - detection, discrimination, identification, recognition and interpretation. The meta-knowledge itself can be grasped as the complete body of knowledge that comprises every possible reference between depicted relations of cartographic entities and geographic relations between the objects represented by them (Barkowsky and Freksa, 1997). Barkowsky and Freksa however outline that in everyday use, maps often are misinterpreted; i.e. cartographic entities and the relations between them are incorrectly related to the geographic objects in the world. Thus the effective use of map based displays needs to be understood.

2.5.1 Ability to perform multiple tasks

Human multitasking is defined as the best performance of the user to be able to handle more than one task at a time. And the ability to multitask varies from one user to the other. It is thus important to consider this during the instructional design of the mobile interaction for efficient use of such systems by users while on the move. Perception and control are the key focus points for human communication and thus modality refers to the various sensory systems which transform the incoming feedback from the mobile systems into high level user understandable information. A purely visual interface for interaction with the device would mean a lack of balance in attention between the primary task (walking) and the secondary task (using the device for assistance). On a bright sunny day or during rains and snow, it will not be possible to use the visual interface effectively and thus the user can switch to non-visual modes of feedback.

In a car, route directions in speech form might be more appropriate than graphical presentation. On foot, where stops are easier, directions drawn on a map make more sense. Looije et al. highlights some of the major challenges in the usability of maps based mobile interaction as it involves interactions like zoom, pan, and most importantly visualisation (Looije et al., 2007). Due to the relatively small size of mobile screens, within visualisation there are various aspects like level of detail, enhancement of data representation and displaying off-screen information that needs to be addressed. Since such map based visual feedback systems on mobile are used in an outdoor environment with other real-world distractions like vehicles, other pedestrians, it is not always ideal to use such a map based interface on the move.

2.5.2 Mobile interaction based on physical/contextual information

According to Reichenbacher incorporating adaptation within the geovisualisation process seems to solve some usability problems encountered in the mobile environment (Reichenbacher, 2001a). Here the author's main objective is to shift the focus from LBS to Context Based Services where the service is tailored to the current usage situation. Reichenbacher proposes a general approach for including the various parameters within a model of map-based LBS, the concept of 'adaptation' (in the sense of user-dependent adaptation of a cartographic communication process). This concept involves describing the links or mutual dependencies between various parameters involved and the results are connected to impacts on data modelling and cartographic visualisation.

Most applications providing mobile location based services are designed with the belief that the user will devote their full attention to the interaction. However, in the many situations that people deal with in the real world, the use of mobile spatial interaction is most often than not the secondary task. The primary task like driving a car or walking along busy streets avoiding other pedestrians and obstacles along the way as the user moves should not be directly affected while using assistive technologies. Mobile Spatial Interaction techniques and presentation of such information on mobile terminals with fairly small screen size was/is always a big challenge. The need to ensure that the user can also attend to other tasks while on the move and using such location based services is also important. A major goal is to minimize user interaction through service adaptation, and to provide context-sensitive and personalized information to the user (Raubal and Winter, 2002).

The range of applications involving mobile location based services includes pedestrian navigation, shopping, searching for cafes, bars, tourism information, public transport information and safety. Thus the need for providing interaction techniques that caters to scenarios where such services can be used without much distraction for the user performing another primary task is of great importance. Most of the applications catering to the mobile location based services market are ideally suited for desktop based interactions. The mobile users will need to divide their attention between the primary task they are performing and the use of such mobile services on the move.

2.5.3 Providing relevant information on the move

The small screen of a mobile phone would not always display the contents of points of interest (POI) search as legible as one would like to view. The search result is usually provided as a map interface with an overlay of icons to represent the locations of various features around them. This overload of information in a small screen will be difficult for the user on the move to decipher while he is avoiding obstacles and navigating his way around other people.

Due to the continuous shift of attention between the real physical world and the mobile device while using such services, the understanding of how much information should be provided through the interface and what are the best ways to represent such information is an area that requires more research. While there is no one single application that caters to the needs of all mobile location based services, the integration of multi-modal interaction techniques for mobile users will give the user the flexibility of choosing one modality over the other based on how it suits the user at that given point in time.

2.6 Key challenges in visual MLBS

We have seen the various visual interaction techniques available for mobile location based services and also seen the need for non-visual feedback when it is inappropriate to use visual interfaces. On summarising the key features of the mobile location based services, we can highlight how at certain times or contexts, the visual interfaces are not the effective medium of communication with the user on the move. We now look at some of the key challenges of visual MLBS. According to Pascoe et al., the major challenges of using computer applications in a small screened, mobile environment are (Pascoe et al., 2000):

1. Mobile devices are used in a minimal attention environment; users have neither the time nor attention to navigate through complicated menus or to interpret confusing results.
2. The screens of mobile devices are small and do not provide the kind of resolution of a desktop monitor.

(Rinner et al., 2005) describes that 'simplicity in design' is needed to overcome some of the above listed challenges. We will now discuss the key challenges while developing and using visual mobile location based services.

2.6.1 Integration of user context

Reichenbacher notes that the usage of visual information display is mainly controlled by the context and not all of these user tasks necessarily afford a visual information representation (Reichenbacher, 2001a). The visual interfaces have high distraction potential. While the benefits of visual interfaces and maps in general can be seen, the need for modelling various other user related contexts is also important which addresses the usability issues of such interfaces. These contexts are:

- the users are highly mobile: unlike the environment of an office with a computer, the user is on the move while performing the tasks.
- the outdoor environment being inappropriate to use a visual interface at all times: rainy day, too sunny, outdoor trek, very busy streets, dark alleys, etc.
- the spatial abilities of the user: those who are not good with directions, inability to use maps on mobile.
- primary task versus secondary task: to understand that using these assistive technologies through mobile devices is most often the secondary task and the actual primary task being the user having to walk, avoid obstacles and oncoming pedestrians on busy streets.
- obtaining spatial knowledge: can the service ensure that the user is gaining some spatial knowledge about the environment? Thus this enables the user to navigate without assistance the next time.
- user maintaining anonymity: User not wanting to display a map or use a visual mobile interfaces requiring the user to hold it out and drawing the attention of others on the streets.

There are a few challenges and issues with visual interfaces given all environmental (physical or cultural) conditions. We look at the issues with regard to use of mobile devices and also some of the important challenges like language barrier, pedestrian walking behaviour, spatial memory or cognition and priority of tasks and need for attention division.

2.6.2 Mobile device hardware

The smart mobile devices (or smart phones) have complex functionalities with the integration of various sensors (proximity, light, GPS, gyroscope, accelerometer, magnetometer) in small hand held units. Better processors and sensors are integrated to perform and process complex information. The ISO 9241 standard defines usability as "*the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments*" (Standard, 1997). In 2000, Bjork et al. highlighted some of the restrictions in visualisation when we move from desktop and adapt it on mobile (Bjork et al., 2000). They are:

Figure 13: Visual interfaces are ineffective at certain times

- Less calculation ability,
- Small screen size,
- Low memory on mobile devices
- Poor network bandwidth

Zooming, panning, and visualisation are the main interactions with a map based mobile system. Looije et al. described the inability to provide detailed information efficiently in such small mobile display screens (Looije et al., 2007). With the coming of smartphones like iPhone and Android devices into the market, the quality of displays (including size) and processing power of these phones increased many folds. Network bandwidth has increased over the years which ensure high data transfer capabilities. The memory on mobile phones has also increased thus enabling more data storage and fast processing.

However, regardless of the major strides made in the development of capable hardware coupled with sophisticated software, their small display size limits their ability to convey information as effectively as desktop computers. When a user is using a mobile device in an outdoor environment while walking, the screen readability issues are caused due to bright sunlight or other conditions like rain or snow (Figure 13).

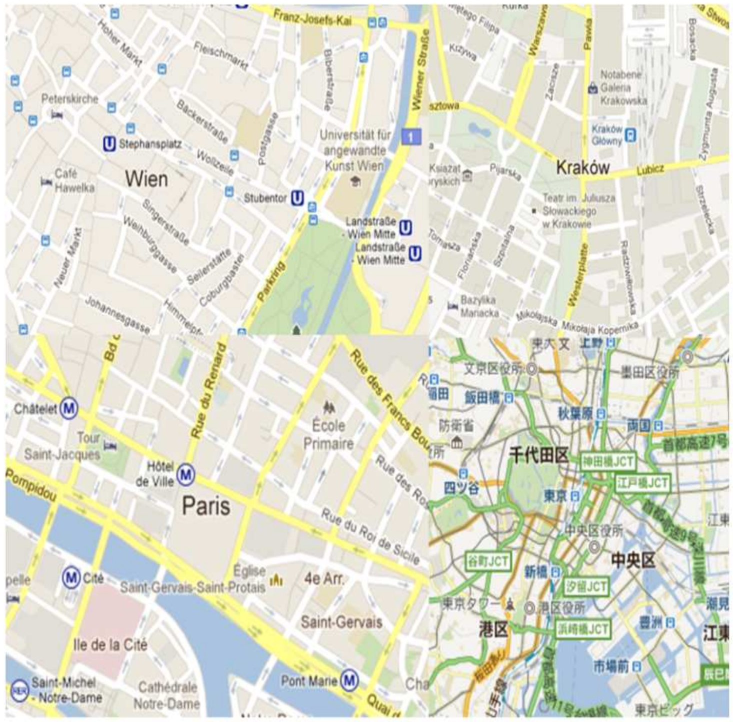


Figure 14: Map interfaces will need different map-tiles (made up of pictures) for different languages/cultures

2.6.3 Language barriers

Google Maps (GoogleMaps, 2012) provide web and mobile map interfaces with map-tiles (made up of image files) for 12 different languages (Figure 14). Thus customising the map for various languages is important for use. Jacob et al. finds that the description of a route in English and Chinese follow quite different language styles (Jacob et al., 2009). This makes it difficult to build a standard route description for navigation assistance which works across all languages. *Natural Semantic Metalanguage* (NSM) is a body of linguistic research that has identified the few specific spatial relations that are universal across languages. Stock and Cialone show how these spatial relations can be used to describe a range of more complex spatial relations, including some from non-Indo-European languages that cannot readily be described with the usual spatial operators (Stock and Cialone, 2011).

Bartie and Mackaness find for a speech based navigation system, the user must have a good understanding of the language, the speed and accent and it is thus difficult to scale across all geographies (Bartie and Mackaness, 2006). Thus, there is a requirement to build systems that provide feedback based on the language the user understands best. Hence a project like *SpaceBook* by Mackaness et al. will need to integrate speech based audio in multiple languages to be used effectively by tourists from different countries (Mackaness et al., 2011).

2.6.4 Pedestrian walking behaviour

Human crowd motion is mainly driven by self-organized processes based on local interactions among pedestrians (Moussaid et al., 2010). Study by Moussaid et al. finds that 70% of people in a typical crowd are actually moving in groups such as with friends, family or couples walking together. As the number of people in a group increases, the walking pattern changes from a line to a V-shape, this then changes to U-shape as the group size increases to 4 or more people. The work also highlights that crowd dynamics is not just determined by physical constraints induced by other pedestrians and the environment. Communicative, social interactions among individuals also contribute significantly to crowd dynamics (Moussaid et al., 2010). According to Daamen and Hoogendoorn, different factors affect the walking speeds of pedestrians, such as:

1. Personal characteristics of pedestrians (age, gender, size, health, etc.),
2. characteristics of the trip (walking purpose, route familiarity, luggage, trip length),
3. properties of the infrastructure (type, grade, attractiveness of environment, shelter), and
4. environmental characteristics (ambient, and weather conditions).

Daamen and Hoogendoorn also note that besides these exogenous factors, the walking speed also depends on the pedestrian density (Daamen and Hoogendoorn, 2002). At some traffic condition beyond free flow, pedestrians are limited in forward movement by people to the front and side. Considering these walking behaviours along with interaction (viewing a map for navigation assistance) with mobile devices while walking along busy streets will hamper efficient use of both the walkway and also the mobile device for effective feedback. Hence in such situations it is impractical to use visual mobile interfaces which usually need continuous interactions to provide spatial information to the user. This brings us to the next topic related to human spatial abilities and spatial cognition which we will discuss in the following section.

2.6.5 Spatial cognition and spatial abilities

Cognition is defined as the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses. *Spatial cognition* is thus defined as the mental action or process for acquisition, organization, utilization, and revision of knowledge about spatial environments. Over four decades researchers have been interested in understanding how people construct mental representations of the physical environment that they interact with on a daily basis (Downs and Cialone, 1973). *Cognitive maps* are mental maps which are built from experience or from expectations of the real world (Timpf et al., 1992). Timpf et al. states that tasks such as deciphering verbal route instructions, rendering scene descriptions and navigating involve the creation of cognitive maps (Timpf et al., 1992). Wayfinding tasks are carried out by humans by retrieving information from their cognitive maps. Humans add more information to their cognitive maps as they move around in space or perform wayfinding tasks. If they come across differences between the real-world and the cognitive maps, appropriate corrections are made to their cognitive maps.

Spatial abilities are cognitive functions that enable people to deal effectively with spatial relations, visual spatial tasks and orientation of objects in space (Sjolinder, 1998). Sjolinder adds that the spatial abilities of the city inhabitants may have evolved with the new living and cultural conditions. One aspect of these cognitive skills is spatial orientation, which is the ability to orient oneself in space relative to objects and events; and the awareness of self-location (Sjolinder, 1998). Sjolinder also states that the spatial abilities are a part of the fluid intelligence, which is usually assessed with tests of general reasoning ability and with maths.

A person's cognitive map, or knowledge of large-scale space, is built up from observations gathered as he travels through the environment. It acts as a problem solver to find routes and relative positions as well as describing the current location (Kuipers, 1978). Depending on the modes of information available to humans and by considerations of efciency and aesthetics, they are capable of using a variety of methods of wayfinding (Golledge, 1999).

An individual's *sense of direction* could be important to all of these methods. Cornell et al. states that a person with a good sense of direction may be better able to look for areas likely to contain landmarks and can use that information to direct actions at intersections on routes (Cornell et al., 2003). They add that this is possible as a good sense of direction can provide a reliable bearing when an individual is registering the degree of a turn.

Use of visual interfaces will take away the ability (or makes it difficult) to notice landmarks along the path and register them and update one's cognitive map. This will hamper the orientation ability based on their mental representation of a configuration of landmarks to match the scene they are viewing even though they have a good sense of direction. Thus division of attention and prioritising tasks is a big challenge.

2.6.6 Attention division and priority of tasks

Most mobile interfaces are designed with the view that the users are going to be devoting their full attention to the interaction. However while using geo-spatial mobile applications, the use of such applications/services are primarily done while performing another task like driving or walking through streets. Thus we can see that the actual interaction is the secondary task. Thus these assistive technologies should provide feedback such that the user can perform the primary activity (driving a car or walking along street avoiding obstacles) effectively and use the assistive device while on the move without much burden to his cognitive resources. While multitasking between the two tasks, the best performance from the user is when he can properly manage the tasks and toggle between the tasks effectively to achieve the final goal. Krum et al. lists the following as key challenges while using mobile geo-spatial applications (Krum et al., 2007).

- Division of attention,
- Cognitive load management,
- Information legibility, text entry, dialogue initiative

Wickens's *Multiple Resource Theory (MRT)* illustrates how different tasks will need to tap into similar resources (Wickens, 1992). Wickens adds that cognitive resources are limited and a supply and demand problem occurs when the individual performs two or more tasks that require a single resource. Wickens suggest that the most important application of the multiple resource model in the design phase is to recommend design changes when conditions of multitask resource overload can exist (Wickens, 2008). In today's day-to-day tasks, multitasking is prevalent. There are often dangers associated with types of multitasking. Example of one such multitasking activity is 'using a cell phone while driving'. Wickens stresses that "only in cases where overload is caused by multiple concurrent tasks does multiple resource model theory help to predict performance problems".

Krum et al. adds that most of the issues regarding use of geo-spatial applications require revised approaches to interaction design. However once these applications are designed keeping in mind that the interaction and use of this system is the secondary tasks, more people will integrate such systems into their day-to-day lives.

2.7 Multimodal Interaction using non-visual cues

With pure visual interfaces, we see shortfalls with regards to expecting high mobile interaction for proper use of such systems by the user. A need for users being able to switch between interaction modes based on the current context is very important. We now look at multi-modal interaction techniques to help users switch between one form of interaction to the other as the context of use demands. While use of augmented reality based interaction is great for use on a nice and pleasant day in a not so densely populated street, we need to look at non-visual feedback for users while they are trying to make their way avoiding obstacles and other pedestrians in a busy street or a rainy day.

Thus the need for a multi-modal mobile spatial interaction technique is essential. It should give the user the ability to easily switch between various modalities like the visual interface (map/textual display/icons overlay) and non-visual modalities like audio and haptic feedback according to the physical condition or context of use. The user can thus use a map based system to understand locations of various POIs when he/she is at a comfortable location and not needing to divert attention to oncoming pedestrians or other obstacles along the way. When the user is on the move they can switch to non-visual interaction techniques to ensure less attention on the device and being attentive to the physical environment.

Haptics is a promising modality which take advantage of our sense of touch. Haptics based systems ensure less interaction with the device and thus give the user greater opportunity to perform multiple tasks at a given point in time. It is thus possible to let the interaction with the geo-spatial mobile interface for assistance to become the secondary task by programming such mobile devices to integrate haptics into such services. Chapter 3 describes in detail what haptics is and how it is being used currently in a broad range of applications. The chapter also covers research in the area of use of haptics in wearable systems and current day smartphones to provide spatial information to the user.

Table 1: Advantages and disadvantages of a speech-based tourist city guide (Bartie and Mackaness, 2006)

Advantages	***Disadvantages***
Low power consumption compared to LCD	Speech recognition errors in noisy streets
Natural conversational communication	User's accent and speed of speaking affects accuracy of voice recognition (system coaching required)
No distraction from viewing the surroundings (hands free, eyes free)	Does not allow a user to browse the information
Accessible to visually impaired people	Cannot be used by hearing impaired
Lightweight hardware (headphones, microphone), inexpensive - unlike head mounted displays	
Compact, yet without the constraints of limited screen area and map design	
Secure and discreet - the user may not want to be seen looking at maps or appearing lost	

3 Haptics

3.1 Introduction

"*Touch is a fundamental aspect of interpersonal communication. Whether a greeting handshake, an encouraging pat on the back, or a comforting hug, physical contact is a basic means through which people achieve a sense of connection, indicate intention, and express emotion.*" (Brave and Dahley, 1997)

The word *haptics* is derived from the Greek word *haptesthai*, which means 'of or related to the sense of touch'. In the psychology and neuroscience literature, haptics is the study of human touch sensing, specifically via kinesthetic (force/position) and cutaneous (tactile) receptors, associated with perception and manipulation. The sense of touch is found on all parts of the body unlike the other four senses - sight, vision, hearing and smell, which are located at specific parts of the body. Here thousands of sensory cells (nerve endings) detect pressure/weight, temperature, pain and other lesser stimuli. The sense of touch allows the user to differentiate between rough and smooth, soft and hard, and wet and dry.

Haptics is a *tactile feedback technology* that takes advantage of our sense of touch by applying forces, vibrations and/or motions to the user through a device. The key factor of the use of such a system is that the user can *feel the information* when they interact with devices. The benefit of using the human sense of touch is that it is faster than vision, it is the first sense one develops when born and the last sense to fade at death.

According to (Van Erp et al., 2010), applicability considerations for haptic interactions includes the following:

- limits to effectiveness,
- workload considerations (efficiency),
- user acceptance considerations (satisfaction),
- meeting user / environmental needs (accessibility),
- health and safety considerations, and
- security and privacy.

3.2 Where is Haptics used?

"Haptic interfaces, such as force feedback and tactile devices, offer the opportunity to present dynamic visualizations in a non-visual manner to the sense of touch: whether the data being visualized is real-time stock exchange data in the form of a graph, maps from route-finding applications, or the progress of a multiplayer on-line game." (Wall and Brewster, 2005)

Haptic feedback has been used in broad area of research spanning various disciplines like tele-operation, 3D surface generation, Braille systems, virtual reality laboratory environments, gaming and much more. The sense of touch is used to provide feedback to the user about various object position and shape. This maybe making contact with a virtual object Morris and Joshi (2004), or providing visually impaired people with information about object shape and size by *feeling* the object's edges.

Massie and Salisbury describes the *PHANToM* haptic interface (Figure 15) - a device that measures a user's fingertip position and exerts a precisely controlled force vector on the fingertip (Massie and Salisbury, 1994). The device enables users to interact with and feel a wide variety of virtual objects and will be used for control of remote manipulators. Morris and Joshi used force-feedback haptic display to haptically render a three-dimensional surface that represents key aspects of a visual scene (Morris and Joshi, 2003). They also rendered depth and contour information with the Phantom, and also captured optic flow and present this to the user using sound cues. This helped visually impaired users explore the 'visual' world.

The use of touch-based interfaces to provide new computer interaction techniques for visually impaired people and those with physical disabilities have been an important area of research. The work by Sjöström deals with haptic interfaces that can be used with many different kinds of computer programs for blind people (Sjöström, 2001). This helps them perform various challenging tasks like understanding objects (by feeling the outline of an object and thus its shape and size), finding objects and searching for navigation assistance using easy reference points. Since visual impairment makes data visualisation techniques inappropriate for blind people, Yu et al. developed a system that makes graphs accessible through haptic and audio media (Yu et al., 2001). McGee et al. demonstrates that through force feedback, texture information in virtual environments can be provided as the user can feel the roughness/smoothness (McGee et al., 2001).

Figure 15: PHANToM haptic interface invented by Thomas Massie

Nikolakis et al. used the PHANToM to create a user-friendly haptic environment that allowed blind or visually impaired people to access interactive presentations based on HTML web pages (Nikolakis et al., 2004). Here audio and haptics were combined to provide users with an interactive interface for reading HTML pages via sound and touch. Kaklanis et al. extended this work to develop the 3D HapticWebBrowser which is a framework that allows haptic navigation through the Internet in addition to the haptic exploration of conventional 2D maps found on the web (Kaklanis et al., 2010). Kuber et al. provides a design guidance that could be used as a standard reference tool for Web designers wanting to develop an accessible browsing application, using the benefits offered by a force-feedback mouse (Kuber et al., 2011).

The performance of surgical knot tying is enhanced while using haptic feedback as compared to knots tied without feedback (Bethea et al., 2004). Agus et al. discusses a haptic and visual simulation of a bone-cutting burr that is being developed as a component of a training system for temporal bone surgery (Agus et al., 2003). For performing complex activities like a robotic surgery, the ability to feel the parts (via forced feedback) as the robotic arm is used by a surgeon operating from a different location is very useful. This ensures that although the surgeon can see on the screen what he/she is touching, the forced feedback lets the surgeon actually feel what is being touched.

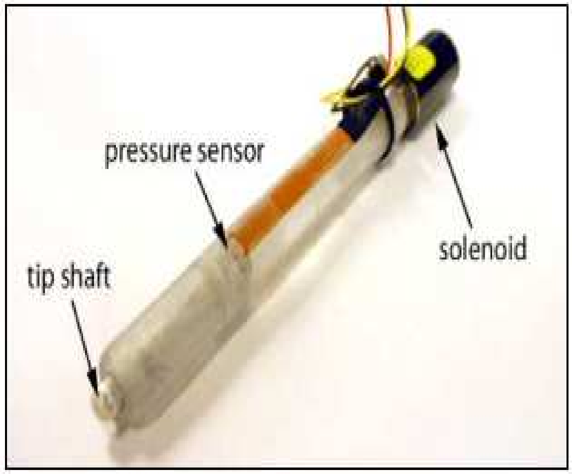


Figure 16: *Haptic Pen*: a tactile feedback stylus

Realistic kinesthetic and tactile cues in a computer generated environment can be received by integration of haptic technology into such systems. Integration of haptic feedback has been popular in gaming. People can get a higher sense of immersion and interesting ways to interact with the game environment by integration of haptics into such video games. *HaptiCast* is using haptic interaction and effects in 3D games (Andrews et al., 2006). Here players assume the role of a wizard with an arsenal of haptically-enabled wands which they may use to interact with the game world. Morelli describes how haptic/audio based exergames (video games that are also a form of exercise) can be used by visually impaired individuals (Morelli, 2010).

Haptic Battle Pong is a competitive networked game that makes extensive use of three-degree-of-freedom force-feedback and six-degree-of-freedom input (Morris and Joshi, 2004). Force-feedback is used here to haptically display contact between a ball and a paddle. Houten et al. in their study evaluated a device to encourage seat belt use by applying haptic feedback (Houten et al., 2011). Whenever unbuckled drivers exceeded preset speed limit criteria without buckling their seat belts, there was an increase in the accelerator pedal back force. When the drivers fastened their seat belt, this counterforce was removed.

The *Haptic Pen* is a simple device that provides tactile feedback for multiple simultaneous users that can work on large touch screens (Figure 16) (Lee et al., 2004). A pressure-sensitive stylus is combined with a small solenoid to generate a wide range of tactile sensations. Brewster and Brown introduce a new form of icon which integrates tactile feedback called a *Tacton*. Tactons, or tactile icons, are structured tactile messages that can be used to communicate message to users non-visually (Brewster and Brown, 2004). The parameters that can be included to create a Tacton are: frequency, amplitude, waveform and duration of a tactile pulse. The body location is also a key feature as different parts of the body have different response to the sense of touch.

We have seen that haptic feedback is used in a wide variety of applications and is integrated into various fields of research where the user can *feel* the provided information. We now highlight the key benefits of haptic feedback.

3.3 Key benefits of haptic feedback

The human sense of touch is faster than vision, it is the first sense one develops when born and the last sense to fade at death. Thus humans have the ability to use our sense of touch longer than our senses like vision and hearing which fades of faster with age. Using haptics, we can provide non-intrusive subtle feedback that can provide different kinds of information to the user (as seen in the examples in section 3.2). Haptic feedback helps provide information on the contact between two objects in a game (Morris and Joshi, 2004) and to navigate in a virtual environment. It provides assistance to visually impaired users for navigation, finding and understanding objects and data visualisation. This is useful since visual feedback is of no use to them. In a steering task similar to menu interaction, Campbell et al. find reduced task time and error rate with the use of tactile feedback (Campbell et al., 1999).

Oakley et al. in their study finds that subjective workload measures showed that participants perceived many aspects of workload as significantly less with haptics (Oakley et al., 2000). They add that although the haptic effects did not improve users performance in terms of task completion time, the number of errors made was significantly reduced.

Heikkinen et al. finds in their study that the most appropriate use cases of haptic communication were found to be conveying emotions and binary information (Heikkinen et al., 2009).

Thus we see that it can be challenging to provide effective visual information to users; haptics can be a very good alternative or additional mode via forced feedback or vibration. By varying the different parameters of haptic feedback like frequency, amplitude, waveform and duration of a tactile pulse, we can provide different information to the user. The location on the body where the feedback is provided can also be an important feature in identifying possibilities to provide effective feedback in the most efficient way.

The key benefits of haptics can thus be listed as:

- the sense of touch lasts for longer period in life as compared to vision and hearing
- it can provide an easy subtle feedback method to deliver simple information
- it reduces cognitive overload on the user
- information can be provided in a private, non-intrusive manner
- it is the ideal form of communication when the primary task of the user requires their full attention
- it allows the user to use their other senses while performing tasks

We will now look at where and how haptics has been integrated into systems to provide ‘spatial information’ to the user.

3.4 Haptics for the provision of spatial information

Wayfinding is the ability of pedestrians to walk from one place to the other. Golledge lists two main factors that are related to this kind of walking ability and they are orientation and mobility (Golledge, 1992). Haptic feedback can be used to display temporal-spatial data and augment the display of global visual models (Erp and Kern, 2008). Haptic feedback can be used to provide spatial information to the user.

When a cyclist is exploring an unknown area, they sometimes lose their orientation. *Tacticycle* is a haptic feedback based orientation assistant that does not influence the cycling experience but improves the orientation and awareness of the overall direction (Poppinga et al., 2009). Here two vibrotactile actuators were used to indicate directions and to also inform the user about the presence of interesting places along the route. Interrupted, subsequent vibrations were used to provide information about the direction of the destination. Hence the overall experience for the user is much better than having to use a map for interaction and stopping along the route.

Figure 17: *GentleGuide*: Control unit and wrist devices and also shows how it is worn by a user

Generally haptic feedback can be provided through a wearable device (belts, etc.) or through a hand-held mobile device.

3.4.1 Wearable computers

Ertan et al. describes one of the early implementation of a wearable haptic navigation guidance system (Ertan et al., 1998). The system consisted of a 4-by-4 array of micro-motors for delivering haptic navigational signals to the users back, an infrared-based input system for locating the user in an environment, and a wearable computer for route planning.

Bosman et al. developed the *GentleGuide* that investigates how haptic output can be used to deliver guidance to pedestrians (Bosman et al., 2003). All users can use GentleGuide to find their way to a particular destination indoors, e.g., a room in a hospital. Here the vibration pulses delivered by two wrist-mounted devices (Figure 17) are used to deliver guidance information for pedestrians indoors. Tsukada and Yasumura developed a prototype called the *ActiveBelt* which is used to provide directional information by in-

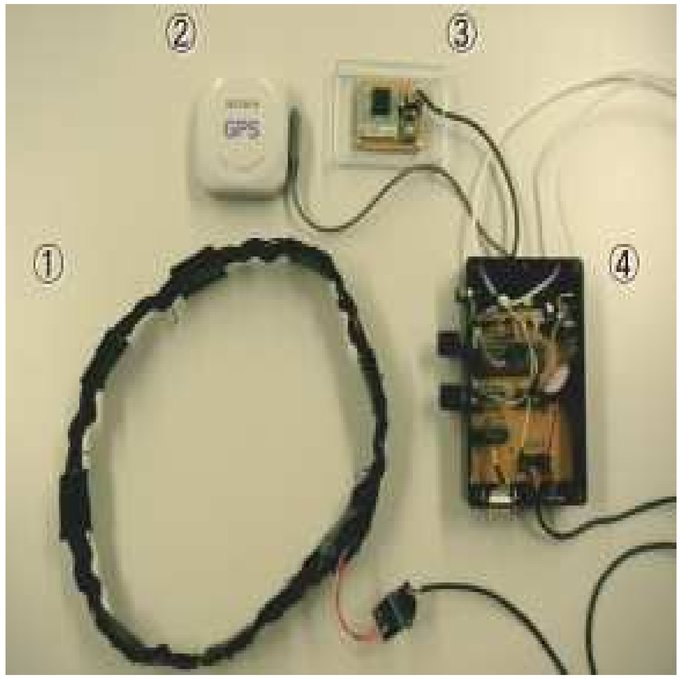


Figure 18: *ActiveBelt*: 1) ActiveBelt hardware, 2) GPS, 3) directional sensor, and 4) Microcomputer (Tsukada and Yasumura, 2004)

tegration of actuators with global positioning system (GPS) and a compass (Figure 18) (Tsukada and Yasumura, 2004).

Erp et al. describes how the most important like direction and distance information must be coded in a tactile belt (Erp et al., 2005). Eight tactors were used around the user's waist. Here distance was translated into vibration rhythm while the direction was translated into vibration location along the belt (Figure 19).

McDaniel et al. extends the use of *ActiveBelt* and explains how a *Haptic Belt* is used to convey non-verbal communication cues during social interactions to individuals who are blind (McDaniel et al., 2009). The belt's capability to provide non-verbal cues pertaining to communicators, namely direction and distance were evaluated. *Haptic Belt* was found to be effective in conveying this information. McDaniel et al. integrated four tactile rhythm designs into the Haptic Belt architecture to provide distance and directional information to the user (Figure 20) (McDaniel et al., 2009).

Bial et al. investigated opportunities for presenting navigation information (direction and distance to a destination) using vibration actuators at the user's hand (Bial et al.,

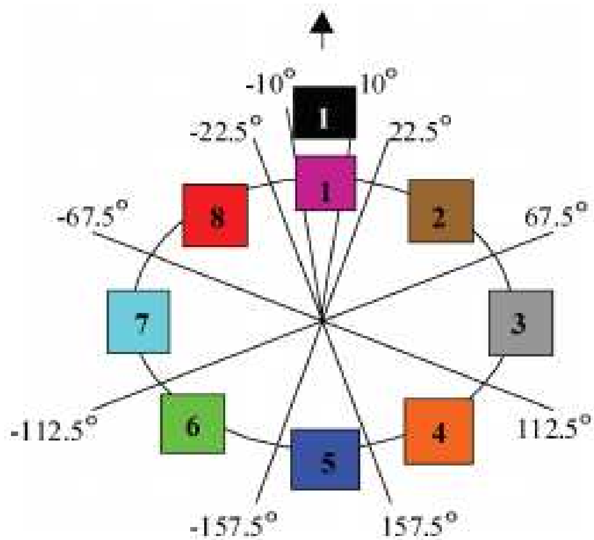


Figure 19: Working of the tactile belt for orientation information.

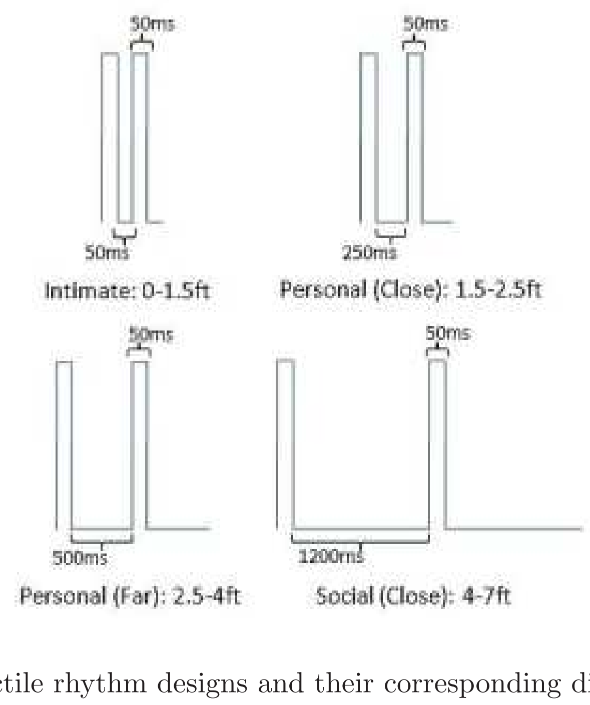


Figure 20: Four tactile rhythm designs and their corresponding distances are shown.

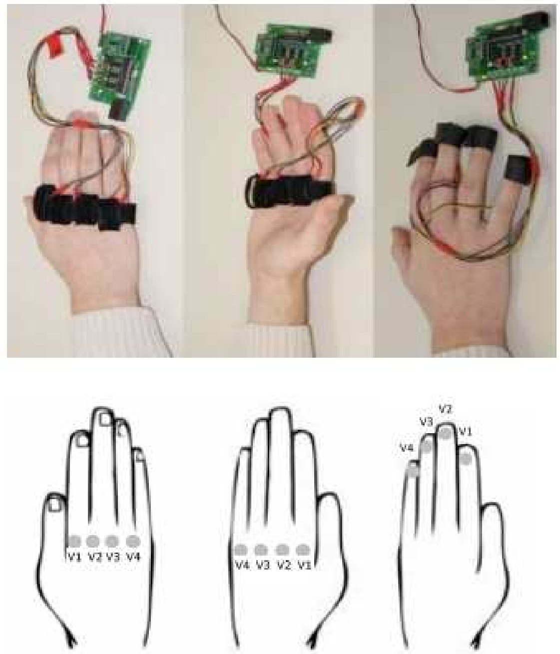


Figure 21: Vibration actuators on fingertips/back of palm are used to provide feedback

2011). Four vibration actuators were mounted either on the back or the palm of the hand or at the fingertips to provide feedback (Figure 21).

Spelmezan et al. evaluated the performance of vibro-tactile patterns triggered at key body locations to represent specic movements and signal how to adjust posture (Spelmezan et al., 2009). These instructions included *turn your upper body to the right, shift your weight to the left foot, or ex your legs*. The users were able to understand with accuracy the information conveyed using haptic feedback.

Le Chal (Hindi translation of 'Take me there') is one of the most recent developments in providing navigation assistance for visually impaired users (Sharma, 2011). The Le Chal shoe (includes an arduino board) and a mobile phone with a GPS receiver is used to provide navigation assistance (Figure 22).

The mini-vibrational actuators that are placed on all sides of the shoe provide the directional haptic feedback so that an approaching turn triggers the vibration. When the user arrives at a waypoint, mild vibrational feedback activated in the shoe informs the user the direction he or she needs to turn to.

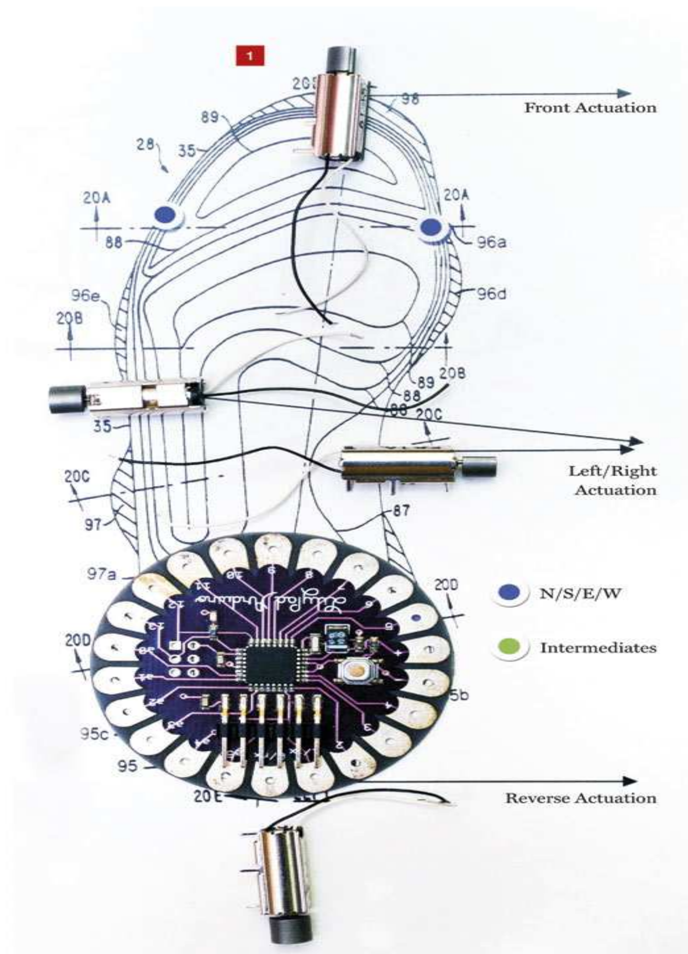


Figure 22: *Le Chal*: Shoe for navigation assistance for the visually impaired

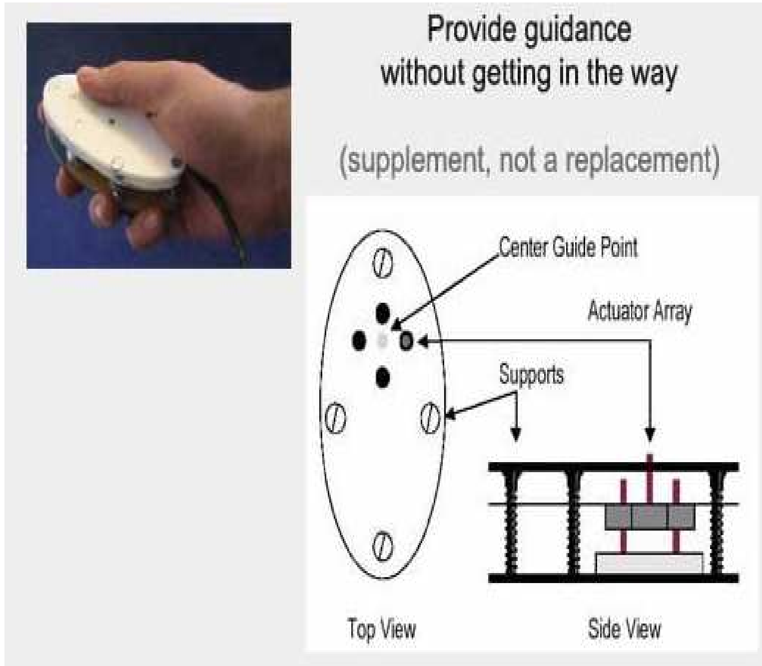


Figure 23: *Tactguide*: Uses the sense of touch on the thumb to provide feedback

We have seen how spatial information is provided using wearable computers and the use of belts to provide orientation information using actuators being the most popular form. Let us now look at how it can be delivered using mobile phones and other hand held devices.

3.4.2 Mobile phones and other handheld devices

Most people carry their mobile device with them as they move around in the real physical environment. Thus, the use of haptic feedback in mobile devices is an area of research that is of great interest as some of the key benefits of using haptic feedback as a modality for information is when the user is on the move and use of visual interfaces is not ideal.

Tactguide is a navigational aid that engages one of the user's spare senses which is the sense of touch on the thumb (Figure 23) (Sokoler et al., 2002). It has a flat smooth ellipsoidal shaped surface and four holes positioned around a 1mm high raised dot. Here 1 of 4 pegs is raised to indicate relative direction.

Figure 24: *Lead-me*: device providing pull-push sensation

Lead-Me device (Figure 24) gave the user holding the device a typical kinaesthetic illusion experience which has the characteristics of the sensation of being continuously pushed or pulled by the device (Amemiya et al., 2008). Here a 1 degree-of-freedom (DOF) haptic device based on a crank-slider mechanism was constructed. Pulling and pushing sensations were produced by using different acceleration patterns by a perceived force. To help the visually impaired in wayfinding tasks like orientation, Amemiya and Sugiyama developed a haptic based novel method called the "pseudo-attraction force" technique where perception of force is used as an indicator of direction (Amemiya and Sugiyama, 2009).

Luk et al. designed and built a handheld prototype called *Tactile Handheld Miniature Bimodal* (THMB) (Luk et al., 2006). Its interface consists of a plastic casing containing a tactile display for the thumb (Figure 25). The system creates haptics icons in three basic modes - distributed vibration mode, time-based mode, and space-based mode.

Hoggan et al. placed C2 actuators in four different positions on the PDA corresponding to locations on the hand: the lower thumb (bottom left side), the upper thumb (top left side), the tip of the index finger (top right on the back of the PDA) and the tip of the ring finger (middle right side) (Figure 26) (Hoggan et al., 2007). This experiment shows the benefit of using actuators in four locations to provide non-visual vibration feedback to the user.

Use of vibration motor available on small portable mobile devices can be used to provide haptic feedback to the user. Vibration with varying frequency, pattern, and amplitude can be used to represent different kinds of spatial information like distance and ori-

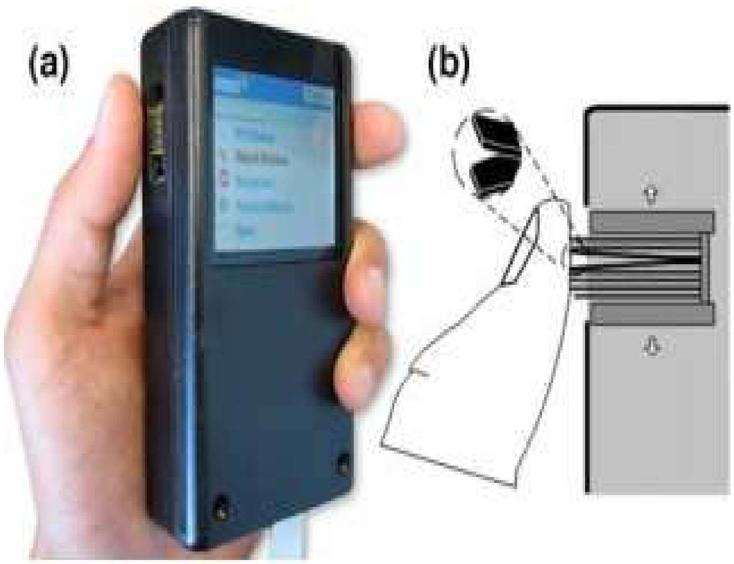


Figure 25: a) Prototype of Tactile Handheld Miniature Bimodal (THMB). b) Bending action of the actuators, causing lateral skin stretch

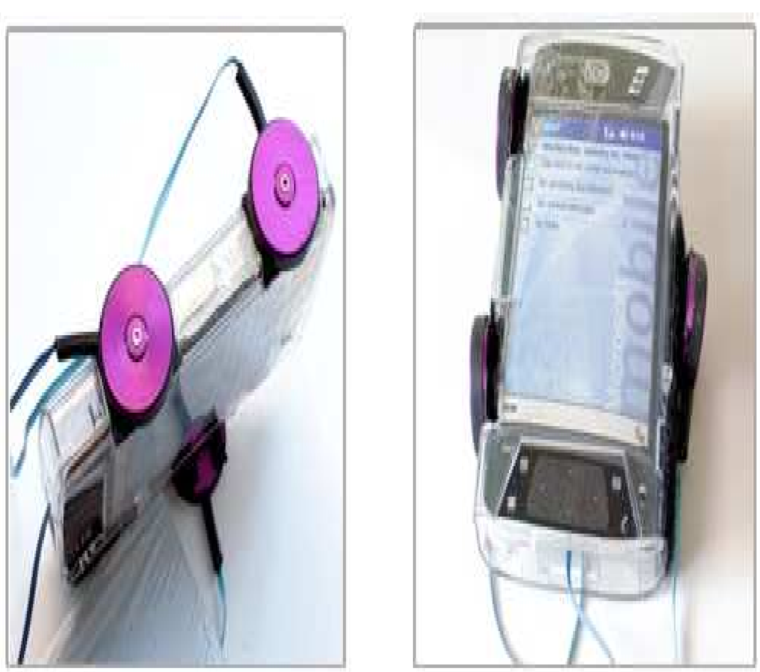


Figure 26: Multi-actuator PDA

Figure 27: *Pocket Navigator*: providing tactile cues for pedestrian navigation

entation. The intensity of a vibration required for detection by users depends on the frequency.

Pielot et al. describe an android smartphone based system called the *Pocket Navigator*. Here the users can leave the device in the pocket while being guided non-visually through vibration cues (Figure 27). For navigation, distance and direction information to the next waypoint is provided by encoding its direction and distance in vibration patterns (Pielot et al., 2010).

3.5 Haptics enhancing multimodal interaction

The use of multiple human modalities (various senses in the body) in the interaction between human and a computer (mobile device) for output, input or both kinds of interactions is called *Multimodal interaction*.

Robinson et al. discusses about the heads-up interaction with mobile devices by integration of multimodal feedback using gestures (Robinson et al., 2010a). The user is alerted about geo-tagged (related to a location) information using a vibration alarm. And the user is able to find out what form of information (information in the form of images, text, audio and/or video) is available by performing the gestures (Figure 28).

Figure 28: Browsing geo-tagged information about a given point of interest by gestures (Robinson et al., 2010a)

Haptic feedback by various patterns of feedback is used to provide this information to the user.

The work by McGee et al. introduces the 'Integration of Information' as one important dimension of haptic-audio interaction (McGee et al., 2000). They discuss the importance of incorporating many modalities like haptic-audio interfaces rather than pure visual interfaces to enhance the effectiveness of the information conveyed. Ahmaniemi and Lantz discusses the usefulness of the integration of haptic cues with augmented reality to assist in target finding and the tests they performed showed that the user were able to easily find targets (Ahmaniemi and Lantz, 2009).

3.6 Haptic Syntax

Conveying information using haptic feedback depends on the kind of hardware that is being used. There are many ways to do so using wearable devices and some examples are listed below:

- Wearable belts: Belts like the ActiveBelt, and the Haptic Belt provides directional information by integration of actuators with GPS and a compass.

- Hand-held guides: Lead-Me is a hardware device that uses imbalance in acceleration patterns in two directions that produce a push or push sensation.
- GentleGuide: Hardware devices are strapped on each wrist of the user and pull/push mechanism is used to provide directional information in an indoor environment.
- Le Chal shoe: This includes an arduino board that provided navigation assistance for the visually impaired using vibrations at different parts of the foot for direction.
- PocketNavigator: This mobile app provides directional information using the vibrational alarm of the phone using combinations of 8 different patterns and frequencies.

While each of these devices are trying to convey information using haptic feedback, they all follow different haptic syntax. Thus, the haptic syntax varies based on the kind of system that is built and the target audience who would use such systems. Multimodal interaction techniques that combine visual and haptic feedback can provide rich content for the user while ensuring the key benefits of haptics (subtle, private, minimal interaction, less distracting, easy to comprehend) are ensured.

The inherent limitations of haptic feedback include the inability to convey detailed, highly accurate information based on the small range of possible symbols (haptic syntax) using mobile-phone haptics. Another limitation of using such mobile-phone haptics is that it lacks full vibration motor controls and thus the inability to integrate more information by varying the amplitude of vibration. In order to use vibration amplitude to create symbols, other full vibration motor controls must be integrated to the existing hardware. The range of feedback symbols is limited as the addition of more symbols will increase the complexity of the system and inhibit it's usage as the user will have to memorise and be familiar with more symbols (vibration patterns based on frequency). The Haptic Syntax within the system we built require multi-modal interaction where we integrate both visual and haptic feedback. The key considerations for integration of haptic syntax with visual interfaces were as follows:

Haptic feedback:

i) must work with off-the-shelf device like the mobile phone,
ii) does not need additional hardware to provide information,
iii) provides subtle, private, easy to comprehend feedback and
iv) must provide high level/low resolution information and thus ensuring quicker adap-

tation and less learning.

Based on these conditions, we developed a haptic syntax for various systems to provide simple, easy to understand feedback.

- Density/Distance information: The vibration pattern with varying frequencies is used to represent high level information about distance (near, far, very far) and density (one, few, many) of features. To provide low level detail, visual feedback is used. More description is provided in Chapter 5 while describing whereHaptics and whichHaptics as part of Haptic GeoWand.
- Hot/Cold Concept with continuous feedback: The use of varying vibration patterns to represent user moving outside the region of travel and is following the path to take. This provides continuous feedback about ideal walking path. This is described in more detail in Section 6.4.1 where the Haptic StayonPath system is discussed.
- Approaching (notification): When one is nearing a region/area of interest (nearing a bus stop, waypoint, POI), they are notified with vibrations with varying frequency.

3.7 Summary of using haptics in mobile location based services

GoogleMaps for Mobile (GoogleMaps, 2012) is one of the most popular mobile cartography based system that has seen worldwide acceptance. The visual feedback provides different kinds of information - about a user's current location, about the POIs around the user, and about the walking/driving directions from one place to the other. While the visual content in this system is very rich, when the user is mobile, continuous interaction with the mobile device for visual cues can hamper the walking speeds of the user and also disrupt the ability to interact with the physical environment like avoiding obstacles. Landmarks are an important ways to help people in navigation and various systems (Raubal and Winter, 2002; Caduff and Timpf, 2005; Dale and Geldof, 2005; Walther-Franks et al., 2009; Schöning et al., 2009; Wenig and Malaka, 2010) have been developed that provides visual information about landmarks using textual description and photographs along the route. While this provides rich content about the landmark, the user will need to continuously have their attention on their mobile screen. This does not allow the user to freely interact with the physical space around them and will restrict their motion. *Layar* is one of the most popular augmented reality browsers with over 10 million downloads (Layar, 2012). While the visual interaction of such augmented reality based systems provide information to the user, such systems are not beneficial for use in a crowded city environment.

Various research works (Holland et al., 2002b; Strachan et al., 2005; Tsuruoka and Arikawa, 2008) demonstrate the use of non-speech audio feedback to provide spatial information to the user. While these are useful to ensure the users can have their eyes free to explore the real-world and avoid obstacles and not be distracted by interacting with a mobile device, such system will require the user to wear a headphone and thus will take away the ability to listen to warning and other important sounds (car horn, pedestrian crossing alerts, birds chirping) in the real world. (Bartie and Mackaness, 2006) developed a speech-based tourist city guide. The key advantages of using this system are - Low power consumption as compared to LCD, no distraction from viewing the surroundings (hands free, eyes free) and is lightweight, compact, secure and discreet. However, speech recognition errors could occur in noisy streets. The ability to understand the accent and speed of the voice differs from one user to the other and such speech based systems cannot be used by the hearing impaired.

Some of the key limitations of the visual feedback based systems discussed above are that they do not take into consideration some important features like - ease of use in crowded environments, providing subtle and private feedback. In our system we overcome issues of these visual feedback based system by integrating haptic feedback to mobile location based services. The shortfalls of audio based systems is overcome by integrating feedback using haptics into the system that is functional in crowded and noisy environments and is not affected by the language the user understands. Haptic feedback based systems like ActiveBelt, and Lead-Me require extra hardware and does not work with off-the-shelf device like the mobile phone. We overcome this by integrating our Haptic Interaction Model with existing mobile devices with no extra hardware required. Thus, while various visual and audio systems provide high resolution feedback, the key considerations which are not integrated is the simplicity, ease of use, private usage without getting the attention of passers by and the removal of language barrier (including accent) required for map reading and understanding audio feedback. We overcome these issues while integrating haptic feedback into mobile location based services made available on of-the-shelf devices like the smartphone.

The benefit of using the human sense of touch is that it is faster than vision and has more longevity. Consequently sense of touch (haptic interaction) is the last sense to fade off among humans and thus can be effectively used for a longer duration than visual feedback (traditional methods like map reading, visual interfaces). Another important feature of this kind of communication is that unlike visual or audio based interaction, this overcomes the language barrier and can thus be extended to other geographies with ease. The use of a non-visual system means that the user can query features by performing pointing and/or scanning gestures and not having to look into the mobile device. Thus such operations can be performed privately by having the phone in the jacket/loose pant pocket and by pointing and waiting for feedback ensuring the user is "one among the crowd". While we see benefits in haptics enabled systems, it should be 'integrated to visual or audio based systems as a complimentary mode of interaction/communication and not substitutive'.

While we have classified Mobile Location Based Services to be standalone systems, it is also possible to understand how they work as stages within a single user query can be understood (Figure 29). There are three stages in Mobile Location Based Services for a user to get from one location to another, as listed below.

- Stage 1 [Knowledge Discovery]: Query for the destination (e.g. a POI, business, etc) - This is discussed in detail in Chapter 5 while describing the Haptic GeoWand. The review of literature related to the area of Knowledge Discovery based systems are also included in Chapter 5.
- Stage 2 [Pedestrian Navigation]: Receive navigation cues to get to the destination (e.g. Walking from current location to the nearest ATM) - This is discussed in detail in Chapter 6 while describing the Haptic Pedestrian. Here we also discuss the four prototypes to provide navigation cues using distinctive interactive techniques. The review of literature related to the area of Pedestrian Navigation systems are also included in Chapter 6.
- Stage 3 [Notification System]: Be notified when reaching (or very close to) the destination. This is discussed in detail in Chapter 5 while describing the Haptic Alert. The benefits of this system is understood by describing a Haptic Transit system which encompasses Haptic Alert and Haptic Pedestrian to provide public transport users with assistance. The review of literature related to the area of Location Based Notification Systems and systems for public transport are also

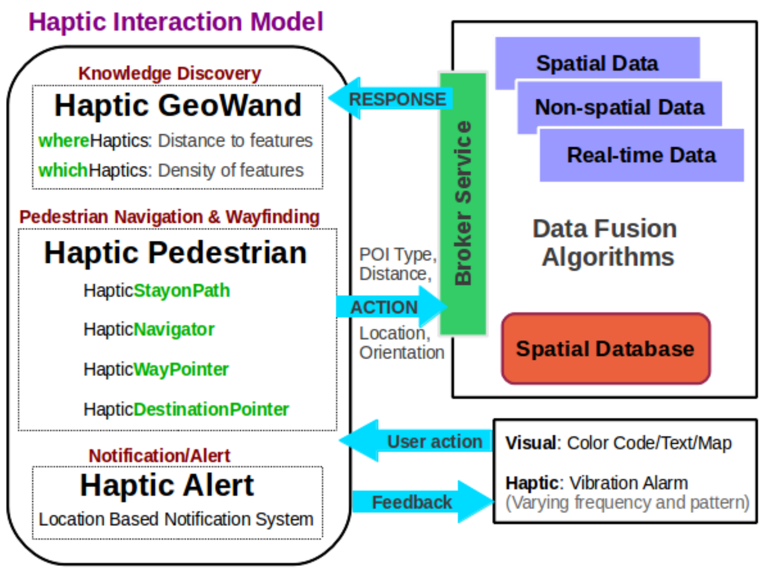


Figure 29: The haptic enabled systems developed in this thesis describing the 3 Stages in Mobile Location Based Services

included in Chapter 7.

Haptic feedback can be integrated to mobile location based services to provide assistance to the user when it is not optimal to use visual or audio feedback. Thus, complimentary modes of interaction using different modes (visual, audio, haptics) of communication can be used provide spatial information. To demonstrate how haptics can be integrated to provide information in the above listed stages, the systems (and prototypes) have been developed (Figure 29) and is described in the thesis in more detail. A knowledge discovery system called the *Haptic GeoWand* is a low interaction system that allows users to query geo-tagged data around them by using a point-and-scan technique with their mobile device. This system is described in detail in Chapter 5. *Haptic Pedestrian* is a navigation system for walkers. Four prototypes have been developed classified according to the users guidance requirements, the user type (based on spatial skills), and overall system complexity. This system is described in detail in Chapter 6. *Haptic Alert* is a notification system that provides alerts using haptic feedback most importantly to users of public transport. This system is described in detail in Chapter 7.

In the following chapter by providing some case studies, we demonstrate how such haptics enabled systems can be used in the real-world.

4 Case studies

4.1 Pedestrian navigation-eCampus

Let us understand how haptic feedback can be used to help pedestrians explore places and get information about interesting places, events and also provide navigation assistance to the user to get from one place to the other. We will see how integration of haptic feedback to mobile location based services can help by considering an example of an eCampus system for a University student who recently registered for an undergraduate degree in Computer Science.

Objectives: Provide the user with personalised information which are spatial in nature and are dynamic in the local environments (For example: a University campus).

4.1.1 System Functionalities

The system includes integration of 3D models of buildings on campus along with pedestrian navigation information and user centred information delivery via various modalities like vision (map, textual, geotagged images), or touch (haptic feedback for notification and walking directions by mobile phone pointing gestures) or a combination to use augmented reality based feedback. Location, time, user profile data, and other dynamic data within the functional area (eg: campus, shopping mall, etc) are considered. In this eCampus system for students, the following questions among others must be answered:

- Where am I?
- Where is the ATM on campus?
- Where is my next lecture?
- How to get to that lecture hall?
- How long will it take to get to that lecture hall?
- Where can I grab a quick cup of coffee?
- When and where is the talk on cloud computing happening next on campus?

The mobile interaction system here lets the student query about buildings, locations of lecture halls and other point of interest (POI). The system informs the user about the events happening on campus and at near-by locations around campus. The system also provides navigation assistance to various locations within the university campus based on user context and preferences and timetable/calendar information. The Haptic GeoWand (as discussed in chapter 4) query is used to explore and query the features in the 2D/3D model of the campus for POIs (eg: lecture halls, ATM, toilets, cafes) that are of interest to the user. The user can point towards a building and based on the user's position and pointing direction, more information about a feature is obtained. Details and time about lectures and other information associated with that feature is listed for the user. The Haptic GeoWand query is used to also help in exploring distant objects not within sight of the user. It helps provide the user with information about the general heading direction and distance to any particular POI of choice. This is done by the use of varying vibration patterns by using vibration frequency to encode distance information when the user points in the direction of the POI. The Campus Navigation module in the eCampus system helps users to find a pathway between two specific locations (between the current location and another specific location) on the campus. Users can also indicate options like taking into account weather conditions or noise conditions so that the route to the destination could be the driest (including maximum indoor pathways in the route) or the most quietest (based on previously stored information about information within the campus). The HapticPedestrian prototypes as described in Chapter 5 can be used by the user based on the kind of navigation assistance they need. A location based notification system, HapticAlert ensures that it the user is notified about events or other user preferred information based on the user location and the time taken to get to the event location based from current user location.

4.1.2 Scenario

Raj is a registered student at the Department of Electronics Engineering. Figure 30 shows his schedule for a day.

When Raj enters the North Campus through a side entrance (at 9:43 am), he needs navigation assistance (Figure 31) to get to the Engineering building where the Seminar is at 10am. The *Haptic Pedestrian* module ensures he gets directional assistance to

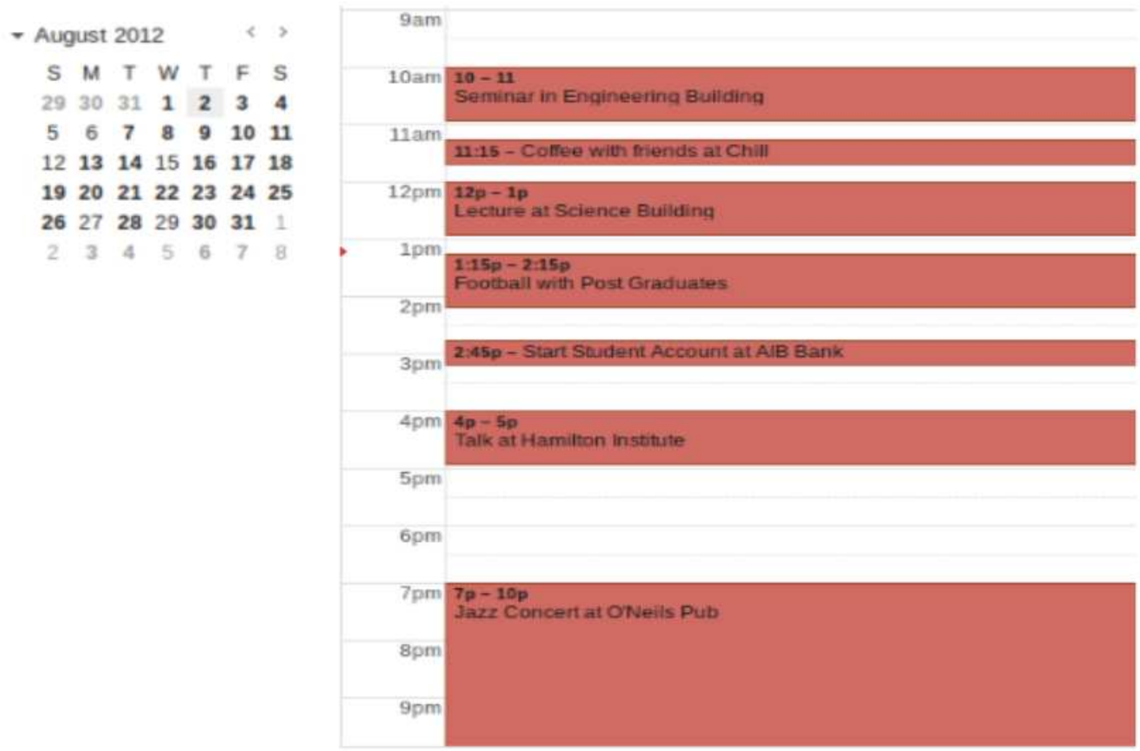


Figure 30: eCampus: Schedule of the user for a day

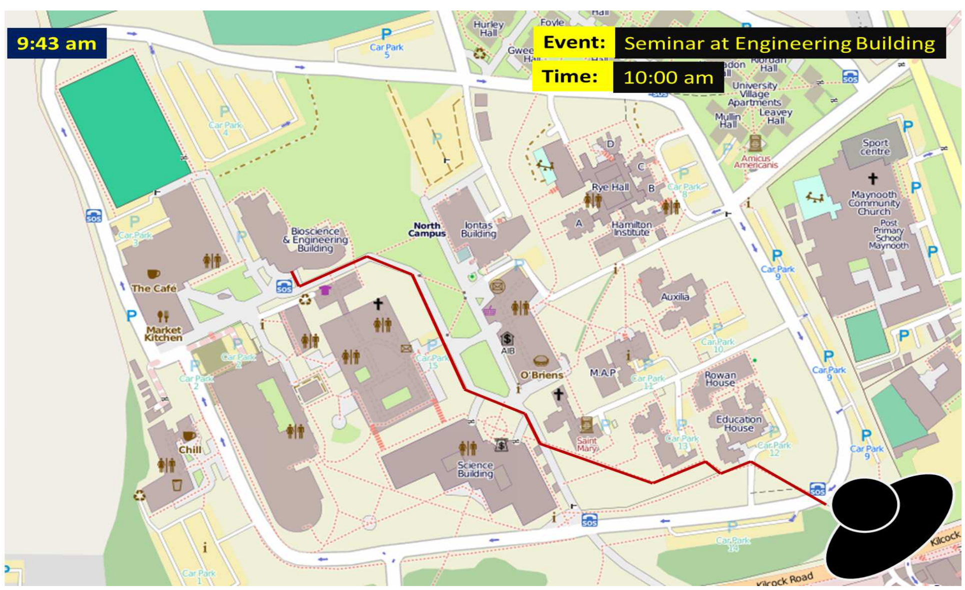


Figure 31: eCampus: This is a screenshow of the user getting navigation assitance to walk to the Engineering building

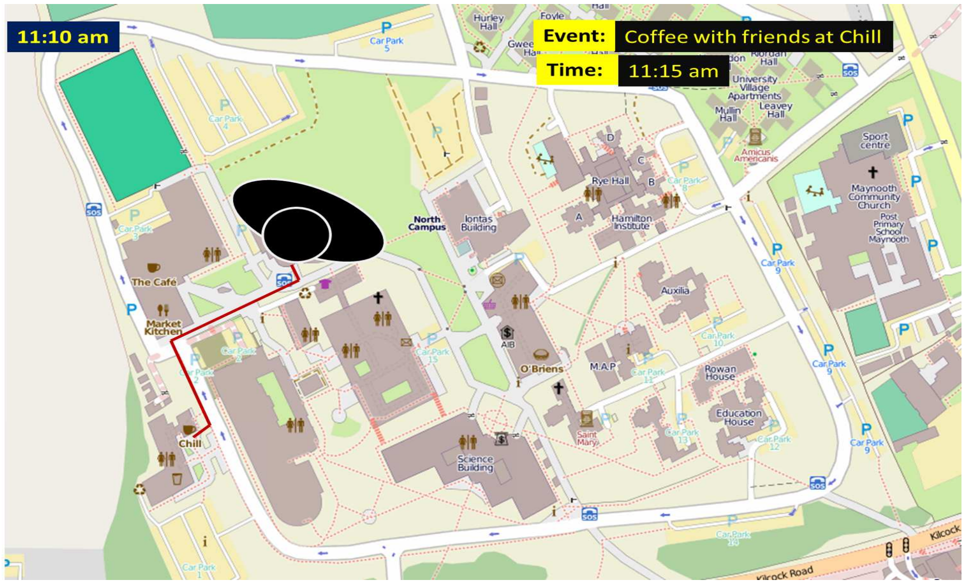


Figure 32: eCampus: This is a screenshow of the user getting navigation assistance to get to Chill Restaurant

reach the Engineering building entrance where the seminar is on. He gets a notification at around 11:03 alerting him that he has to get to *Chill* restaurant by 11:15am as his friends are waiting there. He uses the *Haptic GeoWand* to query for the restaurant and get directional assistance to reach there (Figure 32). At around 11:50am he gets an alert (*HapticAlert*) about the lecture which is at the Science Building and he gets navigation assistance to get there as he has never been to the Science Building before (Figure 33). He has a lecture from 12:00pm until 1:00pm. Soon after he realises that he needs to get to the football pitch where his friends and other Post Graduates are getting ready for their regular Thursday noon football session. He uses the Haptic DestinationPointer to get navigation assistance to get to the all-weather football pitch from the Science Building (Figure 34). He enjoys a great game of football and then he is alerted about the appointment he had with the AIB Bank officer on campus to start a student account. He has never been to the bank before so gets navigation assistance using Haptic Navigator/DestinationPointer to get directions to the bank in time for the 2:45pm meeting (Figure 35). Later in the day, at about 6:45pm he will be alerted about the Jazz concert.

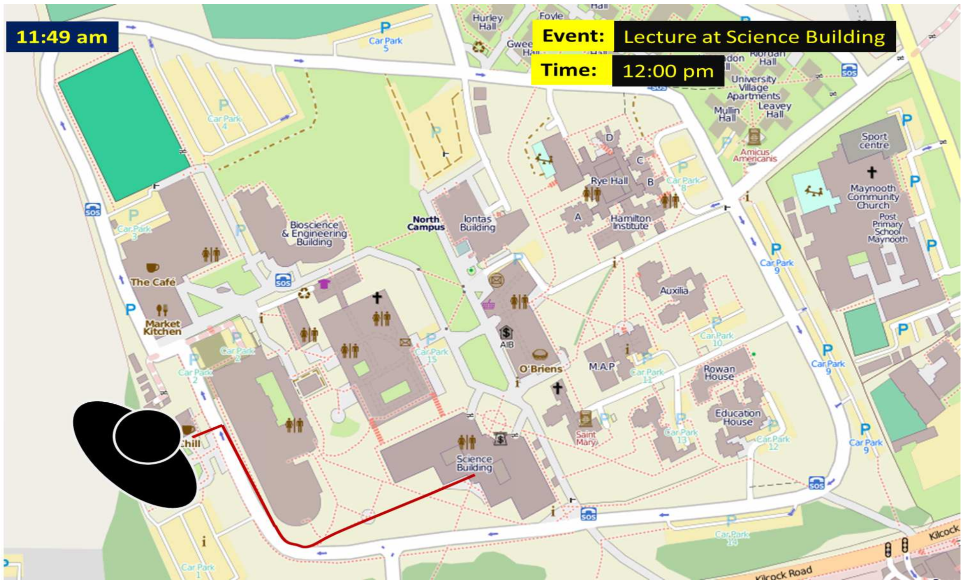


Figure 33: eCampus: This is a screenshow of the user getting navigation assistance to get a lecture at Science building

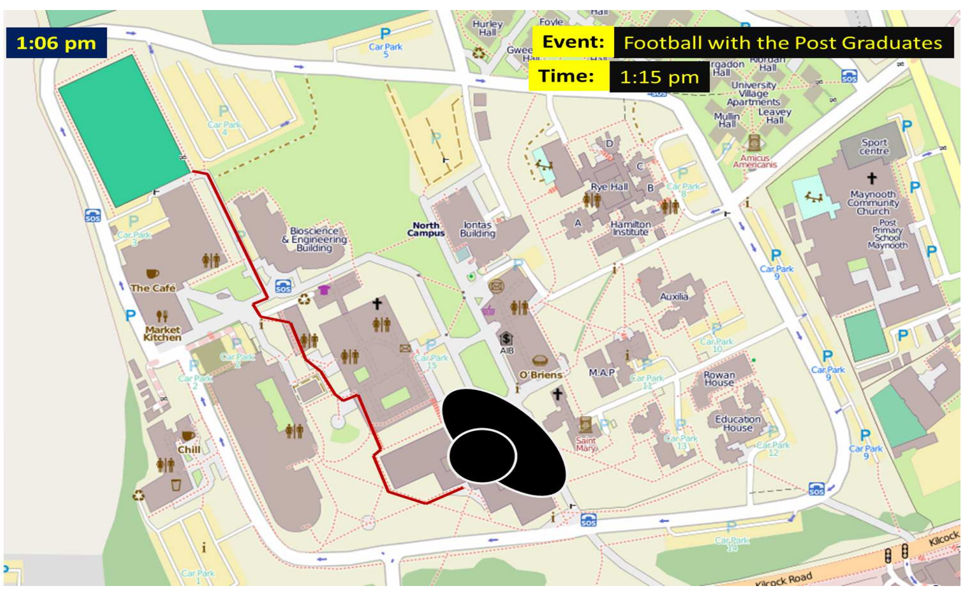


Figure 34: eCampus: This is a screenshow of the user getting navigation assistance using *Haptic Pedestrian*

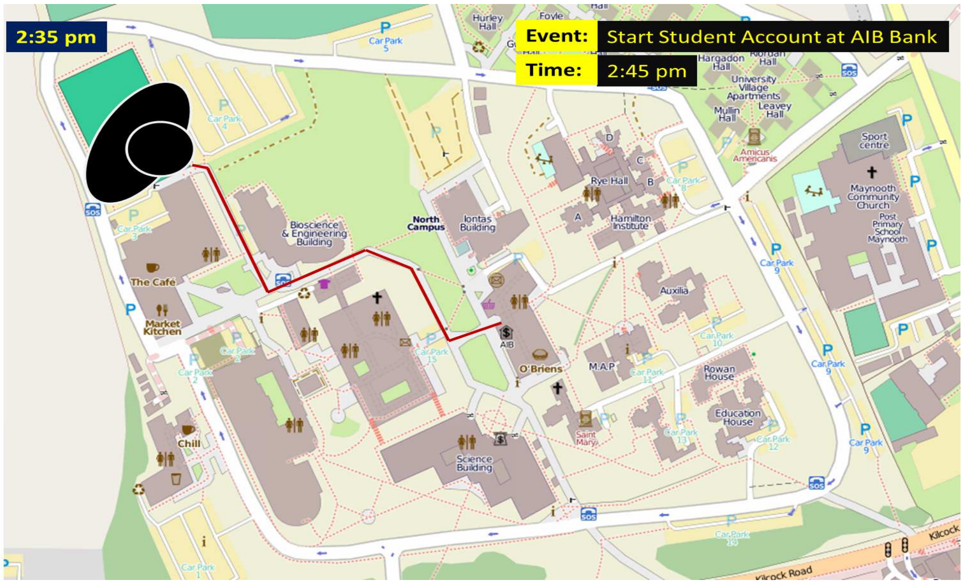


Figure 35: eCampus: This is a screenshow of the user being alerted (*HapticAlert*) about an appointment at AIB bank on campus and also gets navigation assistance to get there

4.2 Tourist/shopping trip

Objectives: Provide the user with information about distance and direction to POIs or shops where the user can find the things they are looking for apart from dynamic information of new offers/sales that are available in places close to the user's location.

4.2.1 System Functionalities

The Haptic GeoWand query is used to also help in exploring distant objects not within sight of the user. It helps provide the user with information about the general heading direction and distance to any particular POI of choice. This is done by the use of varying vibration patterns by using vibration frequency to encode distance information when the user points in the direction of the POI. The HapticAlert system (with integration of Shopping Sales data) provides the user with location specific notifications about information that is important to the user. The HapticPedestrian system provides navigation cues to get to a particular POI of choice of the user.

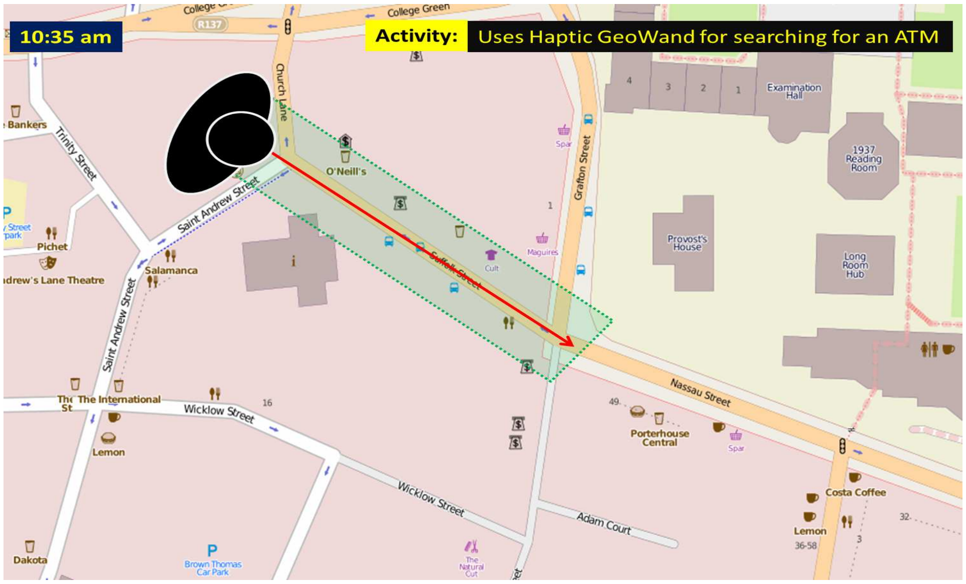


Figure 36: Tourist Shopping: This is a screenshow of the user getting direction and distance information to get an ATM machine using *Haptic Pedestrian*

4.2.2 Scenario

Deborah lives in Lucan and travels to Dublin on a Saturday for some shopping and also meeting up with friends later that day.

Deborah reaches *Church Lane* in Dublin and looks for an ATM to withdraw some money and uses *Haptic GeoWand* (Figure 36). After withdrawing money she now looks for a nice coffee shop before heading for shopping. The *Haptic GeoWand* ensures she gets directional assistance to search for coffee shops along various streets before picking the one she likes to visit. She selects *Costa Coffee* along *Nassau Street* (Figure 37). After picking her favourite cup of coffee and catching up on some news there, she decides to step out and go shopping. She gets an notification via *HapicAlert* about a sale that is on at one of her favourite brand of clothes, H&M (Figure 38). She has never been to this part of town and is not aware of the exact location of H&M near her. So she uses the HapticPedestrian to get walking assistance to help her reach the shop (aFigure 39). Her friends meet her at H&M and after shopping there at H&M, they decide to go to the nearest McDonalds for lunch.

Figure 37: Tourist Shopping: This is a screenshow of the user getting information about a coffee shop using *Haptic GeoWand*

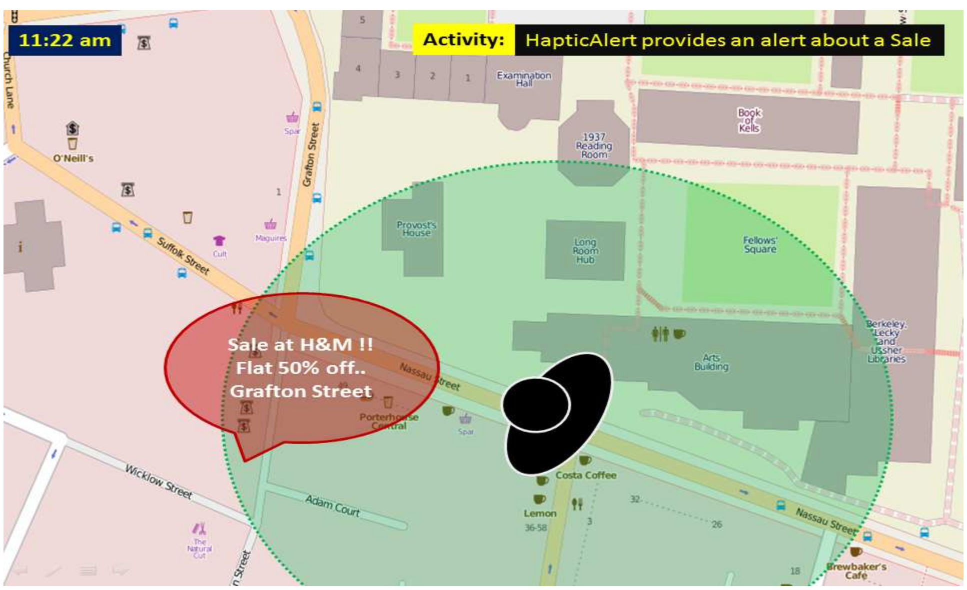


Figure 38: Tourist Shopping: This is a screenshow of the user getting a notification (*HapticAlert*) about a shopping Sale at one of the user's favourite brands

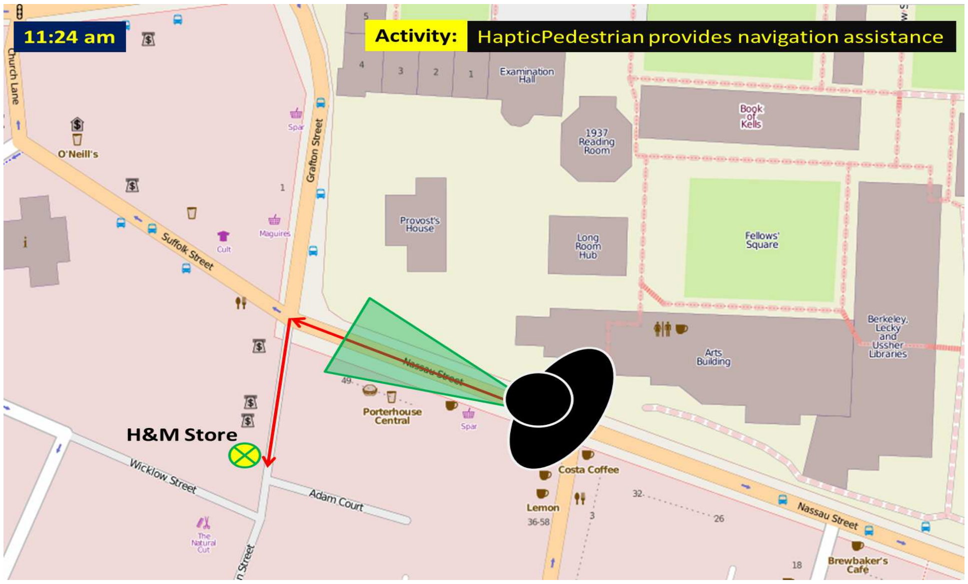


Figure 39: Tourist Shopping: This is a screenshow of *Haptic Pedestrian* providing the user with distance and direction information to a shop.

4.3 Door-to-door system integrating haptics Multiple mode of transport

Objectives: Provide the user with information about location, distance and direction to POIs or other transport related features like car parking spot, bus stop location, arrival time at destination stop, etc.

4.3.1 System Functionalities

For providing travel and transit information for a door-to-door transit system, the HapticTransit system is used along with the HapticPedestrian and Haptic GeoWand. The *Haptic Transit Model* includes the various sub systems: *Haptic Navigation* (pedestrian navigation module), *HapticAlert* (the notification system), *User Interaction Model* (local user or tourist to provide relevant information), and *Expected Arrival Time* system (the system that predicts arrival time of bus/train).

The Haptic GeoWand query is used to also help in exploring distant objects not within sight of the user. It helps provide the user with information about the general heading direction and distance to any particular POI of choice. This is done by the use of

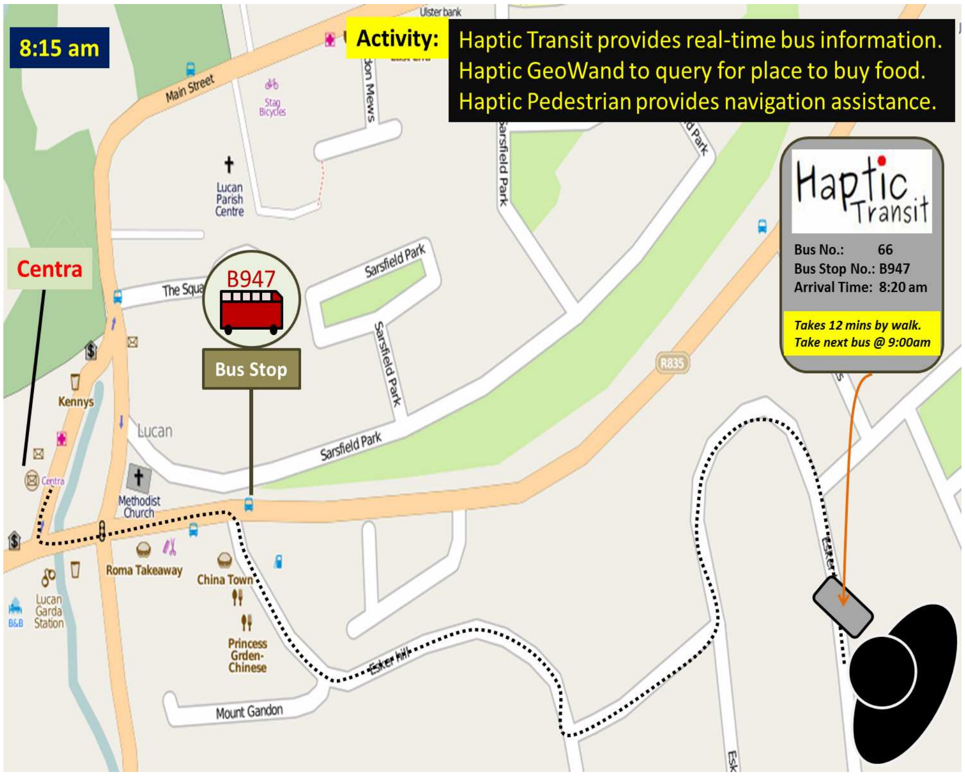


Figure 40: Multiple modes of travel: This is a screenshow of the user querying public transport information using *Haptic Transit* and using *Haptic GeoWand* to query for POIs

varying vibration patterns by using vibration frequency to encode distance information when the user points in the direction of the POI. The *HapticAlert* system provides the user with location specific notifications about information that is important to the user. The *Haptic Pedestrian* system provides navigation cues to get to a particular POI of choice of the user.

4.3.2 Scenario

Oliver just moved to Ireland from Austria and lives in Lucan. He wants to travel to Dublin to visit his friend, Nicole near 'The Porterhouse Temple Bar' on Sunday. Since Oliver is new to the place he uses Haptic assistance for his travel to meet his friend.

It is 8:15am and Oliver runs the *Haptic Transit* system and inputs 'The Porterhouse Temple Bar' as his destination. He then uses the pointing gesture to query for the bus

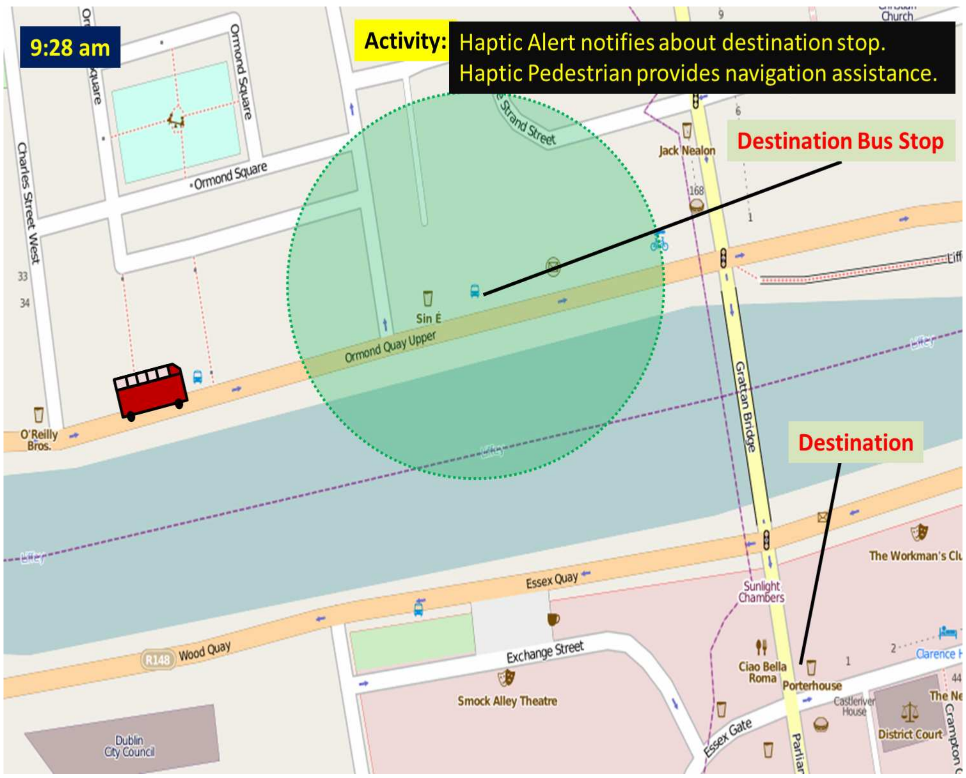


Figure 41: Multiple modes of travel: This is a screenshow of the notification provided to users of *HapticAlert* when they within a short distance from the destination stop.

stop he needs to walk to. It provided him haptic feedback with distance when he was pointing towards the direction of the bus stop (Figure 40). He also gets real-time bus arrival time inforamtion. It provides him information that the next bus arrives in 5 minutes (8:20am) but also added it would take him 12 minutes by walk to reach his destination. Thus the system recommended he start a little later as he would miss this bus and the next bus is only at 9:00am. He then thinks of picking up a cup of coffee and a sandwich before catching the bus to Dublin as he also realised he needed some coins for the bus. He thus uses the *Haptic GeoWand* to search for distance and direction and also navigation assitsance to the nearest shop that is open on Sunday. He found 'Centra' was open and was within walking distance and also close to the bus stop. He gets walking direction to 'Centra' from his home using the *Haptic Pedestrian* system (Figure 40). He reaches 'Centra' by 8:30am, on querying the real-time transit information he learns that the bus is 5 minute late and so will reach the bus stop only at 9:05am. He thus realises he has enough time to finish breakfast and walk to the bus stop as it is only a 5 minute walk from Centra to the bus stop. He reaches the bus stop at 8:58am to wait for his bus to Dublin. Once he boards the bus and buys his ticket, he then keeps the *Haptic Transit* system running as he wants the *HapticAlert* system to notify him when he is nearing the destination bus stop nearest to 'The Porterhouse'. The system displyaed the arrival time at the destination bus stop and since it was a a 30 minute trip, he decided to listen to some music on his iPod and look outside the window to look for interesting landmarks along the way. And then after about 20-25 minutes he got a subtle vibration alert notifying him that he has to get off at the next bus stop (Figure 41). As he began preparing to get off, *HapticAlert* provides stronger vibrations which suggested that he press the 'Stop' button in the bus (for the driver to know that he has to stop) to alight from the bus at the next stop. Once he alights from the bus he using the *Haptic DestinationPointer* to get walking directions to 'The Porterhouse' (Figure 41). He walks across the bridge and reaches the entrance to 'The Porterhouse'. It is about 9:45 now as he meet Nicole they decide to walk through Temple Bar towards Trinity college (Figure 42). After spending 2 hours in Trinity college they decide to go to an Indian restaurant which Nicole's friend had suggested for lunch (Figure 42). So they typed in 'Madina Restaurant' as their destination and used the Haptic Navigator to get walking directions to reach the restaurant. After this, Oliver then used the Haptic Transit system and queried for bus information to get back to Lucan and found a bus stop near Trinity college where he could catch a bus.

In the following chapters we describe the integration of haptic feedback into various

Figure 42: Multiple modes of travel: This is a screenshow of the user getting navigation assitance by using *Haptic Pedestrian*

types of mobile location based services as listed below:

- Knowledge Discovery: Haptic Geowand (Chapter 5)
- Pedestrian Navigation: Haptic Pedestrian (Chapter 6), and
- Notification System: Haptic Alert (Chapter 7)

5 Knowledge Discovery

5.1 Introduction

Knowledge discovery can be defined as the stage 1 activity (referred to in the section 3.6) where the user performs local searches for features nearby to check what/where are the Points of Interest (POIs). Users usually limit their search to features that are within walking distance.

In the past few years, mobile phones have developed into devices not only capable of making and receiving phone calls but can now access the internet via Wi-Fi or mobile networks. The majority of devices called 'smart' phones also come embedded with a GPS receiver as well as other in-built sensors such as a gyroscope, proximity sensor and accelerometer (Robinson et al., 2010b; Robinson and Jones, 2010; Coelho et al., 2011; Jacob et al., 2012a). People use their smartphones to perform local searches to obtain information about various features, for example restaurants, entertainment, retail/grocery, and travel. In the UK alone, 84% of smartphone owners use their device to search for local information with 78% of these users taking action afterwards (GoogleMobileResearch, 2012). This demonstrates the demand for these types of application and their benefit to local businesses and communities. Thus it is beneficial to provide such information about local searches to the user in the most usable format.

In this chapter we discuss the various processes involved in a knowledge discovery system. The chapter deals with how the information from such systems is represented to the user and how haptic feedback can ensure quick decision making when querying such information. We first understand the various sub systems in a knowledge discovery system. The representation of information using visual and non-visual techniques are discussed. Our *Haptic Geowand* model is described and the functionalities and implementation are discussed. We then conclude on how a *Haptic Geowand* can be used as a quick knowledge discovery tool and integrated into other systems.

5.2 Processes involved during Knowledge Discovery

Knowledge discovery is the process where the user looks for local information (usually within short walking distance) about specific places of POIs. The process of finding the relevant information based on the user requirements involves various steps to get accurate and useful information. The first step involves the user performing the query by providing various information like the 'type of POI' they are looking for and the 'maximum distance' within which they wish to find that particular type of POI. Based on these inputs the system queries the database and filters out the results and the information relevant to user is available to be provided to the user. The final step is to provide the query results to the user in an easy to understand way by using visual interfaces or non-visual feedback using audio/haptics.

Knowledge discovery involves three sub-systems:

- the querying process,
- query results filtering, and
- query results representation.

We first discuss these three sub-systems of knowledge discovery in detail with respect to the existing research done in these areas. We then discuss our *Haptic Geowand* system in detail with it's limitations and capabilities.

5.2.1 The querying process

The querying process, or local search, uses the location and/or orientation of the user to provide information/services. In 1999 Egenhofer predicted that various *'Spatial Appliances'* would appear in the future that could be used with gyroscopes and GPS receivers to use both location and orientation information for knowledge retrieval like *Smart Compasses* (Egenhofer, 1999). As compared to query feedback based on location information, orientation information can help provide a filtered set of results to the user. In early 2000 some interesting applications appeared that included orientation information integrated with other types of sensors such as the *AudioGPS* (Strachan et al., 2005) and *M3I* (Wasinger et al., 2003). Since then, there has been a growing interest among the research community in using the orientation of the user (gathered via the digital compass on the mobile device) for querying spatial information (Strachan and Murray-Smith, 2009; Wasinger et al., 2003; Strachan et al., 2005; Pombinho et al., 2010; Robinson et al., 2009a,b, 2010a; Simon et al., 2007, 2008; Lei and Coulton, 2009; Carswell et al., 2010; Shalaik et al., 2011a; Jacob et al., 2012a). Lei and Coulton proposed a pointing gesture-based POI search which also allows users to create additional content for a particular POI in the form of photographs which can be tagged both by location and the direction from which the photograph has been taken (Lei and Coulton, 2009). Thus *pointing gesture-based* mobile interaction technique started to gain importance and popularity.

5.2.2 Query results filtering

The results from a query can be filtered and provided to the user based on various factors. Some of the most popular filtering techniques are based on:

- the distance-range specified,
- the line-of-sight,
- the user-context (physical/social/cultural),
- the opening hours or weather conditions, and
- the reviews and recommendations of others.

Cheng et al. incorporated traffic-information into location-based web searches to filter out the optimum route from the road network data (Cheng et al., 2011). Thus along with traditionally considered factors like distance or popularity, it is also important to consider factors like times of peak traffic in such locations (which can be acquired by mining location sharing service databases).

Carswell et al. used the concept of field-of-view (FoV) to filter out query results (Carswell et al., 2010) to provide more specific information to the user. Thus only information about features that are within the actual line-of-sight is returned rather than all features within a distance range specified by the user. The initial work done on a 360 degree 2D visibility query (Isovist) to filter out information (Figure 43). Carswell et al. describes a pointing based novel querying approach for determining a user's visible query space in three dimensions based on their line-of-sight (ego-visibility) called the 'threat dome' (Carswell et al., 2010). Figure 44 represents a 3D FoV visibility query (frustum).

Sarjakoski and Nivala stressed the need for User Interfaces (UIs) to be adaptable and flexible for each situation (Sarjakoski and Nivala, 2005). Thus good design in Human

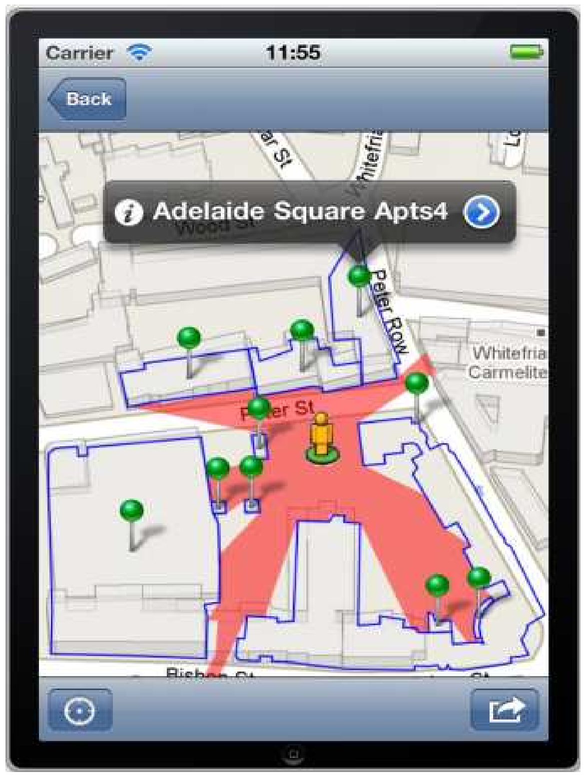


Figure 43: A 2D Isovist query centred on the user with returned query results (Carswell et al., 2010)

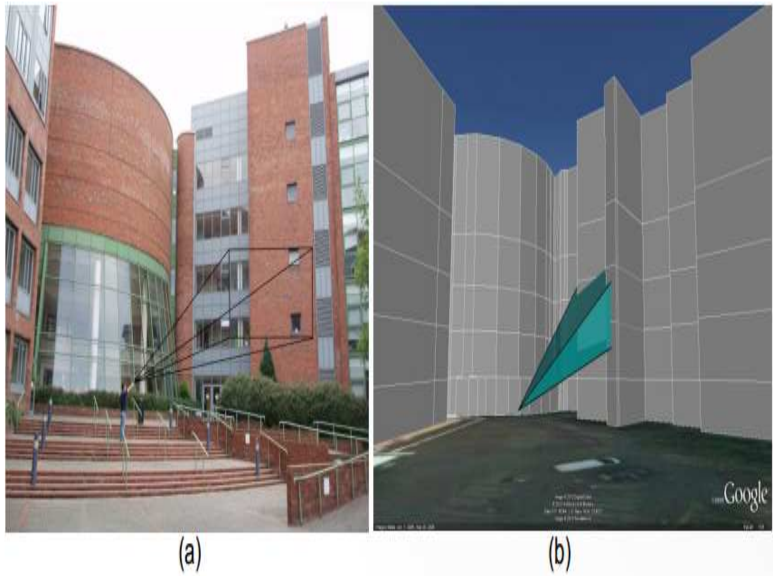


Figure 44: A 3D FoV visibility query (frustum) based on user's pointing gesture. a) A frustum view in the real-world b) Visualisation of the same frustum view inside a spatial database (Carswell et al., 2010)

Computer Interaction (HCI) could be achieved by being sensitive to the context of the user, by providing feedback based on the context.

We will now discuss the various feedback techniques used to provide query results back to the user on mobile devices.

5.2.3 Query result representation using visual feedback

Once a system understands the user requirements and filters search results based on this, the results then have to be represented in an easy to understand way on the user's mobile device. Representing filtered query results to the user can be broadly classified into two categories - visual, and non-visual feedback. In this section we will review the various visual feedback techniques for representing spatial information from such queries.

Choudary et al. describes two approaches for using representative visualizations: artistic views that represent an arbitrary deformation made by an artist, and *perspective views* (3D-like) obtained from 3D models which can be useful in both outdoor environment

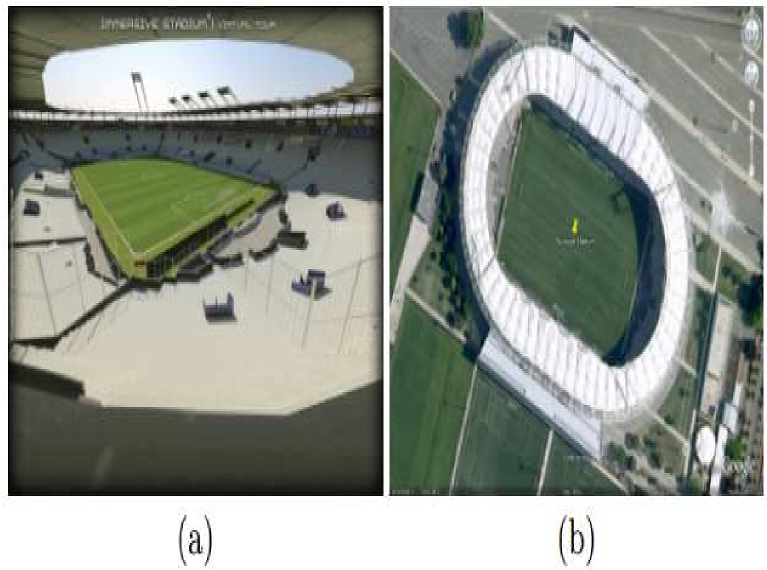


Figure 45: a)Perspective image and, b) aerial photo of TFC Stadium, Toulouse (Choudary et al., 2008)

and venues (Choudary et al., 2008). In Figure 45 we can see a comparison between an aerial photo and the perspective view of the same location (TFC Stadium, Toulouse). Here Choudary et al. show a novel method for positioning the user inside images that are more convenient and familiar than traditional maps. Figure 46 represents the user interface in the mobile device based on the artistic view and the perspective view of the user.

Displaying video clips with augmented location information or to show image panoramas with virtual signpost overlays of important POIs is a technique proposed by Kolbe (Kolbe, 2004). Damala et al. presents an augmented reality based mobile tourist guide for a museum (Damala et al., 2008). An *augmented reality annotation* is virtual information that describes in some way, and is registered to, an existing object (Wither et al., 2006). Figure 47 shows *Wikitude*, a popular Augmented Reality (AR) browser which can be used on mobile devices to provide information to the user (Wikitude, 2012). For mobile augmented reality (AR) users, according to Biocca et al., knowledge of objects, situations, or locations in the environment can be productive, useful, or even life-critical (Biocca et al., 2007).

We have seen the various ways in which information can be represented visually to the

(a) (b)

Figure 46: a) Artistic view user interface b) perspective view user interface (Choudary et al., 2008)

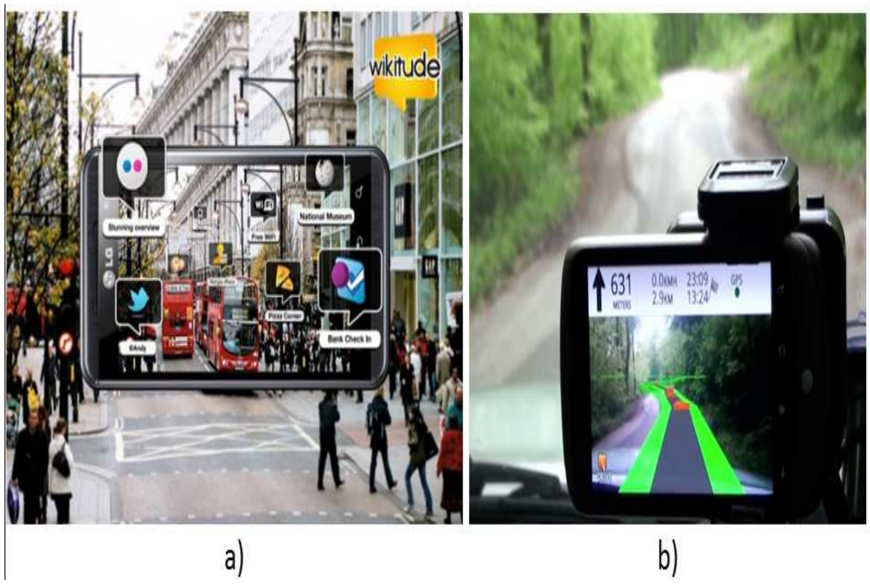


Figure 47: a) Wikitude AR browser b) WikitudeDrive for AR car navigation (Wikitude, 2012)

user. In the next section we look at ways in which such query results can be presented using non-visual feedback.

5.3 Query result representation using non-visual feedback

Due to the relatively small size of mobile screens, during visualisation there are various aspects, such as level of detail, enhancement of data representation and displaying off-screen information, that need to be addressed. Since such location based systems on mobile are used in an outdoor environment with other real-world distractions (vehicles, other pedestrians), it is not always ideal to use such a map based interface on the move.

Various issues concerning mobile devices and interfaces were discussed in chapter 2. With the shortfalls of purely visual mobile interfaces, there is a growing need for non-visual feedback for providing spatial information to the user. Non-visual feedback is primarily delivered in two ways - audio, and haptics. We will now look at how audio feedback is used to deliver knowledge discovery based systems.

Figure 48: Combination of image, text, and audio to give user information (Liu et al., 2006)

5.3.1 Using audio feedback

Moving away from traditional map based feedback, speech based feedback has been used to provide eye-free feedback to the user. Liu et al. proposed a multi-modal indoor navigation system for people with cognitive impairments by using images, audio and text (Figure 48) (Liu et al., 2006). Here speech based audio feedback would provide distance information to the user to features of interest. Flintham et al. discusses the use of the audio channel to provide less direct contextual information about the location details (Flintham et al., 2003).

Apart from speech based feedback, non-speech based feedback has also produced some interesting and positive research. The work by Vazquez-alvarez et al. proposes an *urban sound garden* where both overlapping proximity zones and "spatialized" animal sounds were used to attract the user's attention to particular landmarks in a non-guided exploratory environment (Figure 49). Holland et al. describes the *AudioGPS* where

Figure 49: *urban sound garden*: experimental setup a) sensor used to get orientation of head b) GPS receiver c) mobile device (Vazquez-alvarez et al., 2010)

non-speech audio feedback is used to provide information like direction and distance (Holland et al., 2002b). Here the number of pulses of sound, together with their rapidity, gives an indication of how far it is to the next waypoint.

Heuten et al. provides an interactive 3D sonification interface to explore city maps (Heuten et al., 2006). A visually impaired person can build a mental model of an area's structure by virtually exploring an auditory map at home. Here the geographic objects and landmarks are presented by sound areas, which are placed within a sound room. Each type of object is associated with a different sound and can therefore be identified. By investigating the auditory map, the user perceives an idea of the various objects, their directions and relative distances. The study based on a location based game by Kurczak et al. showed that ambient audio improved player's sense of presence in the virtual world, and increased player's safety, measured here by the number of obstacles they bumped into (Kurczak et al., 2011).

5.3.2 Using haptic feedback

During the initial stages of integration of map applications on mobile devices, the map visualisation techniques that were primarily used for desktop applications were directly used in mobile devices. Looije et al. (2007) highlights some of the major challenges in the usability of map based mobile interaction as it involves interactions like zoom, pan, and, most importantly, visualisation.

The use of haptic feedback along with pointing gesture based interaction has been used for knowledge discovery about the physical environment of the user (Simon et al., 2007; Robinson et al., 2009a,b; Shalaik et al., 2011a; Jacob et al., 2012a). Simon et al. outlines the features of a *Point to Discover* which is a system and application development framework for orientation-aware location based mobile services. Here the user gets geo-tagged information about features they are pointing towards in the real world (For example the name and height of a mountain they are pointing at).

Robinson et al. describes a haptic browsing framework where users can explore and discover POIs that are near their current position. Four different hand gestures with the mobile device were used to browse specific data types - audio, text, images and video (Robinson et al., 2009b). Shalaik et al. develops a pointing gesture based system where users get feedback about public transport information based on the *scanning operation* around the user's physical space using their mobile device. When the user is pointing in the direction of a bus stop, they are alerted by vibration feedback to give the user general heading directions. We thus see the benefits of using haptic feedback as a modality to provide users with spatial information about POIs that are around the user based on their current location.

We have understood some of the uses and benefits of haptic feedback in knowledge discovery by various researchers. We will now discuss our *Haptic GeoWand* system, the interaction model and its implementation and prototypes.

5.4 Haptic GeoWand

Egenhofer (1999) predicted that various 'Spatial Appliances' will be used to query spatial information. They are:

- *Smart Compasses*: provide users information about the direction (orientation) of points of interest,
- *Smart Horizons*: allow users to look beyond their real-world field of view (distant objects),

- *GeoWands*: allow users to retrieve information about nearby objects by pointing at them.

The *Haptic GeoWand* is a low interaction system that allows users to query geo-tagged data along a street or around them by using a point-and-scan technique with their mobile device, it provides information using haptic feedback (Jacob et al., 2012a). This integrates the functionalities of the three *Spatial Appliances* discussed by Egenhofer along with haptic feedback to represent that information. Here the orientation of the user (mobile device) along with the location information and selected POI are used as inputs to the haptics enabled system. Thus, this is a combination of the pointing gesture based queries with haptic feedback to represent the results. Along with the textual description of available near-by objects in the direction the user is pointing, haptic feedback in the form of vibration alarm with varying frequencies and patterns is used. The feedback is provided using haptic feedback to reduce the cognitive burden on the user by delivering quantitative information about the distance/density to interested feature type using variations in vibration frequencies. Figure 50 shows the comparison of the typical 'circular query' used by many LBS as compared to the *pointing-gesture based* 'haptic geowand query'. The circular query returns information about all POIs *around the user* that are within a specified distance. The haptic geowand query on the other hand returns information about all POIs along the *direction the user points* the mobile device and that are within a specified distance.

5.4.1 Haptic GeoWand Model

The *Haptic GeoWand* is a system that helps the user to take quick decisions at road intersections regarding which street to take in order to visit their POI of choice. This system can be extended to work in target finding in an open area environment and also while walking along streets to discover POIs. There is often information overload in the typical visual map interface with overlays showing all the features of interest to the user. Figure 51 represents the *Haptic GeoWand* model. The input to the system is via a visual interface. The user selects the maximum distance he/she wishes to walk in any direction (POI search distance) and the type of feature(s) they wish to visit within that distance. Figure 52 shows how the query region is reduced based on the pointing gesture performed by the user where the user holds the phone parallel to the ground and 'scans' the area. Scanning is performed by moving the phone parallel to the ground along each

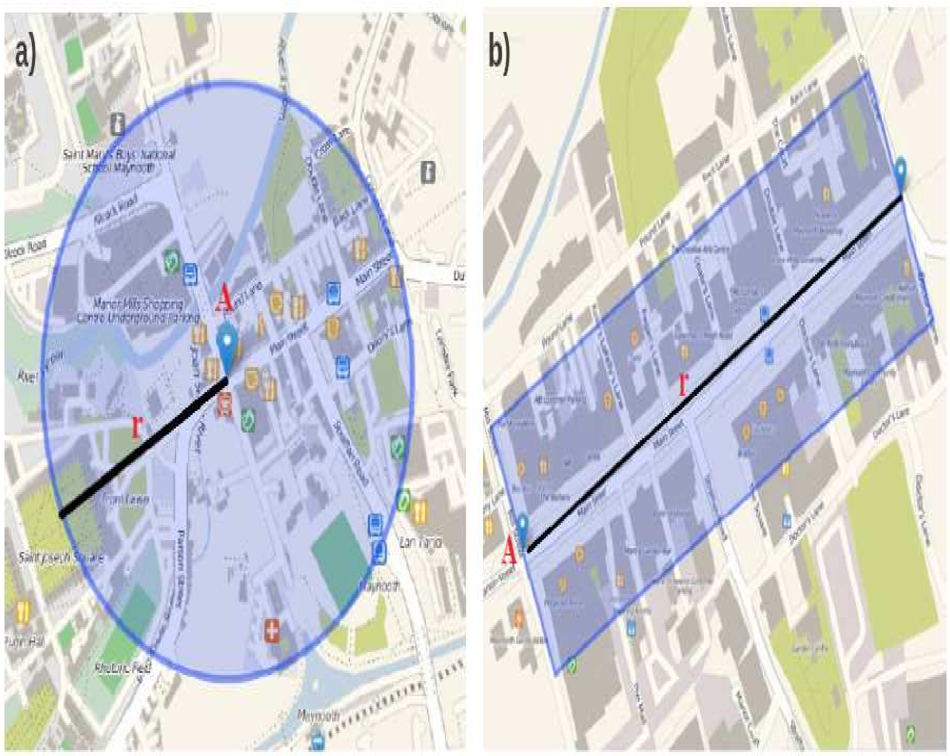


Figure 50: a) The circular query b) The Haptic GeoWand query

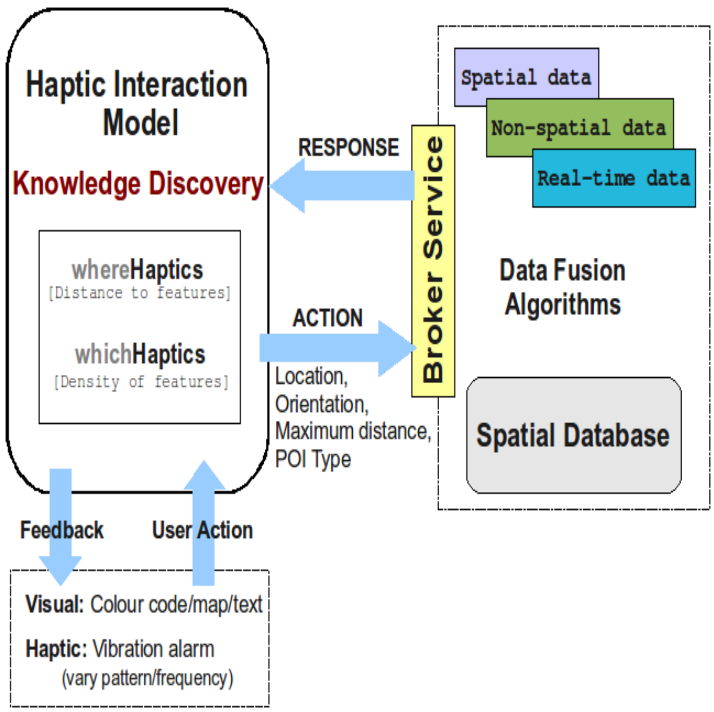


Figure 51: The *Haptic GeoWand* Interaction Model

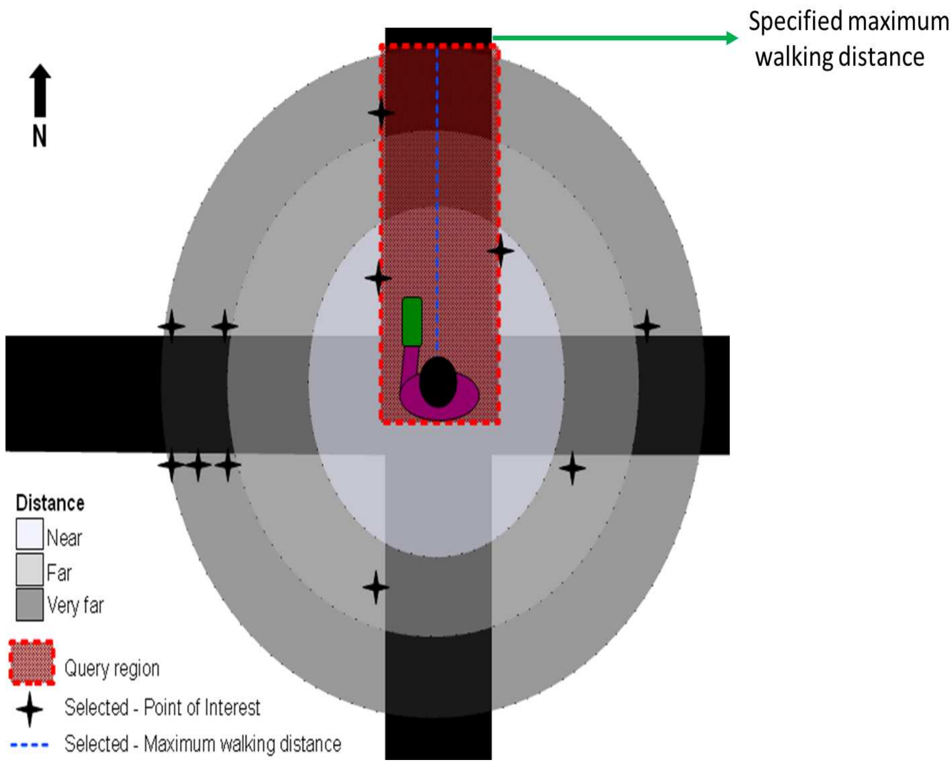


Figure 52: The *Haptic GeoWand* querying process

street from the user's current location. The user's current location and orientation along with the selected maximum distance and type(s) of POIs are sent to the server. The broker service receives these input values and queries the spatial database for matching features. The broker service then sends responses back to the interaction model. This response is provided to the user by various feedback mechanisms. Textual description of the n nearest features with name and distance along a street is provided. Haptic feedback is used for two different types of information requested by the user a) distance to features (nearest) and/or b) density of features (more options).

Information regarding the distance(s) to features is provided by the *whereHaptics* module of the system. Here haptic feedback is used to inform the user about the zone (near, far, or very far) that the features are available along any particular street. Vibration frequency increases from near to very far with distinctly varying patterns ensuring the user is able to understand the feedback without having to look into the mobile. Information regarding density of feature(s) along a street is provided by the *whichHaptics* module of the system. Varying frequency and patterns of vibration are used to inform the user about the density of features/POIs along any given path. This enables the user to check which street he/she should take when they have multiple choices of a particular feature(s) available to them.We will now describe the two *Haptic GeoWand* prototypes in detail.

5.4.2 Haptic GeoWand Prototypes

The Haptic GeoWand has two prototypes that can be a useful to provide mainly two kinds of information. The *whereHaptics* is a prototype used to provide information (via haptic feedback) about distance and *whichHaptics* is the prototype that is used to provide information about density of POIs. Thus these prototypes are used to ensure the user is quickly alerted of the ideal street he/she could possibly take based on choice of POIs and its availability and distance. The user manually inputs the maximum walking distance and POI. Unlike other usual visual interfaces based POI searches where the query range is a circular region around the user of a specific radius; here we see in Figure 50 that the 'query region' is narrowed down based on the direction the user is pointing the device.

The *whereHaptics* prototype is used to provide users with haptic feedback to inform the user about the distance to the feature by providing vibration patterns of different frequencies. Based on the selected maximum distance, *whereHaptics* provides the user with haptic feedback based on the distance to feature. So for the selected distance range D, the three distance zones that are created are:

- a) Near (zone between Current location to distance $\frac{D}{3}$ meters),
- b) Far (zone between $\frac{D}{3}$ to $\frac{2D}{3}$ meters) and
- c) Very Far (zone between $\frac{2D}{3}$ to D meters).

Figure 53 represents the vibration pattern and frequency used by the *whereHaptics* prototype to convey distance information to the user. If the feature is very far away (zone between $\frac{2D}{3}$ to D meters) from the user along a particular street, the user is provided information by high frequency vibration feedback with a distinct pattern of short duration. Vibration of very low frequency is provided if there are POIs which are very close (zone between Current location to distance $\frac{D}{3}$ meters) to the user and a different vibration pattern of medium frequency is used to represent distances from the

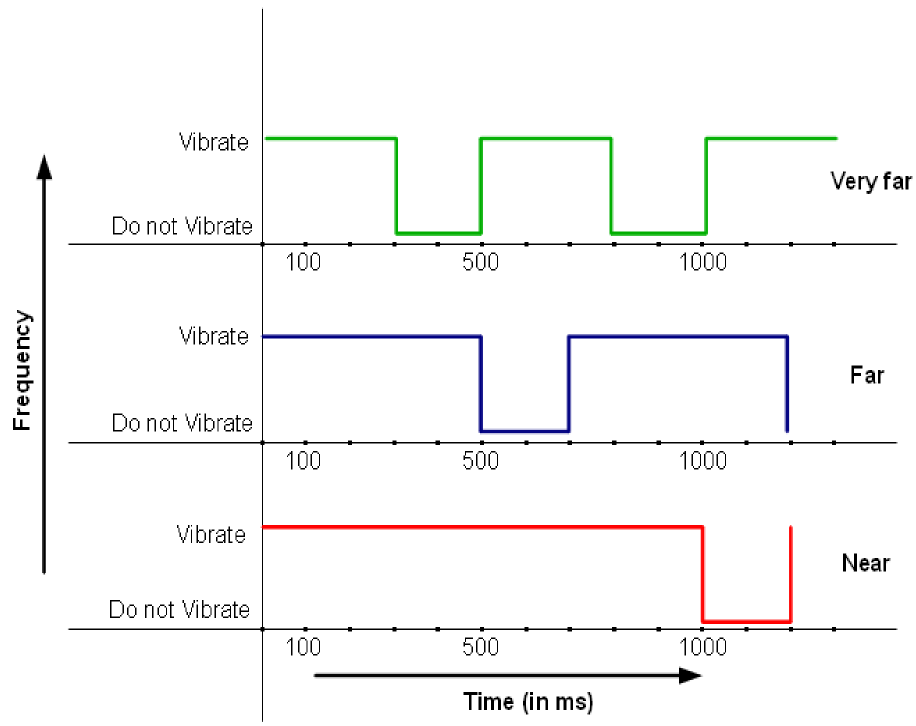


Figure 53: The haptic feedback provided by *whereHaptics* for 'distance to features' information.

user which is not very close (zone between $\frac{D}{3}$ to $\frac{2D}{3}$ meters). The varying pattern and frequency of the vibration alarm (Figure 53) is used to provide distance information to the user.

The *whichHaptics* prototype is used to provide users with haptic feedback to inform the user about the density of features by providing vibration patterns of different frequencies. Based on the selected maximum distance, *whichHaptics* provides the user with haptic feedback based on the density of features along the pointing direction. So for the selected distance range D with minimum features n, the three density ranges that are created are:

- a) Many (greater than n features along that direction),
- b) Few (2-n features along that direction) and
- c) One (Just one feature along that direction).

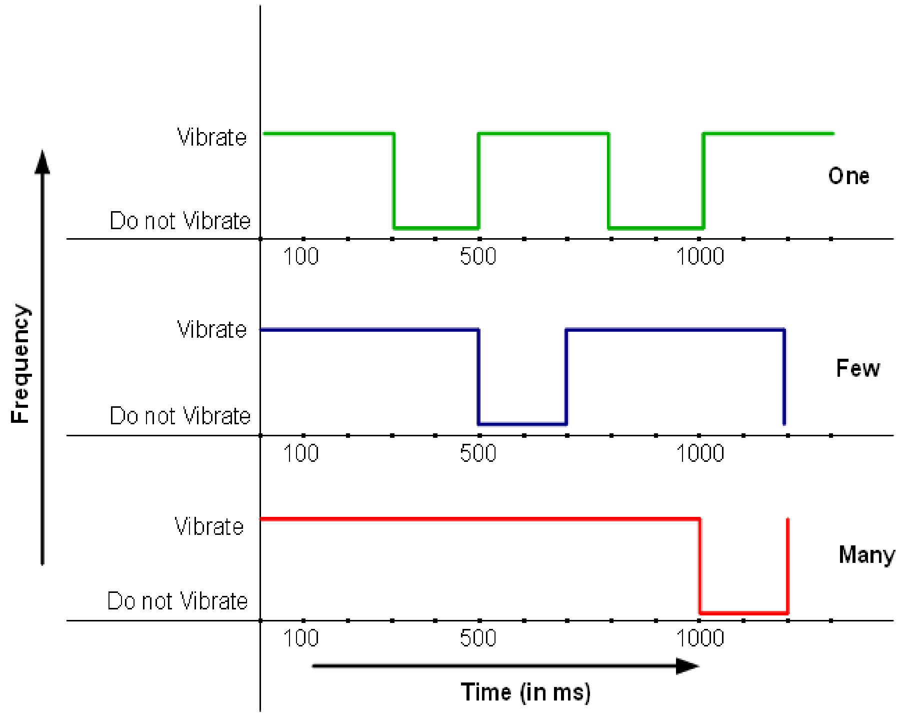


Figure 54: The haptic feedback provided by *whichHaptics* for 'density of features' information.

Figure 54 represents the vibration pattern and frequency used by the *whichHaptics* prototype to convey density information to the user. If there is only one feature (just one feature) along a particular street, the user is provided information by high frequency vibration feedback with a distinct pattern of short duration. Vibration of very low frequency is provided if there are a few POIs (between 2 and n features) exist along a particular street and a different vibration pattern of medium frequency is used to represent density of features when many (more than n features) exist along a particular street or pointing direction. The varying pattern and frequency of the vibration alarm (Figure 54) is used to provide density information to the user.

5.4.3 Implementation of Haptic GeoWand

The smartphone running on the Android operating system that has an inbuilt GPS receiver, digital compass, and an accelerometer was used to implement the system.

The Android Software Development Kit (SDK) enables us to customise the vibration alarm pattern and frequency. Thus by varying the frequency and vibration pattern, we can provide meaningful information to the user. The geographic data used to test the system was OpenStreetMap. A version of the Ireland OpenStreetMap database was stored locally on our server in a PostGIS database. OpenStreetMap provides us with a rich spatial dataset to test the application. However, we have designed the application with flexibility to access other sources of vector spatial data if available. In our system we log a number of important variables: the location, the orientation of the user's phone, and the accelerometer reading. These log files are retained and used for further analysis. The ability to integrate all the sensors into an off-the-shelf smartphone has allowed quick development and implementation of the system. The three methods providing control of the vibration of the device through the android SDK (GoogleAndroid, 2012) are:

- `public void cancel()`
- `public void vibrate (long[] pattern, int repeat)`
- `public void vibrate (long milliseconds)`

To understand the query in detail, let us consider as an example: a user at a particular location using the *Haptic GeoWand* query (Figure 52). If the user chooses *whereHaptics*, the varying pattern and frequency of the vibration alarm (Figure 53) is used to provide distance to features information to the user. The user gets low frequency feedback (1000ms long each) when he user points towards the north. The user will obtain feedback of medium frequency (500ms vibration with 200ms intervals) when the user points towards east or south and will obtain very high frequency feedback when they point towards the west. In this case all of the POIs fall in the outermost zone and thus are farthest away from the user.

If the user chooses *whichHaptics*, the varying pattern and frequency of the vibration alarm (Figure 54) is used to provide density of features information to the user. The user gets low frequency feedback (1000ms long each) when the user points towards west as it is along east where there is the highest density of POIs within the specified 'maximum walking distance'. The user will get a varying pattern (300ms vibrations with 200ms intervals between them) of high frequency when they point towards the south direction as there is only a single POI of the selected category along that street.

In both the *whereHaptics* and *whichHaptics* prototypes the visual feedback provides names and distances of the nearest POIs along a particular direction. The user may or may not choose to use the visual interface and instead chooses to walk in the direction based on the haptic feedback received. As they walk in the chosen direction the names and distances are updated on the visual interface.

5.5 Summary of Haptic GeoWand as a tool for Knowledge Discovery

Haptic GeoWand integrates haptic feedback to provide a "point to query" scanning application which reduces the visual interaction required with the mobile device. Scanning the immediate area around the current location is a very simple physical task. There is a reduction in the overall time the user must be attentive to the mobile screen for information. They are only required to "look down" into the screen when there is some relevant, additional, information displayed. The user in the meantime can be attentive to their actual physical environment. Integration of haptic feedback with the pointing gestures for querying is showing great potential as an effective communication tool in situations when a visual interface is not appropriate to use. A multi-modal system for user interaction brings the added advantage of choosing one modality over the other when either one is not-appropriate. In the Haptic GeoWand, the user can choose haptic-feedback and/or the more traditional text-based feedback or mobile map use. We believe that there is now a trend which looks beyond the location-aware system to more orientation and context aware interactive applications. (Sjolinder, 1998) summarises spatial abilities as the cognitive functions that enable people to deal effectively with spatial relations, visual spatial tasks and orientation of objects in space. With Haptic GeoWand, we see that the cognitive burden on the user is reduced the interaction with the visual interface in minimal here. The users are quickly and easily able to orient themselves in the direction of the destination and thus improve their spatial abilities. The application relies heavily on GPS signal accuracy and continuity along with uninterrupted internet connectivity.

Haptic GeoWand based pointing and scanning to query for location of interest and obtaining feedback in the form of haptic feedback can be useful to the user. So once the user queries and finds POIs or the destination where they need to go to, the user would like to be presented with information to provide navigation assistance to get to that particular POI/destination. In chapter 5 we look at how pedestrian navigation information can be provided along with some of the benefits and shortfalls of such information representation techniques.

6 Pedestrian Navigation

6.1 Introduction

Pedestrian navigation is the physical task of getting from one location to the other by foot with or without navigation aids. In the previous chapter we described how a user can query for information about POIs or find a destination. Travelling from one location to the other with assistance from car navigation systems is extremely popular and these provide people with a map and audio feedback for route description. However, the use of such navigation assistance systems on mobile devices by pedestrians has resulted in no single, most suited technique of delivering this information.

In this chapter we discuss the various steps involved in using mobile pedestrian navigation systems to travel on foot from one place to another. We describe the key benefits of using visual interfaces to represent this navigation instruction. We also discuss the issues about how such visual interfaces can be unsuitable in certain situations. We propose in detail how haptics can be an important way of representing navigation cues to the user, including a description of some prototype systems.

6.2 Processes involved during pedestrian navigation

Pedestrian navigation can be defined as a stage 2 activity as described in Section 3.6. There are various subsystems/steps involved in a pedestrian navigation system:

1. Query processing to find the optimal route
2. Representation of navigation details on the mobile device
3. The physical task of walking to the destination

Conventional mobile pedestrian navigation applications present the user with position and orientation details visually using a map with various layers of information. Generally, the shortest pedestrian route is overlaid on the map. Text-based turn-by-turn instructions are also provided. In the following sections we will look at the route types that the users query, the various visualisation techniques of the route information and also the challenges involved for mobile device users in the actual physical activity of walking from a given origin to the desired destination.

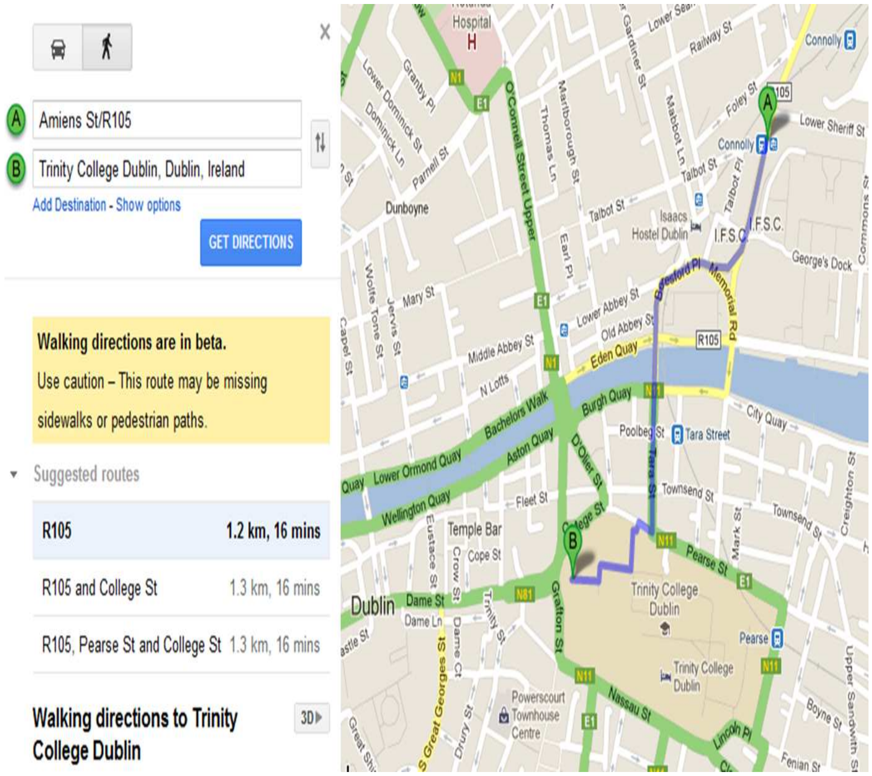


Figure 55: Shortest path between the given two points according to Google Maps.

6.2.1 Query processing to find an optimal route for pedestrians

While processing the user queries and calculating the optimal route for pedestrians is outside the scope of this, we describe some of the existing ways in which this is performed. In our work, we use some of the existing web services that provide optimal routes between any given two points. The initial step involved in pedestrian navigation is the user selecting the kind of route they wish to take. By default most systems provide the least cost path taking into consideration the walking distance and time taken to walk that distance, for example as provided by Google Maps (Figure 55). Since Google Maps do not have all the side-walks and pedestrian paths mapped, it usually provides routes very similar to the one used by car navigation systems. This is not always the optimal path that a pedestrian should be taking as warned by Google (Figure 55).

Humans are not always inclined to use the shortest or least time path (Golledge, 1999; Hochmair, 2004). Therefore users need to be offered the possibility of selecting between a wide range of other least-cost criteria. The path network can be attributed with environmental metrics such as pollution, noise levels, and weather measurements. Some of these may be collected by the mobile device itself. By collecting this input data, a network can be produced to provide routes that are:

- the shortest (based on the shortest distance between current location and destination),
- the nearest (based on the shortest time taken to reach a destination on foot),
- the cleanest (based on sensors collecting pollution/gases data),
- the quietest (based on the noise levels along various streets/pathways),
- the driest (based on integration of indoor/outdoor data when it is raining),
- the greenest (based on data about tree/parks/water bodies along the way),
- the most scenic (based on location of interesting features or scenic landscapes along the route),
- the most accessible (based on wheel chair access/elevators, etc.), among others.

Kammoun et al. (2010) argues that although usually, path selection for pedestrians is assumed to be the result of minimizing procedures such as selecting the shortest or the quickest path, for the blind a longer route can be more convenient to avoid various difficulties. Therefore there are various possible path options to get from any given origin to the destination of choice. Once the path to be taken has been selected based on the criteria suitable to the user, the next challenge is to convey this information in an easy to understand manner on the mobile device to provide navigation assistance to the user.

6.2.2 Representation of navigation assistance on mobile devices

Representation of navigation information describing route details for the user on mobile devices is an important and challenging task. Various forms of map based route overlay techniques are commonly used along with integration of geo-tagged photographs, panoramic images, landmark information, textual route description, and augmented reality. Raubal and Winter discussed the use of landmark information to enrich the route following instructions for users (Raubal and Winter, 2002). Here, along with the route description to get from waypoint-to-waypoint, the authors have integrated landmarks along the route to provide the user with additional information to assist in navigating to their destination.

Miyazaki and Kamiya propose that low processing power and quick data delivery are requirements for pedestrian navigation on mobile phones using 3D maps (Miyazaki and Kamiya, 2006). This pedestrian navigation system uses panoramic landscape images to provide navigation assistance. Hile et al. present a system that uses an online collection of geo-tagged photographs to automatically generate navigational instructions for the user (Hile et al., 2008). This is presented to the user as a sequence of images of landmarks augmented with directional instructions embedded within the image view. While using the *PhotoMap*, the interaction technique is of the user clicking photos of a public paper map and then using this photo for navigation (Schöning et al., 2009). Here the users have to geo-reference the photo they click and also align so that it can help them with navigation with the help of the 'You are here' red pin on the map. Mulloni et al. describe a novel design of an augmented reality interface to support indoor navigation (Mulloni et al., 2011). Here activity-based instructions (e.g.: *take 10 steps and turn right*) with sparse 3D localisation at selected info points in the building are used. The interface adapts the visualisation by changing the density and quality of information shown based on the users current activity - walking or standing still.

We next try to understand what the challenges of such systems are and why at times they are unable to be useful in the real-world while walking.

6.2.3 Wayfinding task and cognition for pedestrians while walking

Wayfinding is defined as "the process of determining and following a path or route between an origin and destination" (Lynch, 1960; Golledge, 1992, 1999). Wayfinding is something people encounter very often in their day to day life. Humans solve wayfinding tasks such as search, exploration, route following, or route planning in contexts including outdoor and urban environments, indoor spaces and virtual reality simulations (Wiener et al., 2009). The main aspects of human wayfinding for a person is knowing where they are, where they wish to go and the way they need to take to get to that place. To do this, humans use previously acquired knowledge of the route, and also their own spatial awareness and ability to tackle such tasks in the real-world. Siegel and White described three stages in acquiring wayfinding knowledge (Siegel and White, 1975):

- identification of landmarks,
- forming procedural route knowledge, formed when travelling between two landmarks, and
- forming structural survey knowledge, which is equivalent to inferring a map.

An individual's sense of direction could be important to all of these methods. Cornell et al. states that a person with a good sense of direction may be better able to look for areas likely to contain landmarks and can use that information to direct actions at intersections on routes (Cornell et al., 2003). They add that this is possible as a good sense of direction can provide a reliable reference bearing when an individual is registering the degree of a turn. Use of visual interfaces will take away the ability (or makes it difficult) to notice landmarks along the path and update one's cognitive map. This will hamper the orientation ability based on their mental representation of a configuration of landmarks to match the scene they are viewing even though they have a good sense of direction.

A person's cognitive map, or knowledge of large-scale space, is built up from observations gathered as he travels through the environment. It acts as a problem solver to find routes and relative positions as well as describing the current location (Kuipers, 1978). Depending on the modes of information available to humans and by considerations of efficiency and aesthetics, they are capable of using a variety of methods for wayfinding (Golledge, 1999). Wickens in the *Multiple Response Theory* (MRT) illustrates how different tasks will need to tap into similar resources (Wickens, 1992). Wickens adds that cognitive resources are limited and a supply and demand problem occurs when the individual performs two or more tasks that require a single resource. A typical example here is using vision for mobile services providing navigation and the actual physical task of walking to avoid obstacles (including physical objects and other incoming pedestrians along the way).

Context can be defined as "the set of environmental states and settings that either determines an application's behaviour or in which an application event occurs and is interesting to the user" (Chen and Kotz, 2000). Chen and Kotz defined two classes of context-aware computing: active and passive, in which the first influences the behaviour of an application by automatically adapting to the discovered context. By passive context awareness they mean that an application presents new or updated contexts to an interested user or makes the context persistent, enabling the user to retrieve and use

Figure 56: Use of signboards to: a) provide users with directional information towards landmarks and b) provide distance information along with direction.

it later. The use of various interaction techniques providing directional information to the user can be used to help the user integrate such systems into their day-today lives.

Mobile Spatial Interaction techniques and presentation of such information on mobile terminals with fairly small screen size was and still is a big challenge. The need to ensure that the user can also attend to other tasks while on the move and using such location based services is also important. A major goal is to minimize user interaction through service adaptation, and to provide context-sensitive and personalized information to the user (Raubal and Winter, 2002). Krum et al. adds that most of the issues regarding use of geo-spatial applications require revised approaches to interaction design (Krum et al., 2007). However once these applications are designed, keeping in mind that the interaction and use of this system are secondary tasks, more people will integrate such systems into their day-to-day lives.

The use of direction information in signage at road intersections has been used in various places over the years to give the user a sense of direction towards his/her destination. Some provide only direction information whereas others provide distance information along with direction (Figure 56). This helps the user re-orient and head along the direction required to reach their destination. Sweeney Research describes the road signage for pedestrians to cater for both micro-minded and macro-minded pedestrians (Sweeney Research, 2010). Micro-minded pedestrians are those who prefer prompting and continual guidance required for reassurance and security; Macro-minded pedestrians looks for detail required for empowerment and knowledge. This kind of information used for road signage can be incorporated into mobile devices providing pedestrian navigation services. For pedestrians with a macro-mindset, visual interfaces on mobile devices are suitable for providing information like detailed street maps, contextual maps, pictogram, street names, public transport and landmarks. For pedestrians with a micro-mindset, non-visual interaction techniques can be more useful for providing information like continuous directional information, information about arrival at an important waypoint or landmark, and low level information like distance information (e.g.: near, far or very far). When we develop a mobile wayfinding system we should cater to both the macro and micro-mindset.

Stark et al. adds that the degree of freedom in pedestrian movement is one of the most important features as pedestrians are not constrained (and would not like to be) to the road network (following car lanes, road restrictions and so on) unlike drivers (Stark et al., 2007). Apart from paved walkways, there are other walking areas such as grasslands, parks and open ground where pedestrians can walk freely and are not constrained to following a fixed path. They also add that new path finding algorithms and route following pedestrian navigation systems must be used to help pedestrians while also considering the degree of freedom in pedestrian movements.

6.3 Non-visual feedback for navigation assistance

While visual interfaces (as seen in section 6.2.2) can provide navigation assistance by calculating route information and delivering it on mobile devices, the physical task of walking from one place to the other and simultaneously use assistance from a mobile device can be quiet challenging.

We have seen that the use of pure visual interfaces is not optimal at all times. With pure visual interfaces, we see shortfalls as they expect high levels of interaction by the user. A need for users being able to switch between interaction modes based on the current context is very important based on the physical conditions while navigating. Thus the need for a multi-modal mobile spatial interaction technique is essential. Multi-modal interaction techniques can help users switch between one form of interaction to the other as the context of user demands.

A multi-modal system should be flexible to give the user the ability to easily switch between various modalities, from a visual interface (map/textual display/icons overlay) to non-visual modalities like audio and haptic feedback. The user can thus use a map based system to understand locations of various POIs when he/she is able to devote full attention to the visual interface. When the user is on the move, they can switch to non-visual interaction techniques to ensure less attention on the device and being more attentive to the physical environment they are navigating. We now look at how audio and/or haptic feedback can be important non-visual modalities to deliver navigation information to the user.

6.3.1 Using audio feedback

Holland et al. present a backpack mounted *AudioGPS* providing audio feedback (via speech based audio) to the user to help in navigation (Holland et al., 2002c). On the other hand Strachan et al. (2005) describes the first prototypical implementation of a system, *gpsTunes* which adapts the music currently playing, in order to guide a user to a desired physical location (Strachan et al., 2005). The drawback with such an application is the need for the user to have their sense of hearing fully involved to understand the feedback along with the requirement to carry the backpack mounted application.

Bartie and Mackaness (2006) highlight some of the key advantages and disadvantages of using a non-visual feedback system like speech-based audio. The key benefits listed were low power consumption as compared to LCD, accessibility to the visually impaired, and security. Some of the main disadvantages included speech recognition errors in noisy environments, user's accents and speed of voice affecting understanding (system coaching required), no browsing of the information and unavailability to hearing impaired. Erp et al. believes that an interaction model for mobile devices should contain characteristics such as:

- being customisable based on the activity the user is involved in,
- delivering easily understood interaction cues, and
- not overly interfering with the user's current activity.

In situations when vision-based or audio-based feedback for pedestrian navigation is inappropriate, we believe that haptics can provide feedback for navigation/ route following to users in real world situations. We will now discuss some existing haptics enabled pedestrian navigation systems.

6.3.2 Using haptic feedback

Erp et al. describes waypoint navigation with a vibrotactile waist belt where there are eight tactors around the user's waist to represent the eight directions (Erp et al., 2005). The distance is translated to vibration rhythm and the direction is translated into vibration location on the belt. They found that while mapping waypoint direction on the location of vibration is an effective coding scheme that requires no training, coding for distance does not improve performance compared to a control condition with no distance information.

To help the visually impaired in wayfinding tasks like orientation, Amemiya and Sugiyama (2009) developed a haptic based novel method called the "pseudo-attraction force" technique where perception of force is used as an indicator of direction (Amemiya and Sugiyama, 2009). Robinson et al. uses a technique where people are guided in the general direction of their destination via vibration (Robinson et al., 2010b). Here by varying feedback based on the potential for taking alternative routes, additional exploratory navigation is stimulated where people do not have to stick to a pre-defined route. Pielot et al. describe an android smartphone based system called the *Pocket Navigator*. Here the users can leave the device in the pocket while being guided non-visually through vibration. For navigation, distance and direction information to the next waypoint is provided by encoding its direction and distance in vibration patterns (Pielot et al., 2010).

In the experiments carried out by Amemiya and Sugiyama (2010), they found that the haptic direction indicator allowed people with visual impairments to walk safely along a predefined route at their usual walking pace without any previous training,

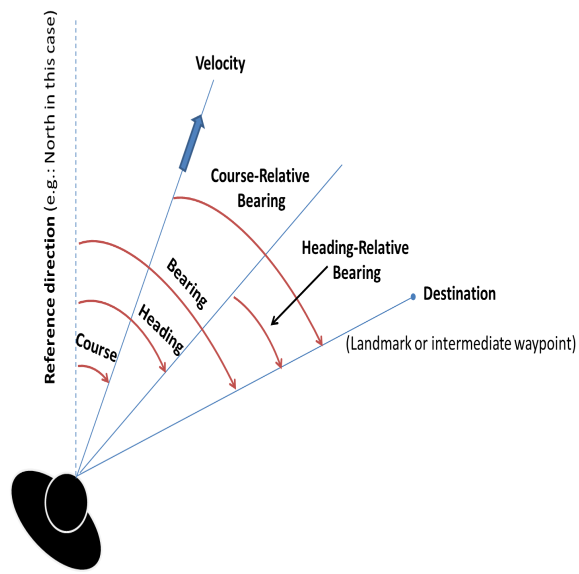


Figure 57: Depiction of various navigation terms used in this chapter adapted from Loomis et al. (1999).

independent of the existence of auditory information (Amemiya and Sugiyama, 2010). The findings indicate that the haptic direction indicator is effective at delivering simple navigational information, and is a suitable substitute for and/or enhancement to conventional wayfinding methods.

6.4 Haptic Pedestrian Model

A slightly modified depiction of various navigation terms described by Loomis et al. (1999) is used (Figure 57). *Destination* is the location that is selected by the user to get from the current location (*origin*) of the user. The instantaneous velocity of a traveller, depicted by the velocity vector (Figure 57), has two components: the direction of motion over the ground, referred to as *course*, and the velocity magnitude, referred to as *speed*. The *reference direction* which is used to define the course (based on an angle) is usually based on true north or magnetic north (the direction a compass points toward the magnetic north pole). The *velocity vector* shows the direction of course of the user with respect to the reference direction (North in this case).

In our haptic interaction model, *heading* refers to the compass value on the mobile device obtained from the user's pointing gestures. *Bearing* refers to the direction from any

Figure 58: The user performing the *scanning* operation.

given point to the destination which is measured with respect to the reference direction. The bearing from point A to point B is the angle between the reference direction and a straight line from A to B. Loomis et al. also adds that if one knows the bearing of an unseen desired destination, one steers a course equal to its bearing. *Bearing difference* refers to the difference between two bearings from a common origin; thus, for two visible landmarks, the bearing difference can be measured without knowledge of the reference direction. According to Beall and Loomis, *heading-relative bearing* refers to the direction from a traveller to some other location (destination or landmarks), measured with respect to the traveller's *heading* and *course-relative bearing* refers to the direction from a traveller to some other location, measured with respect to the traveller's *course* (Beall and Loomis, 1996).

While location information is useful in helping to provide navigation assistance, the availability of bearing and heading information can ensure more useful data with respect to user movement. The availability of information like bearing and heading can help enhance the service provided to the user. Jacob et al. describes four different user interaction models for pedestrian navigation using haptic feedback (Jacob et al., 2011c). Here the users can query for spatial information by performing the scanning operation by pointing gestures with the mobile device (Figure 58). By varying the vibration frequency and pattern different distance information along with directional information

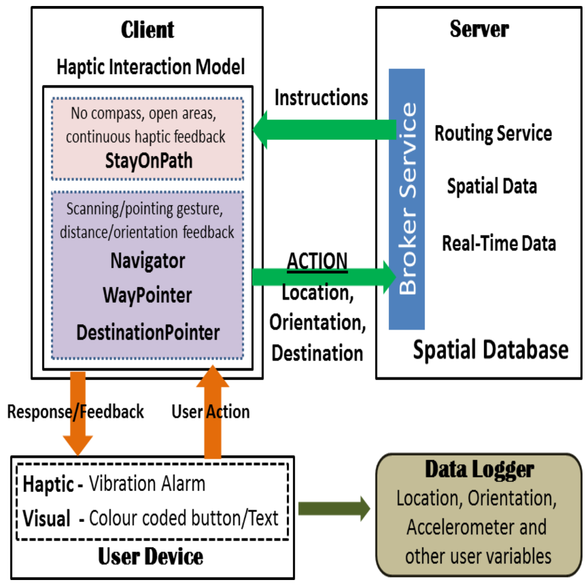


Figure 59: HapticPedestrian: pedestrian navigation model using haptic feedback.

could be easily provided. The pedestrian navigation prototypes considered various ways in which the user could be provided with navigation assistance based on various methods like:

1. Hot and cold technique (HapticStayOnPath),
2. optimal path waypoint-by-waypoint navigation method (HapticNavigator),
3. general shortest path heading method (HapticWaypointer), and
4. navigation via direction information about general heading towards the destination (HapticDestinationPointer).

The haptic interaction model for *HapticPedestrian*, the system that provides navigation cues for pedestrians on the move, encompasses these four different interaction methods (Figure 59).

The spatial database that resides on the server integrates the routing service, spatial data, non-spatial data, real-time data and other data sources to help provide the user with spatially rich information. The user performs actions in the client side of the model through a mobile device and these user instructions and other input data is sent as actions to the broker service. The input data includes location, orientation and other data like the user destination and the type of assistance prototype chosen. The broker service acts as the pathway where data to the server acts as input (actions) and processed information from the server acts as output (instructions) is sent. Based on the input from the client to the server through the broker service, and the processing of the data on the server, instructions are sent back to the client. These instructions that are provided as feedback to the user through a mobile device are provided via visual cues - colour coded buttons, and textual feedback, and via non-visual feedback in the form of haptic feedback. When the user does not have internet connectivity, these features and functionalities should work in an offline environment. The data logger module ensures information is locally stored on the device and is accessible and it works without disrupting the navigation assistance for the user.

The four prototype/subsystems provide information based on the different user interaction and feedback types. These prototypes and their interaction techniques are now described in detail.

6.4.1 Haptic StayOnPath

The *Haptic StayOnPath* is a prototype which uses only the current location of the user to guide them along a pre-calculated route (Figure 60). By modulating the frequency of the vibration alarm we are able to convey messages about deviation from the shortest path to the user. While the user navigates from the current location to the desired destination, short pulses of uniform vibration pattern helps the user understand that the user is within the inner track of the shortest path between the origin and the destination route. As the user moves away from the inner track to the outer track, the intensity of vibrations help the user understand that they are moving away from the desired path and if the intensity of vibration changes to stronger vibrations, it shows the user has moved outside the outer track and now needs to reorient to move towards the destination. The continuous vibration alerts the user about arrival at the destination. The user can choose to just casually hold it in their hand or put it in their jacket/pant pocket and be alerted as they walk towards the destination.

The user is initially at an origin point, O which is at a distance d from the destination, D. The shortest path between origin, O and destination, D is stored as a line string L. Buffer zones are created around the track - inner track, I_t with a buffer distance of I_d

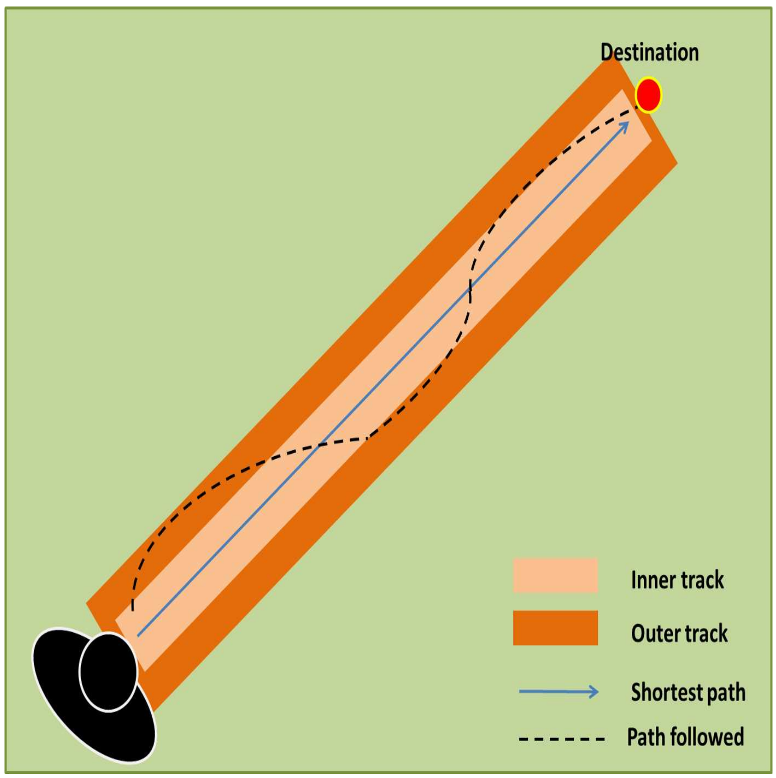


Figure 60: Haptic StayOnPath: prototype using the hot/cold technique.

from the line of travel (L) and the outer track, O_t with a buffer distance of O_d from L. When the user walks from the origin towards the destination, based on the distance and deviation from the shortest path, the user is provided with feedback both visual (colour coded buttons and distance displayed on screen) and non-visual (haptic feedback using varying vibration patterns).

The Haptic StayOnPath prototype could be used as a navigation aid for visually impaired pedestrians or users trekking/hiking and must follow a predefined route. In hiking/trekking situations it is sometimes impossible to find easily identifiable landmarks making Haptic StayOnPath a very suitable candidate for use. The key features/functionalities of this prototype are:

- No Compass used.
- Works using the 'Hot/Cold' technique.
- Phone can be held in the hand or put in the pocket
- Could be useful while walking across open areas.
- Continuous feedback as you walk along a path.

We looked at how haptic feedback can be used to provide users with navigation assistance when there is no availability of a digital compass and just the location information along with the bearing of the device is used. The following three sections describe prototypes that are categorised under "HapticCompass", as they utilise the current orientation of the user/device along with the location of the user/mobile device.

6.4.2 Haptic Navigator

The *Haptic Navigator* is a waypoint-to-waypoint navigation assistance system which provides users with information about general walking direction to the next waypoint using haptic feedback and simple visual cues. A waypoint is defined as a node in the path where the user must change the direction of movement, such as an intersection (Figure 61). Typically users would view the map (paper or digital) and then try to reorient themselves in the direction of movement by comparing the buildings or landmarks represented on the map to the features they see around them.

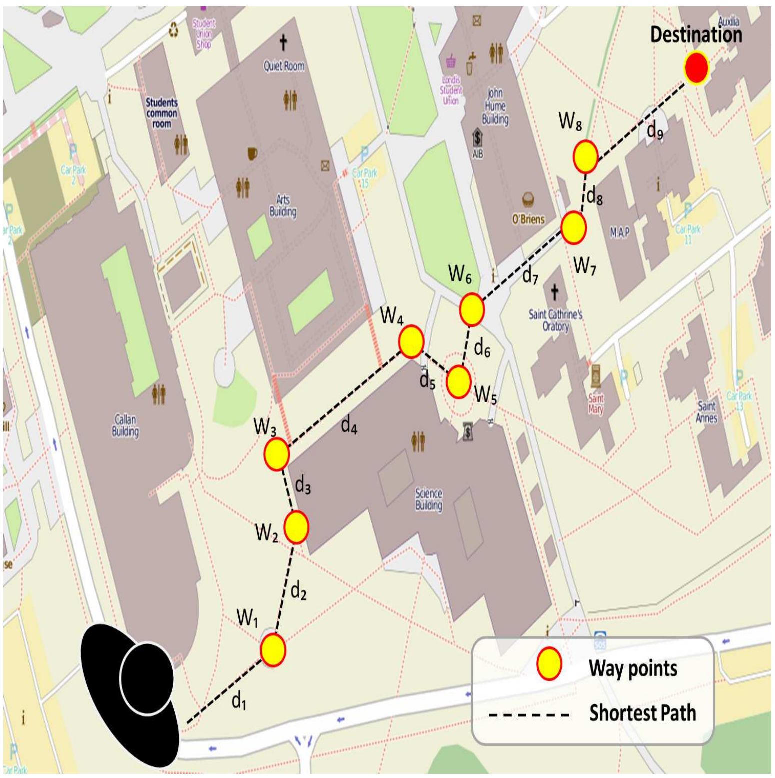


Figure 61: Haptic Navigator: prototype using the waypoint by waypoint navigation.

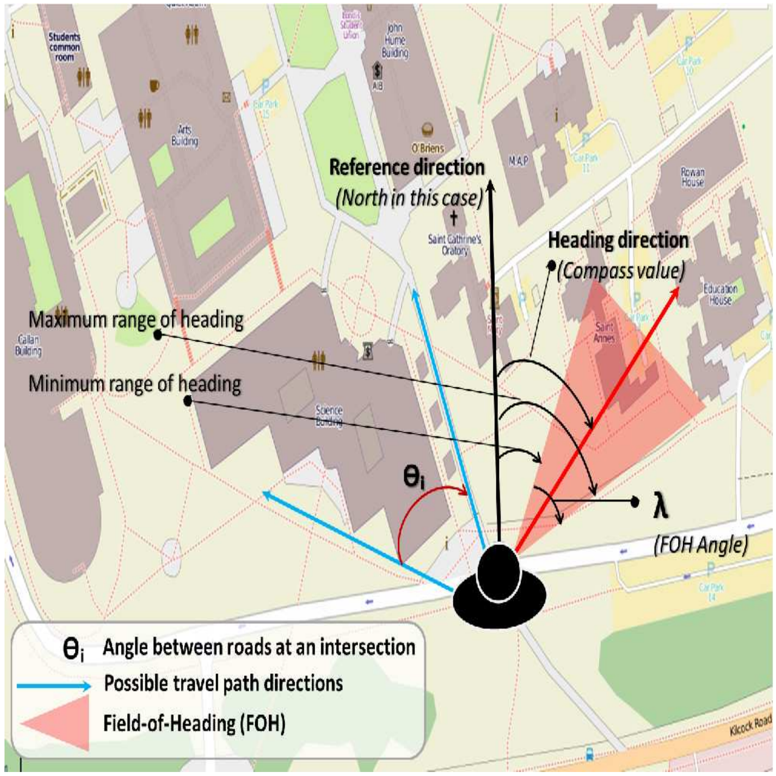


Figure 62: *Field of Heading* (FOH): Maximum heading range to provide accurate direction information.

The user is initially at an origin point, O which is at a distance d from the destination, D. The shortest path between origin, O and destination, D is stored as a line string L. The user traverses all the intermediate waypoints represented as W_1, W_2,... W_{n-1}, W_n before reaching the destination, D through the path, L. The way points between the origin and destination are W_1, W_2,... $Wn - 1$ that are each at distances d_1, d_2,... d_{n-1},d_n from each other (Figure 61). The bearing from the origin to the first waypoint is b_0, the bearing from the first waypoint W_1 to the next waypoint W_2 is b_1 and so on until the last waypoint where the bearing from the last waypoint W_8 to the destination D is b_8.

Field-of-Heading (FOH) is the range of the heading based on the compass value of the mobile while performing the pointing and scanning gesture. The Field of Heading Angle λ is calculated as the difference between the maximum range and minimum range of heading (Figure 62). The angle between any two paths originating from an intersection is represented as θi. In order to provide accurate directional instruction, the value of

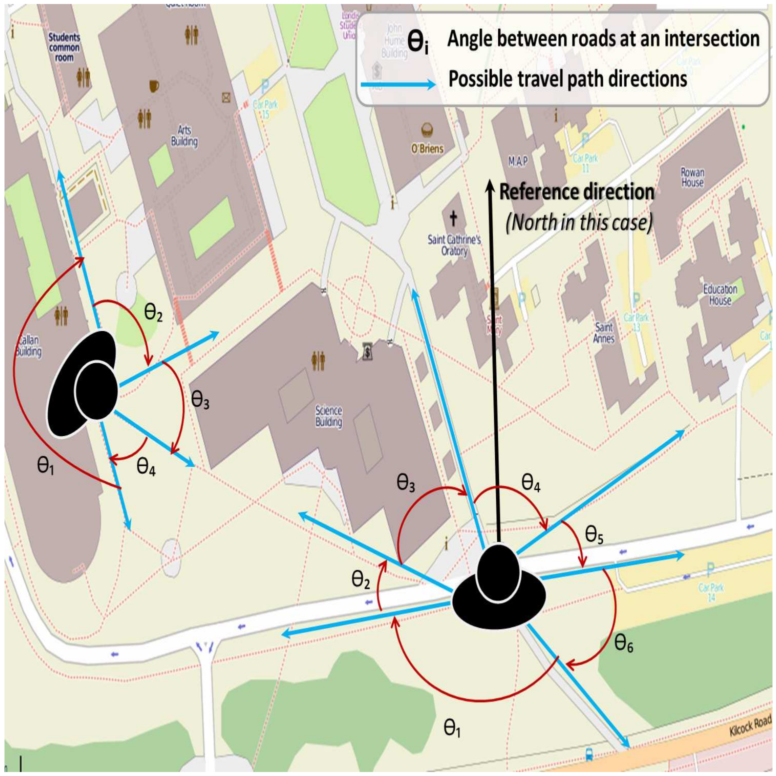


Figure 63: Varying numbers of paths at intersections and also varying angles between them.

λ must be less than the smallest value of θi at any given intersection. We see that the number of paths originating from any given intersection is not a fixed number and can vary from point to point (Figure 63). We can also see that the values of θi vary based on the angle created between any given pair of paths at an intersection.

Using Haptic Navigator, the user scans the area by holding the phone horizontally and slowly moving along the horizontal plane. This is depicted in Figure 64 where the user holds the phone out and looks for a waypoint by scanning the area. When the user is pointing in the direction (heading, h) of the next waypoint, the user is provided with feedback both visual (colour coded buttons and distance displayed on screen) and non-visual (haptic feedback using varying vibration patterns).

We say a user is pointing in the direction of the next waypoint when the Field of Heading (FOH), created when the user performs pointing gestures to scan the area overlaps with the bearing between the current point and the next waypoint (Figure 64). There is a

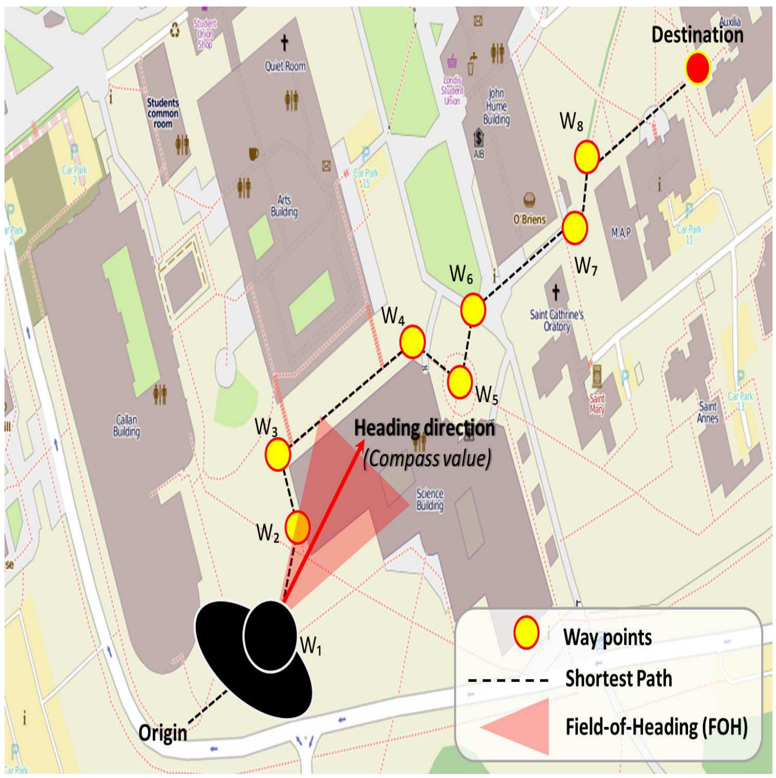


Figure 64: User pointing in the direction of the next waypoint using *HapticNavigator*.

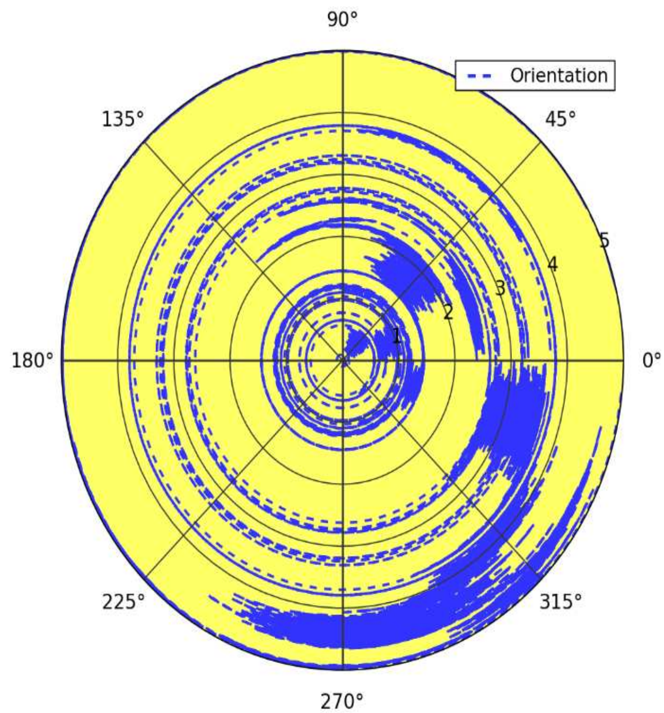


Figure 65: Visualising the scanning activity of a *HapticNavigator* user.

buffer distance of d_b metres that is set at every waypoint to ensure we account for the possible GPS error. Here in this example, the user is at the first waypoint, W_1 and is scanning to find the direction to the next waypoint, W_2. Once the user gets feedback about direction to the next waypoint, the user starts to walk in that direction and will then be alerted (via a unique vibration pattern) when he is within a buffer distance, d_b metres away from the next waypoint. The user understands they are now within the waypoint and have to perform the next scan to find direction to the next waypoint along the path towards the destination. The user performs these sequences of steps until they finally reach the destination, D. The user is alerted about arrival at the destination via a continuous vibration pattern when they are within d_b metres from the destination.

The scanning activity of the user can be stored and visualised and in Figure 65 we can see the scanning activity performed by the user during one of the walks from a given origin to a destination using the *Haptic Navigator*. The origin of the walk here would be the point in the centre and the perimeter of the circle here represents the destination. The bunched blue sections represent the part where the user is walking from one waypoint to

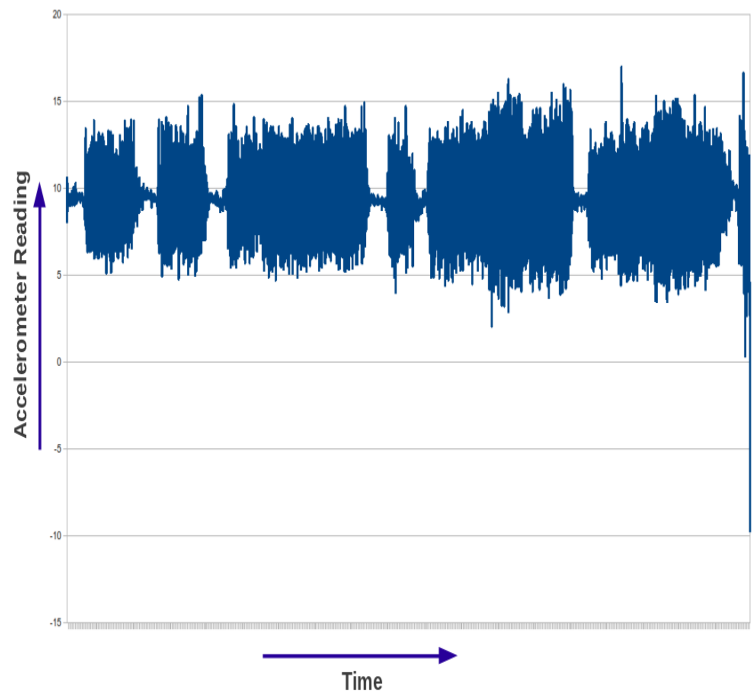


Figure 66: Visualising the accelerometer readings of a *HapticNavigator* user.

the other where no real scanning operation is performed here. And the other complete circle shows waypoints in the path when the user performed the scanning operation. The accelerometer reading on the mobile device helps to keep track of the user motion and steps taken (Figure 66). The peaks in the graph represent the user walking and the sections in the graph where the value is around 10 represents sections in the path where the user is standing still and performing the scanning operation. From the graph plotting accelerometer values (Figure 66) we can note that the user would have paused 7 times during the entire trip. This data when checked with the number of waypoints, we see that it matched the 6 waypoints and origin when the user had paused at waypoints to scan the area to find the direction to the next waypoint till they reached the destination.

The Haptic Navigator provides waypoint-by-waypoint navigation assistance from origin to destination using a non-visual feedback technique. In hiking/trekking situations it is sometimes impossible to find easily identifiable landmarks making Haptic Navigator a very suitable candidate for use. The key features/functionalities of this prototype are:

- Works using the ‘waypoint-by-waypoint’ navigation assistance technique.
- Phone is held in the hand for performing the *scanning* operation.
- Does not require user attention while walking towards the next waypoint as they will be alerted when they need to make a change in their walking direction.
- Feedback only when pointing in the direction of the next waypoint or about arrival at a new waypoint.

6.4.3 Haptic WayPointer

Robinson et al. mentioned about the fact that pedestrians unlike car drivers do not prefer the turn-by-turn feedback system and expect a more ‘exploratory’ system helping people navigate spaces and also learn and understand the surroundings (Robinson et al., 2010b). At times, the user does not want the complete waypoint-by-waypoint navigation assistance but only needs assistance about initial walking directions along the shortest path.

The *Haptic WayPointer* is a prototype designed to help the user navigate where the user is allowed to “explore or wander” along the route. At any location the user selects their destination and they are alerted when they are pointing in the correct direction of the shortest path (or their path of choice based on noise, air quality, scenery, time taken, etc.) to their destination. After being instructed as to the initial direction of movement it is the users responsibility to request feedback along their route when in doubt. The user can divert off route as they please and are not forced to follow a particular path via continuous feedback as seen in Haptic Navigator.

The user is initially at an origin point O which is at a distance d from the destination D. The shortest path between O and D is stored as a line string L (Figure 67). The bearing from the origin to a point along the initial walking direction of line string L is b_0. The user scans the area (Figure 58) and is alerted by a unique vibration pattern when the user is pointing in the correct direction (Figure 63) that they need to start walking to reach the destination. The sequence of actions at the initial origin location (Figure 67) where there are various roads origination from the users current location but is alerted when pointing in the direction they need to move which is in the direction of the first waypoint along the ideal path.

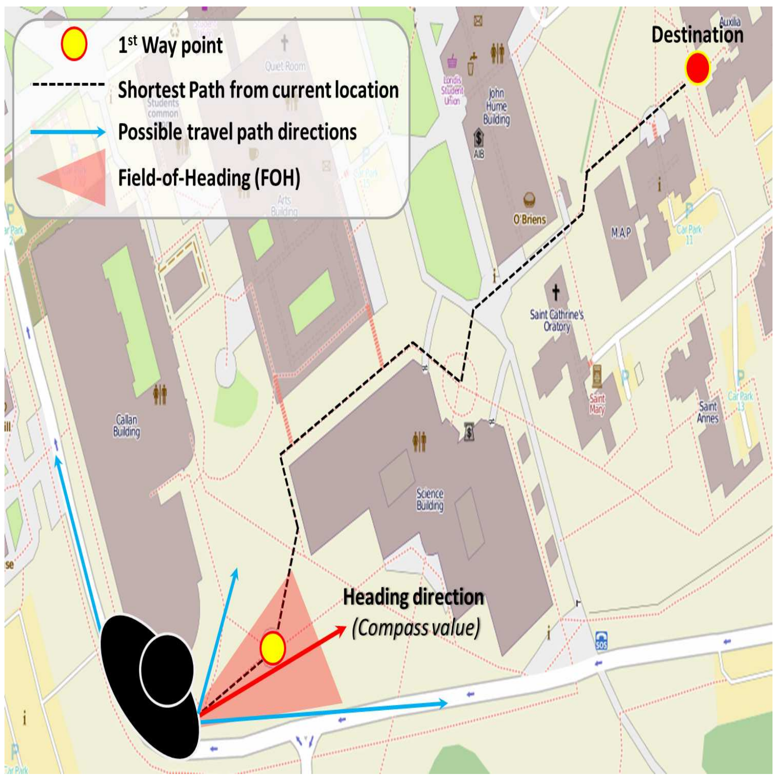


Figure 67: Haptic WayPointer: prototype using the 'point towards initial waypoint' technique.

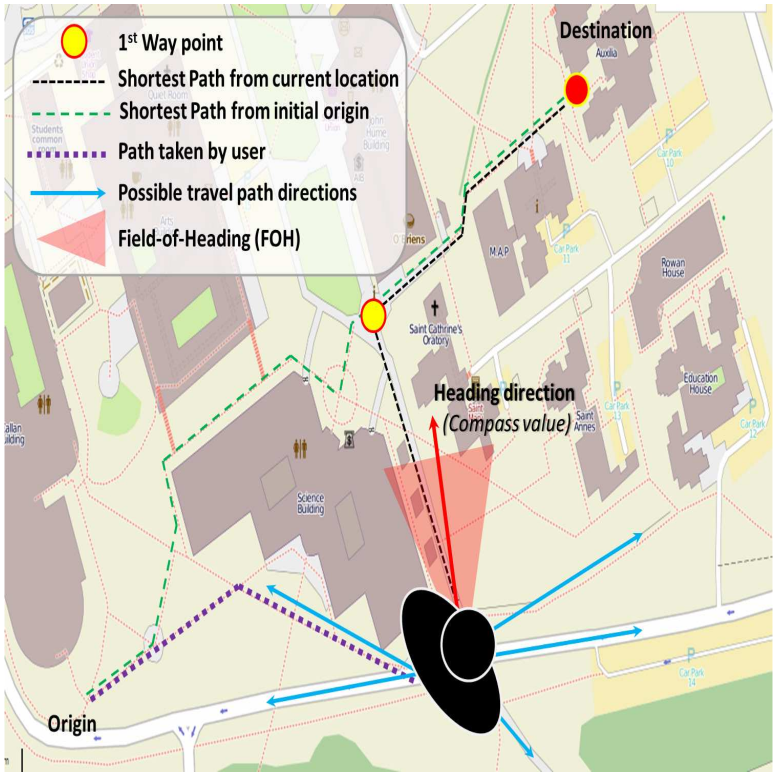


Figure 68: Haptic WayPointer: User continues walking in a general direction along shortest path (Figure 67) and scans again when in doubt.

When the user begins to move, there is no further notification about arrival at a waypoint. This form of navigation assistance is for users who like guidance and do not want to follow a strict path but just be notified when in doubt directions for optimal path to the destination. The user makes judgements about walking directions until in doubt. The user can scan at any point along the path to find the direction along the optimal route (towards the next waypoint) which may or may not be a point along the path generated initially (Figure 68).

The *Haptic WayPointer* provides navigation assistance using a non-visual feedback technique for situations when the user prefers to 'explore a place' as compared to merely following the shortest pre-defined fixed route. The key features/functionalities of this prototype are:

- Works using the 'point-to-waypoint' navigation assistance technique.
- Provides assistance when expecting initial general heading information along the

shortest route.

- Phone is held in the hand for performing the *scanning* operation when at points along the trip the users wish to reassure themselves of the shortest path from current location.
- Does not require user attention while walking as they are in 'explore mode' and so will only need to query when in doubt.
- Feedback only when pointing in the direction of the next waypoint from any point in the path.

6.4.4 Haptic DestinationPointer

We have seen the *Haptic WayPointer* which enables the user to explore the place and navigate to the destination rather than getting to destination following the shortest route in the shortest possible time. At times, the user needs to be assured about the general heading towards the destination and the user makes judgements about which route to take.

The *Haptic DestinationPointer* is a prototype designed to partially help the user explore (like *Haptic WayPointer*) the place while assisting them to navigate to the destination. This allows the user to "explore a place" and still not get completely lost or wander away too far from the destination. At any location the user selects their destination and they are alerted when they are pointing in the correct direction of the destination. The user then makes a judgement as to how to start walking based on the pathways in front of them. After being instructed as to the initial direction of destination, it is the user's responsibility to request feedback along their route when in doubt. The user can divert off route as they please and are not forced to follow a particular path via continuous feedback as seen in *Haptic Navigator* nor are they direction along the initial walking direction of the shortest path from the current location.

The user is initially at an origin point, O which is at a distance d from the destination, D. The shortest path between origin, O and destination, D is stored as a line string L (Figure 69). The bearing from the origin to the destination location, D is b_0. The user scans the area (Figure 58) and is alerted by a unique vibration pattern when the user is pointing in the correct direction (Figure 63) that they need to start walking to reach the destination. The sequence of actions at the initial origin location (Figure 69) where

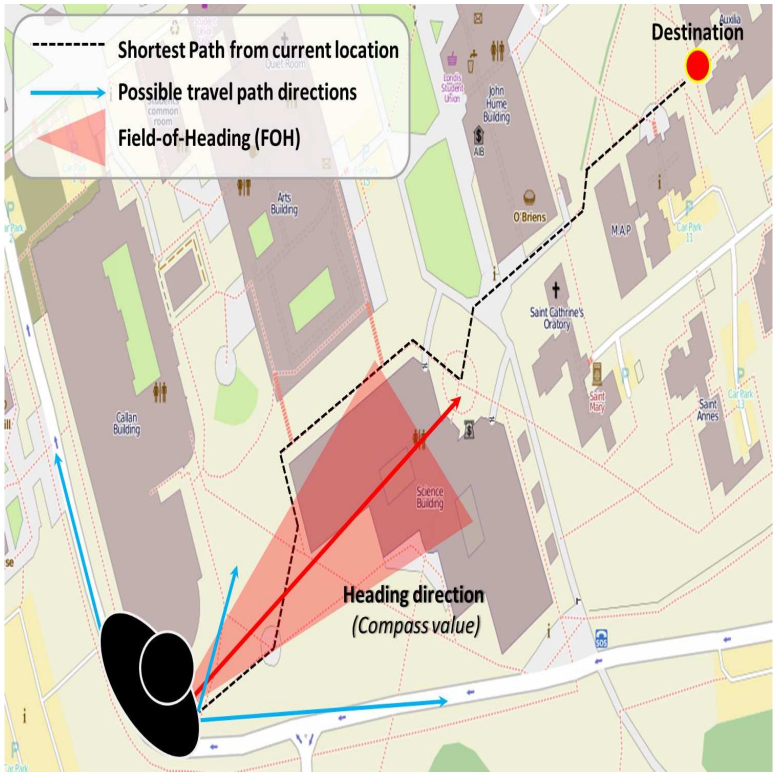


Figure 69: Haptic DestinationPointer: prototype using the 'point towards destination' technique.

there are various roads origination from the user's current location but is alerted when pointing in the direction of the destination which is not necessarily is the direction along the shortest path. This is similar to work by (Robinson et al., 2010b) who feel that users should have opportunities to "explore place while trying to get to their destination". Haptic feedback provides the direction to destination and the straight line distance to the destination information.

Three distance zones are created based on the distance between current user location (origin, O) and the destination (Figure 70). So for the distance, d, the three distance zones that are created are

- Near (zone between Current location to distance $\frac{d}{3}$ meters),
- Far (zone between $\frac{d}{3}$ to $\frac{2d}{3}$ meters) and
- Very Far (zone between $\frac{d}{3}$ to d meters).

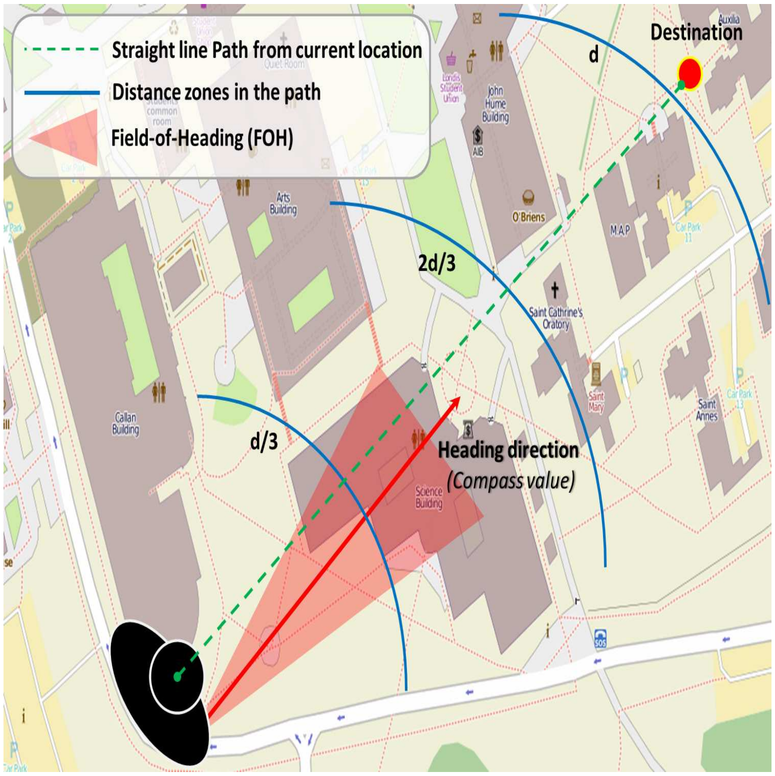


Figure 70: Haptic DestinationPointer: prototype using the 'point towards initial waypoint' technique.

Vibration pattern and frequency similar to Figure 53 is used by the Haptic DestinationPointer prototype to convey distance information to the user when pointing in the right direction (FOH) of destination. If the user is *very far* away (zone between Current location to distance $\frac{d}{3}$ meters) from the destination D, the user is provided information by high frequency vibration feedback with a distinct pattern of short duration (300ms each). Vibration of medium frequency is provided if the user is *far* away (zone between $\frac{d}{3}$ to $\frac{2d}{3}$ meters) from the Destination (D), and a different vibration pattern of low frequency is used to represent distances when the user is very close (zone between $\frac{2d}{3}$ to d meters). The varying pattern and frequency of the vibration alarm (Figure 53) is used to provide distance information to the user. When the user is within a short buffer distance B from the destination, continuous vibrations alert the user of reaching their destination/POI.

To validate the Haptic DestinationPointer, three routes were chosen which had three different levels of complexity based on the origin and destination chosen and the fre-

Distance (m)		Time Taken (min)	
Routing Service	Using Haptics	Routing Service	Using Haptics
660	660	8	7

Shortest Path

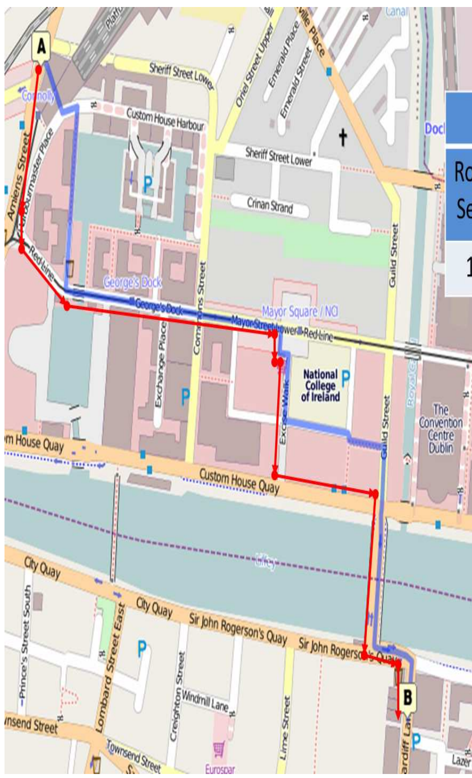
User trail

Route type
Simple route. Very little change in general direction.

Figure 71: Simple route navigated using *Haptic DestinationPointer*.

quency of turns/change in direction along the path. Figure 71 represents a *simple path* which had very little deviations/intersections to confuse the user regarding the best path. Hence the user took the path exactly similar to the path as provided by the routing service using the OpenStreetMap data (OpenStreetMap, 2012). The user got to the destination faster while using *Haptic DestinationPointer* as the user did not need to interact with the visual interface to check for route description and thus could walk faster.

Figure 72 represents a *moderately complex path* which has more deviations/intersections and thus the user had to make judgements regarding the best path from certain way-points. The path had lots of straights and turns and here the user took a path almost similar to the shortest path as given by the routing service. The time taken by the user while using *Haptic DestinationPointer* is less than as mentioned by the routing service as the user did not need to interact with the visual interface to check for route description and thus could walk faster along straight roads.



Distance (m)		Time Taken (min)	
Routing Service	Using Haptics	Routing Service	Using Haptics
1200	1220	15	13

Route type
Moderate route. Mix of long straights and changes in direction in between.

Figure 72: Moderately complex route navigated using *Haptic DestinationPointer*.

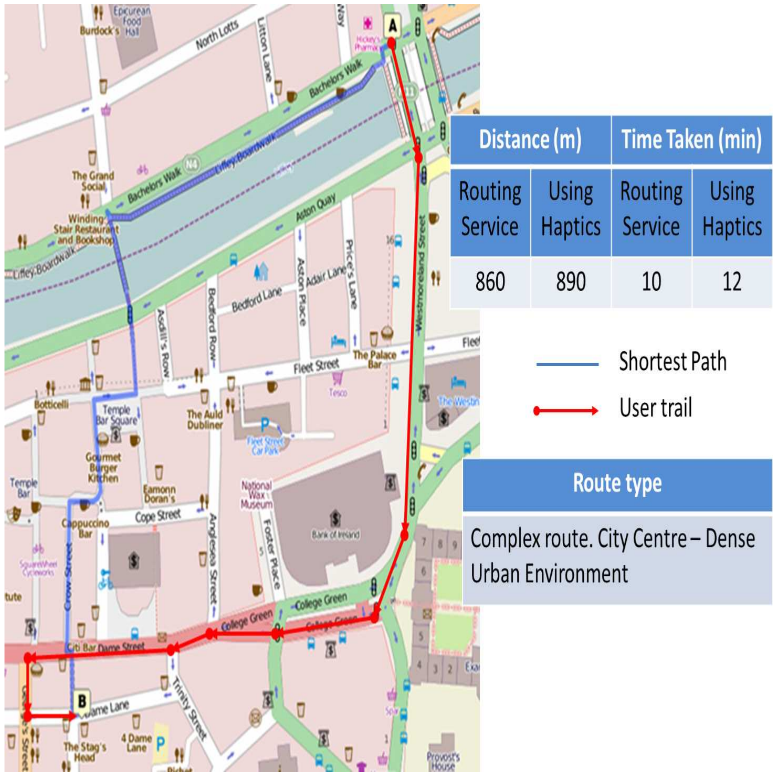


Figure 73: Very complex route navigated using *Haptic DestinationPointer*.

Figure 73 represents a *complex path* which has lots of deviations/intersections and involves the dense urban environment. Thus the user had to make judgements regarding the best path from certain waypoints and points during the trip. The path had lots of straights and turns and was in between dense streets with tall buildings. The user took a path completely different from the shortest path provided by the routing service. The time taken by the user was longer while using *Haptic DestinationPointer*. The main benefit here is that the user did not need to interact with the visual interface to check for route description and thus could walk faster avoiding obstacles and other pedestrians.

The *Haptic DestinationPointer* provides 'direct to destination' navigation assistance from origin using a non-visual feedback technique. In situations when the user prefers to 'explore a place' and only wants to know the general heading information towards the destination, Haptic DestinationPointer is the ideal prototype to use. The key features/functionalities of this prototype:

- Works using the 'point-to-destination' navigation assistance technique.

- Provides assistance when expecting general heading information towards destination.
- Phone is held in the hand for performing the *scanning* operation when at points along the trip the users wish to reassure themselves of the direction towards destination.
- Does not require user attention while walking as they are in 'explore mode' and so will only need to query when in doubt.
- Ensures faster walking speed in the general direction of destination.
- Feedback only when pointing in the direction of the destination from any point in the path.

From the above four prototypes we saw how haptic feedback can be integrated in different ways to suit various user contexts and need of information. Haptic feedback for pedestrian navigation is useful to provide simple, subtle information which along with complex detailed information via visual interfaces can help users navigate all kinds of environments very easily.

6.5 Summary of Haptic Pedestrian as a tool for Pedestrian Navigation

Table 2 provides an overview of the various properties of the four prototypes. From Figure 74 we see that system complexities and functionality increase along the X-axis direction (as does requirement for Internet connectivity). Battery usage (use of haptic feedback) increases along the Y-axis. The comparison of the features and functionalities of all the four pedestrian navigation prototypes of the *Haptic Pedestrian* model has been summarised in Table 3.

Yamabe et al. (2008) feels that current mobile interaction methods is not designed well enough to consider human mobility factors. They add that although user attention is considered an important human factor for user interface design, current mobile location based service is too much attention-consuming for users on the move to perform tasks like walking and using the mobile service simultaneously. Yamabe et al. feel this is because such mobile services are still pursuing the desktop-miniaturization trend and thus, these mobile services are intended to work in situations when the user is stationary like when the user is standing on a street or sitting on a chair.

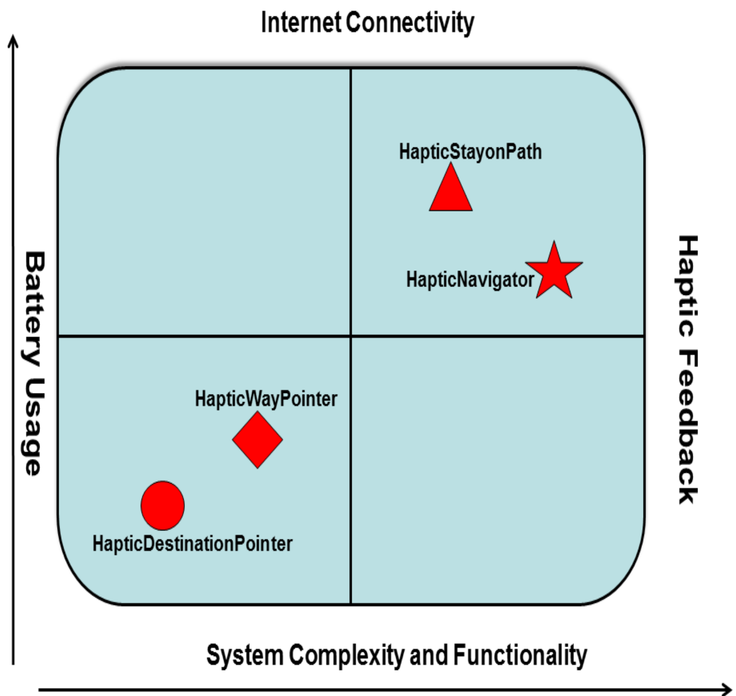


Figure 74: The comparison of functionalities of the four *HapticPedestrian* prototypes.

Table 2: Summary of the mobile device features of the four *HapticPedestrian* prototypes

	StayOnPath	**Navigator**	**WayPointer**	**DestinationPointer**
Haptic feedback	Yes	Yes	Yes	Yes
Compass usage	No	Yes	Yes	Yes
GPS on	Yes	Yes	Yes	Yes
Vibration	Continuous	At Waypoints	On request	On request
Internet usage	High	Medium	Low	Low
Battery usage	High	High	Low	Low

Revised approaches to interaction design are the key issue that needs to be addressed with regards to a wider use of geo-spatial applications like pedestrian navigation systems (Krum et al., 2007). However once these applications are designed keeping in mind that the interaction and system designers understand that the use of such automated system is always the secondary task for pedestrians, more people will integrate such systems into their day-to-day lives. User Centred Design is the key to develop a mobile pedestrian navigation system that is flexible to provide the user with the option to switch between modalities (vision, audio, touch) based on the user context like for example in conditions which do not allow use visual interfaces effectively like when it rains (Figure 75).

We know that wayfinding tasks are performed by humans very regularly. And humans use previously acquired knowledge of the route, and also their own spatial awareness and ability to tackle such tasks in the real-world. Parush has found that, in general, there is degradation of spatial knowledge amongst the general public caused by the extensive use and reliance upon automated systems for navigation and spatial data discovery (Parush, 2012). And the work by Jacob et al. shows that users who used haptic feedback as compared to landmark image based navigation produced better maps based on memory recall (Jacob et al., 2012a). This shows that haptics is an important modality that should be integrated to mobile location based services like pedestrian navigation systems to provide subtle feedback to users and enabling low-interaction use of technology based on the physical context of the user. Haptic feedback for navigation assistance while walking along busy streets in known or unknown places ensures that the user can concentrate on the physical world and can easily avoid obstacles like other pedestrians while on the move. Haptic feedback ensures privacy as the subtle feedback by casual pointing and scanning gestures ensures quick response by system and faster

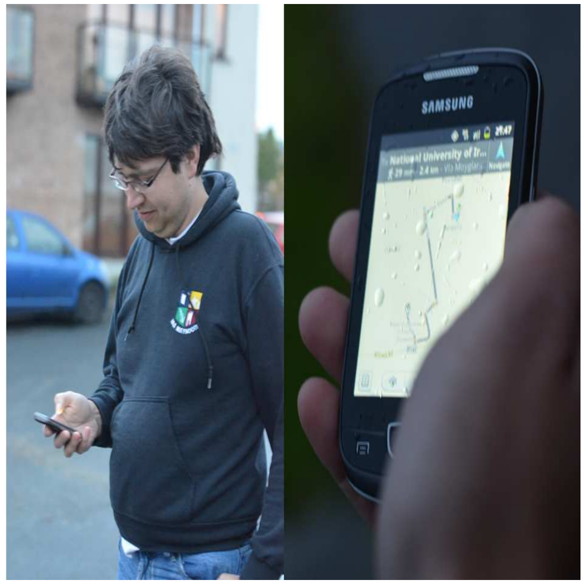


Figure 75: Visual interfaces for navigation are inappropriate and not very useful in conditions like a rainy day.

action taken by users with respect to change in walking directions especially at decision making waypoints. While audio feedback in car navigation systems ensure that the driver can concentrate on the road and be provided with feedback in a non-obtrusive way, for users on the move by foot, haptic feedback can be suitable to provide navigation assistance in a non-obtrusive way to pedestrians.

In Chapter 4 we saw integration of haptics into knowledge discovery based systems. And in this chapter we have seen how haptic feedback can be used to provide information to assist pedestrians in navigating from one place to the other. In chapter 5 we describe the stage 3 activity as described in Chapter 3 which is about notifying the user or alerting them with regards to location information. We discuss location based notification systems and also discuss the integration of haptics to provide information to a public transport user which comprises of pedestrian navigation assistance and in-transit information.

Table 3: Overview of the features and functionalities of the four *HapticPedestrian* prototypes

StayOnPath	**Navigator**	**WayPointer**	**DestinationPointer**
No compass used. Works using the 'Hot/Cold' technique	Works using the 'waypoint-by-waypoint' navigation assistance technique	Works using the 'point-to-waypoint' navigation assistance technique	Works using the 'point-to-destination' navigation assistance technique
Phone can be held in the hand or left in the pocket	Provides navigation assistance through the optimal path in getting to destination via visiting all waypoints	Provides assistance when expecting initial 'general heading' information along the shortest path	Provides assistance when expecting initial 'general heading' information towards destination
Could be suitable for use while walking across open areas	Phone is held in the hand for performing the scanning operation	Phone is held in the hand for performing the scanning operation when at points along the trip the users wishes to reassure themselves of the shortest path from current location	Phone is held in the hand for performing the scanning operation when at points along the trip the users wishes to reassure themselves of the direction towards destination
Continuous feedback as you walk along a path	Does not require user attention while walking towards the next waypoint as they will be alerted when they need to make a change in their walking direction	Does not require user attention while walking as they are in 'explore mode' and so will only need to query when in doubt	Does not require user attention while walking as they are in 'explore mode' and so will only need to query when in doubt
	Feedback only when pointing in the direction of the next waypoint or alert about arrival at a new waypoint	Feedback only when pointing in the direction of the next waypoint along the shortest path from any point in the path	Feedback only when pointing in the direction of the destination from any point in the path
			Ensures faster walking speed in the general direction of destination

7 Notification System

7.1 Introduction

When a user receives an incoming phone call, he is not always able to look at the phone or have the ringer turned on. If the user is busy with some activity, they use the vibration alarm to ensure subtle and less intrusive ways to provide that information. Kanai et al. used visual and audio cues to issue notications for assisting the elderly in identifying dangers intuitively and recognizing them visually (Kanai et al., 2008). Rossnagel and Scherner proposed a disaster management system, based on mobile telecommunication where civilians will be notified of a disaster based on the user's locations close to the disaster (Rossnagel and Scherner, 2006). Thus the use of such notification systems vary based on the situation.

In this chapter we show how location based notification systems (LBNS) are used and where they can be improved by integrating haptic feedback. We also learn the importance of such location based notification systems by describing a model for a public transport user.

7.2 Location Based Notification Systems

Location Based Notification Systems (LBNS) are those systems which convey information to the user related to their location using various visual, audio or haptic cues. Currently mobile phones can provide useful information to the user about places, people or other objects around them. They have the ability of detecting and reporting 'nice to know' situations that are of interest to the user (Li et al., 2008). With the availability of GPS enabled phone, it has become easier to alert the users with information such as 'close proximity of another friend' from one's location, 'availability of a special deal' at a nearby restaurant. While the mobile phones provide such services, ideally they can be used without interrupting the current task of the user.

A typical scenario of use of such notification systems is when a local business owner is notified when a valued customer is within some distance of a retail outlet. The customer is delivered a coupon or some notice of a special promotion (Munson and Gupta, 2002). A more detailed description of the system functionalities of the high level model of a location based notification system is shown in Figure 76. Some of the situations where notification systems can be used are as follows:

- When tourists enter a tourist area, provide them with historical data and descriptions.
- Notify a user when they enter a shopping mall about a sale in a store which is due to finish the next day.
- The user at a fair is notified about the interesting events going on around a particular venue based on the user's current location.
- The tourist in a new city who is travelling by bus is alerted when approaching the destination bus stop.

While notification can be used to provide such cues to the user, they can also be beneficial with regards to notifications regarding public safety and security:

- If there are some road blocks coming up due to heavy traffic or construction, notify the driver beforehand about taking a detour.
- Alert drivers about reducing speed either because they are above the current speed limit on that stretch of road or to warn them against upcoming hazards like low visibility due to fog or wet and slippery road.
- Alert people in a locality with urgent utility information like a power cut or water stoppage.

In Figure 76 we see that the stage 1 for a notification system is that the user 'subscribes' (the user chooses to be notified). Stage 2 filters the relevant information for that particular user based on proximity and context in the 'notification area' (by calculating user proximity). Stage 3 involves delivering the notification to the user through their preferred methods depending on the 'client specifications' (information delivery).

We have seen in the previous chapters how the mobile device can be used for querying spatial information around the user and also how it can help the user get to a particular location. Alert/notification systems are using such devices to notify the user about information that is relevant to the user based on proximity to a person, place or object. There are various kinds of notification systems associated with various kinds

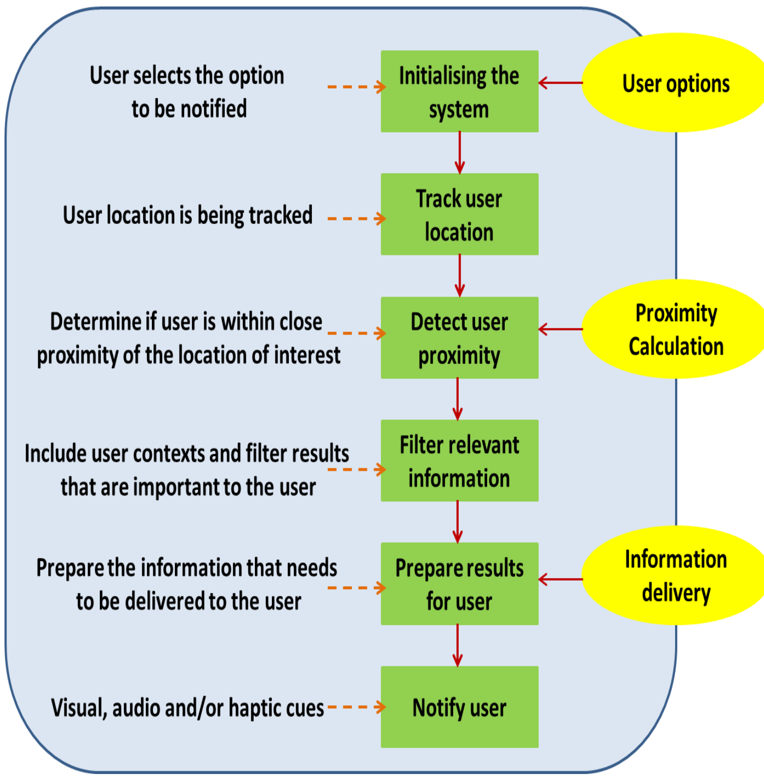


Figure 76: Description of the high level model for location based notification system derived from Munson and Gupta (2002).

of functionalities but in this chapter we try to understand how notifications about a location can be conveyed to the user effectively and in a non-intrusive manner. We will now discuss the various ways of detecting a user location and filtering information to notify users who subscribe to a notification system.

7.2.1 Detection of user location and information filtering

The main functionality of a location based reminder system is that a reminder is delivered for any particular location when the user is within close proximity of that location. Here the 'Geo-fence' concept is used. A *Geo-fence* can be considered as a virtual perimeter for a particular area in the real-world. At first the user subscribes to be alerted or notified based on the location and particular task being carried out. There are various ways in which location information can be obtained to notify the user with relevant information. Li et al. used an algorithm that compares locations of cell towers seen by the mobile phone client. This ensures privacy as exact location information is not required or used (Li et al., 2008). *Place-its* is a location-based reminder application that runs on mobile phones (Sohn et al., 2005). Ludford et al. developed a location-based reminder system, *PlaceMail* to support everyday tasks (Ludford et al., 2006). Wahid et al. presents *Calendar-Based Notifications* (CaBN), a notification system designed to deliver personal information in a prioritized fashion (Wahid et al., 2006).

Dhar and Varshney lists the pull versus push based applications as one of the location based service that can be used by advertisers to provide information about deals, offers or sales happening close to the user (Dhar and Varshney, 2011). Here the pull-based services are those where the user initiates the request asking to be served with information. The push-based services uses the geo-fence concept to deliver information to the mobile terminal (the end user here) with information automatically when events occur such as the user entering a geo-fence of a local business.

Streefkerk et al. describe an intelligent filtering system for police officers for notifications to ensure less interruption or distraction from other incidents (Streefkerk et al., 2008). Here notifications are filtered based on incident priority, time of day, or other important characteristics such as it being a criminal hotspot (Figure 77). The interface has a notification pop-up on top of the map interface to display notification information.

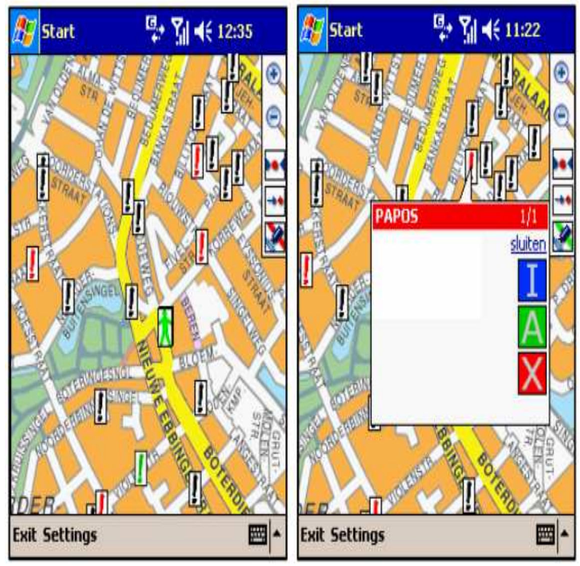


Figure 77: Screenshots of an LBNS, showing the overview with icons (left), and a notification pop-up (right) (Streefkerk et al., 2008).

7.2.2 Visual representation of notifications/alerts

We see from Figure 76 that the visualisation of the notification cues on the client device using one or more modalities is the last but important phase in a notification system. System should not be a distraction in dynamic physical environments (Tarasewich et al., 2003).

The *Reminder Bracelet* (Figure 78) is worn on the wrist and connected to a PDA. It notifies its user of scheduled events in a subtle and silent manner using light, colour and patterns (Hansson and Ljungstrand, 2000). Nair et al. describes *SeeVT Alumni Edition* which is a location-based tour guide system developed specifically for Alumni visiting Virginia Tech (Nair et al., 2006). They have integrated 'time as a dimension' to provide notification cues about historical data about that particular location as they move around campus.

While visual interfaces have the ability to provide notification cues in the most detailed manner, it requires higher attention of the user. Such 'attention overload' is not suitable for users especially when the user is on the move in the real physical environment. Jenkin and Harris added that attention involves the allocation of perceptual or cognitive

Figure 78: *Reminder Bracelet* worn by a user with 3 LEDs (Hansson and Ljungstrand, 2000).

resources to something at the expense of something else (Jenkin and Harris, 2001). Since humans have a limited amount of resources available for allocation to various tasks, all cannot be attended to at once. Jenkin and Harris also show that although people can attend to one modality (vision, hearing, touch, taste, smell), a colour, a shape, or a location, the decision to attend to one task over the other arises from the importance of the task at hand. Non-visual feedback ensures the attention required from a user is minimal as compared to a visual interaction based system as it is less intrusive. We now look at the ways notification information can be provided to the user via non-visual feedback

7.3 Non-Visual representation of notifications/alerts

Non-visual notification cues can be provided using audio and haptics to deliver meaningful notification/alerts to the user. More attention has been given to audio feedback because audio systems are more common in computer systems.

7.3.1 Audio feedback

Earcons were defined by Blattner et al. as "nonverbal audio messages used in the user-computer interface to provide information to the user about some computer object, operation or interaction" (Blattner et al., 1989). Brewster et al. described them as "abstract, musical tones that can be used in structured combinations to create auditory messages" (Brewster et al., 1993). Unlike earcons, auditory icons utilise metaphors to relate them to their virtual referents (Gaver, 1986). An example is the use of 'sound of shattering dishes' to represent the 'drop of a virtual object into the (virtual) recycle bin' (Gaver, 1989). Auditory icons however can sometimes be confused with the actual-world sounds.

Garzonis et al. suggest that with the ever increasing number of mobile services, the use of meaningful audio notifications could be used to effectively inform users of the incoming services with minimal interruptions (Garzonis et al., 2009). Two types of audio (auditory icons and earcons) as mobile service notifications are evaluated. They are compared based on 4 measures: intuitiveness, learnability, user preference and memorability. Garzonis et al. investigated how semantic richness of different types of audio stimuli can be utilised to shape the intuitiveness of mobile service notifications (Garzonis et al., 2008). They found that speech performed better than non-speech sounds and overall auditory icons performed better than earcons.

Jones et al. describes a *Smart Helmet* which is a project from the MIT Media Lab that incorporates context-aware technology into a bicycle helmet for the purpose of enhancing rider safety (Jones et al., 2007). The Smart Helmet (Figure 78) ensures that the rider does not need to take the eyes off the road as it does not include any display or controls that the rider must attend visually while riding the bike. Audio files are stored associated with a location based on the safety information attached to that particular location (eg. a dangerous pothole). Voice recording associated with a particular location is played back when the rider is within close proximity of that stored location.

While we see the benefits of an eye-free notification system in the form of audio cues, we have seen from previous chapters that using audio as a feedback mechanism can be inappropriate at certain times. Here the user needs to be attentive to the audio via headphones that can cut the sense of hearing from other sound sources in the real physical world. Therefore, an alternative is using haptic feedback.

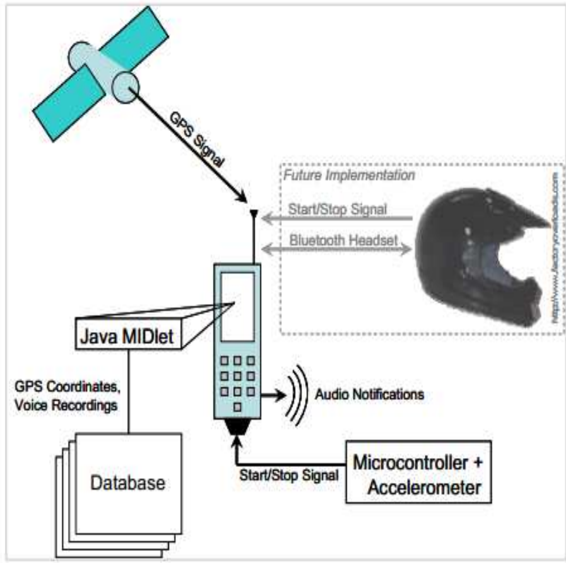


Figure 79: System diagram of the *Smart Helmet* for bicycle riders (Jones et al., 2007).

7.3.2 Haptic feedback

Users are notified mainly via visual displays or by audio cues (sounds, beeps or voice) that are attention-demanding. Due to a person's constant interaction with the real-world, it would be inappropriate to have such feedback systems as it can disturb the other people nearby or also be very demanding for the user to constantly look for notifications. People switch off their mobile phone or turn it to 'silent mode' when at a public place, especially when in places like a lecture, library, or at a theatre.

Tactons, or tactile icons, are structured, abstract messages that can be used to communicate non-visually. Brewster and Brown (2004) suggest the use of the frequency, amplitude and duration of a tactile pulse, plus other parameters such as rhythm and location can be used to provide useful information. Hansson et al. (2001) proposed the use of vibration alarm provided by mobile phones as these tactile cues are subtle and private. Li et al. (2008) developed a buddy proximity notification system called *PeopleTones*. They used unique audio clips to relate to each of the buddies of a particular user and converted to unique vibration cues relating to the audio clip.

In the work by Jacob et al., this concept of tactons is coupled with the vibration alarm of mobile devices to provide subtle notification to the user about arrival at a users destination stop (Jacob et al., 2011c). This notification technique was also used to convey such eyes-free information for pedestrian navigation systems about arriving at a decision making waypoint or notification about arriving at the actual destination by altering amplitude and frequency of the vibration pattern (Jacob et al., 2011b) as discussed in section 6.4.2. Let us now discuss public transport information delivery systems in detail to understand how integration of haptics can help such systems.

7.4 Public transport information delivery

The use of public transport for daily commutes or for journeys within a new city is something most people rely on. To ensure users actively use public transport services the availability and usability of information relevant to the traveller at any given time is very important. A web interface can provide real-time bus/train information using a website (Shalaik et al., 2010). While this can be useful when the traveller is making some pre-trip plans, mobile interfaces that enable easy interaction and easy to understand responses are important (Shalaik et al., 2011b). Improved access to transit services is very dependent on the effectiveness of communicating information to existing and potential passengers. The mobile system should provide similar information to the user through visual user interfaces, simple interaction techniques like gesture based querying, and visual/haptic feedback of the results.

Good quality information system and services can also ensure positive response and increased use of public transport. Dynamic 'at-stop' real-time information displays are becoming popular in modern public transport across the globe. Dziekan and Kottenhoff (2007) show that user reactions and attitudes towards these systems are very positive. However there is a need to provide a comprehensive framework of the possible effects that these types of displays can have on customers.

There are seven main effects of having a dynamic public display system providing real-time information that are described by Dziekan and Kottenhoff (2007). They are:

1. reduced wait time,
2. positive psychological factors, such as reduced uncertainty, increased ease-of-use and a greater feeling of security,
3. increased willingness to pay,

4. adjusted travel behaviour such as better use of wait time or more efficient travelling,
5. mode choice effects,
6. higher customer satisfaction and,
7. better overall image.

The study by Fujii and Van (2009) explores the behavioural intention to use the bus while considering the perceived quality of bus service, problem awareness, and moral obligation to use public transportation in Ho Chi Minh City (HCMC), Vietnam. They find four psychological factors related to various aspects of bus usage:

- moral concerns,
- negative expression,
- quality perception, and
- social status.

There are a couple of services involved while using public transport:

1. Pre-journey information,
2. In-bus information system and information about destination stop

7.4.1 Pre-journey information requirements and interaction

The first activity involves pre-journey planning using web or mobile services that help the user with information about the location of the origin bus stop (or train station), navigation assistance to the origin bus stop from the user's current location, and bus arrival time information.

There are several services that can be used when planning a trip which could be by public transport:

1. UbiBus (Banatre et al., 2004)

2. ROuting SErvice (ROSE) (Zenker and Ludwig, 2009)

3. BAIM plus by (Bühler et al., 2010)

4. OneBusAway (Watkins et al., 2011)

5. Google Transit (GoogleTransit, 2012)

The BAIM plus by Bühler et al. is a system that provides information about schedules, vehicles and stations (Bühler et al., 2010). This journey planner has a query interface with different user profiles (For example: no limitation, wheelchair user, or restricted in walking) which can be chosen in order to get customized suggestions for barrier-free travel connections as well as information about the accessibility of facilities to be used during the journey. Banatre et al. describes an application called *UbiBus* which is used to help blind or visually impaired people to take public transport (Banatre et al., 2004). This system allows the user to request in advance the bus stop of his choice, and to be alerted when the right bus has arrived.

Koskinen and Virtanen (2004) presents *Personal Navigation and Guidance for the blind (NOPPA)* that provides real-time public transport information in personal navigation systems to help the visually impaired in catching a bus or a train. Zenker and Ludwig (2009) describe a system *ROuting SErvice (ROSE)* that provides the following:

- calculates a route to the next best public transport stop,
- what mode of transportation to take,
- where to interchange transportation, and
- how to walk from the last stop to final destination.

The *OneBusAway* transit traveller information system provides real-time next bus countdown information for riders of King County Metro, Seattle, USA, via website, telephone, text messaging and smart phone applications (Watkins et al., 2011). Watkins et al. found in their study that real-time information reduces not only the perceived wait time but also the actual wait time experienced by customers. The users arriving using real-time information waited almost 2 minutes less than those arriving using traditional schedule information.

Journey planners (GoogleTransit, 2012; Shalaik et al., 2010) or provision of real-time/time-table based information about buses at the bus stop and/or mobile devices (Koskinen and Virtanen, 2004; Shalaik et al., 2011b) are some of the most common research areas of services related to public transport systems. Mobile real-time information has the ability to improve the experience of transit riders by making the information available to them before they reach the stop. Although previous studies have looked at traveller response to real-time information, few have addressed real-time information via devices other than public display signs.

Foth and Schroeter (2010) investigated opportunities to enhance the experience of commuters in all aspects of their journey such as:

- planning the trip,
- waiting at bus stop,
- payment before journey,
- in journey activity, and
- post journey feedback.

Instead of focusing on efficiency and speed of each of these steps their focus was on making the public transport experience more enjoyable and meaningful, in particular through the innovative combination and interaction of technologies such as mobile devices, real-time data, and social media.

7.4.2 In-bus information system and information about destination stop

Once the user has the required pre-journey information, the next phase is the in-bus transit phase. In public transportation research, the 'in-transit' information for passengers has been an area of research that has not received as much attention as the pre-trip planning and solutions to help people get to the bus stop and catch the right bus. Visual and Vocal Information Platform (VVIP) is a cost effective and easily deployed dynamic location based system which offers passengers a visual and auditory display of where the bus is in relation to its next stop facilitating and improved bus travel experience (Thomson et al., 2007). Here an on-board display system which provides information about the upcoming stop and time to reach along with auditory feedback to assist visually impaired or other passengers who are not paying attention to or are not aware of their destination stop.

The aim of the RAMPE project was to design and experiment a system based on a light hand-held device for the assistance and information of blind people so that they can increase their mobility and autonomy in public transport (Venard et al., 2008). This system offers detection abilities and guidance in the spatial area surrounding the stop point and delivers relevant information using Wi-Fi from these fixed stations to the mobile device of the user. Most recently the UK National Rail developed *National Rail Enquiries*, a new smartphone based app for both iOS and android (UKRail, 2012). Along with a real-time journey planner, information about service notifications, one feature that has been highlighted is a "Wake me up alarm" alerting passengers of their final destination.

Predic et al. presents an algorithm to predict the arrival time of public buses as a central component of the traveller information services (Predic et al., 2007). Apart from providing information about arrival time, the users have the option to set queries like: "Notify me when the bus will be at a specific location, or when it is N minutes from a specified location/bus stop". The steps involved here includes the user choosing a specific location/bus stop on the bus route and setting the alarm to notify them when the bus reaches the selected location. A sample query is: "Notify me when the bus is 5 minutes from bus stop B". While visual or audio feedback are commonly used to provide public transit information, multi-modal interaction can be an effective method for systems that provide pre-journey, in-transit or destination stop notification services.

7.4.3 Multimodal interaction for transportation information

Mobile devices such as smartphones and personal digital assistants can be used to implement efficient speech-based and multi-modal interfaces (Kristoffersent and Ljungberg, 1998). Turunen et al. (2006) present approaches for mobile public transport information services such as route guidance and to push timetables to the user via speech based feedback. The MUMS system described by Hurtig and Jokinen is a mobile PDA-based route navigation system which allows the user to query public transportation information using spoken language commands and pen-pointing gestures on a map (Hurtig and Jokinen, 2005).

Researchers have investigated multi-modal communication with users of public transport. *TravelMan* is a multi-modal mobile application for serving public transport information in Finland (Turunen and Hakulinen, 2007). This application includes different kinds of input and output modalities (speech input and output, a Graphical User Interface (GUI), and text input). The main design principle of the *TravelMan* application was to ensure that different modalities can function in tandem and support multiple, simultaneous or alternative modalities. The main output modalities used here (speech and GUI) were designed to work independently or simultaneously. Results suggest that speech input outperforms other input methods, even with high error rates and slow response times (Melto et al., 2008).

Tarasewich et al. (2004) used the 3 coloured LEDs similar to the Reminder Bracelet (Figure 78) in providing 'pixel-based' (using one or more individual lights) visual feedback for notification and then coupled it with private tactile cues that ensured positive perception of the cues. Interactions by multi-modal (using more than one communication channel) systems are usually considered advantageous over uni-modal (using only one communication channel) systems as they provide flexibility and give a more natural feeling (Jokinen and Hurtig, 2006). All the users however responded unanimously that a system with both speech and tactile/visual input/output-possibilities is preferable to a uni-modal one.

7.4.4 User survey about public transport use

We needed to better understand the passenger usage pattern of public transportation infrastructure and services and the importance of multi-modal communication. To quantify motivation for this work we conducted a survey on public transport usage. We contacted 50 adults for the survey and received 45 responses. There are a number of important results from this survey that was conducted online which show that there is a need for improvements in public transport information systems. Sum of percentages for various questions adds up to more than 100% as the respondents had the option to select more than one answer from the check-list. Figure 80 shows that a majority of respondents used bus as compared to train and tram due to greater road network connectivity to work place and other important places.

Figure 81 shows some of the factors that prevented people from taking private transport:

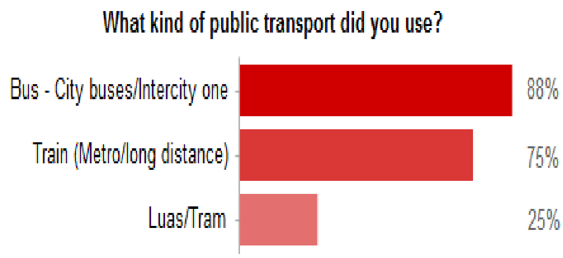


Figure 80: Types of public transport usage.

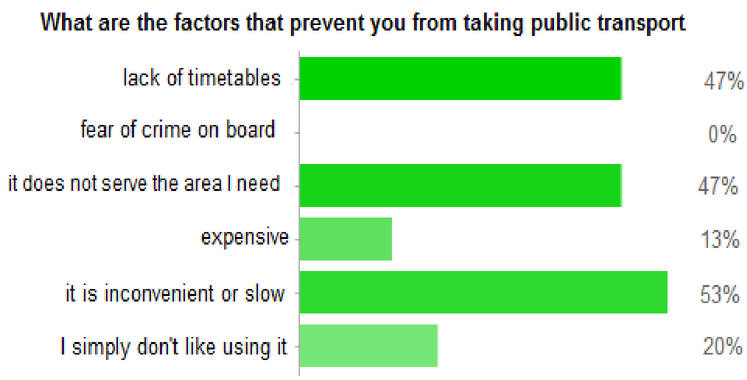


Figure 81: Factors that prevent the user from taking public transport.

- public transport was inconvenient and slow (53%),
- it had not served the area that user was (47%) and
- due to lack of proper timetables.

Figure 82 represents a summary of the types of "in-bus" activities that users indicated they are normally engaged in. The majority of these users said that they would listen to music (50%) or just look out of the bus window (63%). One of the other most popular activities which half of the people taking the survey mentioned involved if travelling with another person, they would usually be busy talking to them (50%). Reading a book is another activity of interest (31%) and about 19% respondents said they would sleep.

Among the 83% respondents who said they would use public transport in a new country, a vast majority of users (88%) said that in-transit, they would look out of the window

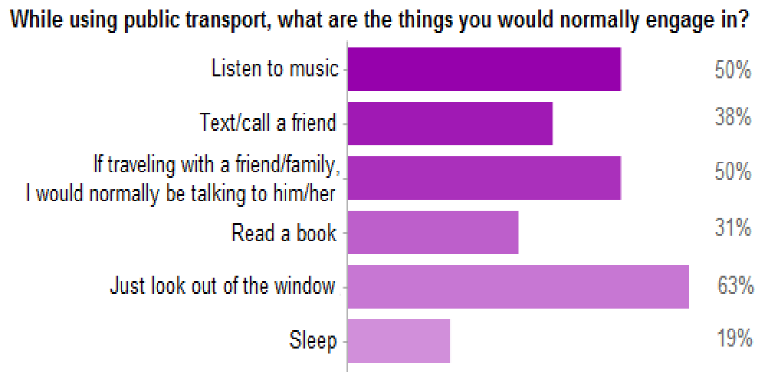


Figure 82: Activities involved in while travelling using public transport.

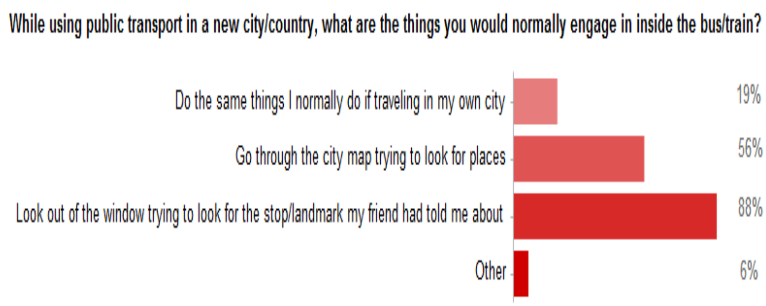


Figure 83: Involved activities while visiting a new city/country.

trying to look for the stop/landmark their friend told them about (Figure 83). While 56% users said they would go through the city map trying to look for places and stop names, about 19% users said that they would engage in activities they would do when they are in their home town. These results show there is a great amount of anxiety among travellers ensuring they get off at the right stop and not miss it.

The majority of the respondents (72%) felt that the feedback from the in-bus displays was useful. Figure 84 gives a list of techniques that users said they would do to keep track of their destination bus stop. About 63% of respondents would 'ask the driver to alert them' or 'look for landmarks' to notify them about arrival at their destination bus stop. 50% of respondents said they 'carried a map' or printed version of the route itinerary for reference when they are in-transit.

A small percentage of users (38%) said that they would use journey planner software

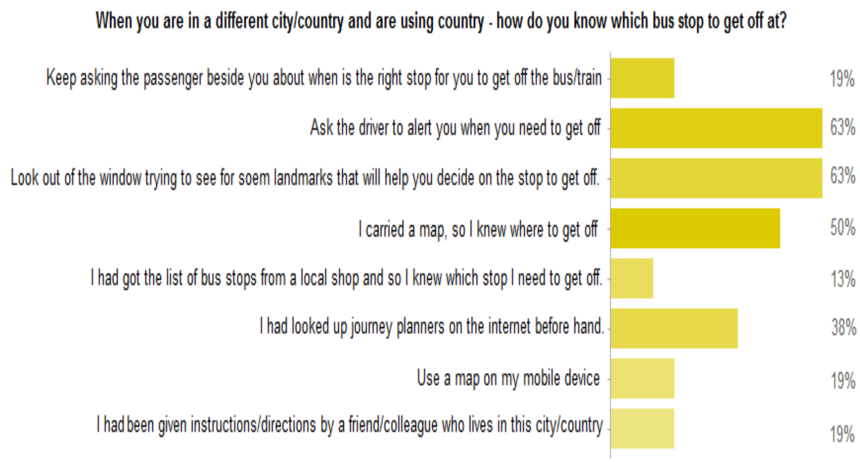


Figure 84: How to find out about the destination stop in a new city/country.

before the trip. Asking the passenger sitting beside the user, remembering directions from friends and use of mobile maps were the other options the respondents relied on. About 60% of respondents reported that they had missed their stop while travelling by bus at some stage in the past and the reasons for missing the stop is listed in Figure 85. The most commonly cited reason for missing a stop was attributed to travelling when it was dark (64%). As it was dark outside, the users found it difficult to recognise (using landmarks and POIs) that they had reached their destination. The second most commonly cited reason for missing a stop was a result of the passengers falling asleep on the bus.

The survey participants were also asked what form of alert feedback they would most prefer. From the survey "displaying user position on a map" and "vibration alert to inform them of the bus stop" were the most popular responses. In providing the reasons for choosing the vibration alerts feedback, 30 out of 45 respondents explained that they chosoe this since they don't need to devote all of their attention to the phone screen. The participants explained that since the phone is in their pockets/bag most of the time, the vibration alert would be a suitable form of feedback. Based on the feedback from the passengers, we describe a multi-modal feedback system to help public transport users.

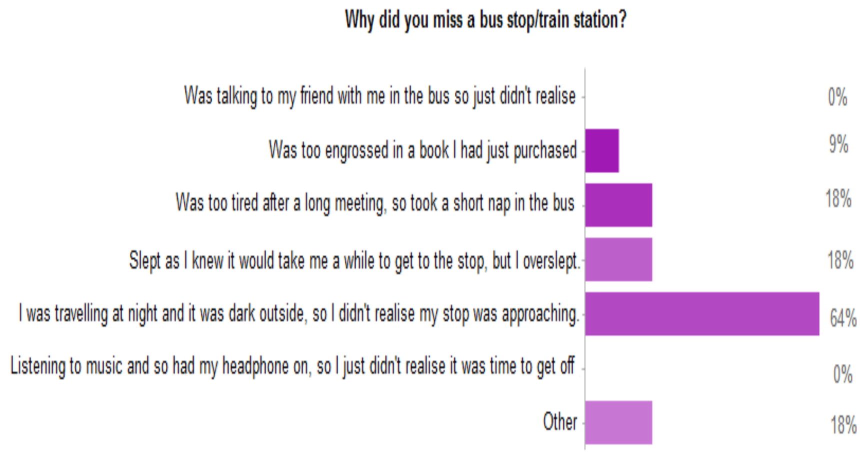


Figure 85: Reasons of missing a stop while using public transport.

7.5 Haptic Alert

HapticAlert is a tactile feedback based alert/notification system that provides spatial information to the user about arrival at a location through vibrational alarm. The system can be a notification system for a public transport user (Jacob et al., 2011c). The model uses real-time bus location with other spatial information to provide user feedback about the user journey. The system allows users make better 'in-bus' use of time. It lets the user be involved with other activities and not be anxious about the arrival at the destination bus stop. Our survey shows a majority of users have missed a bus stop/station (Figure 85), and thus this system ensures such an information system can be of great advantage to certain user groups. The vibration alarm is used to provide tactile feedback. Visual feedback in the form of colour coded buttons and textual description. This model on further research can provide the platform to develop such information systems for public transport users with special needs deaf, visually impaired and those with poor spatial abilities. We now understand the beenfits of Haptic Alert by discussing the Haptic Transit system where such a notification system can be integrated.

7.6 Haptic Transit

Haptic Transit is a tactile feedback based user interaction system that provides spatial information to the users of public transport (Jacob et al., 2011a). We propose an interaction model for using haptic feedback as an alternative to visual interfaces for the provision of public transport information to passengers with smartphones. We now discuss the Haptic Transit system in detail by looking at the various sub-systems involved which enables proper use of such services.

7.6.1 The Haptic Transit Interaction Model

The *Haptic Transit Model* is an integration of various sub-systems that combine to provide the public transport user with all the relevant information based on the needs of the user. In Figure 86 we see the *Haptic Transit Model* which has the *Haptic Navigation* (pedestrian navigation module), *HapticAlert* (the notification system), *User Interaction Model* (local user or tourist), and *Expected Arrival Time* system (the system that predicts arrival time of bus/train).

Every trip for a user of public transport involves 3 main phases.

1. Getting to the bus stop to catch the next bus
2. In-transit and getting off at the destination bus stop
3. Getting to desired location from the destination bus stop

The first phase is getting from the current user location to the nearest bus stop/train station. They need to reach the bus stop in time for the next available bus/train to the stop closest to the user's final destination. This usually involves querying for the nearest stop, the arrival time of the next bus and walking towards that stop. The second phase is the in-transit phase where the user is in the bus/train and engaging in some activity till they reach their destination stop. The third phase involves getting to the desired destination from the destination stop where the user disembarks the bus/train. *HapticNavigation* is the pedestrian navigation module that helps the user involve in the pedestrian navigation task by using one of the suitable pedestrian navigation systems as discussed in chapter 5. This is useful both for the first and third phase of the journey using public transport.

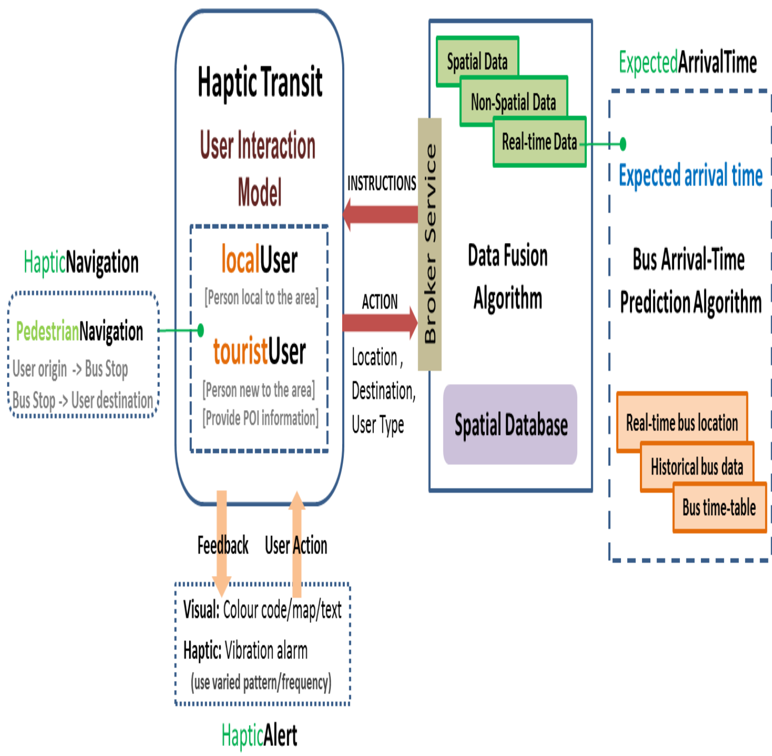


Figure 86: The Haptic Transit Model.

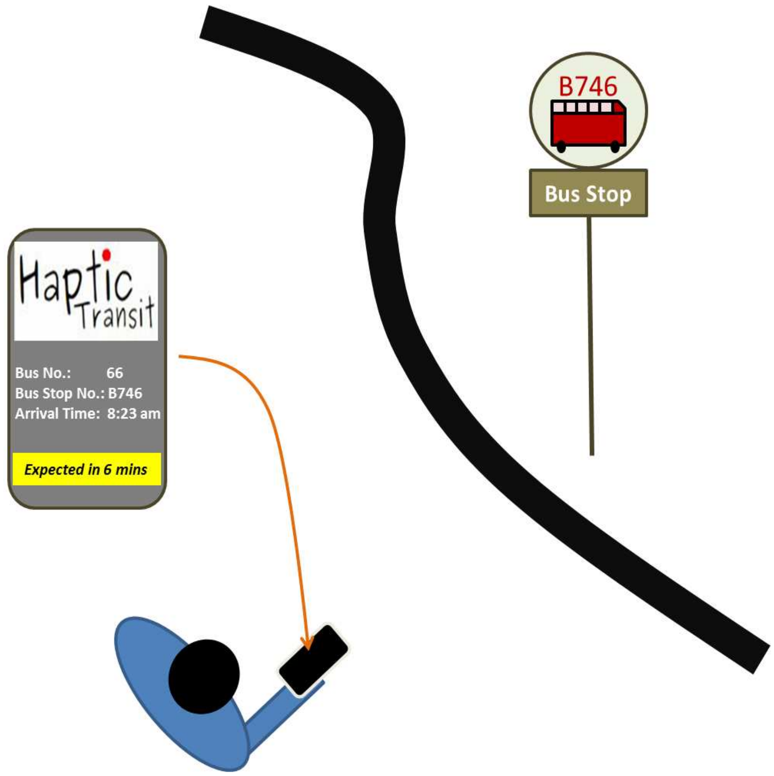


Figure 87: Using pointing gestures to query real-time public transport information.

The *Haptic Transit* system notifies the user if they want to be alerted when at the destination bus stop. If the user selects tourist mode (when in a new city/country), the system notifies the user about the various landmarks/POIs along the route using the non-intrusive, low interaction vibration alarm. The user can choose to read through the contents displayed about landmarks when alerted. The *Haptic GeoWand* concept to query by using pointing gestures was used for querying the location and direction of bus stop of origin B_o (Figure 87) (Shalaik et al., 2011a). When the user selects the *HapticAlert* module of the system, they will be notified about the destination stop by a unique vibration alarm when they reach the stop (B_{n-1}) just before the final stop. This gives them ample time to prepare to disembark the bus/train (Jacob et al., 2011a). There is another alert again when the user is within d metres from the destination stop to ensure that the user can inform the driver about the need to get off from the bus at the next stop (B_n).

The *ExpectedArrivalTime* module uses bus location, historic data, time table data and bus stop location data to provide almost accurate results about arrival time at the origin

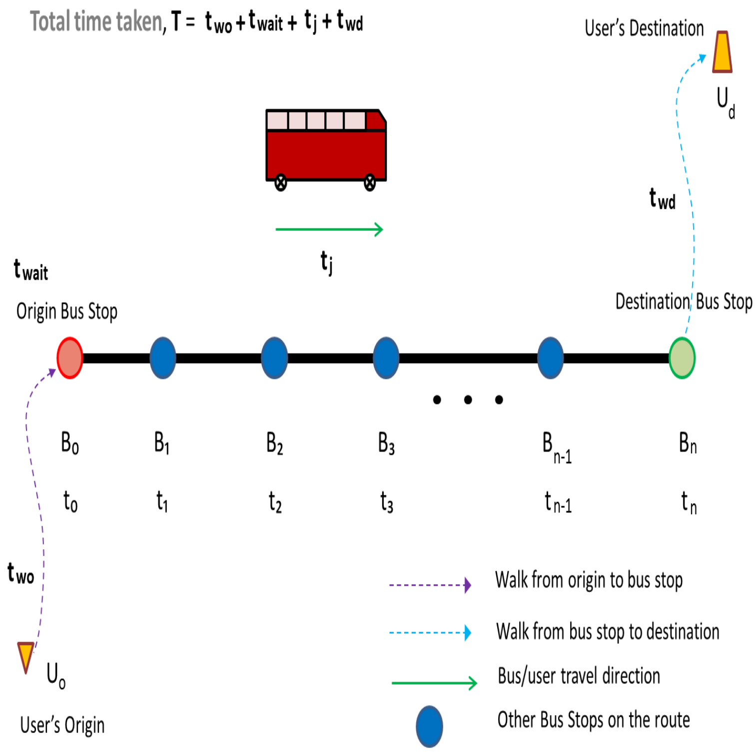


Figure 88: Schematic diagram of phases in public transport.

bus stop, B_o (Shalaik et al., 2010). And this provided the real-time information about arrival time of buses on mobile devices at the origin bus stop (Figure 87) (Shalaik et al., 2011b).

The schematic diagram of the public transport system model represents the various phases of a user of public transport is represented in Figure 88. The total time taken for the user to get from current location (U_o) to the final destination (U_d), $T = t_{wo} + t_{wait} + t_j + t_{wd}$

Here, the symbols represent:

- t_{wo}: Time taken to walk from the users current origin (U_o) to the origin bus stop (B_o)
- t_{wait}: Time that the user waits at the origin bus stop (B_o) before boarding the bus towards the destination (U_d)
- t_j: Travel time in the bus from origin bus stop (B_o) to the destination bus stop

(B_n)

- t_{wd} Time taken to walk from the destination bus stop B_n to the users destination, U_d

The *ExpectedArrivalTime* module ensures that the wait time at the origin bus stop (B_o) is minimal (Shalaik et al., 2010). Let us now look in detail at the interaction model that provides the initial pre-journey querying to find and reach the origin bus stop.

7.6.2 Pre-journey interaction and querying

When a user needs to get from any point A (U_o) to another point B (U_d), there are different kinds of information the user needs. They are as follows:

- Trip-Planner that gives complete details about bus stop, bus route, bus arrival time (Shalaik et al., 2010, 2011b, 2012).
- Which bus stop to go to catch the bus, directions to get there (Shalaik et al., 2010, 2011a,b).
- Time taken to get to the bus stop to reduce wait time at the bus stop (Shalaik et al., 2010).
- Arrival time of the bus at the bus stop (Shalaik et al., 2011a,b).
- Walking directions to get to a bus stop (Jacob et al., 2012a; Shalaik et al., 2011a).

The first phase involves getting from user's current location U_o to the origin bus stop, B_o. The use of web services providing this information is still the most popular method for trip planning as planning a trip in advance is usually done at the comfort of a computer at home or in office. Here the interaction with the web service can ensure complete attention of the user as there are no other distractions. The use of printed transit information is still very popular with its availability mostly free of cost at train/bus stations.

The main types of information the trip planner provides is the bus stop to go to, the bus number to take, the arrival time of the bus at the origin bus stop, the expected arrival time of the bus at the destination (thus knowing total in-transit time), and the distance to the actual destination from the destination bus stop. In our previous work, we integrated pedestrian navigation functionality with a real-time web service to enable better quality of service by reducing the wait time of passengers at bus stops (Shalaik et al., 2010). This was achieved by combining the time taken to get to the bus stop from the users current location and the arrival time of the bus (the user intends to take) at the bus stop. This system which worked on a web browser was extended to provide these services on a mobile device called *TransitDroid* (Shalaik et al., 2011b). This system provided information about arrival time of bus at the bus stop and the time taken to reach the bus stop to ensure the user does not miss the bus and have to spend more time waiting at the bus stop for the next bus on that route towards the destination. This was beneficial as apart from the web service that can be used when the user is in the comfort of an indoor environment, when the user is on the move, or an easy to use service must provide information about expected bus arrival time. on mobile devices. We compared the use of web and mobile services and provided a model that integrates both user interaction models based on user location (Shalaik et al., 2012). Shalaik et al. in the paper emphasised the need for an easy to use mobile interaction model. Thus a model where the user could query for bus stops by using pointing gestures using their mobile phone was highlighted. The pointing and scanning gesture based querying for public transport information uses a *Haptic GeoWand* based querying system that provides haptic feedback when the user points the device in the direction of the desired bus stop (Jacob et al., 2012a).

The model of the route is stored in the spatial database. Each route R is an ordered sequence of stops B_o, B_1, ... B_{n-1}, B_n. Here, the corresponding arrival time of the bus at each of the stops are represented as t_o, t_1, ... t_{n-1}, t_n. The expected arrival time of the next bus at the origin bus stop, B_o is t_o. The destination stop on a route is given by B_n with the bus arrival time at destination is t_n and the stop just prior to this destination stop is B_{n-1} has an arrival time of t_{n-1}. The time taken to walk from the user's current location (U_o) to the origin bus stop (B_o) is t_{wo}. Based on the time taken to walk to the bus stop, B_o the user is provided with information about the bus arrival time and the system advises the user about the appropriate actions to take. Each stop B_i has attribute information associated with it including: stop number, or stop name. Using the timetable/real-time bus arrival information for a given journey R_i along route R, we store the timing for the bus to reach that stop as t_o, t_1, ... t_{n-1}, t_n. This can be stored as the number of minutes it will take the bus to reach an intermediate stop B_i after departing from B_o. This can also be stored as the actual time of day that a bus on journey R_i will reach a stop B_i along a given route R. This is illustrated in Figure 88.

The user initiates the 'point-to-query' element of the system where the user selects the destination and then scans the area to find the general direction of the origin bus stop B_o. The "scan" operation is performed when the user holds the phone parallel to the ground and moving it around them (Figure 58). The user 'scans the area to find the location (and general heading) of the origin bus stop, B_o. The information also provided is the expected arrival time of the bus at the origin bus top. By comparing the walking time to the origin bus stop and the expected arrival time of the bus at the bus stop, user is also alerted if they will be able to make it in time for the bus or if they will miss it. The user is said to miss the next bus from B_o if the walk time t_{wo} from users current position U_o to the origin bus stop is greater than the time remaining for the bus to reach the origin bus stop B_o.

The compass and the location information via GPS will help query the system and provide directional information to the bus stop. This feedback is provided by textual description with bus number and arrival time at the bus stop along with the walking distance and time taken to reach the bus stop. Haptic feedback in the form of a vibration alarm is used to provide the user with information of the general direction of the bus stop when the user points the smartphone in the direction of the bus stop, B_o. Thus, this minimises the interaction with the visual interface while the user walks towards the bus stop thus ensuring faster travel to the bus stop. The user gets real-time information about the arrival time of the ideal bus to take to get to the bus stop $B_n$which is nearest to the actual destination U_d of the user.

The *HapticNavigation* sub-system within the public transit system for mobile provides the user with information about the bus stops, the arrival time of the bus at the origin bus stop based on the real-time location of the buses and also navigation assistance to get from the users current location U_o to the bus stop B_o. The wait time at the origin bus stop before boarding the bus is represented by t_{wait}. The real-time bus tracking system that provides the expected arrival time of the bus at the bus stop ensures that the user's wait time at the bus stop is minimal.

We will now discuss the kinds of in-bus information and notification for public transport users and how tactile cues are used to provide the users with such information.

7.6.3 Tactile cues for in-bus information and destination stop notification

Once the user boards the bus from the origin bus stop, the expected time from this bus stop to all the bus stops from B_1 to B_n is set to t_1 all the way to t_n. These time values are dynamic and value change based on the bus location and the time taken to get from the origin bus stop B_0 to the destination bus stop B_n is t_n.

The *HapticAlert* system provides assistance to the user to indicate when their destination bus-stop B_n is approaching. Instead of providing the user with a map based system which provides detailed information which may/may not be of use to the user, instead the users are informed using haptic feedback when their stop is approaching (via subtle vibration pulse) when the bus is past the bus stop B_{n-1}. This gives them enough time to prepare to disembark from the bus.

The user has the option to select user mode local/tourist. Along with the destination, the user also selects the information mode destination only or tourist mode. This provides additional assistance with information/alerts about POIs along the way using haptic/visual feedback. The user is alerted by a unique vibration feedback corresponding to being close to a landmark/POI along the route. Along with haptic feedback, visual feedback with name and description of the landmark POI is provided.

The arrival time prediction algorithm is used to ensure that the expected arrival time at their destination bus stop is provided accurately. There is a broker service running on the server responsible for calculating the proximity of the user to their destination bus stop. The visual interface on the device provides the user with the time and distance to the destination stop with colour coded buttons to represent proximity information.

The system computes the time and distance to the user's destination stop and gives a subtle alert to the user when they are nearing the destination. This alert is provided by a low frequency vibration feedback. The alert is triggered when the user reaches the stop just before the destination stop. This enables the user to prepare to disembark the bus when the next stop is reached. The intensity of the vibration alert on the mobile device increases as the bus is approaching the desired stop. As an alternative the colour-coded button on the visual interface provides the user with information to represent far, close and very close using the red, amber and green colours. An amber button displayed indicates that the user is very close to their destination stop. A red button indicates that the user has reached the penultimate stop. Green indicates that the user still has some distance to travel.

There is a set buffer distance D_{buffer}. The distance of the user (or bus) to the bus stop just before the destination stop represented as B_{n-1} is D_{dest-1}. The distance of the user to the destination, D_dest is calculated at all points in the route. Thus if the distance value of the user to bus stop B_{n-1} which is D_{dest-1} is less than D_{buffer}, then the user is also alerted by a unique pulse of small frequency to alert them that their destination stop is nearing. And when the user is within a set buffer distance value D_buffer from the destination bus stop B_n, the tactile feedback is provided using a unique pulse (of continuous vibration) notifying the user that they are very close to their destination stop. This happens when $D_{dest} < D_{buffer}$.

The tactile feedback ensures the subtle feedback is non-intrusive and the user can engage in any activity that they want to get involved in when in-transit as described during the survey. The user has reached their destination stop and can now disembark from the bus and orient themselves to get from the destination bus stop (B_n) to the final destination of the user U_d. The travel time in-transit to get from B_o to B_n is t_j.

7.6.4 Pedestrian navigation phase

The final phase of travel while using public transport is the pedestrian navigation stage where the user needs to get from the destination bus stop (B_n) to the actual destination, U_d. The time taken to travel from the destination bus stop (B_n) to the actual destination, U_d is t_wd. The user must specify the requirements of their journey and provide information about their destination. The user chooses which mode of pedestrian navigation they want to use - visual or haptic feedback. Within the haptic feedback option the user can choose from two pedestrian *HapticNavigation* system options: the waypoint by waypoint optimal path information using haptic feedback (*HapticNavigator*) or the destination pointer system where the user is alerted (via vibration alarm) of the general walking direction (*HapticDestinationPointer*) to the destination (Jacob et al., 2011b).

Thus the total time spent by the user to get from the user origin to the user destination is the sum of:

- Time taken to walk to origin bus stop,

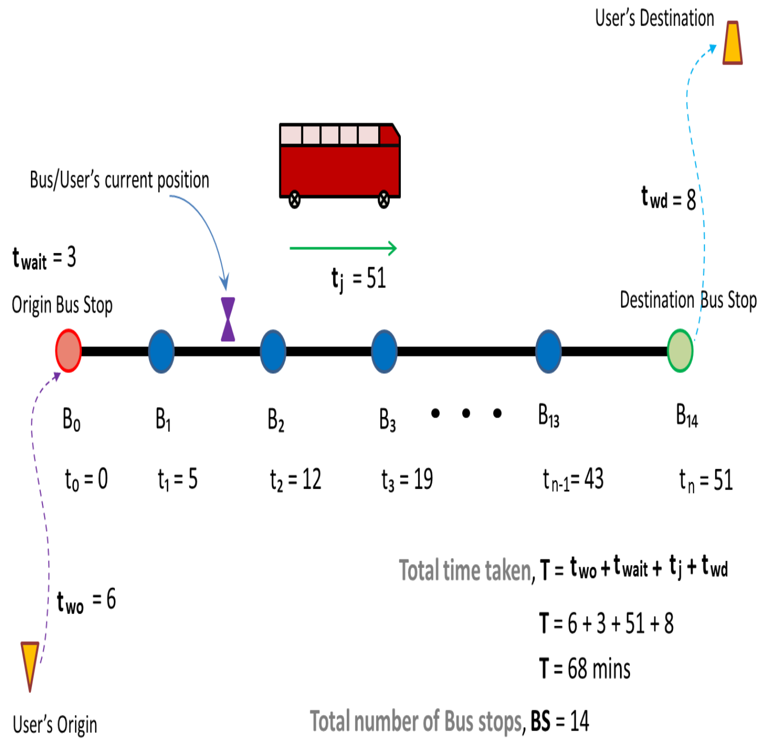


Figure 89: Haptic Transit sample route.

- time spent waiting at origin bus stop for the bus,
- time spent in-bus travel to the destination bus stop and
- time after disembarking from the bus, walk from the destination bus stop to the users desired destination.

Figure 89 represents a sample route with values to help understand the total travel time during the four phases of a public transport user. The total time taken to complete all these tasks and to reach the final destination (U_d) is: $T = t_{wo} + t_{wait} + t_j + t_{wd}$

7.6.5 Implementation of Haptic Transit System

To implement the Haptic Transit prototype we used a smartphone running on the Android operating system. The smartphone has an inbuilt GPS receiver, digital compass, and an accelerometer. The Android Software Development Kit (SDK) enables us to customise the vibration alarm pattern and frequency (GoogleAndroid, 2012). Thus by varying the frequency and vibration pattern, we can provide meaningful information to the user. The geographic data used to test the system was OpenStreetMap. A version of the Ireland OpenStreetMap database was stored locally on our server in a PostGIS database. OpenStreetMap provides us with a rich spatial dataset to test the application. However, the application has the flexibility to work with any other sources of vector spatial data if available. In our system we log a number of important variables: the location, bearing, speed of the user's phone, and the accelerometer reading. These log files are retained and used for further analysis as it can tell us about the sections of the route where the user stopped, the travel speed, or wait-time at bus stops.

The ability to integrate all the sensors into an off-the-shelf smartphone has allowed quick development and implementation of the system. Use of colour coded buttons and textual description about distance to destination and time is provided along with the subtle haptic feedback if the user wishes to use the visual interface. To integrate pedestrian navigation with real-time bus arrival time information, we used time taken and distance information from Cloudmade (Cloudmade, 2012). Using Cloudmade, we were able to obtain the distance of the bus stop from the current location and the time taken for the user to get from the current location to the origin bus stop. Based on the expected arrival time of the bus at the origin bus stop, we were able to calculate if the user will make it in time for the next bus or will he/she miss the bus if the time taken to walk to the bus stop is greater than the time in which the bus will arrive at the bus stop means the user will miss the bus. While we integrated this model to work with bus as the mode of transport, this model extends easily to incorporate other modes of public transportation including: long distance coach services, intercity trains, and trams.

7.7 Summary of integration of Haptics in notification/alert systems

Reed and Wright proposed an experiential account of a real-time system called BLISS (Reed and Wright, 2006). They combined a theory of technology with passenger interviews and empirical observation and reflection, and presented it in a narrative structure of analysis and storytelling. They talk about the importance of taking into consideration the passenger's thoughts and feelings as they are performing various actions related to public transport use. These things need to be addressed to attract more users to give up their cars for daily commute and choose public transport instead. Thus ways need to be looked at to give the user a complete satisfactory experience throughout various phases of a trip involving public transport use.

Simplicity of use along with accurate and efficient services ensures user interest in the use of public transport services. The web interface is a great tool for trip planning when sitting in the comfort of your home or office on a desktop PC or laptop which has big screens and can have almost complete attention of the user. The interaction techniques and use of similar services should be altered to attract the mobile user to using such services on their mobile phones with small screen and non-availability of complete user attention. Amongst the respondents of the survey, haptic feedback is the preferred mode for providing feedback to the user regarding arrival at destination stop. Haptic feedback ensures that the feedback is not distracting or embarrassing like voice feedback and it also lets the user engage in other activities in the bus. Haptic feedback can be used by people of all age groups and by people with or without visual impairment. It provides a very suitable modality for information for passengers who are unhappy with the use of continuous audio feedback modality (Thomson et al., 2007).

Vibrotactile cues can be used as a channel which provides 'private information' in an easy to understand manner for the user (Li et al., 2008). While the granularity of detail that can be represented using such systems is limited, it can be efficiently used to convey a certain notification message in a high level form. Hansson et al. proposed a model for visualizing subtleness versus publicity with regard to notification cues (Hansson et al., 2001). Accoring to Hansson et al. (2001), the main four tangents of the graph in the model are public, private, subtle and intrusive cues. But the authors discuss the need to combine both subtle and public qualities. This is so as public notification cues (a mobile phone ringing) in a public gathering ensures that the course of actions following the notification of a call is known to the people around as they saw the user pick up the phone to answer the call. In the case of private notification cues (subtle tactile feedback), the others are not aware of the incoming call and the resultant actions following a call notification is hidden from others around the user and thus they actions can also be misinterpreted by those people. Warnock et al. conducted experiments to see if there are any negative effects to unwanted notifications. The results from their work showed that unwanted notifications have the potential to be more disruptive than notifications requiring a response, highlighting the need for effective notification scheduling systems (Warnock et al., 2011).

The user survey suggests that there is a need for an information system that caters to various phases of a user of public transport. Using our system with haptic feedback drastically reduces the amount of time a user needs to have their phone out on display. With the vibration feedback to alert passengers of their stop location it is hardly necessary at all to have the phone device displayed in public throughout the journey. Also the interaction for the pedestrian navigation phase can ensure the user can do so in a less obvious way for others on the street that the particular user is a stranger to the area. As some of our participants in our user trial put it: “we can look like locals rather than tourists”. When a user travels to a new place, subtle and private haptic feedback ensures more interaction with the real-world and less interactions with the mobile device.

To test the benefits and performance of haptics enabled systems for providing spatial information to the user, a set of tests and experiments were performed. In chapter 7 we will discuss the various user trials and experimental analysis carried out and highlight the key outcomes from them.

8 User trials and experimental analysis of client-server spatial queries

8.1 Introduction

To test the potential use of haptic feedback as a means to deliver spatial information, we carried out various user trials. Experiments were carried out to test how the user performed while using haptic feedback for navigation. Two tests were carried out to evaluate various aspects of pedestrian navigation. One was to see how effectively and successfully the user can navigate from a given origin to destination by using haptic feedback while being distracted by another person walking along and talking at all times till the completion of the task. This is to test the real-world situations that arise where the primary task is walking and/or performing some other activity and the use of assistance technologies for navigation is only a secondary task and thus dividing attention between the two needs to be considered. The second test was designed to test the user's memory recall of the region after completion of navigation tasks based on landmark image based navigation and haptic feedback based navigation. We also test the performance of *Haptic GeoWand* based queries (requiring pointing gestures) without internet connectivity and when the query is processed within the mobile device.

8.2 Pedestrian navigation task with distraction

Research question: Can haptics be used for pedestrian navigation by a user involved in another primary task (in this case - talking to a friend) as they walk towards the destination location?

8.2.1 Experimental setup

To test the haptic interaction model for pedestrian navigation, we tested the *Haptic DestinationPointer* (as discussed in Chapter 5) with 15 participants (adults, undergrads/postgrads). Before the participants performed the test, they were given a 5 minute overview and introduction about the feedback patterns to help familiarise them with the feedback representing distance and direction information. The origin and destination were fixed for all the users, but the users were not informed where the destination is. Tests were carried out at different times of the day. The users were given the mobile device which had the *Haptic DestinationPointer* application installed. They were asked to navigate to this unknown destination based on only haptic feedback they receive from the mobile device without any visual interface. The study area including the pedestrian paths and other roads are well represented on OpenStreetMap by inputs from volunteers. Cloudmade provides various web and routing services using the OpenStreetMap database (Cloudmade, 2012). The start and destination point along with the shortest path described by the Cloudmade routing service between the two points (Figure 90). The total distance between the origin and destination along the shortest path was about 540 metres and 390 metres was the straight-line distance between the two points. According to Cloudmade API, the time taken to cover that distance from origin to destination is 389 seconds (6 minutes and 28 seconds).

When the participants walked towards the destination, another person walked along to distract the user by talking and thus provide a more real-world situation of actually exploring places when the usage of navigation assistance was the secondary activity. Hence the use of a device to assist in navigation was the secondary task and the physical task of walking to the destination avoiding wayside obstacles while conversing with the friend being the primary task. As the user performed the test, the compass and accelerometer readings were stored to understand in detail the path taken for post navigation analysis. The compass readings of the user along the path helps us to understand the spots along the path where they performed the scan operations due to confusions about the direction to destination. The accelerometer reading enables us to understand the spots/regions in the path where they paused or were standing still trying to reorient as the user was uncertain about which direction to head next.

8.2.2 Results from the pedestrian navigation test

All the 15 participants completed the tasks successfully as they all reached the destination. Almost all the users walked over open areas and paved walkways to reach their destination. The average time of completion by all participants was 865 seconds while the average distance travelled to reach destination was found to be 807 metres. The time of 540 seconds to reach the destination by *user 2* was the fastest recorded time while *user 3* took the longest time (1192 seconds) to complete the task. The shortest travelled distance was also recorded by *user 2* (653 metres) where the longest travel

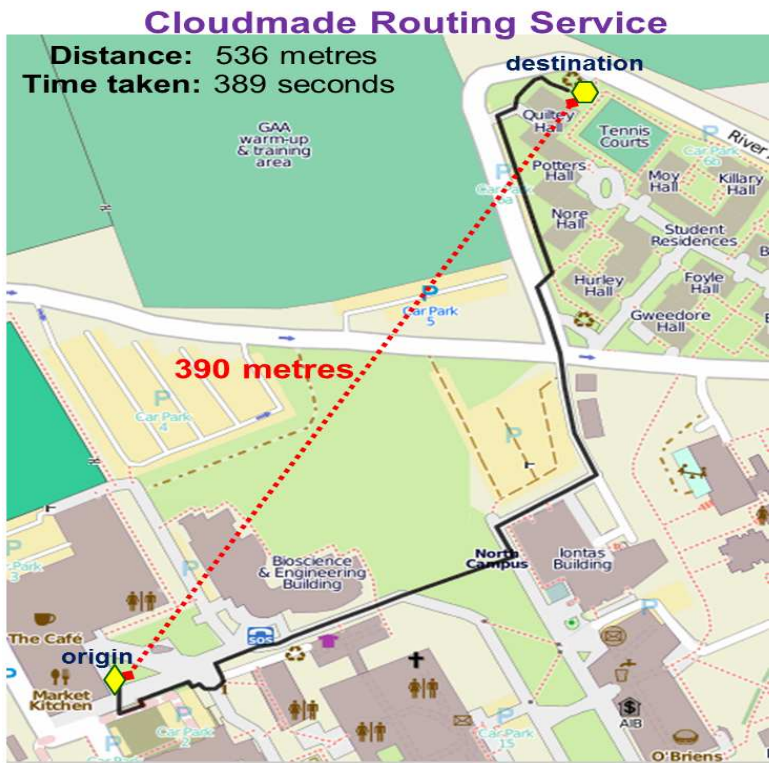


Figure 90: Pedestrian Navigation Task: Shortest path between origin and destination using Cloudmade API.

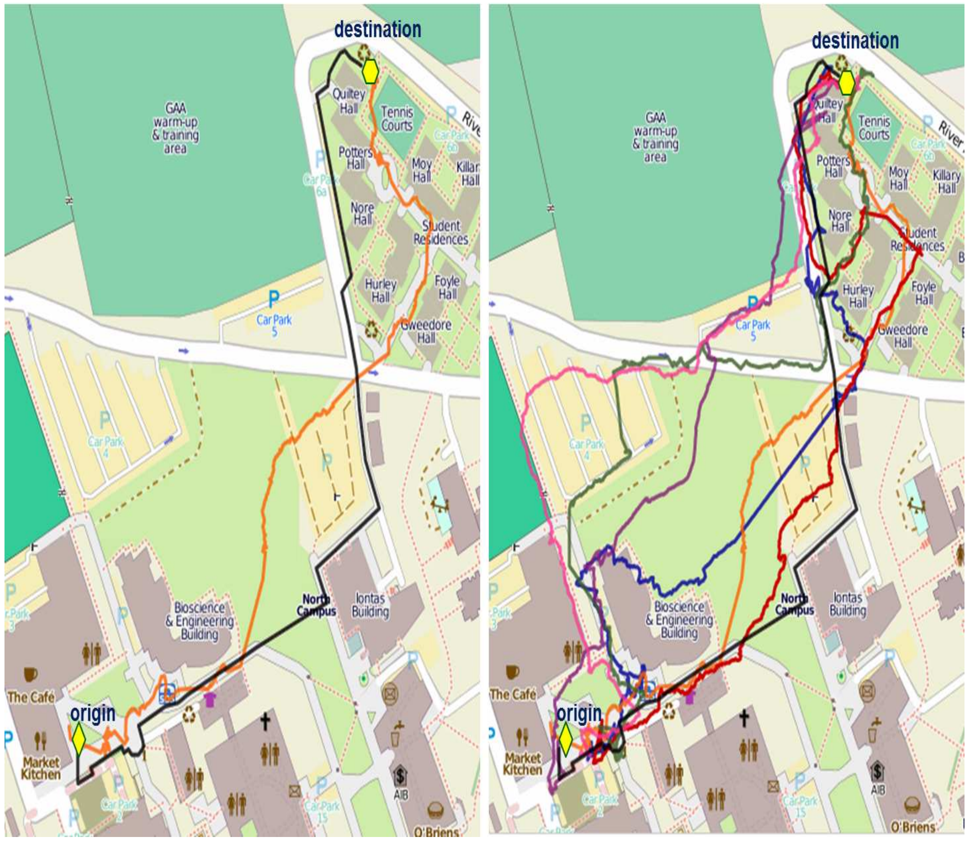


Figure 91: Pedestrian Navigation Task: (a) The path taken by *User 2* who took the least time and (b) comparison of 6 distinct paths taken by different users from origin to destination.

distance of 950 metres was recorded by *user 7*. The details about distance travelled and time taken along with general observations/comments about the user's navigation task have been described in Table 4.

According to the Cloudmade routing service, the time required to traverse the shortest path to the destination was 390 seconds (thus walking at a speed of 1.38 m/s) which seems very unlikely in a real world situation if the user is unaware of the walking direction towards the destination. The average walking speed recorded for the user trials was 0.93 m/s. Some users walked very fast while performing the trials while others chose to walk slowly and check the general walking direction when at certain critical points in the path. The users commented positively on 'how subtle the feedback was' and about not having to continuously interact with the device.

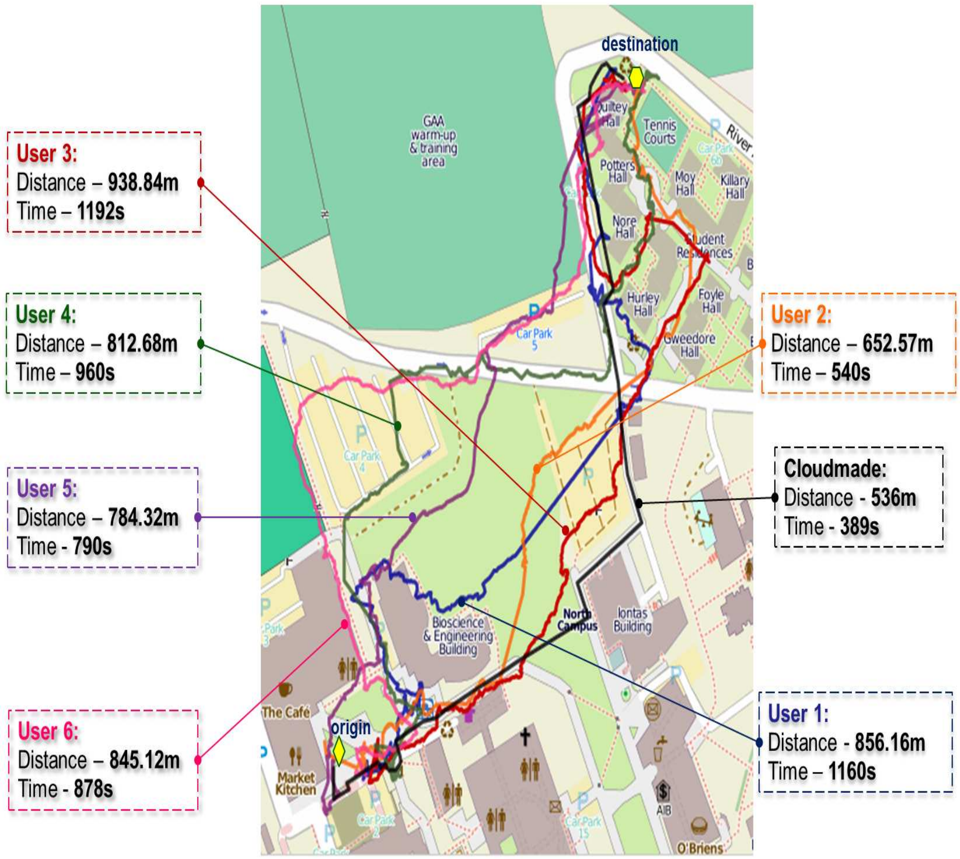


Figure 92: Pedestrian Navigation Task: Unique paths taken by 6 different users with corresponding time and distance values. These paths are compared with the route, shortest path and time taken as provided by the Cloudmade service

Figure 91a shows the path taken by the user (user 2) who reached the destination in the shortest time. The distance travelled and time taken is higher than that listed by Cloudmade. The comparison with 5 other users shows the distinct paths taken to the destination in Figure 91b. Unlike the typical shortest path, the users walked over open areas such as fields, sports pitches, car parking and also took paved walkways when necessary.

Figure 92 gives a summary of some of the unique routes taken and the distance travelled and the time taken to cover that distance in comparison with Cloudmade. In Figure 93 we can see two routes (*User 4* and *User 6*) where the users mostly stuck to paved pathways throughout the journey. Although the users walked across car parks, these car parks were paved and the users choose this as the grass was wet because of the rain.

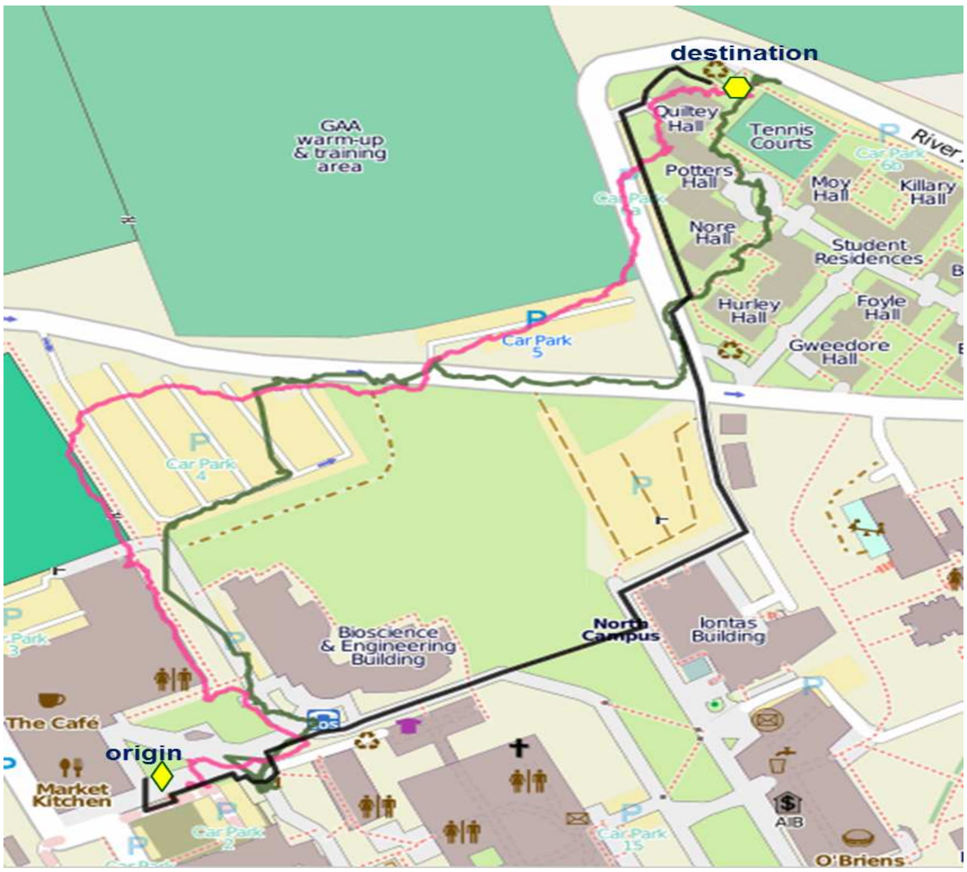


Figure 93: Pedestrian Navigation Task: Comparison of paths taken by 2 different users - *User 4* (test carried out at night) and *User 6* (test carried out on a rainy day and hence the grass was wet) plus the path suggested by *Cloudmade* represented using pink, green and black lines.

User 6 walked along paved path as apart from the grass being wet, it was also dark when the user performed the test and thus the user chose to walk along the lit walkways as compared to the open grass path like other users.

8.2.3 Summary of the pedestrian navigation task

Based on distance and times measured from Figure 92, we can see that at times users have walked faster but ended up walking longer distances and at times reached the destination slower taking shorter routes. Thus here the task mainly tested was how users could perform when presented with real-world distractions such as talking with a friend while walking towards a destination and avoiding other physical obstacles. The time taken to cover that distance as per Cloudmade routing service is only possible if the user knows exactly what route must be taken from the origin to get to the desired destination and walked continuously without pausing. During the tests the users were unaware of their destination location and the route to follow to get there and thus the time taken was greater than that was calculated by Cloudmade. The time taken to get to the destination is also significantly higher as the users were not asked to get there in the fastest possible time and thus users walked at their own pace while chatting with the friend.

During the navigation task, the users could get to the destination without taking their attention off their conversation with a friend while walking towards the destination. During the entire duration of the navigation task from the origin to the destination, not once did the user have to look into the mobile display as the screen was turned-off. This benefit of not having to continuously look into the mobile screen for navigation assistance was cited as a huge positive feature by majority of the users. The users were not aware of the destination and thus took longer even when the destination was in their view-point. So to further test the benefits of haptics during a navigation task, we decided to test how well the users are able to prepare a mental map of the area where the navigation tasks were carried out. The details of the tasks are discussed in the following section.

8.3 Memory recall task

Research question: Can haptic feedback ensure better memory recall of the area by users after a navigation task as compared to vision based systems?

8.3.1 Experimental setup

The 18 students who were selected to carry out this test were unfamiliar with the test area. While some participants attended NUI Maynooth, other participants attended other universities in the surrounding area of Dublin. The participants were randomly allocated to one of the three groups:

- Control Group,
- Experimental Group 1, and
- Experimental Group 2.

The mean age (μ) and the standard deviation (σ) of the age of students in each group is listed in table 5.

Participants were required to complete a number of control tasks including the Cognitive Failures Questionnaire (Broadbent et al., 1982), the National Adult Reading Test (Nelson, 1982), the Trail Making Test (Reitan, 1955) and a Mental Rotations task (Shepard and Cooper, 1982).

The Cognitive Failures Questionnaire (CFQ) was presented to participants in a pen and paper format (Appendix I). The questionnaire consists of 25 questions designed to measure the absent-mindedness, memory lapses and cognitive deficits of the participants. Participants were instructed to indicate on a five-point Likert scale how often different situations applied to them in the past six months. The scores of each participant from each question were combined to give a total rating out of 100.

The Trail Making Test (TMT) was also presented to participants in a pen and paper format (Appendix II). The TMT provides information on attributes such as visual processing, visual search and executive function (Reitan, 1955). The test has two parts, the first consisting of the participant linking 25 encircled numbers, starting at 1, by drawing a line connecting each on the paper provided. The second part of the test involved participants also drawing a connecting line, except this time from number to letter e.g. 1 A 2 B 3 C, etc. Participants were shown a shorter version of the test (Appendix II) before the official part A and part B, which were both timed. The scores taken from the TMT were times for completion of TMTA, times for completion of TMTB and the difference between the two scores, TMTB-A.

The National Adult Reading Test (NART) consisted of 50 single words of varying difficulty that were presented as a word list on a single sheet of paper. In this test participants were required to read aloud these words that have unusual pronunciations while the experimenter marks which words they have read correctly and incorrectly. The NART is used as a prediction of IQ and general intelligence (Nelson, 1982). The number of words that the participant pronounced correctly translated into a score of Full-Scale IQ, Verbal IQ and Performance IQ (Appendix III).

The Mental Rotations Task was presented to the participants in a pen and paper format. The test consisted of 18 questions which required participants to correctly identify two drawings of a three dimensional object that had been rotated different ways (Appendix IV). The Mental Rotations Task is used as a method of assessing participants spatial rotation abilities (Shepard and Metzler, 1971).

The Control Group and the Experimental Group 2 were shown four photographs of the destination point (Figure 94) at the start of the experiment in order to locate it. The Experimental Group 2 was shown a series of six photographs at Starting Point A (Figure 95) and at Starting Point B (Figure 96) which illustrated the route that they should take to reach the Destination Point.

The Experimental Group 1 used haptic feedback to help navigate to the destination point using the HapticDestinationPointer system. Participants were timed while navigating from Starting Point A to the Destination Point and from Starting Point B to the Destination Point using a stop watch device on a mobile phone. At the completion of the experiment participants were instructed to draw a map of the area of the area they were at on an A4 sized paper that already included the outline of the road surrounding the apartment complex(Figure 97).

A map key was used to score the maps, which were given a mark out of 25 for each participant (Figure 98). Marks were given for including the Destination Point, Starting Point A and Starting Point B, as well as marks for including buildings, the Tennis Courts and the bins located beside the Destination Point. Participants were not restricted to

Figure 94: Memory Recall Test: Panoramic images of the destination point that were shown to the control group and the Experimental Group 2.

Figure 95: Memory Recall Test: Images representing the path to get to the destination from origin A that were shown to the control group and the Experimental Group 2.

Figure 96: Memory Recall Test: Images representing the path to get to the destination from origin B that were shown to the control group and the Experimental Group 2.

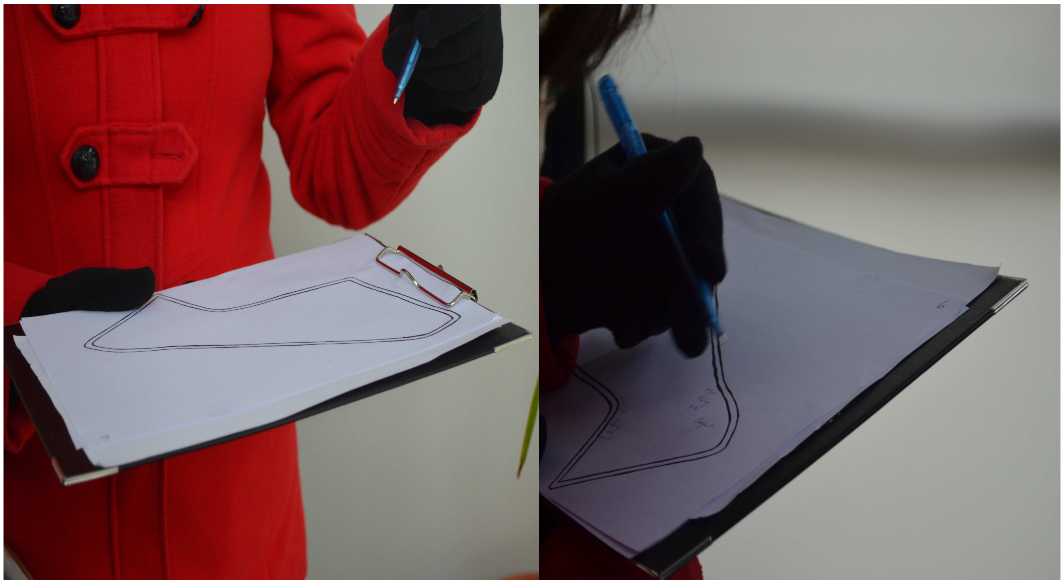


Figure 97: Memory Recall Test: User given a sheet with the road along the border of the area where the test was carried out is marked. They are asked to mark all the landmarks they recall seeing during the navigation tests

drawing buildings and were told to include any information that they could recall. Participants were not told before completion of the test about having to prepare a map as we did not want the participants to intentionally try and remember features for the post navigation task.

The findings from the memory recall test is described in the next section for both the control tasks and the map drawing with discussions about navigation time and overall performance in the post navigation task of map creation.

8.3.2 Results from the memory recall test

All the 18 participants from the 3 groups successfully reached their destination. Due to an overall low number of participants and unequal participant numbers in each of the groups, non-parametric tests were used in each of the control tasks.

Control Tasks: Table 6 shows the Mean Scores and Standard Error Scores for the Control Group, Experimental Group 1 (Exp 1) and Experimental Group 2 (Exp 2) on the Cognitive Failures Questionnaire (CFQ), the Trail Making Test Part A (TMTA),

Figure 98: Memory Recall Test: Map key representing the 25 POIs which the user is expected to mark post navigation task.

the Trail Making Test Part B (TMTB), the difference between them (TMTB-A), the NART scores Full Scale IQ (fsIQ), Performance IQ (pIQ) and Verbal IQ (vIQ) and the Mental Rotations Task (Rotation).

Results from the CFQ showed an overall mean score of 46.67 (SE = 3.71). An independent samples Kruskal Wallis test also demonstrated that there was no significant differences between the groups on CFQ scores (P = 0.095). Results from the Mental Rotations Task demonstrate that participants had an overall mean score of 26.61 (SE = 1.58). An independent samples Kruskal Wallis test measuring any difference between the groups revealed a significance level of 0.51, which almost approached significance. Further investigation of the means and SEs for each of the groups on the Rotations task revealed that the greatest difference was between the Control Group (M = 23.14, SE = 2.558) and the Experimental Group 2 (M = 33.00, SE = .894).

Results conducted on the Trail Making Test revealed an overall mean score for TMTA as 25.06 (SE = 2.55), an overall mean score for TMTB as 47.33 (SE = 3.83) and an overall mean score for TMTB-A as 22.28 (SE = 2.203). An independent sample Kruskal Wallis test revealed that there was no significant difference found between the Control Group, Experimental Group 1 or Experimental Group 2 on either TMTA scores (p = .365), TMTB scores (p = .342) or the scores on TMTB-A (p = .194).

Results conducted on the NART revealed an overall mean score for full scale IQ as 114.16 (SE = 1.04), an overall mean score for performance IQ as 112.56 (SE = .94), and an overall mean score for verbal IQ as 113.56 (SE = .94). An independent sample Kruskal Wallis test also revealed no significant differences between the groups on full scale IQ (p = 0.079), performance IQ (p = 0.079) or verbal IQ (p = 0.079). Results from the Control Tasks demonstrated that all of the participants had normal cognitive functioning and there were no significant differences found between the Control group, Experimental Group 1 or Experimental Group 2 on any of the tasks.

Map Drawing: A one-way between groups ANOVA was conducted to examine the difference in map drawing scores for each of the three groups. There was a main effect of group with the result almost reaching significance F (2, 15) = 3.1, p = .075. Despite not reaching statistical significance a post-hoc Tukey tests demonstrated that the Control Group differed from Experimental Group 1 at p = .078. An examination of the mean statistics as shown in Figure 99c revealed that the Control Group demonstrated a mean score μ_{md} = 9.43 (Standard deviation, σ_{md} = 2.82), Experimental Group 1 demonstrated a mean score μ_{md} = 13.33 (σ_{md} = 4.03), while Experimental Group 2 showed a mean map score μ_{md} = 10.00 (σ_{md} = 1.00).

Navigation Times: The navigation times for various groups to get to destination from origin A and origin B is listed in Appendix V. A 2 X 3 ((Navigation Time A, Navigation Time B) x (Control Group, Experimental Group 1 and Experimental Group 2)) between groups multivariate ANOVA was conducted to investigate the difference in the times taken by each group to navigate from starting point A to the destination point and from starting point B to the destination point. Preliminary assumption testing was conducted to check for normality, linearity, homogeneity of variance and multi-collinearity, with no serious violations noted. There was a statistically significant main effect of group at Time A (F (2, 14) = 5.28, p = 0.00). There was also a main effect of group at Time B (F (2, 15) = 3.446, p = 0.059), which almost reached significance.

A one way ANOVA was conducted to investigate the statistically significant difference found between the groups at Time A. The results demonstrated (Figure 99a) that there was a significant main effect of group (F (2, 15) = 2.68, p = 0.00). Post-hoc Tukey tests revealed that Experimental Group 1 differed from the Control Group at p = 0.00 and differed from Experimental Group 2 at p = 0.00. An examination of the mean statistics showed that Experimental Group 1 scored a mean time μ_{ta} = 280.17 seconds (σ_{ta} = 63.06), the Control Group had a mean score, μ_{ta} = 155.14 seconds (σ_{ta} = 11.24), while Experimental Group 2 demonstrated a mean score μ_{ta} = 149.4 seconds (σ_{ta} = 14.67).

A one way ANOVA was then conducted to investigate the almost statistically significant difference found between the groups at Time B. The results demonstrated (Figure 99b) that there was a significant main effect of group (F (2, 15) = 3.446, p = 0.059). Post-hoc Tukey tests demonstrated that Experimental Group 1 and Experimental Group 2 differed from each other at p = 0.073. An examination of the mean statistics revealed that Experimental Group 1 scored a mean time μ_{tb} = 237.5 seconds (σ_{tb} = 36.14), Experimental Group 2 demonstrated a mean score μ_{tb} = 193.2 seconds (σ_{tb} = 16.71) and the Control Group scored a mean time μ_{tb} = 201.57 seconds (σ_{tb} = 32.46).

Routes taken: Six key routes taken by the participants were identified - Routes 1, 2 and 3 from Starting Point A to the Destination Point and Routes 4, 5 and 6 from Starting Point B to the Destination Point (Figure 100).

Experimental Group 2 were shown photographs of Route 2 from Starting Point A and photographs of Route 5 from Starting Point B. Analysing the routes taken by each

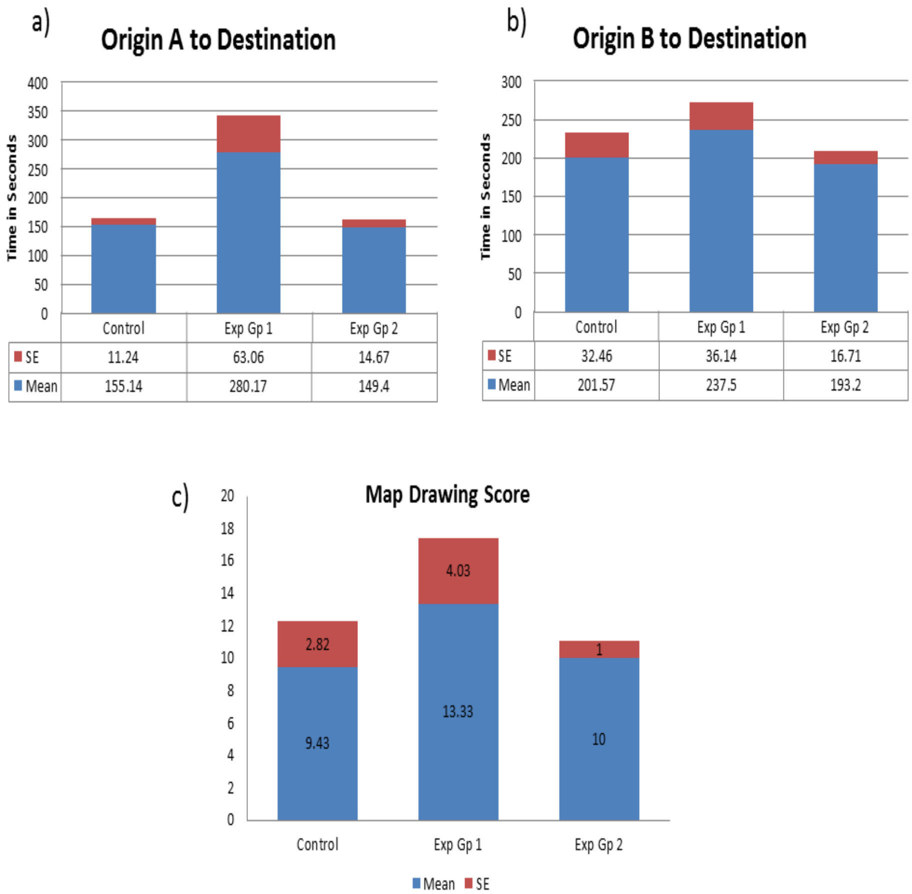


Figure 99: Memory Recall Test: (a) Mean Navigation Times in seconds for each of the groups from Starting Point A to the Destination Point along with the Standard Error Mean, (b) Mean Navigation Times in seconds for each of the groups from Starting Point B to the Destination Point along with the Standard Error Mean and (c) Mean Map Scores based on the number of features recalled for each of the groups along with the Standard Error Mean.

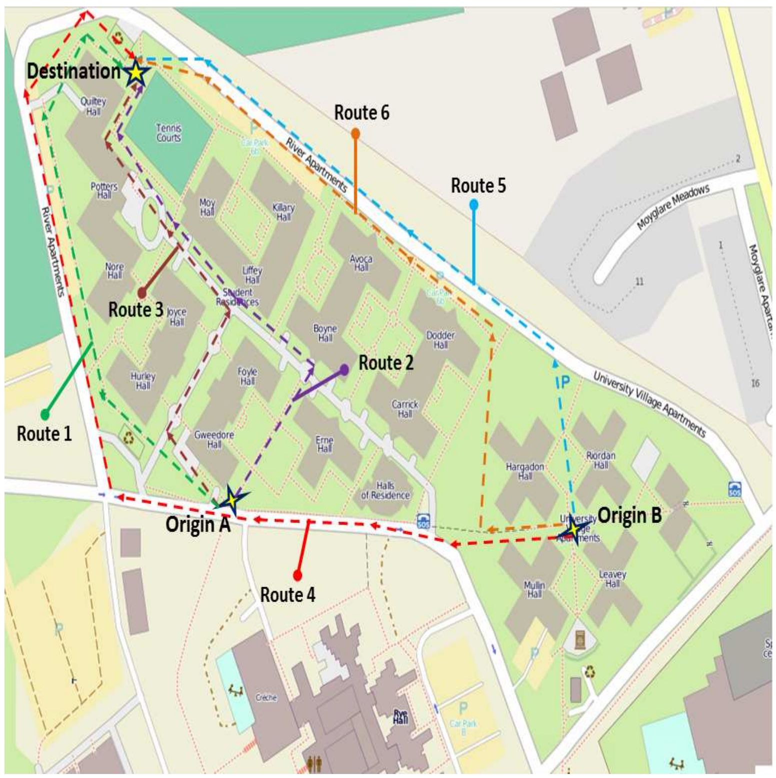


Figure 100: Memory Recall Test: Map of the six unique routes identified, as well as Starting Point A, Starting Point B and the Destination Point.

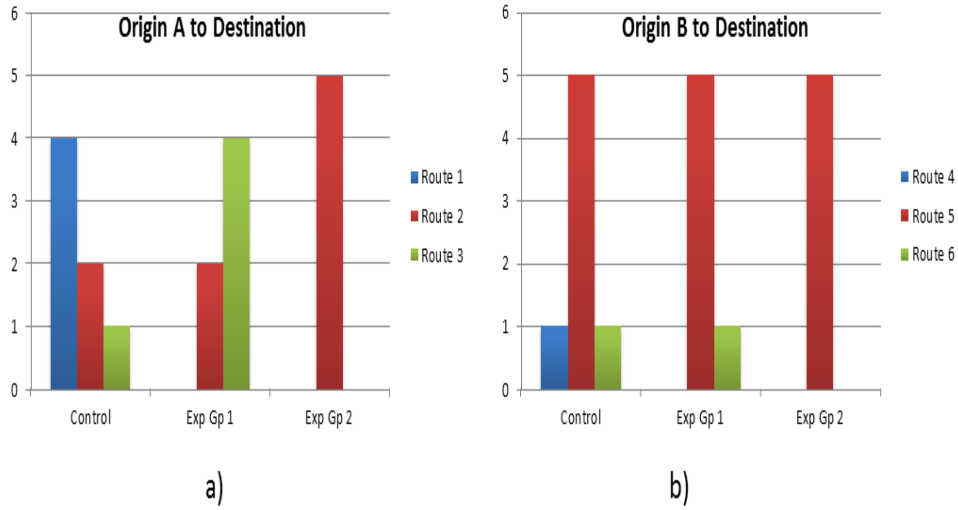


Figure 101: Memory Recall Test: (a) The routes taken from origin A to destination (b) The routes taken from origin B to destination.

participant showed that the majority (57.1%) of the Control group followed Route 1 from Starting Point A, while the majority (66.7%) of Experimental Group 1 followed Route 3 from Starting Point A, with 100% of Experimental Group 2 following Route 2 (Figure 101(a)). Analysing the routes taken by each participant from Starting Point B to the Destination Point revealed that the majority of both the Control group (71.4%) and Experimental Group 1 (83.3%) followed Route 5, while 100% of Experimental Group 2 followed Route 2 also (Figure 101(b)). Overall the most popular route from Starting Point A was Route 2, with Route 1 being the least popular, and the most popular route from Starting Point B was Route 5, with Route 4 being the least popular.

To summarise, the results indicated that the participants using the haptic technology took a significantly longer time to reach the destination point when navigating from Starting Point A and also took a longer time to reach the destination point when navigation from Starting Point B when compared to Experimental Group 2, with the result almost reaching statistical significance. However Experimental Group 1 also demonstrated higher map scores in comparison to the Control Group, who were told to navigate the environment freely, and the Experimental Group 2, who used route based photographs as a guide to navigation, with this difference almost approaching statistical significance.

8.3.3 Summary of the memory recall test

Based on the findings from the navigation tasks using *Haptic DestinationPointer*, it is seen that the users were able to successfully reach the destination without any visual feedback and perform the task even though they were being distracted by another user while the navigation task is to be performed.

Principle findings from the memory recall experiment indicate that those in Experimental Group 1 using the haptic feedback to help navigate the environment took significantly longer than those in the Control Group or Experimental Group 2 who were using the route based photographs as a guide. Experimental Group 1 took significantly longer when navigating from Starting Point A to the Destination Point and also took longer when navigating from Starting Point B to the Destination Point, with the result almost approaching significance. There was also an almost significant effect discovered when examining the map scores of the participants across the three groups those who were aided by haptic technology when locating the destination point had better maps overall, compared to the control group and Experimental Group 2. Figure 102 is an example of a map created by the user based on memory recall test as compared to the same region on OpenStreetMap.

The significant result obtained when comparing the times taken could be explained as follows. As the Control Group and Experimental Group 2 both were shown four photographs of the destination point so they knew what key landmarks to look out for and realise that they had reached their location. Experimental Group 1 who were not given any visual cues, were relying strictly on haptic feedback and did not have this to depend on, and only knew they had reached the location when the mobile phone started to vibrate continuously. It has been demonstrated in previous research that participants can reach an unknown location in an unfamiliar environment assisted only by haptic feedback (Robinson et al., 2010b). However the Control Group and Experimental Group 2 could be at an advantage as they could notice the landmarks of the Destination Point from a distance and therefore navigate towards it when the destination is within their line of sight. This could explain why those in Experimental Group 1 spent a longer time locating the Destination Point from Starting Point A.

Experimental Group 1 also took a longer time locating the Destination Point from Starting Point B, with the result almost reaching significance. This could possibly be explained by the fact that participants would be unfamiliar with the method of

Figure 102: Memory Recall Test: A comparison of the best map drawn after the navigation task versus the OpenStreetMap representation of the same area.

scanning that was used to give haptic feedback to the participant when the device was pointed in the direction of the Destination Point. It is possible that participants could have scanned too fast to pick up a vibration so this would slow the participant down when looking for feedback. It would perhaps be beneficial then to include a longer tutorial on how to accurately scan and search for feedback before commencing the search for the Destination Point and timing the participant. Scanning also has another disadvantage as it is more obtrusive and obvious that someone is trying to navigate their environment (Pielot et al., 2010). Although scanning was the technique that was used for this experiment it is also possible to have the device placed in your jacket pocket, then pointing and scanning for feedback to ensure user privacy (Jacob et al., 2010, 2011c). The user will also be safe in the knowledge that they do not seem like a tourist or stranger to the area, which is an issue for most navigators (Robinson et al., 2010a).

The almost significant result obtained from the map scores which illustrated that those in Experimental Group 1 scored higher maps in comparison to the other two groups can also be explained in reference to the photographs shown at the start. As was already stated the Control Group and Experimental Group 2 had prior knowledge of what the Destination Point looked like via photographs. Experimental Group 1 had no knowledge of what the Destination Point looked like when they began the experiment, therefore it may be possible that this had an effect on recall. Previous work has also indicated that use of tactile displays used to assist navigation can improve the attention of the user (Pielot et al., 2010; Jacob et al., 2012c). Studies have indicated that participants who use a tactile display while navigating pay more attention to the immediate surroundings of their environment (Pielot et al., 2010). As well as this, in experiments where the participant was asked to actively search for landmarks and other items while navigating the environment it was demonstrated that those using tactile displays are able to locate and notice more items (Elliott et al., 2010). Pielot et al. also noted a positive tendency in their study for those in the tactile condition to notice more entities (benches) than those in the visual condition. This could be a possible reason for the higher map scores of Experimental Group 1.

All participants in Experimental Group 2 followed the routes they were shown on the photos at both Starting Point A and Starting Point B to reach the Destination Point. The 2 routes were: Route 2 from Starting Point A and Route 5 from Starting Point B (Figure 100). Experimental Group 1 followed mainly similar routes to Experimental

Group 2, especially when navigating from Starting Point B to the Destination Point. It is interesting to note that nearly all participants in the Control Group navigated left (Route 1) when instructed to navigate freely. This can be explained by the fact that in the four photographs of the Destination Point, the site of the general rubbish and recycling bins was clearly visible and participants may have been attracted to the bins situated to the left of Starting Point A, thinking that they could possibly be the bins in the photograph of the destination. The examination of the routes taken by the participants provided another possible reason why Experimental Group 1 had higher map drawing scores, with the result approaching significance. The majority of participants in the Control Group took an alternative Route (Route 1) that did not bring them into the central part of the apartment. None of the participants in Experimental Group 1 or Experimental Group 2 followed this route to reach the Destination Point, instead choosing Routes that took them into a more central part of the campus accommodation area where they were navigating. This could have made a difference to the map drawing scores as it is possible that these Groups were exposed to more landmarks than the Control Group and were therefore able to recall and draw more landmarks such as buildings, and bins on the map.

If there is no internet connectivity most of the location based services listed above in the previous three chapters fail to perform as the processing of queries happens at the server side and not on the mobile device. In the *Haptic GeoWand* discussed in Chapter 5, we have seen the integration of spatial data and querying based on mobile interaction models that require internet connectivity for these services to work. We now look at how the typical location based circular queries (based on a radius around the user) and the geowand queries (based on the *Haptic GeoWand* model) perform when the processing is done on a mobile device.

8.4 Querying spatial data stored in mobile devices

Research question: Can complex queries like the haptic geowand query perform well in offline location based services where there is no internet connection and spatial data is stored in the mobile device?

In most cases location based services for knowledge discovery are dependent on the availability of an internet connection on the phone. Thus the use of such services is lost in scenarios where an internet connection is not available or not used (due to expensive internet contract/tariffs) such as when visiting another country. Coelho et al. (2011) proposes an Offline Location Based Services (OLBS) that user's access location based content by scanning a 2D barcode or RFID tag. This location trigger then accesses the location content from a local database stored on the device. The model proposed by Coelho et al. however fail if a user wants to query what is in their vicinity instead of just accessing information for a single location. They also do not consider the case where an application queries spatial data using geometric functions based on the users current position and what is in their vicinity.

There are currently LBS applications available for smartphones that function offline such as Google Maps (GoogleMaps, 2012) or OSMAnd (OSMAnd, 2012) and MapDroyd (MapDroyd, 2012) which provides offline OSM maps for Android users. These apps for android are just simple map viewers, some of which only include basic search options. They do not allow complex spatial queries such as using pointing gestures to get POI information or pedestrian navigation assistance. Google applications such as *Google Places* allow users to search for nearby POIs by category. This however can only be used with data provided by Google and requires an internet connection to function. Here the ability to use custom data would be of great advantage to users. Events such as conferences could provide custom POI and map data to attendees before an event takes place (Jacob et al., 2009). Colleges and universities could also provide detailed information, such as lecture theatre locations, to students on the campus using such custom built apps/services. Also, this information could be provided to International conference attendees who would not want to use an internet connection while in a foreign country.

8.4.1 System design of offline location based services

The development of an offline location based service requires us to consider a few key elements which constitute the system such as data storage, map view, query type, and user interface design. The system design of the Offline Mobile Location Based Service here is shown in Figure 103.

Data storage: Most of the location based services discussed in the earlier chapters use a spatial database stored on their servers which provide feedback to the user via the internet. One of the most important challenges in any offline system is the storage of data on mobile devices for querying and manipulation. This is due to the fact that

Figure 103: Offline LBS: System Design.

storage space in limited as compared to a server machine and the storage of spatial data with its functionalities on mobile devices can be a challenge. SpatialLite is an extension for SQLite that adds spatial functionality and is Open Geospatial Consortium (OGC) compliant. The SpatialLite provides the vector geodatabase functionalities to query and manipulate such SQLite databases. Thus the entire database obtained for the selected area can be stored locally on the phone in the SQLite database.

The data to be stored by the application can be broken into two areas:

1. Spatial data
2. Map data

The OpenStreetMap (OSM) is a free editable map of the world (OpenStreetMap, 2012). The spatial data can be freely used and so we considered the OSM data to create our test prototypes as it has the best coverage in the study area used for the tests. The OSM data is exported and additional meta data is added to improve the information available for users about a particular POI. This data is stored on the server in a PostGIS database.

The OSM data used to build the offline location based service is the *planet_osm_point* table (see Figure 104) taken from a PostGIS database. This table structure is the one used by OpenStreetBrowser (OpenStreetBrowser, 2012) and is created when OSM data is imported to a PostGIS database using osm2pgsql (OSM2PgSQL, 2012). This is then converted and stored as a SQLite file (.sqlite extension) in the external storage of the mobile device. The ogr2ogr (org2ogr, 2012) tool is used to convert this data from PostGIS to a SpatialLite file. This process creates tables of all the spatial data from OSM including the data tables for points (For example: ATM, lamp post, or dustbin), polygons (For example: forest area, park, or lake), and lines (For example: road network, or rail). When we create a spatial database in PostGIS, the *spatial_ref_sys table* is automatically installed. This table satisfies the Open Geospatial Consortium requirement which is used to define which *Spatial Reference system Identifiers* (SRIDs) are allowed in the geometries and provides the coordinate systems for the same.

The required tables are now added and are stored in the SQLite file with the use of an SQL script. This script sets the database to be used on an Android device, creates a table to store user favourites (table name: *favourites*) and also one to store additional information on POIs (table name: *poi_data*).The ‘favourites’ table is used to

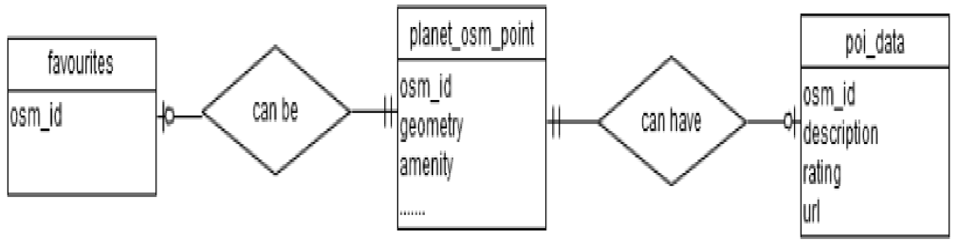


Figure 104: Offline LBS: Database-entity relationship diagram.

store information about the POIs that the user has marked as favourites and can be used for further reference later. While using a mobile service with a map interface that provides map tiles over the internet, various options such as Google Maps for mobile, or OSM tiles can be used. For an offline location based service, the map data used is a single file (.map extension) that is used by the application to render map tiles. This map file is also stored along with the '.sqlite' file in the external storage of the mobile device.

Map view: Representation of geographic data on a map to help users navigate is an important aspect of a location based service. Most of commonly used techniques involve storing map tiles as PNG files in an organised directory structure. These tiles are then stitched together by the map view before being displayed. *Mapsforge* is an open source project that allows you to generate a single map file from OSM data (Mapsforge, 2012). The map file is generated using the Mapsforge plugin by providing an OSM XML file or shapefile. The structure of this file is defined by the Mapsforge project. This map file can be stored locally on the mobile device and is used by the map view provided for Android to render the map at runtime. This removes the need to store individual PNG tiles and is very simple to implement.

POI Queries: Querying for POI information is one of the most common services provided by such systems. There are various query techniques in mobile spatial interaction such as touch2query (Yin and Carswell, 2011), *circular query* (Figure 105) and *geowand query* (Jacob et al., 2012a) (Figure 106).

The circular query takes the current location A and uses a radius, r to select the query region for querying the database. Users can search for POIs by specifying what categories they are looking for and the maximum distance they are willing to travel.

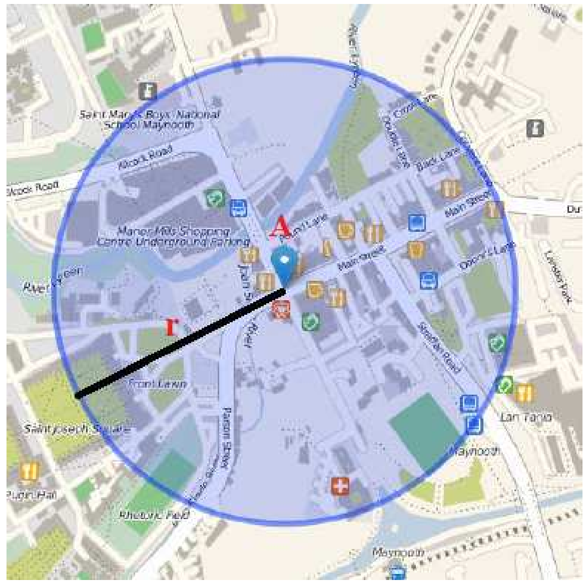


Figure 105: Offline LBS: The circular query for POI search from a point A with radius r.

All relevant POIs within this radius around the user's current position are returned (Figure 105).

For the same location A, the geowand query takes the current location A and uses a breadth, r to select the query region for querying the database based on phone pointing gestures (Jacob et al., 2012a). POI search can be narrowed by using the 'buffered bounding box' based search method. This method requires the user's current position, direction, d in which the device is pointed, the desired POI categories and max distance (r in this case) the user wishes to travel. Based on these three inputs the destination point is calculated which is r metres away from point A at an angle of d degree.

From this information, a box is constructed that extends out on either side of the user and stretches out as far as the user has specified. Any relevant POI contained within this box is returned (see Figure 106) based on ascending order of distance from the user. This is achieved using the *ST_Within* function as defined by the Open Geospatial Consortium (OGC).

User interface design: There are 2 tabs in the mobile user interface - Search (select POI type) and Map (View the results of the search on a map). The interface was defined to let the user select the POIs that are of interest to the user. After selecting the query

Figure 106: Offline LBS: The geowand query for POI search from a point A with breadth r along direction d.

type and distance information about the POI it is presented to the user with distance information and link to view it on a map. By marking it as ‘Favourite’, the user can save the location information of any of the returned query results (POIs) for further use.

The first tab the user sees is the search tab (see Figure 107a). A list of all POI categories is displayed here in alphabetical order. To search for POIs the user can check boxes beside each category they would like to include. A search button, at the bottom of this screen, will present different search options to the user via a dialog box (see Figure 107b) when pressed. This box asks the user to input the maximum distance they would like to travel, which can be changed using the on-screen slider. The current value of the slider is displayed to help the user select their distance. Below this, the user can choose between the different search methods by selecting one of the radio buttons shown. From here, the user can choose to continue or to cancel. If the user decides to continue the screen will update with a list of results based on the user’s search criteria.

Results are displayed as POI name along with the POI category displayed below it and the distance from the user’s location to that POI (Figure 108).

If a user clicks on any POI from the results list they will be shown a screen containing

Figure 107: Offline LBS: a) The Search tab with POI category list b) Advance features like distance and query type (circular and geowand).

Figure 108: Offline LBS: Search results for POI type Fast Food.

Figure 109: Offline LBS: a) Additional POI information of feature that was marked as favourite. b) Map interface to view location information ((Mapsforge, 2012)).

additional information and detailed description about that particular POI (see Figure 109a). They will also have the ability to add this POI to their favourites or view the POI on the map (Figure 109b). The second tab contains the map interface (Figure 109b). The map view is a familiar and intuitive interface used in popular map application such as Google Maps (GoogleMaps, 2012). The user has the ability to scroll around the map using swiping gestures and also zoom-in and out using pinch gestures. There is also on-screen buttons for zooming.

On the results tab, various options are available to the user by pressing the menu button on the device. By clicking the menu button on the mobile device, the user will have the option to view their saved favourites, to view additional information on the application, or to select a database file to load (data file of Ireland, UK, or Maynooth) (Figure 110).

When on the map tab, further options are available to the user by pressing the menu button on the device. In this case, the user will have the option to view their current location (places a marker on the map at the user's location), the option to select a map file to load (For example: Map file of Ireland, UK, or Maynooth) or to view additional

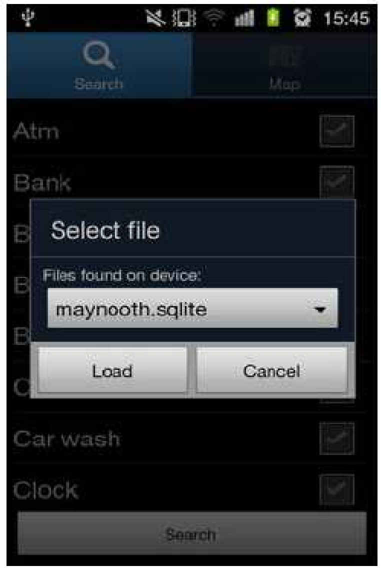


Figure 110: Offline LBS: Selecting the spatial data file for querying.

information.

8.4.2 Preparing data for testing query performance

In order to test the query performance 3 datasets where selected for which both the *.map file* and the *.sqlite files* were created and stored on the mobile phone. The datasets used were:

- Maynooth,
- Ireland and Northern Ireland
- United Kingdom

Selecting a query type: To test performance a location, maximum distance, POI categories and orientation (Table 7) were chosen and searches were performed using these with both the radius and buffered box methods on the 3 databases generated. For convenience the same parameters were used for each database.

8.4.3 Results and query performance

We now look at the system performance with regards to database/map size and storage, and performance of the system while performing the circular (Figure 105) and geowand queries (Figure 106).

Database size: Maynooth has about 1,144 POIs listed (and growing) in their OSM database that was used which is 825 kilo bytes in size and we can see from Table 8 that the size of the files generated increases as the number of POIs increases (Cloudmade, 2012) . These data files and map files were stored on the mobile device for offline access.

Query performance: The circular query (using Radius) and the geowand query (using a bounding box) were performed on all 3 datasets. As the time for these queries varies, each one was performed 3 times and the average time taken as the resultant query response time. The details of the search query for the 3 datasets is listed in Table 9.

The number of POIs in the database does have a direct effect on the performance of the query response times. Also, this response time is much slower for the geowand query when run on larger datasets. When the query is run on a phone with internet access, the calculation and processing in done at the server side and thus the response time is much quicker. However, the response time of systems where the querying and processing is performed on the mobile device, the response time is much slower. The buffer box helps to reduce the query region to give information based on the road the user is willing to take. But depending on the size of the dataset, the buffered box search method can take too long to compute making this method unusable under certain circumstances.

8.4.4 Summary of queries on offline databases

The use of *SpatialLite* meant that SQL written to run in PostGIS on a server can easily be ported to run on a mobile device as SpatialLite is OGC compliant. Such location based services that works without internet access can be very beneficial especially for users visiting a new city/town in a new country and who does not have a data plan on mobile to support internet based services. Maps can also easily be provided offline for users using open source services such as Mapsforge and their implementation of MapView for Android. In experimenting with the two search methods implemented, we see that while these methods are feasible, the size of the dataset has a huge influence on the performance. As seen in the tests, it is possible to store the spatial data required on a mobile device but it may not be possible to perform certain queries on large datasets. This suggests that this implementation is more suited to querying (especially the geowand query) smaller datasets for cities and towns than larger, national, datasets.

The tests which integrated the *Haptic GeoWand* query within offline mobile searches showed larger response times and thus do not look suitable when performed on a SpatialLite database within a mobile device (Jacob et al., 2012b). The current day complex spatial queries which integrates various other sensor data along with image processing and other complicated techniques, are all performed at the server and not within the mobile device itself and so the responses are quick. These systems will fail if there is no internet connectivity and not necessarily respond as quickly as it is required when a user is on the move in the real physical world. The querying technique and the data storage must be optimised to provide results much quicker than in the current offline systems. More improved ways of storing and querying such spatial databases within the mobile device must be developed for fluent, seamless continuous mobile spatial interaction for offline mobile location based services.

8.5 Conclusion of user trials and experimental analysis

Klippel et al. (2009) argues that turn-by-turn direction instructions are often unnecessarily complex or too detailed leading to cognitive overload. Robinson et al. (2010a) provides distance and orientation information to the user via vibrations with varying pattern and frequency. Asif et al. (2010) extend this concept to automobile drivers. The driver perceives countable vibro-tactile pulses, which indicate the distance in turn by turn instructions. They found that the approach is a simple way of encoding complex navigational information. May et al. (2003) indicate that landmarks were by far the most predominant navigation cue and these should be included in directions. The authors found that distance information and street names were infrequently used. Additional information such as landmarks is used to enable navigation decisions but also to enhance the pedestrian's confidence and trust. Learning the layout of an environment can involve strategies such as exploration and search, and in some cases the use of secondary information sources such as maps and photographs can aid the navigator in a novel or unfamiliar environment (Roche et al., 2005).

Two commonly used techniques to learn the layout of the environment are either gaining route-based knowledge or survey-based knowledge. Route-based knowledge is acquired by physically navigating the environment, an egocentric strategy due to the fact that information is obtained depending on the location of the navigator (Roche et al., 2005). Route-based navigation is based on remembering specific sequences of positions that the person obtains by navigating their environment (Foo et al., 2005). Meanwhile, survey-based knowledge can be compared more to an allocentric spatial strategy as it is characterised from an external, global perspective (Roche et al., 2005). Survey-based knowledge is incorporated and developed as a derivative of physical navigation of the environment, but the introduction of a secondary information source such as a map or photographs of the environment can lead to immediate allocentric representation for the navigator, without the need to navigate the environment (Roche et al., 2005). While landmarks are the most predominantly used navigation cues (May et al., 2003), when landmarks are unreliable navigators appear to fall back on survey knowledge to navigate the environment (Foo et al., 2005).

From the above user trials we see that haptic feedback can be effectively used to help people navigate in the real-world. Haptics reduce the requirement for the user to orientate and re-orientate themselves based on the mobile display by comparing the features displayed on the map to the real-world features in their vicinity. The users of our haptic system were able to reach the destination successfully without using any visual cues while having a conversation with a friend. They had positive review about the private, and subtle feedback and also rated very high, the ability to get to the destination without any distraction through a visual mobile interface. The memory recall of the users based on the test suggests that haptics ensure a better mental map of the area as they did not have to pay a lot of attention to the mobile device as it provided unobtrusive feedback guiding users to the destination. Route-based and survey-based knowledge can be acquired with the use of haptic feedback. This can ensure that future trips would not need extensive use of mobile navigation systems for assistance in travel. Based on the tests carried out on client-side, offline databases, we observe that complex spatial queries perform poorly (slower response time) on current mobile devices and are more efficient when performed on the server-side to deliver quick results efficiently.

Table 4: Pedestrian Navigation Task: User performance of pedestrian navigation using *Haptic DestinationPointer*.

User	***Distance Travelled (in metres)***	***Time Taken (in seconds)***	***Comments***
1	856	1160	Walked across grass and car parks.
2	653	540	Finished task in the quickest time.
3	939	1192	Took the longest time to finish the task.
4	813	960	Was taking more time at certain points.
5	784	790	Felt feedbacks were easy to understand.
6	845	878	Walked fast across open areas.
7	950	940	Walked the longest distance, poor with orientation.
8	758	748	Took time to re-orient at certain points.
9	834	850	Used mostly paved ways, paused more often.
10	912	975	Was finding it difficult to re-orient near the buildings.
11	885	914	Walked across grass/car parks.
12	781	843	Felt feedback was very subtle and good.
13	693	689	Walked across car parks and beside closer to buildings.
14	689	735	Took the path between the buildings.
15	712	759	Walked across open grass fields.

Table 5: Memory Recall Test: Mean and Standard deviation of age of the participating students.

	Number of students, n	**Mean age, μ**	**Standard deviation, σ**
Control Group	7	19.29	1.113
Experimental Group 1	6	19.83	0.983
Experimental Group 2	5	21.60	1.517

Table 6: Memory Recall Test: Mean and Standard Error (SE) scores for the various tests for the Control Group (CG), Experimental Group 1 (EG1) and Experimental Group 2 (EG2).

	CFQ	**TMTA**	**TMTB**	**TMTB-A**	**fsIQ**	**pIQ**	**vIQ**	**Rotation**
CG Mean	46.29	28.14	50.17	22.57	115.71	113.71	114.71	23.14
CG SE	8.017	5.701	8.283	3.651	1.643	1.443	1.443	2.558
EG1 Mean	54.83	25.00	51.17	26.17	111.50	109.67	110.67	25.33
EG1 SE	3.628	2.543	5.700	3.919	1.500	1.382	1.382	2.431
EG2 Mean	37.40	20.80	38.00	17.20	116.80	114.40	115.50	33.00
EG2 SE	3.816	3.652	1.378	3.499	1.715	1.536	1.536	0.894

Table 7: Offline LBS: Query information for the offline query performance test.

Location	*53.38301305, -6.60289324*
POI Category	*Cafe*
Distance	*2.5km*
Orientation	90°

Table 8: Offline LBS: File sizes for map and POI data (Cloudmade, 2012).

Area	**No. of POIs**	**Database file size (in bytes)**	**Map file size (in bytes)**
Maynooth	1,144	844,800	213,540
Ireland and Northern Ireland	74,978	17,606,656	59,542,566
UK	1,010,551	231,768,064	432,612,951

Table 9: Offline LBS: Search performance evaluation between circular (using radius) and geowand (using buffered box) queries

Area	**No. of POIs**	**Query Type**	**Time Taken (ms)**			**Average Time**
Maynooth	1,144	Radius	107	66	80	84.33
		Buffered Box	2,831	2,945	2,937	2904.33
Ireland and Northern Ireland	74,978	Radius	1,479	1,444	1,617	1,513.33
		Buffered Box	177,514	177,985	177,122	177,540.33
UK	1,010,551	Radius	14,801	15,190	14,806	14,932.33
		Buffered Box	2,442,799	NA	NA	2,442,799

9 Conclusions

Over the years, with the emergence of smart phones with embedded sensors, mobile location based services are being used by people and seamlessly integrated into their day-to-day activities. People all over the world depend on such systems to help them carry out various activities like shopping, navigation assistance, and real-time public transport information among others. While such systems are capable of providing complex information on the moving user's mobile device, it is also essential that this information is provided in an easy to understand manner. While visual interfaces displaying information over a map coupled with textual description have been around for years, it is not always the ideal communication channel depending on the user's context (For example navigating around busy city streets and being unable to check the mobile device continuously).

Any mobile location-based service needs to ensure fast, complete, and clear delivery of information. It needs to be non-obtrusive and should be easy to use while on the move or performing other tasks (multitasking). The interfaces need to be simple and the interaction technique must be suitable to accommodate all physical/social contexts of the user. When the user's current context does not allow visual feedback for delivering spatial information, non-visual feedback using audio can be an effective modality to convey such information to the user. One of the major shortfalls of both speech and non-speech audio feedback is that it cannot be used by the hearing impaired. Speech-based audio also can be difficult for users to interpret in noisy environments. Additional factors such as the language, and the accent of the speaker makes understanding difficult. Thus the integration of haptic feedback to deliver spatial information to effectively communicate with the user via non-obtrusive systems when visual and audio systems fail is required.

9.1 Research Contributions

The work in this thesis explores the possible integration of haptic feedback and inertial sensors in mobile devices with location information. We have demonstrated that pointing gestures to query and haptic feedback to represent spatial information can ensure effective use of minimum attention mobile interfaces and thus helps the user with non-visual feedback. We refer back to section 1.4 for the objectives laid out at the beginning and evaluate how effectively we have met these objectives in this thesis.

Question 1: Can haptic feedback be used to deliver spatial information like location, direction, distance, density of features? With the description of system models for Haptic GeoWand (Chapter 4), Haptic Pedestrian (Chaptere 5), and Haptic Transit (Chapter 6), we have shown how haptic feedback can be used to deliver spatial information like location, direction, distance and density of features. Overall, the thesis has demonstrated how non-visual feedback for spatial information delivery can enhance the use of mobile location based services while the user is on the move.

Question 2: Can haptic feedback help the user understand information about their physical environment? The *Haptic GeoWand* system (Chapter 4) is a low interaction system that allows users to query geo-tagged data around them by using a point-and-scan technique with their mobile device. Haptic feedback is used to provide the resultant information by integration of the vibration alarm with varying frequencies and patterns to help understand the physical environment. The Haptic GeoWand has two prototypes to provide two kinds of information. The *whereHaptics* provides information about direction and distance to POIs and *whichHaptics* provides information about direction and the density of POIs.

Question 3: Can haptic feedback be effectively used to direct the user towards their destination with low/no visual feedback and with minimal mobile interaction? The *Haptic Pedestrian* system (Chapter 5) is used to deliver spatial information that ensures non-visual feedback for pedestrian navigation. The four prototypes of the Haptic Pedestrian system are - Haptic StayonPath, Haptic Navigator, Haptic WayPointer, and Haptic DestinationPointer. They could be used based on the complexity of the physical environment or on the user's spatial ability such as orientation skills and environment familiarity. These prototypes showed how the user can be successfully directed to the destination using minimal mobile interaction (pointing and scanning gestures) with low/no visual feedback.

Question 4: Can haptic feedback be used to assist public transit users to get information about location and navigation to a stop and be notified when they reach a destination stop? *Haptic Transit* is a tactile feedback-based user interaction system that provides spatial information about public transport including a notification system to alert them about important locations. From the 45 users who took the public transport survey, about 60% of respondents reported that they had missed their stop at some stage while travelling by bus. “Displaying user position on a map” and “vibration alert to inform them of the bus stop” were the most popular responses. In providing the reasons for choosing the vibration alerts feedback 30 out of 45 respondents explained that they chose this since they don’t need to devote all of their attention to the phone screen. The participants explained that since the phone is in their pockets/bag most of the time, the vibration alert would be a suitable form of feedback. In Chapter 6 we demonstrated the use of a haptics-enabled public transit system to provide non-visual feedback to help in decision making for the public transport user. In this scenario querying for public transport information is performed using pointing gestures and haptics is used to provide the user with subtle feedback for decision making. Information is also delivered by text. Thus haptic feedback can be integrated into mobile location based services which provide public transport users with information like arrival at destination stop and direction to the nearest bus stop based on arrival times and walking distances.

Question 5: Can haptic feedback ensure better division of cognitive workload while multi-tasking (walking and using such systems simultaneously) as compared to visual interaction? The user tests and trials carried out in Chapter 7 demonstrate how haptic feedback can be effectively used to assist in travel from a given origin to a destination point successfully. The primary task of the user was to interact with their friend while navigating to the destination. The users did not use any visual assistance and all the 15 who took the test were able to successfully reach the destination by querying using pointing gestures and haptic feedback providing the directional information. We found in our experiments that while using Haptic DestinationPointer, users walked across open areas and non-paved regions rather than always staying on official paved pathways. Some of the positive remarks provided by participants related to: ease of use, the privacy of the feedback, the fact that feedback was non-intrusive.

We demonstrated from the memory recall test that non-visual or low mobile interaction ensures that the user is more attentive to landmarks along the route. We found that as compared to visual cues, users were able to observe the surrounding environment more when they used haptic feedback and thus produced better maps of the area based on memory recall. Haptic feedback can assist users in acquiring route-based and survey-based knowledge. The user can quickly learn the position and structure of geographical features along their selected path because they are not required to delegate their attention to their mobile device. Thus due to the acquired route knowledge from previous walks along the same path, it enables the user to perform navigation tasks better later in the same area.

9.2 Key challenges

In the work carried out in this thesis, we demonstrated how subtle, low interaction, low resolution, easy to understand feedback can be provided to users to help them use mobile location based services. Haptic feedback can be integrated with visual or audio feedback based systems. Haptic feedback can provide high level information while visual or audio can be used to provide more low level/high resolution information. We shall now highlight the limitations about accuracy, precision and resolution while using haptic feedback for providing spatial information to the user using smartphones.

9.2.1 Accuracy

In the work carried out as part of the thesis, we set a location buffer of 10 metres to ensure the location accuracy error due to GPS is handled. For example while performing queries using pointing gestures like for Haptic GeoWand, Navigator, DestinationPointer or WayPointer, we set a 10 metre linear buffer to ensure our query region is able to return meaningful information to the user. While performing high level information like general heading or qualitative values about density of/distance to features, this works fine. But in-order to provide more accurate information like 'the exact distance in metres' or pointing accuracy with regards to the system being able to differentiate between pointing at a building or pointing at a window in that building could return inaccurate information. The hardware on various smartphones have different quality levels and this also affects the accuracy of the feedback provided to the user. The response time (how quickly the orientation value is calculated) and accuracy of the digital compass in the smartphone also determines the quality of feedback. If the user performs the scanning operation (Figure 58) too quickly, it could lead to less accurate feedback if there exists more than one road with originating from that point (Figure 62 - If there is a smaller angle between roads at an intersection).

9.2.2 Precision

The precision of the system during users trials that helped them travel from a given point to the destination (Haptic DestinationPointer) suggested that it was repeatable and it provided acceptable precision based on the accuracy levels that is set for each haptics enabled system. However, during the offline tests of the GeoWand query, we did notice that if it is a larger database, the response time is much longer to process the queries. Such time delays did not appear when testing with online querying using GeoWand. Thus the reliability of the existing GeoWand query when there is no internet connection is lower as the query response time is too large for the the user. Thus, the hardware configuration including processor speed determines the precision (ability to repeat accurate performance) at which feedback can be provided and this will vary from one smartphone to the other. The speed at which the user performs the scanning operation (Figure 58) can also affect the precision of the system. Here if the user performs the scan too quickly, haptic feedback will be provided when pointing at a different direction than that of the desired one.

9.2.3 Limited Resolution of Haptic Feedback

The resolution of information that can provided using vibration patterns with varying frequency is limited as compared to visual and audio feedback where more high resolution information can be easily provided. We thus need to understand the right kind of balance between use and integration of various modalities to provide the user with the most relevant information with the kind of resolution required. Using Haptic-GeoWand we demonstrated how more high level information like near/far/very far or one/few/many could be provided. But for users who want more specific information, they need to depend on visual feedback and the level of resolution is very much limited based on the . The Haptic Syntax (Section 3.6) used in the Haptic Interaction Model is limited as the addition of more haptic symbols (based on vibration patterns and frequency) will require the user to memorise and understand more complex symbols and their related connotations. The possible symbols (Haptic Syntax) made available via smartphone haptics is of limited resolution. Thus, for high resolution information, visual and audio feedback are more useful as compared to haptic feedback which is more useful for providing low resolution/high level information. These are some of the short comings of haptic feedback.

We acknowledge that the amount of information provided accurately with high resolution and precision to the user is limited using haptic feedback on a mobile device using vibration alarm. Thus further work which is outside the scope of this thesis needs to be carried out to ensure how different modalities can be synchronised and integrated with eachother to provide the most optimum information based on user context and use of the service.

9.3 Future work

Integration of non-visual feedback (especially haptic feedback) into mobile location based services is still an area of research that has major potential and is far from being a fully solved problem. There are many avenues to extend the work presented in this thesis. Enhanced versions of the developed algorithms to encompass various user contexts are necessary. By carrying out extensive user trials, a deeper understanding of the usability requirements of such systems can be achieved. Further work in this area of research has been outlined below.

9.3.1 Detailed large-scale user trials

Preliminary results from the user trials carried out as part of the thesis suggest that there are benefits of using haptics enabled systems for pedestrian navigation. Apart from successfully getting the user to the destination with subtle low-interaction feedback, it also ensured that the user was able to recollect more features from the surroundings they travelled. Thus we believe that more extensive user trials considering various user contexts and environmental situations must be considered and user trials carried out with a larger and more diverse group must be carried out. Trials carried out with visually impaired users will also help us understand the best ways to integrate such systems into the day-to-day navigational and exploratory activities of such users. Thus developing a rich more complex 'haptic language for visually impaired' is an area of research that can benefit users who are visually impaired and do not want to carry additional hardware devices to help them navigate around the physical world around them.

9.3.2 Algorithm enhancements

The algorithms described in the thesis demonstrated how haptic feedback can be used to represent spatial information like notification of arrival at a location, direction towards destination using various techniques and information about distance to and density of POIs. These algorithms should be enhanced and extended to integrate various user abilities and seamlessly switch between various haptic feedback types based on the user needs. It is also necessary to investigate the various ways systems involving various modalities can be used simultaneously when the requirement arises. Here the user should be able to switch from one modality to the other based on the various sections of the user's navigation tasks and availability of a free resource to use that modality. Visually impaired users are inclined to use audio-assisted feedback to various exploratory or navigation tasks. Integration of haptics with such systems can ensure a more comprehensive use of the modality considering some of the benefits of haptics over audio. While researchers have looked at various aspects of using haptic feedback for helping visually impaired navigate challenging environment, there is still much to be done in this area.

9.3.3 Low interaction indoor navigation

In this thesis we considered integration of haptics in mobile location based services which are primarily for outdoor users and thus assume the use of GPS for localisation. While there is no globally accepted standard for localisation of a user indoors, this is an area of research which has received much attention and interest. While research is ongoing for an ideal localisation technique, conveying feedback by integration of haptics into such indoor localisation and navigation systems will be an exciting topic for further research. The instructional information for user navigation and exploration assistance in an indoor environment conveyed via haptic feedback can ensure a low interaction and easy to understand mode to communication.

9.4 Final words

Wickens's Multiple Resource Theory (MRT) illustrates how different tasks will need to tap into similar resources (Wickens, 1992). Wickens adds that cognitive resources are limited and a supply and demand problem occurs when the individual performs two or more tasks that require a single resource. Wickens suggests that the most important application of the multiple resource model in the design phase is to recommend design changes when conditions of multi-task resource overload can exist (Wickens, 2008). In today's day-to-day tasks, multitasking is prevalent. There are often dangers associated with types of multitasking. Example of one such multitasking activity is using a cell phone while driving. Wickens stresses that only in cases where overload is caused by multiple concurrent tasks does multiple resource model theory help to predict performance problems.

We can draw parallels with the way mobile location based services are designed with regards to assumptions that the user is easily able to use the visual interfaces while on the move. Vibrotactile cues can be used as a channel which provides 'private information' in an easy to understand manner for the user (Li et al., 2008). While the granularity of detail that can be represented using such systems is limited, it can be efficiently used to convey a certain notification message in a high level form. The work presented in this thesis and those carried out by other researches show that a purely visual interface based mobile services is difficult to use effectively while on the move. Thus projects like HaptiMap (HaptiMap, 2012) will lead the way in working towards a seamless integration of haptics along with audio and visual interfaces to ensure a complete multi-modal mobile location based services. This can ensure that the users are provided with context-based interaction and information delivery system for efficient use while on the move. Since touch is the first sense we get at birth and the last sense to fade of before death, the life span of this modality is relatively longer than other senses. Haptic feedback, only requiring low levels of user interaction, has the ability to benefit a very wide range of users.

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Appendix I

The Cognitive Failures Questionnaire
(Broadbent, Cooper, FitzGerald & Parkes, 1982)

Name: ……………………… Age ……………. Date ………………….

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to your in the past 6 months. Please circle the appropriate number.

		Very often	Quite often	Occasion-ally	Very rarely	Never
1.	Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2.	Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3.	Do you fail to notice signposts on the road?	4	3	2	1	0
4.	Do you find you confuse right and left when giving directions?	4	3	2	1	0
5.	Do you bump into people?	4	3	2	1	0
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7.	Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8.	Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9.	Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10.	Do you lose your temper and regret it?	4	3	2	1	0
11.	Do you leave important letters unanswered for days?	4	3	2	1	0
12.	Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13.	Do you fail to see what you want	4	3	2	1	0

	in a supermarket (although it's there)?					
14.	Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0
		Very often	Quite often	Occasion-ally	Very rarely	Never
15.	Do you have trouble making up your mind?	4	3	2	1	0
16.	Do you find you forget appointments?	4	3	2	1	0
17.	Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18.	Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19.	Do you daydream when you ought to be listening to something?	4	3	2	1	0
20.	Do you find you forget people's names?	4	3	2	1	0
21.	Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22.	Do you find you can't quite remember something although it's "on the tip of your tongue"?	4	3	2	1	0
23.	Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24.	Do you drop things?	4	3	2	1	0
25.	Do you find you can't think of anything to say?	4	3	2	1	0

Appendix II

Trail Making Test (TMT) Parts A & B

Instructions:

Both parts of the Trail Making Test consist of 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the patient should draw lines to connect the numbers in ascending order. In Part B, the circles include both numbers (1 – 13) and letters (A – L); as in Part A, the patient draws lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The patient should be instructed to connect the circles as quickly as possible, without lifting the pen or pencil from the paper. Time the patient as he or she connects the "trail." If the patient makes an error, point it out immediately and allow the patient to correct it. Errors affect the patient's score only in that the correction of errors is included in the completion time for the task. It is unnecessary to continue the test if the patient has not completed both parts after five minutes have elapsed.

Step 1: Give the patient a copy of the Trail Making Test Part A worksheet and a pen or pencil.

Step 2: Demonstrate the test to the patient using the sample sheet (Trail Making Part A – *SAMPLE*).

Step 3: Time the patient as he or she follows the “trail” made by the numbers on the test. Step

4: Record the time.

Step 5: Repeat the procedure for Trail Making Test Part B.

Scoring:

Results for both TMT A and B are reported as the number of seconds required to complete the task; therefore, higher scores reveal greater impairment.

	Average	**Deficient**	**Rule of Thumb**
Trail A	29 seconds	> 78 seconds	Most in 90 seconds
Trail B	75 seconds	> 273 seconds	Most in 3 minutes

Sources:

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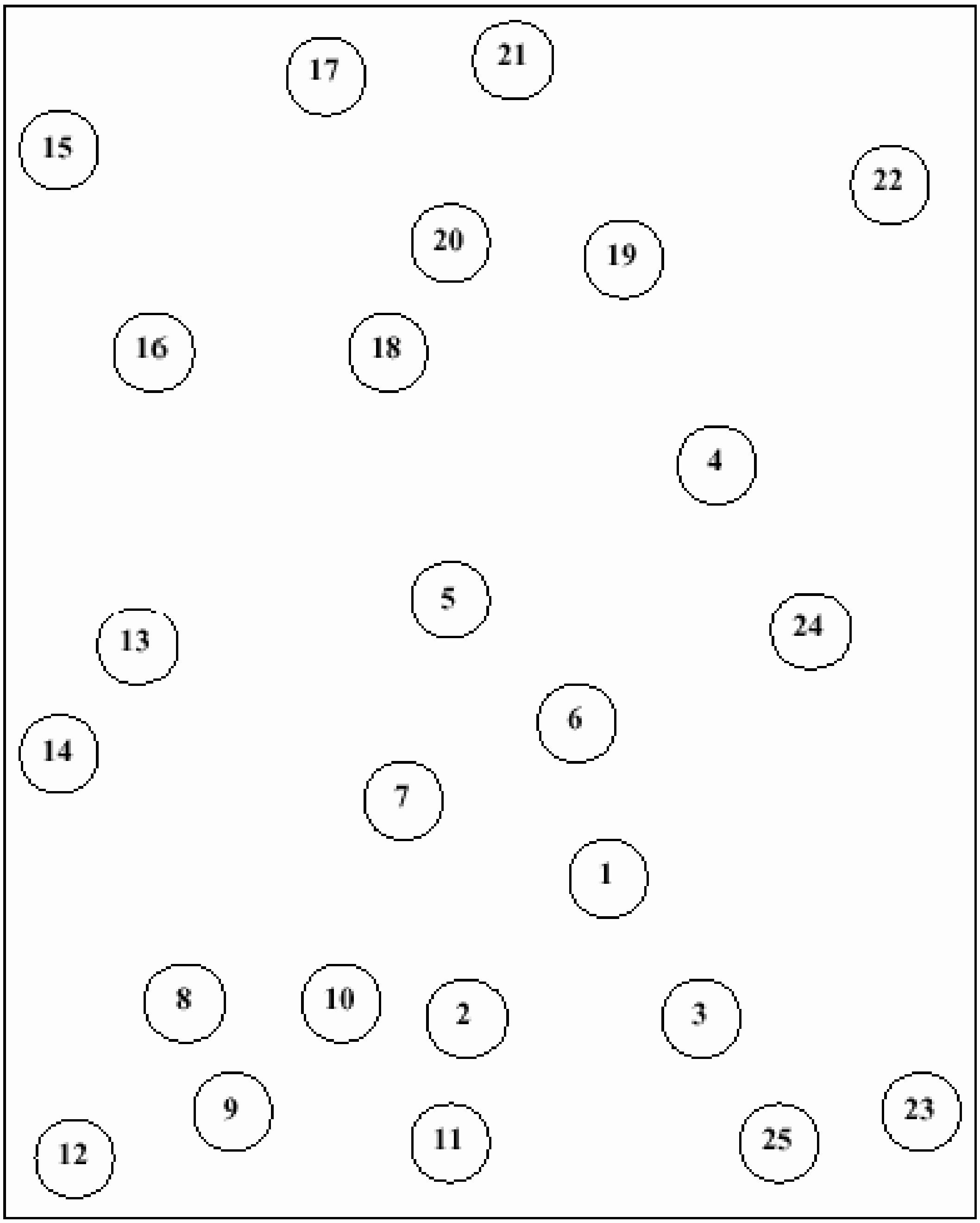
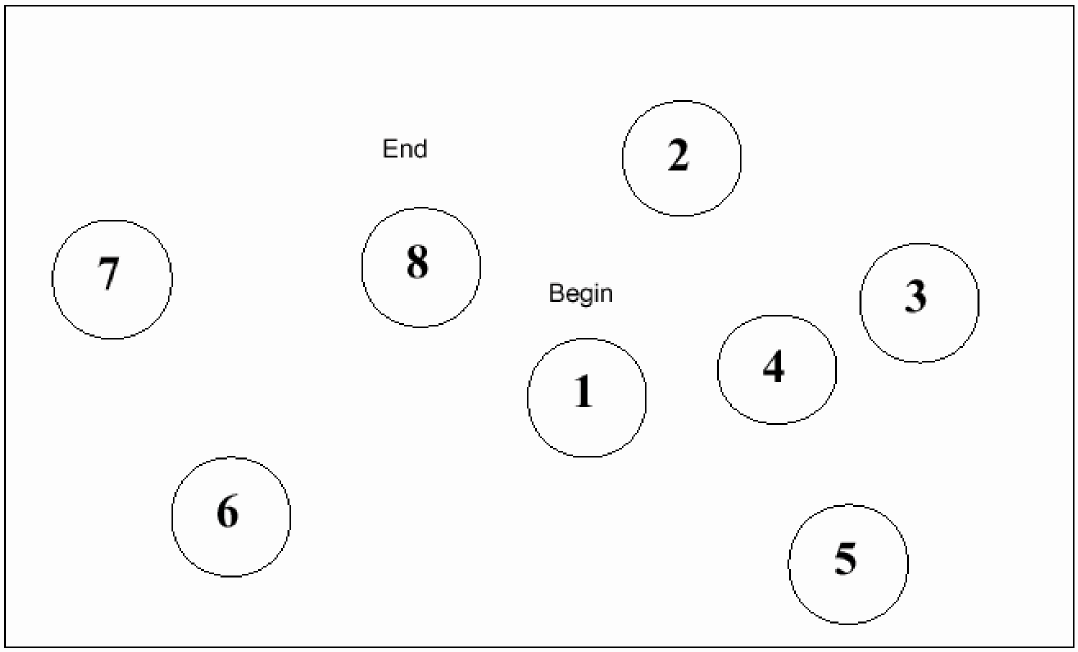
Trail Making Test Part A

Patient's Name: ____Date: _______________________

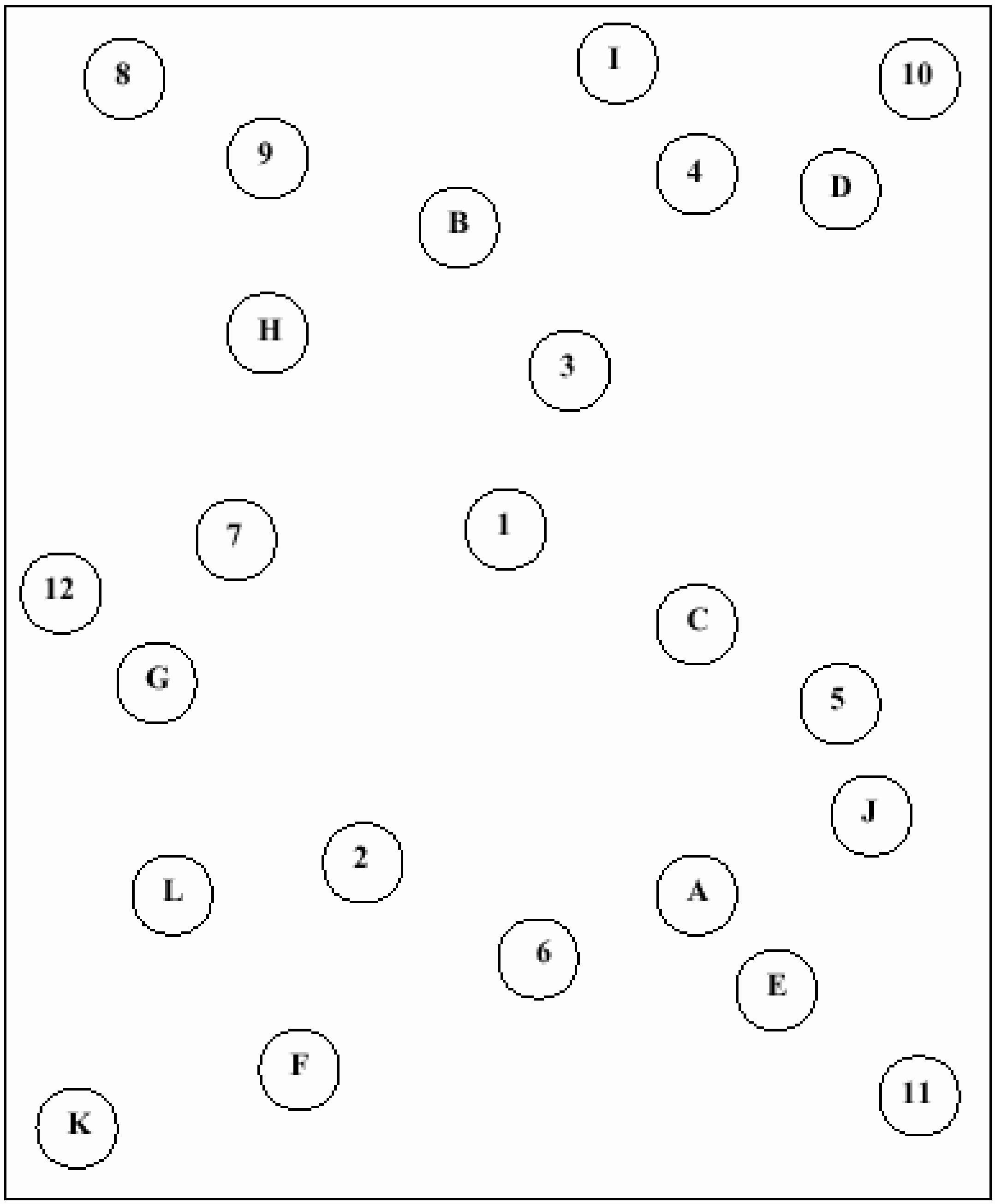


Trail Making Test Part A – *SAMPLE*

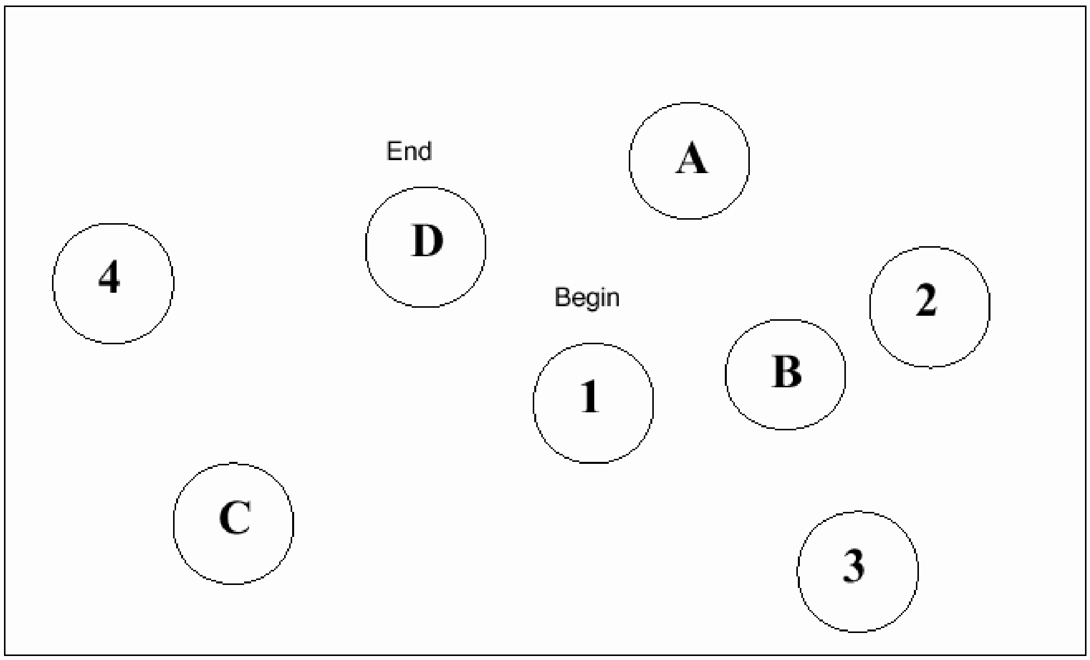


Trail Making Test Part B

Patient's Name: ____Date: ______________________



Trail Making Test Part B – *SAMPLE*



Appendix III

Ache
Debt
Psalm
Depot
Chord
Bouquet
Deny
Capon
Heir
Aisle
Subtle
Nausea
Equivocal
Naïve
Thyme
Courteous
Gaoled
Procreate
Quadruped
Catacomb
Superfluous
Radix
Assignate
Gist
Hiatus
Simile
Aeon
Cellist
Zealot
Abstemious
Gouge
Placebo
Façade
Aver
Leviathan
Chagrin
Détente
Gauche
Drachm
Idyll
Beatify
Banal
Sidereal
Puerperal
Topiary
Demesne
Labile
Phlegm
Syncope
Prelate

National Adult Reading Test

Ache	_____	Simile	_____
Debt	_____	Aeon	_____
Psalm	_____	Cellist	_____
Depot	_____	Zealot	_____
Chord	_____	Abstemious	_____
Bouquet	_____	Gouge	_____
Deny	_____	Placebo	_____
Capon	_____	Façade	_____
Heir	_____	Aver	_____
Aisle	_____	Leviathan	_____
Subtle	_____	Chagrin	_____
Nausea	_____	Détente	_____
Equivocal	_____	Gauche	_____
Naïve	_____	Drachm	_____
Thyme	_____	Idyll	_____
Courteous	_____	Beatify	_____
Gaoled	_____	Banal	_____
Procreate	_____	Sidereal	_____
Quadruped	_____	Puerperal	_____
Catacomb	_____	Topiary	_____
Superfluous	_____	Demesne	_____
Radix	_____	Labile	_____
Assignate	_____	Phlegm	_____
Gist	_____	Syncope	_____
Hiatus	_____	Prelate	_____

FOR EXPERIMENTER'S USE ONLY

NART pronounciation and definitions

Word	*say*	Definition
Ache	*rhymes with* take	any dull, continuous pain
Debt	det	anything which one person owes to another
Psalm	sahm	a sacred song or hymn
Depot	deppo (or dee-po)	a place where things are kept or stored
Chord	kord	1. *Maths:* a straight line segment joining two points on a curve 2. a string on a musical instrument 3. *Music:* a group of three or more notes played together in harmony
Bouquet	bo-**kay** *or* boo-**kay**	1. a bunch of flowers 2. the characteristic smell of wines or liqueurs
Deny	de-**nigh**	1. to declare as untrue 2. to refuse to believe or acknowledge 3. to refuse to grant
Capon	**kay**-pon	a domestic cock which has been castrated to improve its flesh for eating
Heir	air	1. a person who inherits, or will inherit, money, property, title, etc. 2. a person, group or society to which something such as tradition, ideas, etc. is passed on
Aisle	ile	any passage between blocks of seats, as in a theatre
Subtle	**sutt**'l	fine, slight or delicate, so as to be difficult to detect, etc.
Nausea	**naw**sia	1. a feeling of sickness in the stomach, often followed by vomiting 2. a feeling of extreme disgust or loathing
Equivocal	ik**kwivvi**-k'l	ambiguous or unclear
Naïve	nie-**eev**	unaffectedly or unsophisticatedly simple and artless (free from deceit or cunning)
Thyme	time	a low shrub with fragrant leaves used in cooking
Courteous	**ker**tius	polite and well-mannered
Gaoled	jaled	also spelt **jail**: a building where convicted criminals are kept
Procreate	**pro**-kree-ate	to produce offspring
Quadruped	**kwodroo**-ped	any animal with four feet
Catacomb	**katta**-koom *or* **katta**-kome	(*usually plural*) an underground cemetery consisting of tunnels with recesses for graves
Superfluous	soo-**perfloo**-us	more than is needed
Radix	**ray**-diks	*Maths:* a number used as the base of a system of numbers, logarithms, etc.
Assignate		
Gist	jist	the essential part of something
Hiatus	high-**ay**tus	a gap or interruption
Simile	**simmi**-lee	a figure of speech in which two unlike things are

FOR EXPERIMENTER'S USE ONLY

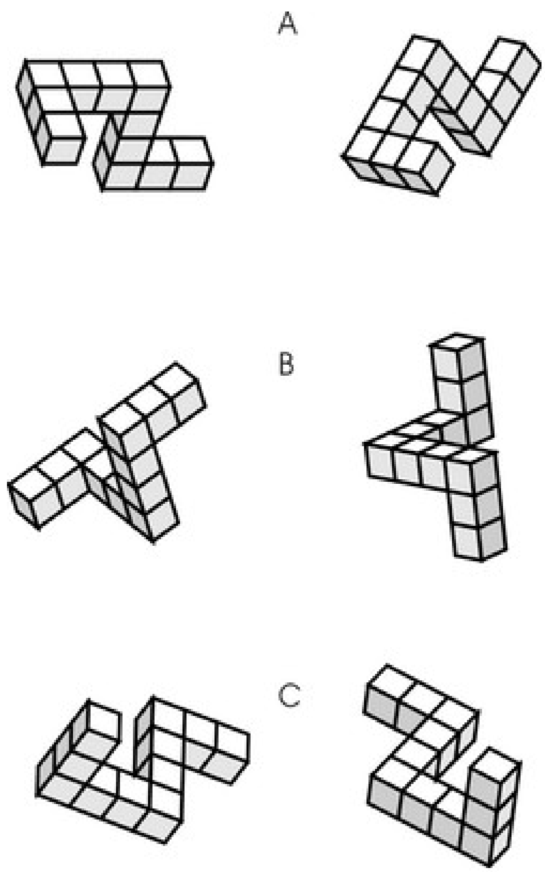
		compared
Aeon	**ee**-on	an immensely long period of time
Cellist		
Zealot	**zell**ot	1. an eager or enthusiastic person 2. a fanatic
Abstemious	ab-**steem**ius	tending to eat and drink sparingly
Gouge	gowj	1. *noun* a chisel with a curved blade for cutting blades 2. *verb* to scoop out with or as if with a gouge
Placebo	pla-**seebo**	a medicine given to a patient for psychological reasons and having no physiological effect
Façade	fa-**sahd**	1. the outside front of a building 2. a false or deceptive exterior
Aver	a-**ver**	to declare in a positive way
Leviathan	lev-eye-a-th'n	anything which is very large, especially in the sea
Chagrin	**shagrin** *or* sha-**green**	a feeling of vexation or disappointment
Détente	day-**tont**	an easing or relaxing of strained relationships between countries
Gauche	**goash**	awkward or tactless
Drachm	dram	a unit of mass equal to about 3.89 g
Idyll	**eye**-dil *or* **idd**il	a short poem or piece of descriptive music concerned with romanticized rural life
Beatify	bee-**atti**-fie	
Banal	ba-**nahl**	hackneyed, ordinary or trivial
Sidereal	sigh-**deer**iul	of or relative to the stars
Puerperal	few-er-peral	of, relating to, or occurring during childbirth or the period immediately following
Topiary	TO-PIE-ARY	of, relating to, or being the practice or art of training, cutting, and trimming trees or shrubs into odd or ornamental shapes
Demesne	da-**mane** *or* da-**meen**	1. the possession of land as one's own 2. the land and buildings possessed
Labile	**lay**-bile	changeable or unstable
Phlegm	flem	also called **sputum**: the thick mucus of the throat, brought up by coughing during a cold, etc.
Syncope	Sin-co-pay	1. loss of consciousness resulting from insufficient blood flow to the brain 2. the loss of one or more sounds or letters in the interior of a word (as in fo'c'sle for forecastle)
Prelate	**prell**it	a high-ranking clergyman, such as a bishop or archbishop

Appendix IV

Mental rotation of three-dimentional objects

(Shepard & Metzler, 1971)

The following pairs of 3D figures were presented to the subjects and they were asked to mark the identical ones. The time taken to decide whether the figures are identical increases the amount of mental rotation necessary to align them.



Appendix V

Memory Recall Test: Completion time of navigation task

Participant	Group	Time A – Destination	Time B - Destination
1	1	2.37	4.16
2	1	2.39	2.55
3	1	2.49	3.57
4	1	2.16	2.55
5	1	2.34	3.22
6	2	4.41	3.36
7	2	6.43	3.26
8	2	3.57	4.06
9	2	4.21	3.24
10	1	2.26	3.04
11	2	3.51	4.16
12	2	4.28	4.57
13	1	2.45	3.02
14	3	2.23	3.32
15	3	2.19	3.28
16	3	2.28	3.04
17	3	2.55	2.52
18	3	2.22	3.10

Groups

1 = Control
2 = Experimental 1 (device)
3 = Experimental 2 (route pictures)

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Pedestrian navigation using the sense of touch

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ABSTRACT

Haptics is a feedback technology that takes advantage of the human sense of touch by applying forces, vibrations, and/or motions to a haptic-enabled user device such as a mobile phone. Historically, human–computer interaction has been visual, data, or images on a screen. Haptic feedback can be an important modality in Mobile Location-Based Services like – knowledge discovery, pedestrian navigation and notification systems. In this paper we describe a methodology for the implementation of haptics in four distinct prototypes for pedestrian navigation. Prototypes are classified based on the user's navigation guidance requirements, the user type (based on spatial skills), and overall system complexity. Here haptics is used to convey location, orientation, and distance information to users using pedestrian navigation applications. Initial user trials have elicited positive responses from the users who see benefit in being provided with a "heads up" approach to mobile navigation. We also tested the spatial ability of the user to navigate using haptics and landmark images based navigation. This was followed by a test of memory recall about the area. Users were able to successfully navigate from a given origin to a Destination Point without the use of a visual interface like a map. Results show the users of haptic feedback for navigation prepared better maps (better memory recall) of the region as compared to the users of landmark images based navigation.

1. Introduction

Conventional pedestrian navigation applications present the user with position and orientation details through visual modalities such as a map with various layers of information. Generally, the shortest pedestrian route is overlaid on the map. Text-based turn-by-turn instructions are also provided. Strachan, Eslambolchilar, Murray-Smith, Hughes, and O'Modhrain (2005) give examples of pedestrian navigation with audio feedback. In-car navigation systems ('sat-nav') provide a turn-by-turn audio assistance combined with a map display. Wikitude (2012) have recently developed a complete augmented reality in car navigation application. Wikitude list a key advantage as not requiring "the users to take their eyes off the road" which is not the case with traditional car navigation systems. Obviously the driver must be alert at all times while operating a vehicle on public roads. Similarly it is also important that pedestrians are attentive to their physical environment. Rather than being engrossed in their mobile device they must pay attention to dangers, such as: physical obstacles, other pedestrians, and road traffic. Unlike the protected environment of a car, the current context, both physical and social, of a pedestrian may not be suitable for them to continuously interact with the mobile device. In these contexts a non-obstructive mode of communication like haptics appears to be a very suitable alternative to text or map-based feedback.

Haptic feedback or "haptics" is a technology that provides forced feedback, vibrations, and/or motions users using a device (Jacob, Mooney, Corcoran, & Winstanley, 2010). Haptics relies on the human sense of touch and recently has begun to appear in a broad range of research and applications (Amemiya, Ando, & Ando, 2008; Hoggan & Brewster, 2010; Paneels & Roberts, 2010; Pascale, Mulatto, & Prattichizzo, 2008; Williamson et al., 2010). Examples include: performing a robot-assisted endoscopic surgery (Tavakoli, Patel, & Moallem, 2005), assisting visually impaired people to navigate and explore a simulated 3D environment (Pascale et al., 2008), and most prominently in computer game consoles. Jacobson (2002) provides a good overview of the accessibility and usability issues in representing spatial information through multimodal interfaces using visual, audio, and haptics modes. Haptic feedback has been used in various other systems like alerting passengers using public transport about the arrival at the destination bus stop to help them prepare for disembarking (Jacob, Shalaik, Winstanley, & Mooney, 2011).

There has been some debate over how humans recall information after navigating environments, with accounts including egocentric and allocentric elements, as well as incorporating route and survey-based information (Roche, Mangaoang, Commins,

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& O'Mara, 2005). Humans require certain spatial strategies in order to navigate their environment – including a mental representation of the area that they are navigating and the ability to determine a suitable route to explore the environment (Tversky, 2000). Kuipers (1978) finds that those with detailed cognitive maps of an area can orient themselves by local features of each place in the street network. Kuipers also adds that such people can often have a sufficient stock of familiar routes that they need not maintain a two-dimensional orientation at all, but can just follow route descriptions. Cognitive functions that enable people to deal effectively with spatial relations, visual spatial tasks and orientation of objects in space is defined as spatial abilities. One aspect of these cognitive skills is spatial orientation, which is the ability to orient oneself in space relative to objects and events; and the awareness of self-location (Sjölinder, 1998).

In this paper we present pedestrian navigation using haptic feedback as the modality to represent spatial information such as location, distance, and orientation. We demonstrate how navigation instructions can be provided to the user by describing four prototypes where the vibration alarm (with varying frequency and pattern) is used to convey navigation instructions. We find that it is easy/faster to help users orient themselves in space while using haptics for navigation assistance especially in orientation is the real-world. Thus, we see that haptic feedback can be used as a modality to deliver information in a wide variety of systems when it is inappropriate to use other modalities like vision and audio. From the overall navigation guidance using haptics, the users can expect subtle feedback for assistance which ensures low attentiveness from the user while on the move.

We report on the tests carried out to see if users can successfully navigate from the origin to the destination without the use of visual cues like a list of landmark images along the way or a panoramic view of the destination. Information extracted from large-scale external environments and stored in human memory exists in some type of psychological space (Golledge, 1999). Golledge adds that it is reasonable to assume that as environmental learning occurs, some of the standard geometry of identifiable physical space will be included in its cognitive representation. We thus test the spatial abilities and memory recall of the user by recreating a map of the region on paper based on memory recall after the navigation task.

This paper is organised as follows. Section 2 provides motivation for the research and an overview of the relevant literature in the field of haptics with emphasis on existing GIS and pedestrian navigation applications. Integration of haptics in pedestrian navigation systems is discussed in Section 3. Our haptic interaction model for pedestrian navigation applications is described in detail in Section 4. Descriptions of the four distinct pedestrian navigation prototypes are also provided. Section 5 describes the experimental setup and the results and key findings from the experiments are listed in Section 6. The paper closes with Section 7 with the key outcomes from the paper and discussion of the future direction of this research.

2. Motivation and overview of related work

Erp (2001) argues that current popular navigation techniques for pedestrian navigation applications are not reasonable or possible at all times. Interacting with the map display on a mobile device means that the user has a "neck-down" approach. The user uses one hand to hold the device and the other to interact with the user interface. The range of interaction includes zoom, pan, and click. During this time the user's attention, while interacting with the map interface, is almost entirely on the device and they are potentially unaware of any physical dangers or obstacles around them. Robinson, Jones, Eslambolchilar, Smith, and Lindborg (2010) argues that the interactions users have with their environment must always be considered more important than interactions they are having with the mobile device interface.

Moussaid, Perozo, Garnier, Helbing, and Theraulaz (2010) found that about 70% of people on a crowded street are actually moving in a smaller group potentially friends or family. The requirement for continuous interaction with the mobile interface means that the user is not able to: interact with that group, carry items in their hands, etc. Some attempts have been made to deal with these issues. In Holland, Morse, and Gedenryd (2001) the authors present a backpack mounted AudioGPS providing audio feedback to the user to help in navigation. The drawback with such an application is the need for the user to have their sense of hearing fully involved to understand the feedback along with the requirement to carry the backpack mounted application. Mata, Jaramillo, and Claramunt (2011) describes an audible user-oriented interface that provides the visually impaired user with location information and orientation guidance to help the user get to the boarding gate.

Flintham et al. (2003) discusses the use of the audio channel to provide less direct contextual information to the user about the location details. Bartie and Mackaness (2006) highlight some of the key advantages and disadvantages of using a non-visual feedback system like speech-based audio. Some of the key benefits listed were – low power consumption as compared to LCD, accessible to visually impaired, secure and discreet, etc. The main disadvantages included – speech recognition errors in noisy environments, user's accent and speed of voice can affect understanding (system coaching required), does not allow user to browse the information and cannot be used by hearing impaired.

Over the last decade the field of haptics has received considerable research attention. A key conclusion drawn by several researchers (Amemiya & Sugiyama, 2008; Erp, Veen, Jansen, & Dobbins, 2005; Jacob et al., 2010; Lee, Cheng, Lee, Chen, & Sandnes, 2009; Paneels & Roberts, 2010; Pielot, Poppinga, & Boll, 2010; Robinson et al., 2010; Williamson et al., 2010) is that in situations where it is inconvenient or less appropriate to use either visual and/or audio feedback; the sense of touch is advantageous. Costanza, Inverso, Pavlov, Allen, and Maes (2006) and Erp et al. (2005) argue that an interaction model for mobile devices should contain the following characteristics: be customisable to meet the user's requirements based on the activity the user is involved in, deliver easily understood interaction cues, and should not overly interfere with the user's current activity. In situations when vision-based or audio-based feedback for pedestrian navigation is in-appropriate we believe that haptics can provide feedback to users in the real world situations. Spatial information which is usually provided through visual channels was delivered using haptic cues by Zelek (2005). Directional information for the shortest path was provided using haptics and the information, such as street names, provided via the auditory channel.

In the next section we provide a formal overview of using haptics in a GIS context. More specifically this classification is focused on applications combining the use of haptic interaction with decision making based on spatial data and information for pedestrian navigation applications.

3. Haptic feedback for pedestrian navigation

Haptic feedback can be integrated for use in a wide range of GIS applications. Examples include: knowledge discovery for a tourist in a city (Robinson et al., 2009a, 2009b) and notifications for users who are using public transport (Jacob, Shalaik et al., 2011). There is potential for integration of haptics into mobile GIS. Researchers have moved from work on haptics in a virtual environment (Erp et al., 2005) to providing navigation assistance in a real environment (Elliott, Erp, Redden, & Duistermaat, 2010). Using haptic feedback for pedestrian navigation for visually impaired and non-visually impaired has gained popularity amongst many researchers recently (Amemiya & Sugiyama, 2008; Elliott et al., 2010; Erp et al., 2005; Jacob, Mooney, Corcoran, & Winstanley, 2011; Pielot & Boll, 2010). A haptic-interaction model from our earlier work (Jacob et al., 2010) was integrated into pedestrian navigation applications in our recent work (Jacob, Mooney et al., 2011). Klippel, Hansen, Richter, and Winter (2009) argue that turn-by-turn direction instructions are often too detailed leading to cognitive overload or unnecessarily complex. Robinson et al. demonstrated the need to move away from the turn by turn instruction to a system which gives the users the freedom to navigate according to their choice using haptic feedback for assistance (Robinson et al., 2010). Robinson et al. provides distance and orientation information to the user via vibrations with varying pattern and frequency. Asif, Heuten, and Boll (2010) extend this concept to automobile drivers. The driver perceives countable vibro-tactile pulses, which indicate the distance in turn by turn instructions. They found that the approach is a simple way of encoding complex navigational information.

Spatial strategies can be either egocentric (body-centred) or allocentric (environment-centred), and O'Keefe and Nadel (1978) have suggested that there is a dichotomy between the two (Roche et al., 2005). Learning the layout of an environment can involve strategies such as exploration and search, and in some cases the use of secondary information sources such as maps and photographs can aid the navigator in a novel or unfamiliar environment (Roche et al., 2005). Two commonly used techniques to learn the layout of the environment are either gaining route-based knowledge or survey-based knowledge. Route-based knowledge is acquired by physically navigating the environment, an egocentric strategy due to the fact that information is obtained depending on the location of the navigator (Roche et al., 2005). Route-based navigation is based on remembering specific sequences of positions that the person obtains by navigating their environment (Foo, Warren, Duchon, & Tarr, 2005). Survey-based knowledge is incorporated and developed as a derivative of physical navigation of the environment, but the introduction of a secondary information source such as a map or photographs of the environment can lead to immediate allocentric representation for the navigator, without the need to navigate the environment (Roche et al., 2005). Studies into what is necessary to help pedestrians to navigate in pedestrian environments have discovered that landmarks are the most predominant navigation cue (May, Ross, Bayer, & Tarkiainen, 2003). However, when landmarks are unreliable navigators appear to fall back on survey knowledge to navigate the environment (Foo et al., 2005).

In the following section we look at the haptic interaction model for pedestrian navigation system. We also discuss various haptic feedback prototypes that can be used for pedestrian navigation.

4. Haptic interaction model for pedestrian navigation systems

Traditionally pedestrian navigation systems have been a visual interface where the user is provided with a map interface and some extra textual information. We see that it is however impractical/inappropriate to use such visual interfaces at all time. We investigated into the integration of haptics as a modality to provide navigation cues to the user. This enables the user to switch to a non-visual feedback mechanism when the user chooses not to use a visual interface. The user can choose between the prototypes based – system complexity, the kind (frequency) of feedback, battery usage, how much (turn-by-turn vs. destination only) feedback they require, and most importantly based on their requirements/needs. Fig. 1 illustrates a model for haptic interaction in a pedestrian navigation system. The user action along with the location, orientation and destination are sent to the server as inputs to the system. The broker service receives this information and provides instructions back to the client after processing this information. Based on the interaction type chosen by the user, they are provided with haptic feedback in the form of vibration alarm along with some simple visual cues like colour coded buttons and textual description.

There are four classifications of client applications for pedestrian navigation applications (Jacob, Mooney, & Winstanley, 2011). *Haptic StayonPath* is a prototype where the user selects a destination at the start point. *Haptic StayonPath* does not use the compass on the mobile device and thus the phone can be held in the hand or left in the pocket. Therefore the user must use their own judgement at street intersections. This system is ideal when having to take the shortest path across an open area.

The *Haptic Navigator* is a waypoint-by-waypoint pedestrian navigation system using haptic feedback at critical waypoints in the path. In the *Haptic Navigator* system, the user is required to follow the shortest path from the initial start point until the destination based on system feedback. However, if the user wishes to be only informed about the general walking direction from a particular point towards the destination along the shortest path, then they can choose the *Haptic WayPointer*. The use of direction information in signage at road intersections has been used in various places over the years to give the user a sense of direction towards the user's destination. Some provide the direction information to various landmarks where as others provide distance information along with the direction to landmarks/points of interest. This helps the user re-orient and head along the direction required to reach their destination. The *Haptic DestinationPointer* is designed to provide the general direction towards the destination from any given point. By varying the frequency and pattern of vibrations we are able to encode the distance information into the haptic feedback while the user is pointing in the direction of the destination while scanning. Low frequency, long duration vibration pattern is used to represent user very close to the destination. The high frequency, shorter duration vibrations are used to represent the distance to destination being far away from the user.

We see in Fig. 2 that unlike the shortest path provided by typical map interfaces, the actual shortest path from any given origin to a destination may/may not include open areas. And the use of haptics in such cases as a modality can help the user navigate through these open areas where finding landmarks might not be possible. Table 1 provides a summary of the four haptic feedback prototypes for pedestrian navigation.

The *HapticDestinationPointer* uses haptic feedback to provide distance and direction information to the user. When the user initially selects the Destination Point, the distance (straight line) from origin (current location) to the selected destination is calculated and divided into three parts as shown in Fig. 3. The querying angle is dependent on this distance information of the user from the destination where the angle decreases to a much smaller range as the user is nearing the destination.

Let the origin (current location) of the user when they run the *HapticDestinationPointer* be O. Let D be the straight line distance to the destination S. The distance value is divided to form three distinct phases to the user's trip. For the walk when the distance ranges from the origin to the point D/3, the angular range for querying is set to 60° and alerted using the vibration patter v1. The querying angular range for the second phase of the walk from distance D/3 to 2D/3 is set to 30° with vibration patter v2 to provide

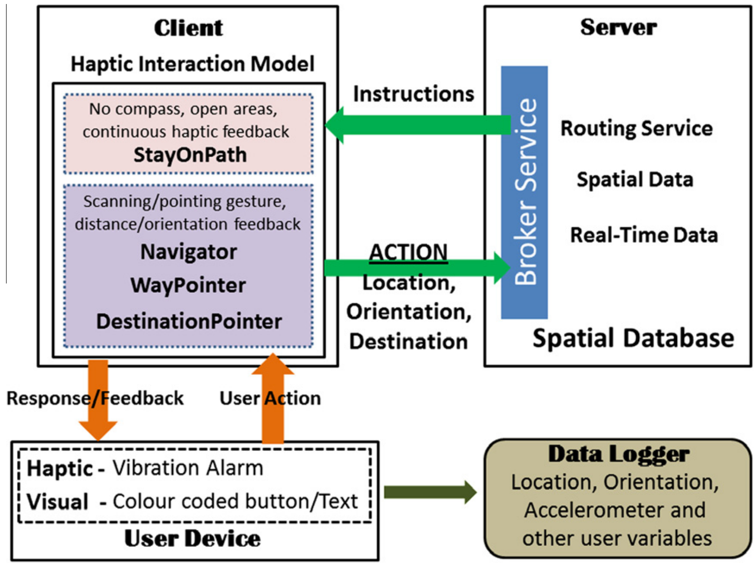

Fig. 1. Haptic interaction model for pedestrian navigation applications.

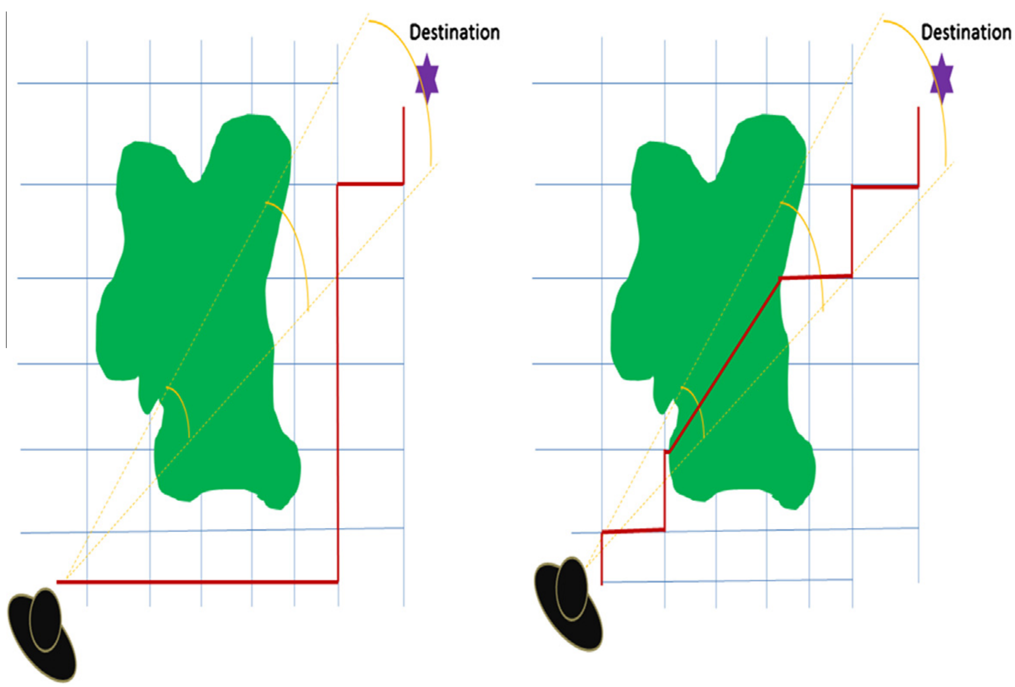

Fig. 2. Shortest path provided in a visual interface whereas the general direction of destination enables the user to walk across open areas.

feedback. During the last phase of the trip when the user is closer to the destination which is between 2D/3 and D, the angular range is set to 10° and the vibration patter v3 is used. The user performs the 'scan function' where they hold the mobile device parallel to the ground and move it around them slowly to be alerted of the direction they need to start walking. The user is alerted with a unique continuous vibration feedback when the user reaches within 10 m of the Destination Point. The bearing between the user's current location and the destination is calculated. When this bearing is equal to the compass value of the mobile device, we say that the user is pointing exactly towards the destination. With the digital compasses available on the devices, it is not ideal to fix this value to a unique angle, so we give a range within which if the user points the device, we say that the user is pointing towards the destination. So during the initial phase the range is set to be an angle that can be ±30° from the actual bearing between current location and destination. This angular range decreases as the user is nearing the destination.

The features and functionality of the four haptic feedback based prototypes are summarised and listed in Table 2.

Table 1
Summary of the four haptic feedback prototypes for pedestrian navigation.

	StayonPath	Navigator	Waypointer	DestinationPointer
Haptic feedback	Yes	Yes	Yes	Yes
Text/colour code	Yes	Yes	Yes	Yes
Compass usage	No	Yes	Yes	Yes
GPS 'always' on	Yes	Yes	No	No
Internet usage	High	High	Low	Low
Battery usage	High	Medium	Low	Low

5. Experiments and user trials

Experiments were carried out to test how the user performed while using haptic feedback. Two tests were carried out to evaluate various aspects of pedestrian navigation. One was to see how effectively and successfully the user can navigate from a given origin to destination by using haptic feedback while being distracted by another person walking along and talking at all times till the completion of the task. This is to test the real-world situations that arise where the primary task is walking and/or performing some other activity and the use of assistive technologies for navigation is only a secondary task and thus diving attention between the two needs to be considered. The second test was designed to test the user's memory recall of the region after completion of navigation tasks based on landmark image based navigation and haptic feedback based navigation.

5.1. Navigation skill test

Research question: Can haptics be used for pedestrian navigation by a user involved in another primary task (in this case chatting with a friend) as they walk towards the destination location?

To test the haptic interaction model, we tested the *Haptic DestinationPointer* with 15 participants. The participants were given a 5 min talk before they do the test about the feedback patterns to help them familiarise with the feedback representing distance information. The origin and destination were fixed for all the users, but the users are not informed what the destination is. The users were given the mobile device which had the *Haptic DestinationPointer* application installed. They were asked to navigate to this unknown destination based on only haptic feedback they receive from the mobile device without any visual interface. The start and Destination Point along with the shortest path described by the Cloudmade (Cloudmade, 2012) routing service between the two points is shown in Fig. 8. The total distance between the origin and destination along the shortest path was 540 m and 390 m was the straight-line distance if measured as the crow flies.

When the participants walked towards the destination, another person walked along to distract the user by talking and thus provide a more real-world situation of actually exploring places when the usage of navigation assistance was the secondary activity. Hence the use of device to help navigation was the secondary task and the actual navigation with the friend being the primary task. As the user performed the test, the compass and accelerometer readings were stored to understand in detail the path taken for post navigation analysis. The compass readings along the path shows the regions where the user performed the scan operations due to confusions about the right path, the accelerometer enables us to understand the spots/regions in the path where the user paused or was standing still trying to reorient as the user was unsure.

5.2. Memory recall test

Research question: Can haptic feedback ensure better memory recall of the area by users after a navigation task as compared to vision based systems?

The 18 participants involved in this experiment were selected from a population of 3rd level students that were unfamiliar with the area where tests were carried out. Some participants attended NUI Maynooth while other participants attended other universities in the surrounding area of Dublin. The participants were randomly allocated to one of the three groups – the Control Group, Experimental Group 1 or Experimental Group 2. The Control Group ($n = 7$) had a mean age of 19.29 (SD = 1.113), Experimental Group 1 ($n = 6$) had a mean age of 19.83 (SD = .983), and Experimental

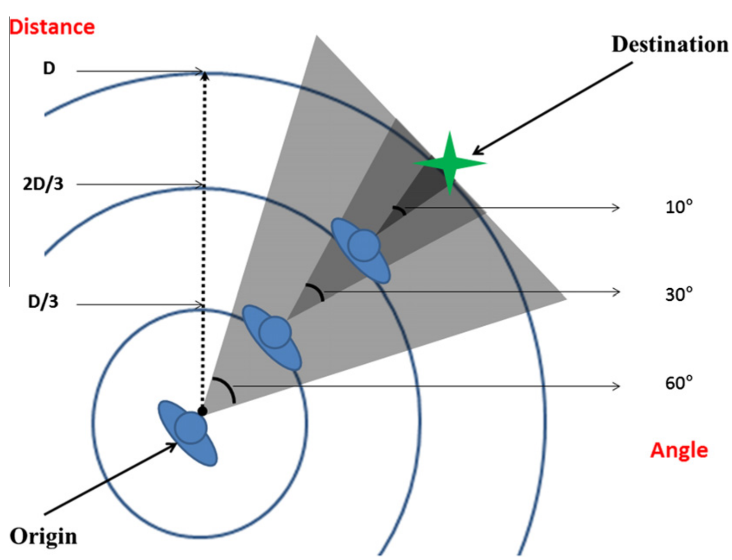

Fig. 3. Change in querying angle based on distance of user from the destination.

Group 2 ($n = 5$) had a mean age of 21.60 (SD = 1.517). All participants gave informed consent to partake in the experiment.

Participants were required to complete a number of control tasks including the Cognitive Failures Questionnaire (Broadbent,

Table 2
Features and functionalities of pedestrian navigation prototypes using haptic feedback.

StayOnPath	Navigator	WayPointer	DestinationPointer
No Compass used Works using the Hot/ Cold' technique	Works using the 'waypoint-by-waypoint' navigation assistance technique	Works using the point-to-'waypoint navigation assistance technique	Works using the point-to-destination' navigation assistance technique
Phone can be held in the hand or left in the pocket	Provides waypoint-by-waypoint assistance when getting from one place to the other in an unfamiliar city/town	Provides assistance when expecting initial general heading information along the shortest route	Provides assistance when expecting general heading information towards destination
Good for walking across open areas	Phone should be held In the hand for performing the scanning operation	Phone should be held in the hand for performing the scanning operation when at points along the trip the users wish to reassure themselves of the shortest path from current location	Phone should be held in the hand for performing the scanning operation when at points along the trip the users wish to reassure themselves of the direction towards destination
Continuous feedback as you walk along a path	Does not require user attention while walking towards the next waypoint as they will be alerted when they need to make a change in their walking direction Feedback only when pointing in the direction of the next waypoint or about arrival at a new waypoint	Does not require user attention while walking as they are In 'explore mode' and so will only need to query when in doubt	Does not require user attention while walking as they are in explore mode' and so will only need to query when in doubt
		Feedback only when pointing in the direction of the next waypoint from any point in the path	Ensures faster walking speed in the general direction of destination Feedback only when pointing in the direction of the destination from any point in the path

Fig. 4. Panoramic images of the Destination Point that were shown to the Control Group and the Experimental Group 2.

Cooper, Fitzgerald, & Parkes, 1982), the National Adult Reading Test (Nelson, 1982), the Trail Making Test (Reitan, 1955) and a Mental Rotations task (Shepard & Cooper).

The Trail Making Test (TMT) was presented to participants in a pen and paper format. The TMT provides information on attributes such as visual processing, visual search and executive function (Reitan, 1958). The National Adult Reading Test (NART) consisted of 50 single words of varying difficulty that were presented as a word list on a single sheet of paper. The NART is used as a prediction of IQ and general intelligence (Nelson, 1982). The number of words that the participant pronounced correctly translated into a score of Full-Scale IQ, Verbal IQ and Performance IQ. The Mental Rotations Task was presented to the participants in a pen and paper format. The Mental Rotations Task is used as a method of assessing participant's spatial rotation abilities (Shepard & Metzler, 1971).

The Control Group and the Experimental Group 2 were shown four photographs of the Destination Point at the start of the experiment in order to locate it as shown in Fig. 4. The Experimental Group 2 was shown a series of six photographs at Starting Point A and at Starting Point B which illustrated the route that they should take to the Destination Point. The Experimental Group 1 used haptic feedback to help navigate to the Destination Point using the *HapticDestinationPointer* system as shown in Fig. 3. Participants were timed while navigating from Starting Point A to the Destination Point and from Starting Point B to the Destination Point using a stop watch device on a mobile phone. At the completion of the experiment participants were instructed to draw a map of the area of the area they were at on an A4 sized paper that already included the outline of the road surrounding the apartment complete. A map key was used to score the maps, which were given a mark out of 25 for each participant. Marks were given for including the Destination Point, Starting Point A and Starting Point B, as well as marks for including buildings, the Tennis Courts and the bins located beside the Destination Point. Participants were not restricted to drawing buildings and were told to include any information that they could recall. Participants were not told before completion of the test about having to prepare a map as we did not want the participants to intentionally try and remember features for the post navigation task.

6. Results and discussions

In this section we discuss the finding and results in detail of the two tests that have been carried out for navigation and memory recall.

6.1. Navigation test

All the 15 participants completed the tests successfully as they all reached the destination. Table 3 provides a summary of the 15 users who took the user trials. Almost all the users walked over open areas and paved walkways to reach their destination. The average time of completion by all participants was 865 s while the average distance travelled to reach destination was found to be 807 m. The time of 540 s to reach the destination by 'user 2' was the fastest recorded time while the 'user 3' took the longest time (1192 s) to complete the task. The shortest travel distance was also recorded by 'user 2' (652.57 m) where the longest travel distance of 949.89 m was recorded by 'user 7'.

According to the Cloudmade routing service, the time required to traverse the shortest path to the destination was 390 s (thus walking at a speed of 1.38 m/s) which seems very unlikely in a real world situation. The average walking speed recorded for the user trials was 0.93 m/s. Some users walked very fast while performing the trials while others chose to walk slowly and check the general walking direction when at certain critical points in the path. The users commented on 'how subtle the feedback was' and the about not having to continuously interact with the device. During the user trials, they could get to the destination without taking their attention off their conversation with a friend while walking towards the destination. This benefit of not having to continuously look into the mobile screen for navigation assistance was cited as a huge positive feature by most users. The time taken to cover that distance as per Cloudmade routing service expects the user to be walking at speeds which is relatively fast when walking along streets casually. The time taken to get to destination is significantly higher as the users were not asked to get there in the fastest possible time and thus users walked in their own pace.

Table 3
Summary of the user trials.

User	Distance Travelled (in m)	Time Taken (in s)	Comments
1	856.16	1160	Walked across grass and car parks
2	652.57	540	Finished task in the quickest time
3	938.84	1192	Took the longest time to finish the task
4	812.68	960	Was taking more time at certain points
5	784.32	790	Felt feedbacks were easy to understand
6	845.12	878	Walked fast across open areas
7	949.89	940	Walked the longest distance. Poor with orientation
8	758.22	748	Took time to re-orient at certain points
9	833.86	850	Used mostly paved ways. Paused more often
10	912.31	975	Was finding it difficult to re-orient near the buildings
11	885.43	914	Walked across grass/car parks
12	781.32	843	Felt feedback was very subtle and good
13	692.54	689	Walked across cark parks and beside buildings
14	688.76	735	Took the path between the buildings
15	711.87	759	Walked across open grass fields

Fig. 5 shows the path taken by the user who reached the destination in the shortest time. The comparison with 2 other users shows the distinct paths taken to the destination. Unlike the typical shortest path, the users walked over open areas like fields, sports pitches, car parking and also took paved walkways when necessary.

6.2. Memory recall test

The findings from the second test is described below for both the control task and the map drawing with also discussions about navigation time and overall performance in the post navigation task of map creation.

6.2.1. Control tasks

Due to an overall low number of participants and unequal participant numbers in each of the groups, non-parametric tests were used in each of the control tasks.

Results from the CFQ showed an overall mean score of 46.67 (SE = 3.71). An independent samples Kruskal Wallis test also demonstrated that there was no significant differences between the groups on CFQ scores ($P = .095$). Results from the Mental Rotations Task demonstrate that participants had an overall mean score of 26.61 (SE = 1.58). An independent samples Kruskal Wallis test measuring any difference between the groups revealed a significance level of .51, which almost approached significance. Further investigation of the means and SEs for each of the groups on the

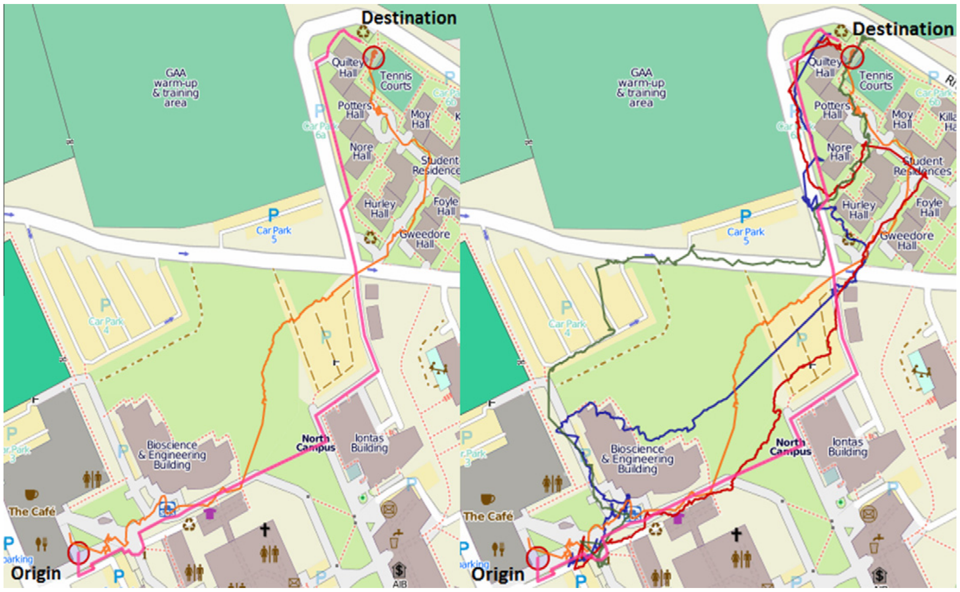

Fig. 5. Shortest path using Cloudmade API represented in pink: (a) The path taken by 'user 2' who took the least time and (b) comparison of four distinct paths taken by different users from origin to destination.

Table 4
Mean Scores and Standard Error Scores for the Control Group, Experimental Group 1 and Experimental Group 2.

	CFQ	TMTA	TMTB	TMTB-A	fsIQ	pIQ	vIQ	Rotation
Control Mean	46.29	28.14	50.71	22.57	115.71	113.71	114.71	23.14
Control SE	8.017	5.701	8.283	3.651	1.643	1.443	1.443	2.558
Exp 1 Mean	54.83	25.00	51.17	26.17	111.50	109.67	110.67	25.33
Exp 1 SE	3.628	2.543	5.700	3.919	1.500	1.382	1.382	2.431
Exp 2 Mean	37.40	20.80	38.00	17.20	116.80	114.40	115.50	33.00
Exp 2 SE	3.816	3.652	1.378	3.499	1.715	1.536	1.536	.894

Rotations task (see Table 4) revealed that the greatest difference was between the Control Group ($M = 23.14$, SE = 2.558) and the Experimental Group 2 ($M = 33.00$, SE = .894).

Results conducted on the Trail Making Test revealed an overall mean score for TMTA as 25.06 (SE = 2.55), an overall mean score for TMTB as 47.33 (SE = 3.83) and an overall mean score for TMTB-A as 22.28 (SE = 2.203). An independent sample Kruskal Wallis test revealed that there was no significant difference found between the Control Group, Experimental Group 1 or Experimental Group 2 on either TMTA scores ($p = .365$), TMTB scores ($p = .342$) or the scores on TMTB-A ($p = .194$).

Results conducted on the NART revealed an overall mean score for full scale IQ as 114.16 (SE = 1.04), an overall mean score for performance IQ as 112.56 (SE = .94), and an overall mean score for verbal IQ as 113.56 (SE = .94). An independent sample Kruskal Wallis test also revealed no significant differences between the groups on full scale IQ ($p = .079$), performance IQ ($p = .079$) or verbal IQ ($p = .079$). Results from the Control Tasks demonstrated that all of the participants had normal cognitive functioning and there were no significant differences found between the Control group, Experimental Group 1 or Experimental Group 2 on any of the tasks.

Table 4 shows the Mean Scores and Standard Error Scores for the Control Group, Experimental Group 1 and Experimental Group 2 on the Cognitive Failures Questionnaire (CFQ), the Trail Making Test Part A (TMTA), the Trail Making Test Part B (TMTB), the difference between them (TMTB-A), the NART scores – Full Scale IQ (fsIQ), Performance IQ (pIQ) and Verbal IQ (vIQ) and the Mental Rotations Task (Rotation).

6.2.2. Map drawing

A one-way between groups ANOVA was conducted to examine the difference in map drawing scores for each of the three groups. There was a main effect of group with the result almost reaching significance $F(2,15) = 3.1$, $p = .075$. Despite not reaching statistical significance post hoc Tukey tests demonstrated that the Control Group differed from Experimental Group 1 at $p = .078$. An examination of the mean statistics revealed that the Control Group demonstrated a mean score of 9.43 (SD = 2.82), Experimental Group 1 demonstrated a mean score of 13.33 (SD = 4.03), while Experimental Group 2 showed a mean map score of 10.00 (SD = 1.00) (see Fig. 6c).

6.2.3. Navigation times

A 2×3 (Navigation Time A, Navigation Time B) $\times$ (Control Group, Experimental Group 1 and Experimental Group 2) between groups multivariate ANOVA was conducted to investigate the difference in the times taken by each group to navigate from Starting Point A to the Destination Point and from Starting Point B to the Destination Point. Preliminary assumption testing was conducted to check for normality, linearity, homogeneity of variance and multicollinearity, with no serious violations noted. There was a statistically significant main effect of group at Time A – ($F(2,14) = 5.28$, $p = .00$). There was also a main effect of group at Time B – ($F(2,15) = 3.446$, $p = .059$), which almost reached significance.

A one way ANOVA was conducted to investigate the statistically significant difference found between the groups at Time A. The results demonstrated that there was a significant main effect of group ($F(2,15) = 2.68$, $p = .00$). Post-hoc Tukey tests revealed that

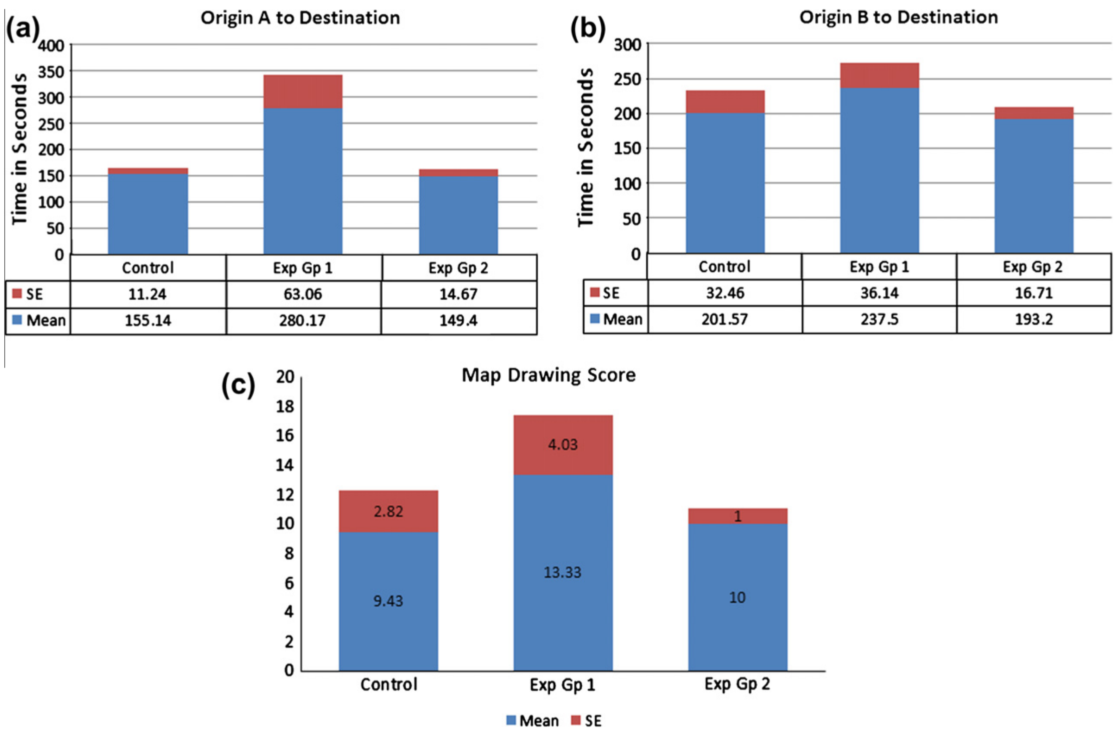

Fig. 6. (a) Navigation time from Starting Point A to the destination, (b) navigation time from Starting Point B to the destination and (c) map scores based on the number of features recalled.

Experimental Group 1 differed from the Control Group at $p = .00$ and differed from Experimental Group 2 at $p = .00$. An examination of the mean statistics showed that Experimental Group 1 scored a mean time of 280.17 s (SD = 63.06), the Control Group had a mean score of 155.14 s (SD = 11.24), while Experimental Group 2 demonstrated a mean score of 149.4 s (SD = 14.67) (see Fig. 6a and b).

A one way ANOVA was then conducted to investigate the almost statistically significant difference found between the groups at Time B. The results revealed demonstrated that there was a significant main effect of group ($F(2,15) = 3.446$, $p = .059$). Post-hoc Tukey tests demonstrated that Experimental Group 1 and Experimental Group 2 differed from each other at $p = .073$. An examination of the mean statistics revealed that Experimental Group 1 scored a mean time of 237.5 s (SD = 36.14), Experimental Group 2 demonstrated a mean score of 193.2 s (SD = 16.71) and the Control Group scored a mean time of 201.57 s (SD = 32.46).

6.2.4. Routes

Six key routes taken by the participants were identified – Routes 1, 2 and 3 from Starting Point A to the Destination Point and Routes 4, 5 and 6 from Starting Point B to the Destination Point (see Fig. 7).

Experimental Group 2 were shown photographs of Route 2 from Starting Point A and photographs of Route 5 from Starting Point B. Analysing the routes taken by each participant showed that the majority (57.1%) of the Control Group followed Route 1 from Starting Point A, while the majority (66.7%) of Experimental Group 1 followed Route 3 from Starting Point A, with 100% of Experimental Group 2 following Route 2 (see Fig. 8a). Analysing the routes taken by each participant from Starting Point B to the Destination Point revealed that the majority of both the Control Group (71.4%) and Experimental Group 1 (83.3%) followed Route 5, while 100% of Experimental Group 2 followed Route 2 also (see Fig. 8b). Overall the most popular route from Starting Point A was Route 2, with Route 1 being the least popular, and the most popular route from Starting Point B was Route 5, with Route 4 being the least popular.

To summarise, the results indicated that the participants using the haptic technology took a significantly longer time to reach the Destination Point when navigating from Starting Point A and also took a longer time to reach the Destination Point when navigation from Starting Point B when compared to Experimental Group 2, with the result almost reaching statistical significance. However Experimental Group 1 also demonstrated higher map scores in comparison to the Control Group, who were told to navigate the environment freely, and the Experimental Group 2, who used route based photographs as a guide to navigation, with this difference almost approaching statistical significance.

6.3. Discussion

Based on the findings from the navigation tasks using *HapticDestinationPointer*, it is seen that the users were able to successfully reach the destination without any visual feedback and perform the task even though they were being distracted by another user while the navigation task is to be performed.

Principle findings from the memory recall experiment indicate that those in Experimental Group 1 using the haptic feedback to help navigate the environment took significantly longer than those in the Control Group or Experimental Group 2 who were using the route based photographs as a guide. Experimental Group 1 took significantly longer when navigating from Starting Point A to the Destination Point and also took longer when navigating from Starting Point B to the Destination Point, with the result almost approaching significance. There was also an almost significant ef-

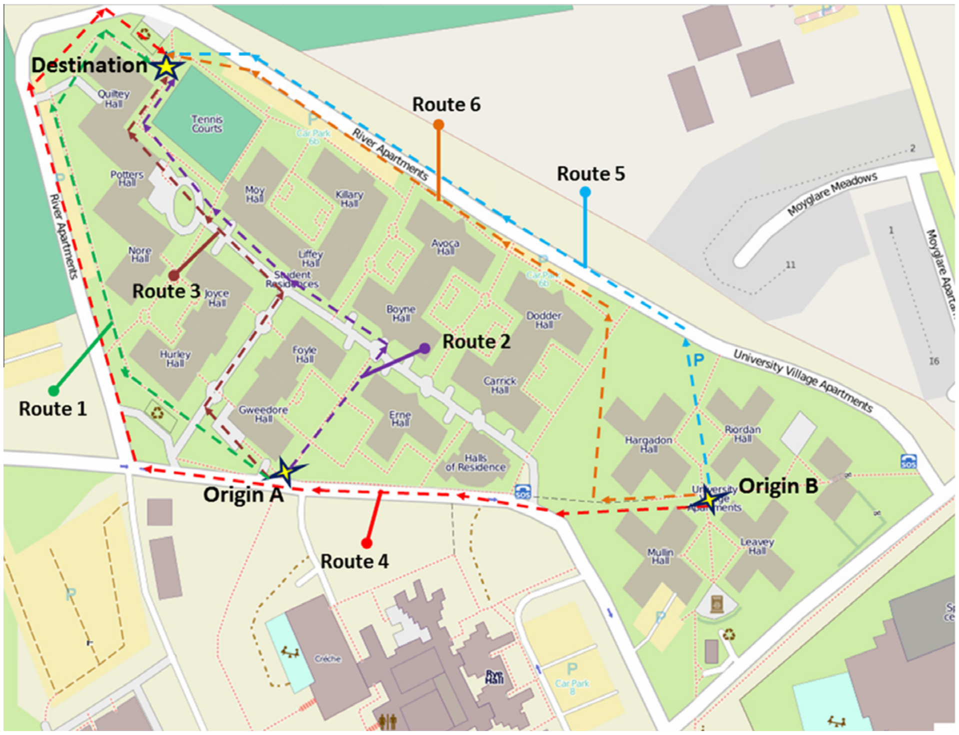

Fig. 7. Map of the six routes identified, as well as Starting Point A, Starting Point B and the Destination Point.

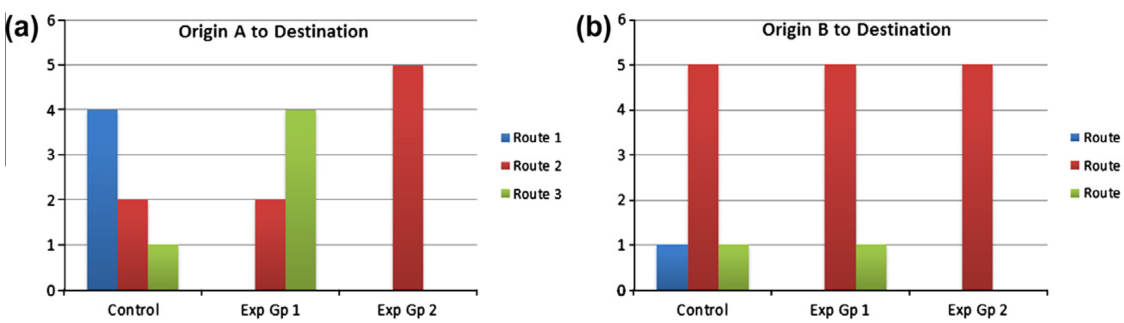

Fig. 8. (a) The routes taken from origin A to destination (b) The routes taken from origin B to destination.

fect discovered when examining the map scores of the participants across the three groups – those who were aided by haptic technology when locating the Destination Point had better maps overall, compared to the Control Group and Experimental Group 2. An example of a map created by the user based on memory recall is shown in Fig. 9 with comparison to the same region on OpenStreetMap.

The significant result obtained when comparing the times taken could be explained as follows. As the Control Group and Experimental Group 2 both were shown four photographs of the Destination Point so they knew what key landmarks to look out for and to alert them that they had reached their location. Experimental Group 1 who were not given any visual cues were relying strictly on haptic feedback did not have this to depend on, and only knew they had reached the location when the mobile phone started to vibrate continuously. It has been demonstrated in previous research that participants can reach an unknown location in an unfamiliar environment assisted only by haptic feedback (Robinson et al., 2010). However the Control Group and Experimental Group 2 could be at an advantage as they could notice the landmarks of the Destination Point from a distance and therefore navigate towards it. This could explain why those in Experimental Group 1 spent a longer time locating the Destination Point from Starting Point A.

Experimental Group 1 also took a longer time locating the Destination Point from Starting Point B, with the result almost reaching significance. This could possibly be explained by the fact that participants would be unfamiliar with the method of scanning that was used to give haptic feedback to the participant when the device was pointed in the direction of the Destination Point. It is possible that participants could have scanned too fast to pick up a vibration so this would slow the participant down when looking for feedback. It would perhaps be beneficial then to include a longer tutorial on how to accurately scan and search for feedback before commencing the search for the Destination Point and timing the participant. Scanning also has another disadvantage as it is

Fig. 9. An example of the map drawn post navigation task for the memory recall test.

more obtrusive and obvious that someone is trying to navigate their environment (Pielot et al., 2010). Although scanning was the technique that was used for this experiment it is also possible to have the device placed in your jacket pocket, then pointing and scanning for feedback to ensure user privacy (Jacob, Mooney et al., 2011). The user will also be safe in the knowledge that they do not seem like a tourist or stranger to the area, which is an issue for most navigators (Robinson et al., 2010).

The almost significant result obtained from the map scores which illustrated that those in Experimental Group 1 scored higher maps in comparison to the other two groups can also be explained in reference to the photographs shown at the start. As was already stated the Control Group and Experimental Group 2 had prior knowledge of what the Destination Point looked like via photographs. Experimental Group 1 had no knowledge of what the Destination Point looked like when they began the experiment, therefore it may be possible that this had an effect on recall. Previous work has also indicated that use of tactile displays used to assist navigation can improve the attention of the user (Pielot et al., 2010). Studies have indicated that participants who use a tactile display while navigating pay more attention to the immediate surroundings of their environment (Pielot et al., 2010). As well as this, in experiments where the participant was asked to actively search for landmarks and other items while navigating the environment it was demonstrated that those using tactile displays are able to locate and notice more items (Elliott et al., 2010). Pielot also noted a positive tendency in their study for those in the tactile condition to notice more entities (benches) than those in the visual condition. This could be a possible reason for the higher map scores of Experimental Group 1.

All participants in Experimental Group 2 followed the routes they were shown on the photos at both Starting Point A and Starting Point B to reach the Destination Point. These were Route 2 from Starting Point A and Route 5 from Starting Point B as shown in Fig. 7. Experimental Group 1 followed mainly similar routes to Experimental Group 2, especially when navigating from Starting Point B to the Destination Point. It is interesting to note that nearly all participants in the Control Group navigated left (Route 1) when instructed to navigate freely. This can be explained by the fact that in the four photographs of the Destination Point, the site of the general rubbish and recycling bins was clearly visible and participants may have been attracted to the bins situated to the left of Starting Point A, thinking that they could possibly be the bins in the photograph of the destination. The examination of the routes taken by the participants provided another possible reason of why Experimental Group 1 had higher map drawing scores, with the result approaching significance. The majority of participants in the Control Group took an alternative Route (Route 1) that did not bring them into the central part of the apartment. None of the participants in Experimental Group 1 or Experimental Group 2 followed this route to reach the Destination Point, instead choosing Routes that took them into a more central part of the campus accommodation area where they were navigating. This could have made a difference to the map drawing scores as it is possible that these Groups were exposed to more landmarks than the Control Group and were therefore able to recall and draw more landmarks like buildings, and bins on the map.

7. Conclusions and future work

When the users use mobile-based navigation systems they are usually in an outdoor environment and not within the protected environment of a car, bus, or train. As outlined in this paper there are situations where interaction with the visual display on a mobile device is inappropriate or unsuitable. We have seen here that the users were able to successfully navigate and reach their destinations without the aid of a visual interface like a map. With the experiments we were able to see in this paper that memory recall of the environment post tests are best while using haptic feedback as the mode for navigation. Thus the usefulness of haptic feedback in pedestrian navigation systems can be highlighted. Our paper outlines taxonomy of approaches to integrating haptics into mobile-based navigation systems for pedestrian navigation. As smartphones continue their technological evolution, more sensors will be integrated into the mobile hardware such as noise sensors (Estrin, 2010) or air quality sensors (Whitney & Richter Lipford, 2011). As the results from the study carried out by Heikkinen, Olsson, and Vanen-Vainio-Mattila (2009) concludes users seen haptic-feedback as a compliment to the existing modalities rather than it being a *stand-alone* modality.

We feel that when integrating tactile with visual feedback environmental awareness should be supported through the visual modality and local guidance through the tactile channel, as concluded by Elliott et al. (2010). Their result confirmed that a haptic-based system is viable and can operate effectively in extremely demanding situations. Some authors such as Parush et al. have found that, in general, there is degradation of spatial knowledge amongst the general public caused by the extensive use and reliance upon automated systems for navigation and spatial data discovery (Parush, Ahuvia, & Erev, 2007). This is an issue for concern. However, we believe that haptics offers many benefits as a key modality for integration into mobile-based GIS applications. Amemiya et al. illustrates how haptic feedback can be effectively used to help visually impaired individuals navigate in an indoor environment (Amemiya et al., 2008). Jacob et al. (2010) described how using haptic feedback via varying vibration alarm patterns in a mobile device can be used to help visually impaired users without burdening them with having to carry extra hardware or devices. While the benefits for visually impaired is one of the feature of haptics, it can be of similar use to users who want low interaction, non-intrusive feedback. Vibrotactile cues can be used as a channel which provides 'private information' in an easy to understand manner for the user (Li, Sohn, Huang, & Griswold, 2008). While the granularity of detail that can be represented using such systems is limited, it can be efficiently used to convey a certain notification message in a high level form. Haptics can provide the opportunities for the user to interact more with the real-world environment around them and rely less on visual interaction with the mobile device. From the results of the user-trials carried out we see potential use of haptics as a modality to communicate with mobile location based services to provide information in a subtle, easy to understand manner without distracting the user. We understand that the tests that are carried out here are not exhaustive. More extensive user trials need to be carried out to determine the use of haptics in a real-world urban scenario for navigation.

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Using haptics as an alternative to visual map interfaces for public transport information systems

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ABSTRACT

The use of public transport for daily commutes or for journeys within a new city is something most people rely on. To ensure users actively use public transport services the availability and usability of information relevant to the traveler at any given time is very important. In this paper we describe an interaction model for users of public transport. The interaction model is divided into two main components – the web interaction model and the mobile interaction model. The web interface provides real-time bus information using a website. The mobile interaction model provides similar information to the user through visual user interfaces, gesture based querying, and haptic feedback. Improved access to transit services is very dependent on the effectiveness of communicating information to existing and potential passengers. We discuss the importance and benefits of our multi-modal interaction in public transport systems. The importance of the relatively new mode of haptic feedback is also discussed.

Keywords: public transit, GPS, haptics, AVL, real-time location, visualisation.

1 INTRODUCTION

One of the main objectives of any public transport system in providing information about its services is to provide relevant information in an accessible way through various kinds of media. The information must be provided while understanding that current or potential users are in different spatio-temporal contexts. Often the same types of information must be provided in different but easy to understand ways. If adequate attention is focused on the user needs then resultant services should match those needs and the public transport operator can deliver an efficient service. Usability is the extent to which a product or service can be used to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use [1]. Public transport operators should try to identify highly user friendly, usable methods, for provision of transit information for passengers. The most important pieces of information provided to transit users are: pre-trip planning services about stops and stations, the available services (buses, trains, trams, etc), accurate arrival times of service vehicles, and also in-vehicle information systems such as expected time of arrival at destination stops, and alerts for when the user is arriving at the destination stop. Additionally the guidance to the actual destination from the destination stop through pedestrian navigation system integration should also be considered thereby offering a complete end-to-end journey planning and assistance system. The increase of smartphone usage [42] means mobile interaction for passengers must also be considered for public transport services.

1.1 OUR PROPOSED MODEL

In this paper, we propose a model for using haptics as an alternative interface for the provision of public transport information to passengers with smartphones. For the purposes of a case-study we have focused on public transportation by bus. However, as we will explain in the paper our model is applicable to any mode of public transport. We chose bus transportation for a number of reasons including: the presence of bus transportation in almost every city in the world, the disruption caused to bus timetables due to buses sharing roads and streets with other motor vehicle traffic, and access to a real-world dataset of bus tracking information. Due to the increase in popularity of mobile interaction our model includes visual interfaces for mobile devices with the addition of haptic-enabled feedback. In any public transport system (in our case bus transportation) a journey begins with planning the trip, finding the nearest location to board the bus, finding the time the bus should arrive, waiting at bus stop, payment before journey, in journey activity, alighting from the bus, and finally moving to the destination. This process has been discussed by many authors [2,3,4,5,6]. In this paper, we describe a public transport interaction model which encompasses both web and mobile interaction techniques. We highlight the need for multimodal interaction techniques of communication and integrate a haptic interaction model for various phases in a user's journey. The structure of the paper is as follows. In section 2 we review literature covering research from both web and mobile interaction techniques for public transport users. In section 3 we describe our public transit interaction model. The system implementation is described in section 4. The user feedback and initial findings are discussed in section 5. We close the paper with some concluding remarks on the integration of haptics for public transportation information provision while providing a summary of possibilities for future work.

2 LITERATURE REVIEW

The traditional format for physical distribution of transit information in the public transit has long been printed media [7]. Transit information in paper form has long been distributed aboard buses, trains and in stations requiring significant human and paper/graphic resources when updates are made. Passengers are always seeking for a printed reference of routes, schedules, or other service information. These materials are typically published by transit agencies and offered freely. The lack of any access cost to passengers to these materials makes them the most popular means of dissemination the transit information. Despite their popularity all transit information disseminated through printed media require the continued publication of printed materials which requires costly and labor-intensive resources. Information about unexpected timetable or service changes cannot be disseminated quickly through printed media. These shortcomings have seen public transit agencies increase their efforts to investigate and develop new replacement media. As an alternative to providing transit information on printed media transit agencies have historically provided free telephone-based support for their passengers [7]. Today it is almost standard that real-time transit information is provided via the Internet and telephone [8]. Public transit agencies have increasingly implemented methods for passengers to access transit information using new media and personal mobile devices. In the recent past interactive-voice-response (IVR) phone interfaces and SMS interfaces were also used for providing real-time transit information. Transit agencies now almost always provide transit information on their web sites. Recently transit agencies have developed the means to distribute real-time information to mobile devices. Real-time public transportation tracking systems combine a passenger accessible web-based/mobile interface with back-end, wireless data-based hardware to continuously transit vehicle location to the Internet and compute estimated arrival times of these vehicles. The use of web interfaces has become the standard way to represent real-time transit data and provide real-time arrival times for services. Overall this has been perceived by passengers as an effort by public transportation agencies to improve quality of service. In the next section we will discuss some literature on web-based interfaces to public transportation information.

2.1 WEB INTERFACES FOR PUBLIC TRANSPORT INFORMATION

Websites have become essential tools in delivering real-time transport information for public transportation agencies. Most transportation agencies have a web site where users can retrieve real-time, static information, including route schedules, vehicle locations, etc. Transit applications can be created as web applications receiving direct input from users via web browsers and then query the transportation agency databases or other sources of information to generate results. Web applications are under constant evolution. Over the past few years there are has been many improvements in client-side web browser technologies which improve the user interface experience. AJAX technologies [9] allow users to dynamically interact with content on the screen to quickly retrieve and display server-side data within the browser view itself. These user experiences enhancements have a great potential to deliver real-time transport information to users. There is now a proliferation of web map Applications Programming Interface (API) [10,11,12] which allow developers to overlay and combine data from different sources and make them appear on a top of interactive web-based maps. Data can be shown as points, such as bus stop locations, or as lines representing service routes. Map-based representations can assist in the visualisation of transportation data. They are particularly well suited to real-time updates. Combined with AJAX technologies the user is not required to interact with the map interfaces to retrieve updates. These updates to the map content can happen automatically on the browser. Icons on a map can represent vehicles and with no action by the user these icons can automatically move representing up-to-minute the last current location of vehicle. One of the first online bus tracking systems, BusView, was developed by Daniel D. et al [13]. This system displays real-time vehicle locations on a digital map for the University of Washington campus community. The system designed an advanced graphical transit information system using data from King Count Metro's existing automatic vehicle location (AVL) system. OneBusAway [14] is a set of transit tools focused on providing real-time arrival information on web-based maps and Internet-enabled mobile devices. This application made use of the increased availability of powerful mobile devices and the possibility of displaying transportation data in machine readable format. The NextBus system [15] uses GPS technology to deliver real time transportation information when and where passengers need it so passengers always know when the next bus will arrive. Each bus is fitted with a satellite tracking system. A web based geographic information system which disseminates the same schedule information through intuitive GIS techniques is described in [16]. Using data from Calgary, Canada, a map based interface has been created to allow users to see routes, stops and moving buses all at once. In transportation services vehicle information can be visualized in an on-line or off-line environment through tables, maps, data plots and other graphical outputs. To visualize real-time information, such as the current/last vehicle location, time at location, this is integrated with real-time data sources from the vehicles. In a joint project between NUI Maynooth and Blackpool Transport [17], methods are being explored to visualise the behaviour of vehicles in ways to allow the operator to better assess and improve the quality of their services. The system uses off-the-shelf GPS/GPRS integrated units programmed to transmit location at regular intervals (45 seconds approximately) while the vehicles are in motion. The data is stored on a server and can be visualised through a standard web browser to provide views representing current locations of vehicles in close-to-real-time. In addition tools are provided to visualise vehicle behaviour over time and to calculate various quality metrics and summaries. The system uses web technologies such as JavaScript, MySql, XML, PHP and AJAX. In addition there is a public interface that can display and update vehicle locations on maps based on the mapping provided by Microsoft Virtual Earth (Bing Maps). The system displays real time locations of buses pictorially, textually and, using the facilities provided by the Microsoft Virtual Earth API, with 2D and 3D map visualizations. The display shows adherence to the published timetable through colour coding. In the next section we provide an overview of the literature related to mobile interfaces as a means of providing public transport information.

2.2 MOBILE INTERFACES FOR PUBLIC TRANSPORT INFORMATION

Applications can be created for smart mobile devices for receiving transportation information. For mobile applications they require the user's current location. Today most smart phones are equipped with built-in Global Positioning System (GPS) receivers. This allows for more user-centric and context-sensitive application development. Mobile applications can take advantage of knowing the smartphone user's current location and then provide information such as the nearest bus stop or the estimated arrival times for the next bus at that stop. These applications bring considerable potential for improvement of the way that people use public transport systems and access information about the services. Shwu-Jing *et al* [19] have developed location aware mobile transportation information services with a map database for a public bus network. Their system provides map-based information of the nearest Mass Rapid Transit (MRT) station, the nearest bus stop of the bus route chosen by the user, and the nearest bus stop of the bus route that can take the user to their chosen destination. Maclean *et al* [20] have shown that a WAP-enabled cell phone is a suitable device for receiving real-time transit information. The development of a transportation vehicle information system that delivers estimated departure times for a large transit fleet is described. Here the physical restrictions of the mobile device were overcome by using an appropriate user interface design. The main issues include the small screen space and difficulty to read small text. The characteristics of the information delivered by the MyBus prediction system are better suited to mobile users such as bus passengers. The overall functionality is to transform a raw transit agency AVL feed into departure-time predictions for display on the MyBus website. The Wireless Markup Language (WML) has been introduced here as the new language for WAP-enabled devices. OneBusAway [14] provides a suite of tools to improve the usability of public transport information. It provides real-time arrival information for Seattle-area buses with details about the design and development of those tools. The main outcomes of their work were – increasing overall satisfaction with public transport, decreased waiting time, increased transit trips per week, increased feeling of safety, increased distance walked when using transit resulting in health benefits as well. Transitr is a transit trip planner (TTP) system from the University of California, Berkeley [21]. The system provides the shortest paths between any two points within the transit network using the real-time information provided by a third party bus arrival prediction system relying on GPS equipped transit vehicles. Users submit their origin and destination points through a map-based iPhone application or through a Javascript enabled web browser. The main functionality provided by the BusCatcher system described by Bertolotto *et al* [22] include: display of maps, overlays of routes plotted on the maps, user and bus location, and display of bus timetables and arrival times. Barbeau, J. *et al* [18,23] have developed Travel Assistance Device software for GPS enabled mobile devices. This system shows the estimated time to arrival of a bus while passengers are waiting at their bus stop. Additionally, the real-time vehicle locations are shown on the maps on the TAD website. Because both of these features are driven by the GPS location of the cell phone and the bus the passenger does not have to supply any additional information such as a bus stop ID or route number in order to receive information. Turunen *et al* [24] present approaches for mobile public transport information services such as route guidance and the supply of timetables using speech based feedback. Bantre *et al* [25] describes an application called "UbiBus" which is used to help blind or visually impaired people to take public transport. This system allows the user to request in advance the bus of his choice to stop and to be alerted when the right bus has arrived. Shalaik et al [5] have shown that transit information collected in real time can be shown on freely available mapping services such as OpenStreetMap (OSM) for tracking and monitoring purposes. The authors developed an application for Internet enabled mobile phones to receive real-time transit information. The system displays the transit information on an OpenStreetMap (OSM) web interface and delivers this information on the Google Android mobile device. Instead of publishing static information on the Internet the development of dynamic transit system applications which can be tailored to mobile devices are rapidly broadening the scope of public transportation information provision. The updated sources of real-time services information, such as feeds from automatic vehicle location (AVL) systems, can be used to create applications that inform public transportation users of the precise location of the transit vehicle they wish to catch or estimate the arrival times of the next vehicle at a particular bus stop.

2.3 QUALITY OF SERVICE FOR PUBLIC TRANSPORT INFORMATION

Qualities of Service (QoS) indicators are metrics that are used in evaluating public transit performance. These provide passengers and operators a measure of how reliable services are and help operators to improve schedule adherence and service efficiency. Similar the regulatory authorities usually require reporting of QoS metrics to comply with licensing rules and the conditions for operating subsidies. QoS is defined as the "overall measured or perceived performance of a transit service from the passenger's point of view"[41]. With respect to QoS, frequency of service can be divided into two categories, high and low depending on the number of vehicles serving an individual route. For low frequency routes, defined as those with four or less vehicles per hour, it is important that the service runs exactly to the time specified on timetable and QoS is specified as the mean deviation of buses from their scheduled time. On high frequency routes (with five or more buses per hour), passengers tend to arrive at stops without consulting a timetable because they expect buses are running at evenly spaced headways. QoS is measured by calculating the average Excess Waiting Time (EWT) that passengers have waited above the theoretical waiting time given by the service interval.

A standard metric, the Excess Waiting Time (EWT) is commonly used to measure the quality of service. It can be defined as the average additional wait experienced by passengers due to the irregular spacing of buses or those that failed to run. This indicator is a key performance indicator since it denotes how much time the passengers had to actually wait 'in excess of' what one would have expected them to if the service were perfect. AWT is the average time that passengers actually waited. SWT is the time a passenger would wait, on average, if the services ran exactly as planned during the periods observed. EWT is calculated by subtracting Scheduled Waiting Time (SWT) from Average Waiting Time (AWT) and it is used as the measure of reliability. The greater the EWT is, the less reliable the service [17].

$EWT=AWT-SWT$

The system can automatically generate daily, weekly, monthly and annual reports of EWT for any stop.

In the next section we will describe our public transportation information provision model.

3 PUBLIC TRANSPORTATION SYSTEM INTERACTION MODEL

To improve the public transport quality of service, the passengers must be provided with easy to use, highly accurate, and reliable information retrieval system based on their needs. Our public transportation system interaction model is shown in Figure 1.

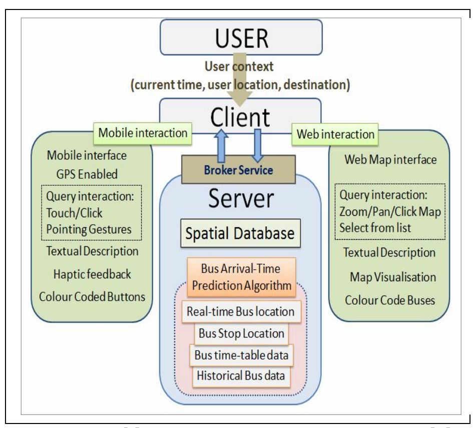

Figure 1: Public transit system interaction model

When using public transportation systems, users engage in a series of high-level activities that include planning, waiting, and moving [29]. Web-based systems for public transportation users are very popular and are of great importance to help users plan their travel and trips. The web based system is provided using a visual map interface displaying locations of bus stops and additional details about walk times to bus stops, bus arrival times, etc. The user interaction with such web-based systems is straightforward when the user is in front of a computer at home or in a closed environment. When the user is on the move and as they walks outdoors such a web-based desktop orientated model may not be ideal. In such cases an interaction system specifically developed for mobile clients is very important. The mobile interaction model in our system consists of a number of subsystems. These interactions between the user and the mobile device ensure activities for all parts of a user's journey. The 3 main phases in a user's journey include – a) pre-journey information about bus stop locations and bus arrival time, b) in-bus information system which provides assistance about the destination stop (using alerts/notification systems) to ensure user does not miss their stop and/or in-bus information about points of interest along the route if the user is a tourist and c) The 'pedestrian navigation phase', to get to the bus stop from the current user location and/or get from the destination bus stop to the actual final user destination (ie a specific shop, tourist attraction, etc).

Updated sources of real-time services information generated by automatic vehicle location (AVL) systems are used to create real-time bus tracking applications. A spatial database stores the road network and all the points of interests in the region. The location of bus stop locations and route geometries are stored in tables within this spatial database. A separate table is created in the spatial database to store the real-time location of the buses connected using the AVL. This information is used to provide the user with real-time information about arrival time and reduces passenger wait time at bus stops. The users want different kinds of information presented in different formats in a trip to suit their needs and the kind of user they are. The user context is also integrated into the system.

3.1 PRE-JOURNEY INTERACTION

At the start of the journey the user needs information about – which is the ideal bus stop to go to [27], when does the next bus leave in real-time [5] and how to get to the nearest bus stop and how long will it take to get there [4]. In Figure 3, the user's current location is taken to be L and the user's actual destination is set to be D. The expected arrival time of the next bus at the origin bus stop, B_o is to. The expected time the bus will reach the desired destination bus stop (B_d) is t_d. The time taken to walk from the user's current location (L) to the origin bus stop (B_o) is t_{wo}. Based on the time taken to walk to the bus stop, B_o the user is provided with information about the bus arrival time and the system advises the user about the appropriate actions to take. The arrival time of the bus at the origin bus stop B_o is t_o. If the user has a smartphone and is new to a city or is unaware about the bus stop to go to they can choose the 'point-to-query' element of the system where the user selects the destination and then scans the area to find the general direction of the bus stop B_o. The "scan" operation is performed as follows.

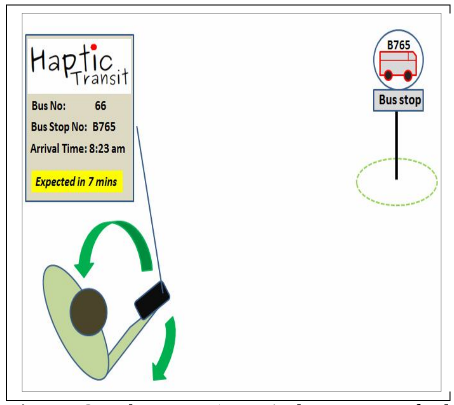

Figure 2: The user 'scans' the area to find the location of the origin bus stop, B_o

The user holds the phone parallel to the ground and moving it around them as shown in figure 2. The compass and the location information via GPS will help query the system and provide directional information to the bus stop. This feedback is provided by textual description with number and arrival time at the bus stop along with the walking distance and time taken to reach the bus stop. Haptic feedback in the form of vibration alarm is used to provide the user with information of the general direction of the bus stop when the user points the smartphone in the direction of the bus stop, B_o. Thus, this minimises the interaction with the visual interface while the user walks towards the bus stop thus ensuring faster travel to the bus stop. The user gets real-time information about the arrival time of the ideal bus to take to get to the bus stop B_d which is nearest to the actual destination (D) of the user. This sub-system within the public transit system for mobile provides the user with information about the bus stops, the arrival time of the bus at the origin bus stop based on the real-time location of the buses and also navigation assistance to get from the user's current location (L) to the bus stop B_o.

3.2 IN–BUS INTERACTION SYSTEM

HapticTransit is a tactile feedback based alert/notification model of a system which provides spatial information to the public transport user [28]. The model uses real-time bus location with other spatial information to provide user feedback about the user journey. The system allows users make better 'in-bus' use of time. It lets the user be involved with other activities and not be anxious about the arrival at the destination bus stop. Our survey shows a majority of users have missed a bus stop/station, and thus this system ensures such an information system can be of great advantage to certain user groups. The vibration alarm is used to provide tactile feedback. Visual feedback in the form of colour coded buttons and textual description is provided. This model on further research can provide the platform to develop such information systems for public transport users with special needs – deaf, visually impaired and those with poor spatial abilities.

The HapticTransit system provides assistance to the user to indicate when their destination bus-stop is approaching. Instead of providing the user with a map based system which provides detailed information which may/may not be of use to the user instead the users are informed using haptic feedback when their stop is approaching. This gives them enough time to prepare to disembark from the bus [28]. Along with the destination, the user also selects the information mode – destination only or tourist mode. This provides additional assistance with information/alerts about POIs along the way using haptic/visual feedback. The arrival time prediction algorithm is used to ensure that the expected arrival time at their destination bus stop is provided accurately. There is a broker service running on the server responsible for calculating the proximity of the user to their destination bus stop. The visual interface on the device provides the user with the time and distance to the destination stop. The system computes the time and distance to the user's destination stop and gives a subtle alert to the user when they are nearing the destination. This alert is provided by a low frequency vibration feedback. The alert is triggered when the user reaches the stop just before the destination stop. This enables the user to prepare to disembark the bus when the next stop is reached. The intensity of the vibration alert on the mobile device increases as the bus is approaching the desired stop. As an alternative the colour-coded button on the visual interface provides the user with information to represent far, close and very close using the red, amber and green colours. An amber button displayed indicates that the user is very close to their destination stop. A red button indicates that the user has reached the penultimate stop. Green indicates that the user still has some distance to travel. The HapticTransit model incorporates additional feedback along the route to improve the 'in-bus' interaction. If the user is a tourist and has selected the option of being informed when they are passing or are nearby an important POI along the way. The user is alerted by a unique vibration feedback corresponding to being close to a landmark/POI along the route. Along with haptic feedback visual feedback with name and description of the landmark POI is provided. The real-time bus arrival time algorithm computes the arrival time of buses at various bus stops [5]. The haptic feedback ensures that the user is not required to constantly interact or looking at the mobile device for assistance during the journey. This allows the user to enjoy the trip and will be informed about the destination stop and/or important landmarks along the route.

The model of the route is stored in the spatial database. Consider a route R is an ordered sequence of stops $\{B_o, B_0, ..., B_n, B_d\}$. The destination bus stop on a route is given by B_d and the terminus or destination stop is given by T_d. Each stop B_i has attribute information associated with it including: stop number, stop name, etc. Using the timetable/real-time bus arrival information for a given journey R_i along route R, we store the timing for the bus to reach that stop. The number of minutes it will take the bus to reach an intermediate stop B_i after departing from B_o is stored. The actual time of day that a bus on journey R_i will reach a stop B_i along a given route R is also stored. Figure 3 illustrates this with a sample route where t_0, t_1, etc are time taken to reach stop B_1, B_2, etc respectively. Other modes of public transportation including: long distance coach services, intercity trains, and trams can be easily incorporated by extending this model.

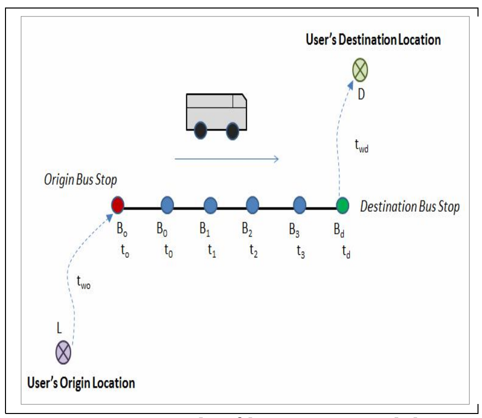

Figure 3: An example of how a route and the stops along that route are stored in the spatial database.

3.3 Pedestrian navigation phase

There are two stages in the trip where the user needs pedestrian navigation assistance. The first stage is getting from their origin location to the origin bus stop and then from the destination to the actual user destination. The time taken to travel from user's origin, L to the origin bus stop B_o is t_{wo}. This is also shown in Figure 3. The user reaches the destination bus stop (B_d) in time t_d. The final phase of travel using public transport is the pedestrian navigation stage where the user needs to get from the destination bus stop to the actual destination (D). The time taken to travel from the destination bus stop B_d

to the actual destination, D is t_{wd}. The user must specify the requirements of their journey and provide information about their destination. The user chooses which mode of pedestrian navigation they want to use – visual or haptic feedback. Within the haptic feedback option the user can choose from two pedestrian navigation system options: the waypoint by waypoint shortest path information using haptic feedback (HapticNavigator) or the destination pointer system where the user is alerted (via vibration alarm) of the general walking direction of the destination (HapticDestinationPointer) where the user has to make decisions on the path to follow [30]. As shown by various authors [31,32,33] haptic feedback can be used at times when the use of other senses like hearing or vision is inappropriate. Users can navigate between any two locations using subtle haptic feedback [33,34,35,36]. The in-bus journey time, T_j is the difference between bus arrival time (t_d) at the destination bus stop and the bus arrival time (t_o) at the origin bus stop and this is represented as, $T_j = t_d - t_o$. Thus the total trip time, T is the sum of - the walking time from user's origin to the origin bus stop (t_{wo}), the in-bus journey time (T_j), and the walking time between the destination bus stop and the actual user destination (t_{wd}). Thus we represent the total trip time, $T = t_{wo}+T_j+t_{wd}$.In the next section we discuss the system implementation.

4 SYSTEM IMPLEMENTATION

The real-time location data of buses in Blackpool Transport were used to develop the web interaction interface and develop the bus arrival time prediction algorithms. The system uses off-the-shelf GPS/GPRS integrated units programmed to transmit location at regular intervals (45 seconds approximately) while the vehicle is in motion. The data is stored in a database server and can be visualised through a standard web browser to show views representing current locations of vehicles in close-to-real-time. For implementing our system using a visual map interface for desktop interaction, we developed a public interface that can display and update vehicle locations in Microsoft Virtual Earth web mapping API. The mapping API provides us with the functionality to provide 2D and 3D map visualizations. These visualisations can display bus vehicle adherence to the published timetable through colour coding as shown in figure 5. Figure 4a shows real-time locations of buses pictorially, textually and, using the facilities provided by the Microsoft Virtual Earth API. Transit user has options to switch between bus routes. A list of bus stops allows transit user to query about the next bus(s) for a stop of interest. Other options are available for transit users to allow bus route or stops to be displayed on the map. Through this interface, transit users can access many other services such as Trip planning service, Arrivals Times for all buses or allocate a particular bus on map. In addition to showing currents location of buses with real-time information of transit vehicles, Figure 4b provides transit operator with options of efficient tools to manage and evaluate transit vehicles performance. Tools for calculating QoS and summaries are provided. Bus bunching can also be detected on map or though the graphical view. Tools for reporting facilities are provided to generate on-line or off-line reports. In addition, tools are provided to visualise vehicle behaviour over time and to calculate various metrics and summaries. A PHP script running on the server acts as the broker service between the server and the client. On the database server the bus arrival time prediction model allows the applications to determine, with greater accuracy, the arrival time of bus at bus stops. This will reduce the passenger wait time and thus improve the overall quality of service. The mobile interfaces for three different kinds of interactions were developed – 1) displaying real-time public transport information 2) querying using the pointing gestures for bus stop location and real-time data and 3) pedestrian navigation phase during commuting using public transport. The applications were developed using the Android SDK. On running the applications, through the broker service (PHP script), the application accesses the database with real-time bus data and bus stop locations and provides the user with details about expected arrival time, time taken to walk to destination, the direction of the origin bus stop etc. To alert the passenger when they reach their destination, the in-bus haptic enabled mobile application provides the user with the expected arrival time at destination. Colour coded buttons representing distance to destination or haptic feedback when the user is nearing their destination provides the user with enough time to get ready to disembark from the bus. Here if the button colour changes to red, it shows that the user is at or very close (within a few metres) from the destination stop. The green colour button shows that the user is atleast 2 stops away from the destination bus stop while amber colour button shows that the next bus stop is the destination bus stop. The user can choose the 'tourist' mode to be notified using haptic feedback when the bus crosses points of interests along the route. The user can thus mark and identify these locations for visiting later. The HapticDestinationPointer integrates the digital compass and the GPS location in the phone and thus provides haptic feedback when the user points in the direction of the destination location.

5 FINDINGS AND REMARKS

To understand how people use public transport, both within their own city and as a tourist in other cities where they are not aware of their destination bus stops, a group of users (50) were sent an online survey form.

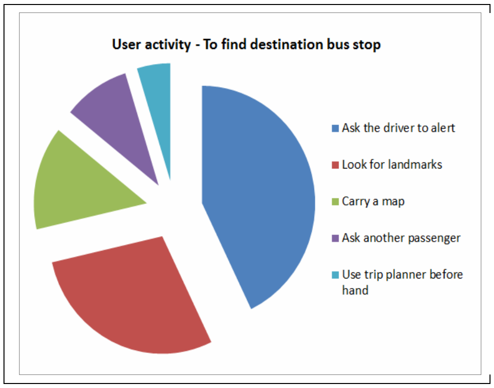

Figure 6: User responses to our survey about public transportation usage.

We received 45 responses. From all of the responses 40 people said they would ask the driver to alert them of their destination stop. The second most popular choice of finding the destination bus stop was to lookout for landmarks. A small percentage of users said they would use a trip planner before the trip. The results are presented in figure 6.

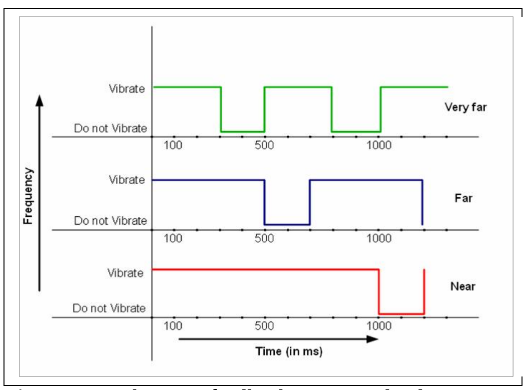

Figure 7: Vibration feedback to provide distance information when pointing in the direction of the destination

To investigate if users can successfully walk from a bus stop to the destination using haptics feedback, the HapticDestinationPointer [31] was used in some user trials. The users, provided with the application and using haptic-feedback, were successful in reaching the destination using haptic feedback when pointing in the direction of the destination. The haptic-feedback was provided using the vibration alarm with varying frequency and patterns. Figure 7 represents the vibration pattern used to represent distance information when pointing in the direction of the destination.

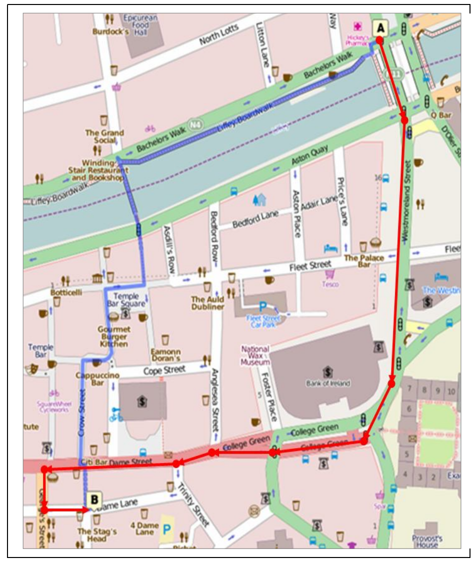

Figure 8: Route 1 - Different path than the shortest path

From our initial trials we see that on 3 different routes, the user chose routes that were (i) 'completely different from' (Figure 8), (ii) 'almost similar to' (Figure 9), and one that was (iii) 'exactly the same as' (Figure 10) the shortest path as provided by the Cloudmade routing service [37] from A (bus stop) to B (actual user destination).

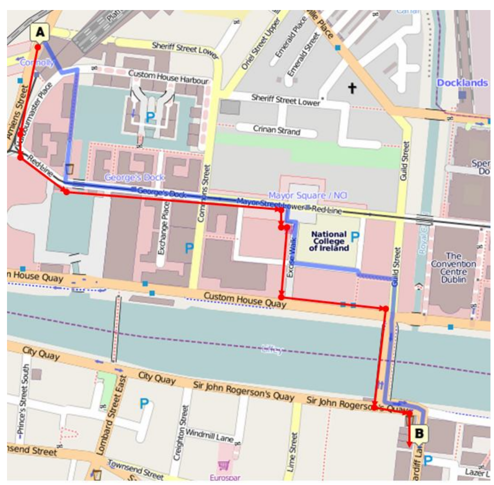

Figure 9: Route 2 - Almost similar path to the shortest path

The paths taken by the user based on the haptic feedback is plotted and we notice that on all three routes, the user stayed on major streets for most of the travel in an unfamiliar location before turning towards the exact destination location.

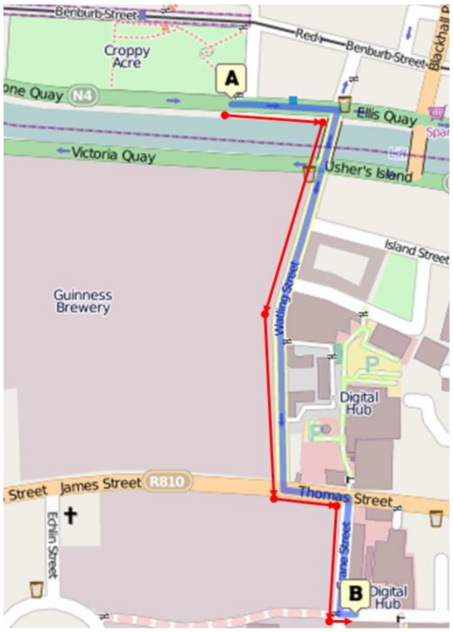

Figure 10: Route 3- Exactly similar path to the shortest path

Route 1 as shown in Figure 8 was the most complex route among the 3 as it was through the most dense and crowded parts of the city. The time required for completing route 1 as suggested by the routing service was 10 minutes and the user reached the destination in about 12 minutes. According to the routing service, it would take the user 15 minutes to complete route 2 (Figure 9), but using haptic feedback the user completed it in 13 minutes. This route consisted on long stretches and small bends in the path. The long stretches allowed the user to move much faster. The route 3 (as shown in figure 10) was the simplest route as the actual roads to take were aligned along the general walking direction and thus meant the user did not have to change the general walking direction to reach the destination. Thus the shortest path and the path taken by the user based on haptic feedback is the same with no substantial difference in time taken to complete the task. We compare the distance travelled and time taken to travel that distance based on the (i) routing service and based on (ii) the haptic feedback enabled navigation test as carried out by the user. The summary is provided in table 1. We see that although there isn't very significant difference in time taken/distance travelled to complete the task, the overall experience while navigating can be improved using haptics as it ensures *heads-up* interaction. The main positive outcomes from these trials are that the navigation was based on purely the user's judgment and the user was able to walk faster as it involved heads-up interaction with the real world as compared to the interaction with the mobile device (for the shortest path) which normally slows the user down [30].

Table 1: User navigation performance using haptic feedback compared to the routing service.

Route No.	Distance Travelled (metres)		Time Taken (mins)	
	Routing Service	Haptics	Routing Service	Haptics
1	860	890	10	12
2	1210	1220	15	13
3	720	720	8	7

6 CONCLUSION AND FUTURE WORK

Public transportation systems are among the most ubiquitous and complex large-scale systems found in modern society. There is a need for easy to use public transit information systems. There are certain groups of passengers such as the visually/mobility impaired, people with cognitive disabilities, senior citizens, and out-of-town visitors who might not be able to use current types of public transit information systems. Providing them with different kinds of interaction based mobile systems can be useful. We have seen here that haptic interaction can be useful for out-of-town passengers and this work can be extended to prepare smart interfaces to help the mobility impaired. To reduce the cognitive burden alternate means of information retrieval and feedback needs to be developed [38]. This paper has given an overview of the interaction model to access public transit information. The haptic-feedback based system assists in providing location based information in a subtle for passengers using public transport (specifically buses). The main benefit of this system is that passengers can now use the system on their mobile devices to reduce the anxiety about finding the nearest bus stop and the actual arrival time of buses and if an out-of-town visitor, missing their destination stops. The vibration alarm provided by the system helps notify passengers about the bus approaching their destination bus stop. The system also provides pedestrian navigational assistance to help users get from origin to the nearest bus stop and from the destination bus stop to the actual user destination. Enhancing the "in-bus" experience of the user is achieved by reducing interaction with visual/audio notification interfaces on the mobile device. The passenger can enjoy the trip and be involved with other activities while in transit. Another aspect of public transportation related to this work is theft on public transport as listed by a number of authors [39,40]. Not all users perceive and interpret visual information in the same way. We have seen in the results in this paper that we can improve the experience for users who use public transport information system by integrating haptic feedback as a modality. This can easily be extended to work with other public transport systems like trains/trams. In the three routes that the user had taken, we see different paths and navigation time. We wish to compare this performance with the actual route complexity and thus hope to draw some interesting results. As future work more user trials based on user profile like age, sex, spatial abilities, disabilities will be tested to understand how different people react to multimodal interaction systems on mobile. A complete door to door travel planner using haptics/gesture based interactions will form a central focus for future work.

ACKNOWLEDGEMENT

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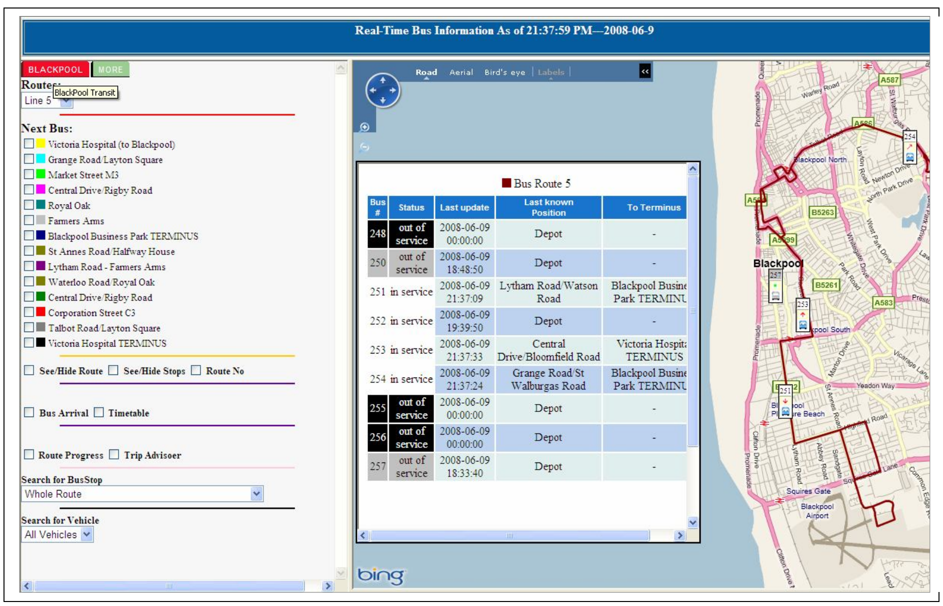

Figure 4a: The Public interface showing updating textual display plus moving locations on Microsoft Virtual Earth.

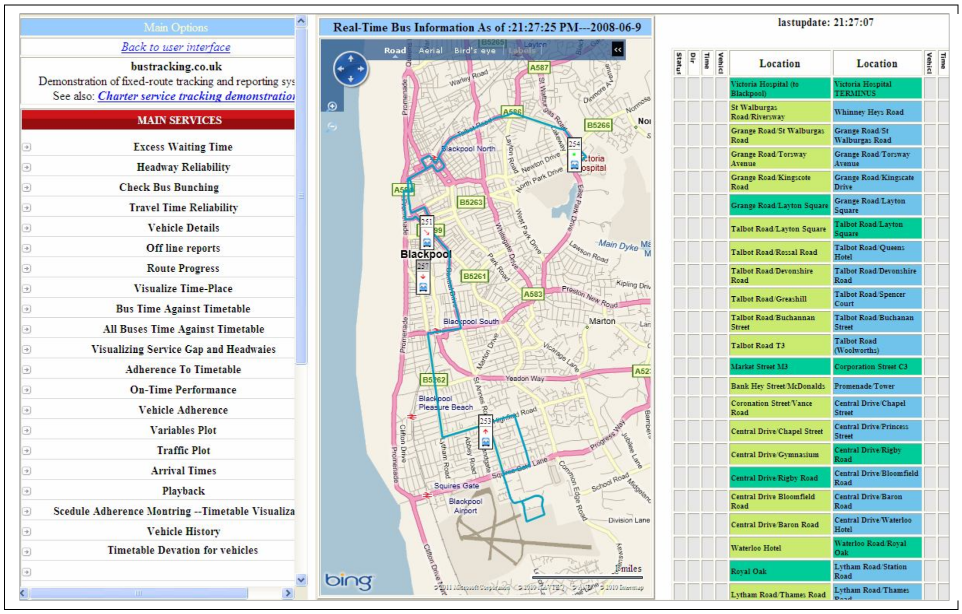

Figure 4b: The operator interface showing updating textual display plus moving locations on Microsoft Virtual Earth.

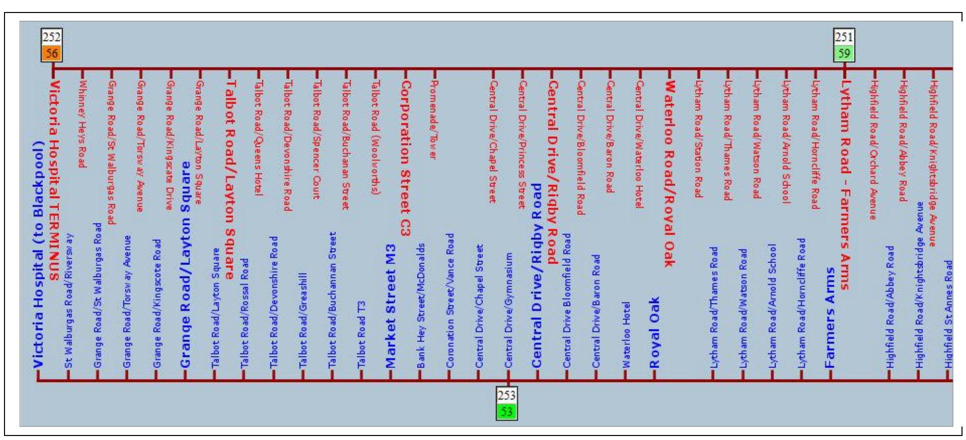

Figure 5: Route diagram visualization (colours indicating adherence to timetable)

Guided by Touch: Tactile Pedestrian Navigation

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ABSTRACT
Haptics is a feedback technology that takes advantage of the human sense of touch by applying forces, vibrations, and/or motions to a haptic-enabled user device such as a mobile phone. In this paper we describe four haptic feedback-based prototypes for pedestrian navigation. Haptics is used to convey location, orientation, and distance information to users using pedestrian navigation applications. We compare the functionalities of four applications of haptics in such applications. Initial user trials have elicited positive responses from the users who see benefit in being provided with a "heads up" approach to mobile navigation.

Author Keywords
Haptic-feedback, pedestrian navigation, sense of touch, mobile devices, interfaces

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): Haptic I/O.

General Terms
Human Factors

INTRODUCTION
Increasingly GPS-enabled smartphones, such as Android and iPhone, are being used by citizens as location and navigational devices. Various commercial products like Navteq, Google and Bing are readily available in the marketplace for free download and use. These produces provide turn-by-turn navigation cues with distance and time information, usually on a map interface. Feedback to the user is provided in several ways: overlays on the map interface displaying the optimal path/route; audio feedback providing instructions; or textual display of the turn-by-turn instructions on path following. Unlike the closed environment inside a car pedestrians are in an open environment. They are not directly protected from the noises and distractions urban environments generate. When a user is walking, following turn-by-turn path instructions, it is very difficult for them to concentrate simultaneously on the mobile screen and the urban environment (pavement, shopping mall, etc) around them. Weather is also a factor. Rainy days or bright sunlight can make reading a mobile phone screen very difficult for some users. Audio feedback is a convenient alternative for providing user instructions [21] and can be used by using the phone's speaker or by using a connected headphone set. Using a speaker could be impractical if the user is walking in a crowded, noisy, environment. Headphones provide a more subtle conduit for aural feedback. However headphone use can diminish the user *sense* or awareness of the environment around them such as moving vehicles, cyclists, etc. Overall visual and/or audio feedback is suitable for many practical situations but could be problematic in crowded urban environments.

Haptics or haptic technology is a tactile feedback technology that utilises of our sense of touch by applying forces, vibrations, and/or motions to the user through a device [34]. Substantial literature has been produced on this technology, such as [21, 34, 42, 3, 37, 38, 23, 10, 28]. These authors conclude that the sense of touch is advantageous in many situations when it is inconvenient or less appropriate to use either visual and/or audio feedback. Researchers, such as (Costanza et al [8] and van Erp et al [10]), stress that an interaction model for mobile device should: be customisable to meet the user's requirements based on the activity the user is involved in, deliver easily understood cues, and should not overly interfere with the user's current activity. In situations when vision-based or audio-based feedback for pedestrian navigation is in-appropriate we believe that haptics can provide feedback to users in the real world situations. In Jacob et al [24] we integrated a model of haptic-interaction (from earlier work in Jacob et al [23]) into pedestrian navigation applications on Android smartphones. This paper presents four haptic feedback-based prototypes we have developed for pedestrian navigation in the real-world environments.

The paper is organised as follows. A review of related literature is provided in the following section. The haptic interaction model is described followed by describing the four haptic prototypes and the data models used. The paper closes with the key outcomes from the paper and a discussion of the future direction of this research.

MLBS'11, September 18, 2011, Beijing, China.

RELATED RESEARCH WORK

Moving away from the traditional use of visual cues for navigation, a backpack mounted AudioGPS providing audio feedback to the user to help in navigation is presented by the authors in Holland et al [22]. The drawback with such an application is the need for the user to have their sense of hearing fully involved to understand the feedback along with the requirement to carry the backpack mounted application. Hoggan and Brewster [21] comment that possibilities offered by integration of various sensors on a smartphone makes it possible to develop simple, but effective, communication techniques on a device as commonplace as the mobile phone. Heikkinen et al [19] remarks that "the human sense of touch is highly spatial and by its nature tactile sense depends on the physical contact to an object or its surroundings". Robinson et al [38] show that pedestrian navigation using bearing-based haptic feedback can be used to guide users toward their destination using vibration feedback. Human touch is also important in human communication as it conveys non-verbal information [19]. Consequently haptic-feedback has been used successfully for navigation assistance to visually impaired users [3, 27]. Zelek [43] developed tactile gloves to augment "the white cane and guide dog" approach to navigational assistance to the visually impaired. Lin et al [30] demonstrate one of the first use of tactons (structured vibrotactile messages) to encode pedestrian navigation information. More recently, Pielot et al [37] describe PocketNavigator, an Android application, which uses haptics to provide pedestrian navigational assistance. They use haptics "continuously" at every decision point on the path by implementing the tacton framework to encode information for tactile stimulus. Jacobson [25] provides a good overview of the accessibility and usability issues of representing spatial information through multimodal interfaces via visual, audio and haptics modes. Elliot et al [9] warns that "when combining tactile and visual display, global awareness should be supported through the visual modality and local guidance through the tactile channel." Sahami et al [39] assesses the potential of tactile notifications on mobile devices. They conclude that "by varying the intensity and pattern of the vibration information can be reliably communicated". Pedestrian navigation in complex environments without assistance is difficult. Hartley et al [17] remarks that "using only cognitive map representations when following routes should not impair accuracy but might increase the demand for perceptual processing and adversely affect speed of travel". Over-reliance of mobile navigation systems may cause to user to not develop the spatial knowledge that may be required when automation fails. Parush et al [35] remark that users should not be always forced to follow automatic navigation systems but instead be more active in the wayfinding task in order to gain better spatial knowledge. Consequently a system that includes haptics could help users interacts more with their environment and less with the mobile device. Lee and Starner [29] present two experiments to evaluate wrist-worn wearable tactile displays (WTDs) that provide easy to perceive alerts for "on-the-go users". Their results indicate that when visually distracted users' reactions to incoming alerts become slower for the mobile phone but not for the WTD. Srikulwong and O'Neill [40] investigate using haptics to alert users about landmarks in a town or city. With training, participants were able to haptic signals for distinguish landmarks from directional signals and recognized over 80% of learned landmarks. They also found that participants did not show high rates of "forgetting" the haptic signals they had learned. Amemiya et al [1] develop a novel handheld kinesthetic force-feedback device is based on the characteristics of human perception. It convey a sense of pulling or pushing the user towards a specific landmark or object and can be used to alert users that they are "near" a specific POI. *Tactile Wayfinder*, as described by Pielot and Boll [36], uses a tactile torso display to present the directions of a route. The device is a torso-based eight tactor belt that is used to provide direction information. While *Tactile Wayfinder* has its advantages it was unable to keep synchronised with the navigational system. Pielot and Boll [36] summarise their findings by concluding that rather than replacing audio-visual interaction with haptics the *Tactile Wayfinder* [36] is intended to combine the advantages of the low interaction tactile display with superior performance of the audio-visual system. Klippel et al [26] argue that turn-by-turn direction instructions are often too detailed leading to cognitive overload or unnecessarily complex. Robinson et al provides distance and orientation information to the user via vibrations with varying pattern and frequency. Asif et al [5] extend this concept to automobile drivers. The driver perceives countable vibrotactile pulses, which indicate the distance in turn by turn instructions. They found that the approach is a simple way of encoding complex navigational information. May et al [31] indicate that landmarks were by far the most predominant navigation cue and these should be included in directions. The authors found that distance information and street names were infrequently used. Additional information such as landmarks is used to enable navigation decisions but also to enhance the pedestrian's confidence and trust. As smartphones continue their technological evolution more sensors will be integrated into the mobile hardware such as noise sensors [11] or air quality sensors [41]. As the results from the study carried out by Heikkinen et al [18] concludes users see haptic-feedback as a compliment to the existing modalities rather than it being a "stand alone" modality.

HAPTIC INTERACTION MODEL

This paper (and in greater detail the full workshop paper) describes the development of four applications which use haptics to provide navigational assistance to pedestrian without requiring the user to constantly interact with the mobile device. The Android-based mobile device used for testing comes equipped with a GPS receiver, digital compass, and accelerometer. The application prototypes uses the Cloudmade Routing API [7] for pedestrian route planning using the OpenStreetMap database. Visual feedback is provided to the mobile device for instances where the user chooses to look into the phone. The user can hold the phone discretely in their hand or leave the phone in their pocket. The GPS traces of users can be logged in a PostGIS database to assist in the analysis of user behaviour along planned routes. The only explicit interaction is when the user initially specifies their destination location. The HapticGPS and/or HapticCompass prototypes can be used in any location which has

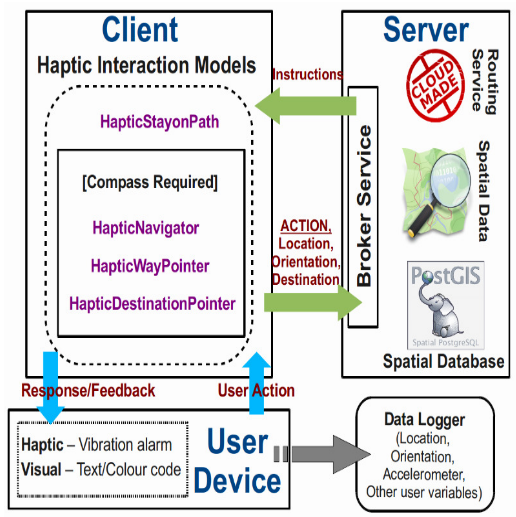

Figure 1. The Haptic Interaction Model

road and street network representations in the global OpenStreetMap database.

The overall haptic-interaction model is illustrated in Figure 1 and consists of of three main components: client, server, and the user/device. The data logger module is used to capture data for research purposes only. PostGIS is used to store all the spatial data. The Haptic Interaction Model works based on inputs (actions/movements) from the user and also the results from the server based on the sensor values from the phone. The model provides dual feedback: as haptic feedback in the form of vibrations and as visual feedback using textual description and colour coded buttons. Section *Application Prototypes* will now explain the model in Figure 1 in more detail and outline the four implementations.

APPLICATION PROTOTYPES

While map-based mobile navigation systems are popular we feel there is research, and commercial scope, for alternative modalities such as haptics particularly in busy and crowded urban environments. Haptics ensure the user's attention is better utilised on the dynamic environment around them and to a lesser extent on the mobile device sceen. The four application prototypes are as follows. Section *HapticStayonPath* describes "HapticStayonPath" which uses only the location information of the user. Section *HapticNavigator* introduces "HapticNavigator" which provides users with information about general walking direction to the next waypoint using haptic feedback. Then section *HapticWaypointer* describes "HapticWayPointer" only partially assists user navigate while the final prototype is described in section *HapticDestinationPointer*. "HapticDestinationPointer" does not provide any information on the shortest path but provides the user with haptic feedback when pointing in the direction of the destination. In all four prototypes information is also presented in the form of color coded buttons and textual description incase the user is confused with the haptic feedback at any stage or if battery consumption becomes an issue. Table 1 summarises the four prototypes based on feedback type and the sensor/battery usage. Table 1 also allows a quick comparision of the features of each prototypes described in Section *HapticStayonPath*.

HapticStayonPath

The "HapticStayonPath" is a prototype which uses only the current location of the user to guide them on the route. By modulating the frequency of the vibration alarm we are able to convey messages of distance and direction to the user. The use of repeated high frequency vibration is used to convey that the user is moving away from the desired shortest path. Small pulses of shorter duration were provided repeatedly in certain intervals to inform the user that they are on the correct path. Using the GPS readings of the moving user the bearing is calculated and feedback can be provided for additional scenarios such as when the user appears to be starting to diverge off the shortest path and take a different direction. The "HapticStayonPath" prototype described in algorithm 1, could be used as a simple navigation aid for visually impaired pedestrians or users trekking/hiking and must follow a predefined route. In hiking/trekking situations it is sometimes impossible to find easily identifiable landmarks making "HapticStayonPath" a very suitable candidate for use. The following subsections define prototypes which are categorised under "HapticCompass" as they utilise the current orientation along with the location of the user/mobile device.

HapticNavigator

"HapticNavigator" is a waypoint-to-waypoint navigation assitance system which provides users with information about general walking direction to the next waypoint using haptic feedback. A waypoint is defined as a node in the path where the user must change the direction of movement, such as an intersection. Typically users would view the map (paper or digital) and then try to re-orientate themselves in the direction of movement by comparing the buildings or landmarks represented on the map to the features they see around them. Using "HapticNavigator", as decribed in algorithm 2, the user *scans* the area by holding the phone horizontally and slowly moving along the horizontal plane. This is depicted in Figure 2 on top of a map layer from OpenStreetMap. When the user is pointing in the direction of the next waypoint they will are alerted by haptic feedback. The user repeats this action at waypoints until they reach their destination. The "HapticNavigator" could potentially be used for users "in a hurry".

HapticWayPointer

The "HapticWayPointer" is a prototype designed to partially help the user navigate as described in algorithm 3. This allows the user to "explore or wander" along the route. At any location the user selects their destination and they are alerted when they are pointing (via scanning - see Section *HapticNavigator*) in the correct direction of the shortest path to their destination. After being instructed as to the initial direction of movement it is the user's responsibility to request

Data: The input current user location s and destination location e. α is a buffer size in meters.
Call Cloudmade Routing Service to obtain shortest path between s and e;
Download XML-encoded result from Cloudmade;
Parse and store route in database;

begin
  $d \longleftarrow setLineStringBufferSize(\alpha)$;
  $v \longleftarrow getRouteLineString()$;
  $U \longleftarrow getCurrentUserLocation()$;
  while $(U.location \neq buffer(e,d))$ **do**
    $U \longleftarrow getCurrentUserLocation()$;
    $x \longleftarrow getDistanceToLineString()$;
    if $(U.location = buffer(v,d))$ **then**
      Vibrate small frequency pulse;
      Display **green** button;
      Display distance to destination e;
    else
      if $((x > d)$ *and* $(x < 2d))$ **then**
        Vibrate Medium frequency pulse indicating user moving away from optimal path;
        Display **orange** button;
      end
      if $(x > 2d)$ **then**
        Vibrate Very high frequency pulse indicating user is now $\geq 2\alpha$ from optimal path;
        Display **red** button;
      end
      Display distance to destination e;
    end
  end
end

Algorithm 1: Algorithm HapticStayOnPath

Data: The input start location s and the destination location e. α is a buffer size in meters.
Call Cloudmade Routing Service to obtain shortest path between s and e;
Download XML-encoded result from Cloudmade;
Parse and store route $W = p_1, p_2, ..., p_n$ in database;

begin
  $d \longleftarrow setBufferSize(\alpha)$;
  $n \longleftarrow getTotalNumberOfWaypoints()$;
  $p \longleftarrow setInitialWaypoint(1)$;
  if $(U.location = buffer(e,d))$ **then**
    User is within d of e;
    Display **green** button;
    Vibrate to alert user;
  else
    while $(U.location \neq buffer(e,d))$ **do**
      Display **red** button;
      Display distance to the next waypoint W_i;
      while $(p \neq end(W))$ **do**
        if $(U.distance = buffer(p,d))$ **then**
          Vibrate indicating user has reached a waypoint W_i;
          Display **orange** button;
          repeat
            User is now pointing towards the next waypoint W_i;
            if $(U.direction = direction(W_{i+1})$ **then**
              Vibrate indicating user pointing towards next waypoint W_{i+1};
              Display **green** button;
              Display distance to the next waypoint W_{i+1};
            end
          until $(Scan() = true)$;
          User walks in the direction of the vibration alert;
          $p \longleftarrow getNextWaypoint()$;
          $U \longleftarrow getCurrentUserLocation()$;
        end
      end
    end
  end
end

Algorithm 2: Algorithm HapticNavigator

Figure 2. At a waypoint the user scans the area for information

feedback along their route. The user can divert off route as they please and are not forced to follow a shortest path.

HapticDestinationPointer

The “HapticDestinationPointer” prototype (Algorithm 4), like “HapticWayPointer”, does not provide any information on the shortest path to the destination. It provides users with haptic feedback when pointing in the direction of the destination. Distance-to-destination is also encoded into the haptic feedback. When the user scans (see Section *HapticNavigator*) they are provided with information about the straightline distance to their destination. This is similiar to work by Robinson et al [38] who feel that users should have opportunities to “explore place while trying to get to their destination”. Haptic feedback provides the direction to destination and the straightline distance to the destination information.

As shown in Table 1 the four prototypes have different requirements in regards to the complexity and functionality of the underlying algorithms. The prototypes also vary in regards to the types of haptic feedback, Internet connection requirements and battery usage. Figure 3 represents the prototypes and how they differ from each other. As we move from west to east in Figure 3 we see the representation of increase in two factors - “System Complexity and functionality and Internet Connectivity”. From south to north we seeing increase of “Battery Usage and amount of Haptic Feedback” represented in figure 3. Providing continuous haptic feedback to the user will result in highest battery as is the case with “HapticStayonPath”. This also requires an Internet connection at all times. “HapticNavigator” is a waypoint by waypoint navigation prototype which needs GPS readings and Internet connectivity at all times. Haptic feedback is only moderately required for “HapticNavigator” as it is only at waypoints that the user is provided with haptic feedback. Consequently battery usage is not overly burdensome. Haptic feedback and Internet usage in case of “HapticWay-

Data: The input current user location s and destination location e. α is a buffer size in meters

User Requests for Direction to next Waypoint;
Call Cloudmade Service;
Download XML-encoded result: parse and store waypoints;

begin
  $d \longleftarrow setRoutePointBufferSize(\alpha)$;
  $U \longleftarrow getCurrentUserLocation()$;
  $D \longleftarrow getLocationOfNextRoutePoint()$;
  if $(U.location = buffer(d, e))$ **then**
    User is now within α of destination e;
    Display **green** button;
    Vibrate to alert user of e;
  else
    while $(U.location \neq buffer(e, d))$ **do**
      repeat
        Until user points their mobile device in the correct direction;
        if $(U.direction = D)$ **then**
          Display **orange** button;
          Vibrate;
          User moved in direction of the waypoint;
          Turn GPS off;
        end
      until $(Scan() = true)$;
      $U \longleftarrow getCurrentUserLocation()$;
    end
  end
end

Algorithm 3: Algorithm HapticWayPointer

Table 1. This table contains a summary of the four haptic prototypes for pedestrian navigation discussed in the paper. The table outlines if haptic feedback is used, if text and/or colour is used to convey information, compass, GPS, and battery usage. The Internet connectivity requirements of the prototypes are also outlined.

	HapticStayonPath	HapticNavigator	HapticWayPointer	HapticDestinationPointer
Haptic feedback	Yes	Yes	Yes	Yes
Text/colour code	Yes	Yes	Yes	Yes
Compass usage	No	Yes	Yes	Yes
GPS 'always' on	Yes	Yes	No	No
Internet usage	High	High	Low	Low
Battery usage	High	Medium	Low	Low

```
Data: The input current user location s and destination
      location e. α is a buffer size in meters. W represents
      walk limit - where it represents a long distance to
      walk until destination e
User Requests for Direction to Destination;
Calculate distance and direction to destination;
begin
    d ⟵ setRoutePointBufferSize(α);
    U ⟵ getCurrentUserLocation();
    D ⟵ getDistanceToDestination();
    Set W to appropriate value - for example 800m;
    if (U.location = buffer(e, d)) then
        User is within α of e;
        Display green button;
        Vibrate to alert user;
    else
        while (U.location ≠ buffer(e, d)) do
            repeat
                Until user points their mobile device in
                correct direction;
                if (U.direction = direction(e)) then
                    if (U.distance > W) then
                        Display orange button;
                        Display straightline distance to e;
                        Vibrate to indicate distance > W;
                    end
                    if (U.distance > α) then
                        Display orange button;
                        Display straightline distance to e;
                        Vibrate to indicate distance > α;
                    end
                    User follows their own path to
                    destination;
                    Turn GPS off;
                end
            until (Scan() = true);
            U ⟵ getCurrentUserLocation();
        end
    end
end
```

Algorithm 4: Algorithm HapticDestinationPointer

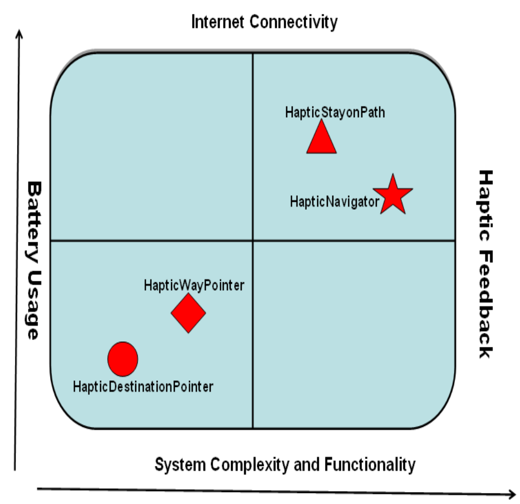

Figure 3. The four haptic feedback prototypes are shown. System complexity and functionality increase along the X-axis direction (as does requirement for Internet connectivity. Battery usage increases along the y-axis

Pointer" and "HapticDestinationPointer" is minimal as the user must explicitly request assistance during their travel. Consequently, the user themselves are in control of the number of requests.

DATA AND CONNECTION ISSUES

The four prototypes discussed in this paper are inherently spatial data driven. The availability and accuracy of spatial data is important for these application to work efficiently, effectively, and correctly. OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. Volunteers or common citizens created these maps using data from portable GPS devices, aerial photography, and most importantly from local knowledge of the area. OSM coverage is not uniform across all places and usually very well mapped are mostly concentrated within cities and towns [20]. The lack of spatial data in a particular region can lead to these systems not performing well. The popularity of OSM is growing quickly and the diversity and quantity of the points of interest provided offer new opportunities and challenges in creating customized and detailed visualization of cities [33]. The systems are developed to use OSM but could switch to an alternative source of spatial data if required. The OSM option allows us to integrate external web-services (Cloudmade) for pedestrian route calculation using OSM data. We believe this option provides us with a better overall spatial data management structure. As several studies have shown (see Girres [14], Haklay et al [16] or Haklay [15]) OSM data is comparable in quality and geometric accuracy to that of traditional mapping products such as those produced by National Mapping Agencies and commerical mapping vendors. OSM data also includes many geographical features that are not available in other spatial datasets. For example for blind or visually impaired pedestrians many cities in OSM have the location of tactile pavements, assisted traffic signals, etc mapped accurately.

An Internet connection is another requirement for the systems outlined in this paper. The mobile device running these applications must be connected to the Internet. While "HapticWayPointer" and "HapticDestinationPointer" require limited internet access and connects only when the user requests for feedback and it is then switched off. "HapticStayonPath" and "HapticNavigator", on the other hand, both require continuous Internet access. In future we shall look to develop these applications that can work "offline" most times. Such extended versions of the applications will only require Internet access initially to set the required system variables for the applications. OSM data, for example, could also be stored directly on the mobile device storage space. "HapticStayonPath" requires Internet access throughout and provides haptic feedback continuously to the user until they have reached the destination. As the position of the user must be continuously updated the GPS is turned on constanly also. These factors combined lead to heavy battery usage and would not be a practical option on very long routes. These issues are summarised in the illustration in Figure 3 which shows the requirements for battery usage and Internet connectivity against overall system complexity and functionality. As stated previous table 1 provides a similar type of overview. In the next section we provide some closing discussions and some conclusions from this work.

DISCUSSIONS AND CONCLUSIONS

There are a number of important outcomes from the integration of haptics as a modality for navigation assistance on mobile devices. These are summarised as follows: there is a reduction in the attention requirements of the user to the mobile device screen; haptic communications have no language/cultural barrier; decision making appears to be made quicker, when the haptic system is learned by the user; and there is an overall reduction in the cognitive burden on the user. We shall now elaborate briefly on each of these four issues.

- Haptic feedback allows navigational information be provided without requiring the user to pay strict attention to the mobile screen. This ensures that the user is attentive to their activity at that time [12]. Similiar to voice feedback on Sat Nav systems in cars (to allow drivers focus on the road) haptics ensures that the use does not have to allocate all of their attention to other tasks such as working with the user interface. As stated above the pedestrian may be involved in activities (carrying shopping, walking with friends) where it may be unsuitable to have a visual guidance system.
- Unlike map displays and voice communication the sense of touch does not have any language barrier [32]. Thus, such a system can be consumed by a global audience regardless of the user's native or spoken languages. This greatly reduces the software development for the applications where multilingual issues must be addressed. Mapping and voice feedback applications must very carefully deliver information in different languages.
- Haptic feedback ensures decision making regarding the navigation task occurs quicker than compared to decision making using a purely visual interface or where the user must orient themselves in the correct direction [2, 34, 38]. Haptic feedback ensures quicker user response time. Users also re-orientate themselves quicker at complex intersections or junctions.
- Finally, it has been shown that haptic feedback reduces the cognitive burden on the user [6]. Haptics reduces the requirement for the user to orientate and re-orientate themselves based on the mobile display by comparing the features displayed on the map to the real world features around them. However, an interesting point commented upon by Parush et al [35] is that while haptics is certainly a very useful and exciting modality if users become dependant on haptics then this could lead to a degradation in overall spatial and navigational knowledge and ability.

Traditional pedestrian navigation systems use visual interfaces (digital maps, textual descriptions, images, etc). Audio-based navigation is another common modality. Haptic-based feedback is gaining interest within the research community and there are now a growing list of applications [34]. Integrating haptics into pedestrian navigation systems provides an environment where the user is not continuously interacting with the visual interface of the mobile device and can follow a "heads-up" [38] approach to route following. Feedback from the user trials was very positive overall. From a qualitative viewpoint some of the user responses were as follows: "These applications do not require me to know much about maps and map symbols and about orienting myself to the correct path" and "the subtle feedback ensure that I don't have to be overly attentive to my phone during my walk". Since "HapticStayonPath" does not use the compass it was difficult for users to orientate themselves at complex junctions and intersections. "HapticNavigator" helps users get to their destination in the shortest time. As the vibration alarm is only used at waypoints battery energy is conserved. In user trials "HapticWayPointer" and "HapticDestination-Pointer" provided users with better control over their route choice. Quantitativ results showed that most users do not take the shortest path but follow a meandering route to their destination.

This paper has introduced a haptic interaction model for mobile-based pedestrian navigation applications. We feel there is great potential for haptic-enabled navigation applications as an alternative to purely visual or audio-based feedback applications. Haptics is an unobtrusive feedback mechanism and this allows the user interacts more with their physical environment. The "scanning" action (refer to Figure 2), by holding the phone horizontally to query about direction, distance, or orientation information, ensures that quick responses are obtained by the user. Our user trials show that waiting time at waypoints is reduced. It is intended that this research will extend to using haptic feedback interaction for pedestrian navigation indoors in the absence of GPS signals. Paths and lines in OpenStreetMap can be tagged specifically as indoor routes and subsequently OSM routing engines such as Cloudmade [7] can plan routes indoors. Ensuring that the spatial data in OpenStreetMap is semantically rich and spatio-temporally correct is also of critical importance to the approaches outlined in this paper. A serious challenge for application development in this area concerns the positioning techniques. Especially in urban environments, due to obstruction effects, the achievable accuracy of conventional GPS systems does not seem to fulfil the requirements for all pedestrian navigation applications [4]. This is also a problem in rural and country areas[13]. However, more and more citizens are using their "smartphones" for every day tasks and consequently are much more likely to embrace new technologies such as haptics for these tasks. It is an exciting time for mobile application technologies and development.

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HapticTransit: Tactile feedback to notify public transport users

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ABSTRACT

To attract people to use public transport, efficient transit information systems providing accurate, real-time, easy-to-understand information must be provided to users. In this paper we introduce **HapticTransit,** a tactile feedback based alert/notification model of a system, which provides spatial information to the public transport user. The model uses real-time bus location with other spatial information to provide feedback about the user as their journey is in progress. The system allows users make better use of 'in-bus' time. It allows the user be involved with other activities and not be anxious about the arrival at their destination bus stop. Our survey shows a majority of users have missed a bus stop/station whilst undertaking a transit journey in an unfamiliar location. The information provided by our system can be of great advantage to certain user groups. The vibration alarm is used to provide tactile feedback. Visual feedback, in the form of colour coded buttons and textual description, is also provided. This model forms the basis for further research for developing information systems for public transport users with special needs – deaf, visually impaired and those with poor spatial abilities.

KEYWORDS

haptic, pubic transport, user experience, modality, location based service.

1 INTRODUCTION

Governments are trying to encourage people to use public transport. A journey for a user of public transport involves various phases which are combined to make up their journey. A journey begins with: with planning the trip, finding the nearest bus stop to board the bus, finding the time the bus should arrive, waiting at bus stop, payment before journey, in journey activity, alighting from the bus, and finally optionally providing some post journey feedback. This process has been discussed by many authors [1,2,3,4,5,6]. There are already many innovative systems to assist passengers in planning their journey on public transportation. One such example is a navigator service for public transport networks that uses a RFID based ticketing system Here the user selects their destination and then text messages are sent by the system to the user to guide them in real time [7]. In the past we have investigated provision of web based graphical interfaces for users to visualize real-time bus data by developing a journey planner combining pedestrian navigation with real-time bus tracking [4]. This is also delivered on mobile devices. As stated by Shalaik et al [5] the real-time data about bus arrival time at a particular bus stop is what the user is really interested in [5]. Much research for visually impaired public transport users is focused on pre-journey solutions, journey planning and 'at the bus-stop' real-time information [8].

Although transit agencies continuously work to improve on-time performance, such efforts often come at a substantial cost to ensure public transport use. One inexpensive way to combat the perception of unreliability from the user perspective is real-time transit information signage. Improvements to information related issues may encourage increased use of public transport. A system that provides various user groups with information about current location and time to the next stop while 'in-transit' is required. Such systems should also ensure that they provides information/feedback to the passengers and allocates sufficient time to allow them to disembark from the vehicle [4]. Various multimodal systems have been developed to meet such needs. A Travel Assistance Device (TAD), that aids transit riders with special needs in using public transportation, provides the passenger with customised real-time audio, visual and tactile prompts for exiting the transit vehicle by announcing actions such as `Get ready`` and `Pull the cord now!` [9]. These `in-bus' visual and/or auditory feedbacks [10] are the most popular methods for providing information

One of the key drivers of this paper is the use of tactile stimuli on mobile devices to alert passengers of 'in-bus' information. Tactile stimuli ('haptics') are used as an alert/notification system for informing the mobile phone users of incoming text messages or phone calls on their mobile devices. Haptics can also be integrated into systems where the location of the phone is known. The goal of this paper is to integrate haptics into the delivery of real-time 'in bus' information for public transit passengers. People using public transport systems need two kinds of basic information - (1) when, where, and which bus/train to board, and (2) when to disembark the vehicle. Haptic feedback integration into mobile GIS applications has many benefits [11]. Tactile feedback to provide pedestrians with navigation cues has shown great potential [12]. In Jacob et al [13] the integration of haptics into public transport systems ensures feedback in the form of the vibration alarm to alert the user about the arrival at their desired destination. Haptics enabled alert systems can also be used for pedestrians who are given subtle feedback when they are within specific distances of desired POIs (Points of Interest) which they can or cannot physically see ahead/around them. This can also be used by businesses to ``check-in'' to the user's device to advertise an offer or deal and subsequently the users get alerts on their mobile device.

The major motivations of this study are as follows: 1) Assistance: Prevent users from missing stops, 2) Information: provide real-time information which is found to be severely lacking in the transport networks of most cities, 3) Guidance: help tourists using public transport where routes are complex and difficult to understand, and 4) Personal security: development of mobile software applications which will not be required to be 'on display' in the user's hands throughout the journey.

The paper is organized as follows. In section 2 we review literature about various aspects of public transport users – pre-journey behavior, real-time information and wait time, multi-modal communication techniques, in-transit display systems and the use of haptics as a modality for providing information to the user. Section 3 describes the haptic interaction model in the system and describes the various elements of the system. In section 3 the implementation of the HapticTransit alert/notification system is also provided. We discuss the results and key findings from the user survey and initial user trials in section 4. This is followed by some concluding remarks and the future direction of this work.

2 LITERATURE REVIEW

Most of the research work related to public transport systems usage is related to pre-journey solutions, which is either journey planning [4] or provision of real-time/time table information about buses at the bus stop and/or mobile devices[3,5,6].

2.1 Pre-journey behavioral intentions

The study by Fujii and Van [14] explores the behavioral intention to use the bus while considering the perceived quality of bus service, problem awareness, and moral obligation to use public transportation in Ho Chi Minh City (HCMC), Vietnam. Psychological factors related to various aspects of bus usage yielded four factors: moral concerns, negative expression, quality perception, and social status. Thus good quality information system and services can also ensure positive response and increased use of public transport. Dynamic 'at-stop' real-time information displays are becoming popular in modern public transport across the globe. Reactions and attitudes towards these systems are very positive. But there is a need to provide a comprehensive framework of the possible effects that these types of displays can have on customers. There are seven main effects and these are described by Dziekan and Kottenhoff [15]: (A) reduced wait time, (B) positive psychological factors, such as reduced uncertainty, increased ease-of-use and a greater feeling of security, (C) increased willingness to pay, (D) adjusted travel behavior such as better use of wait time or more efficient traveling, (E) mode choice effects, (F) higher customer satisfaction and finally (G) better overall image. The *OneBusAway* transit traveler information system [2] provides real-time next bus countdown information for riders of King County Metro, Seattle, USA, via website, telephone, text-messaging and smart phone applications.

2.2 Real-time information and wait time

Although previous studies have looked at traveler response to real-time information, few have addressed real-time information via devices other than public display signs. For this study, researchers observed riders arriving at Seattle-area bus stops to measure their wait time while asking a series of questions, including how long they perceived that they had waited. The study found that for riders without real-time information, perceived wait time is greater than measured wait time. However, riders using real-time information do not perceive their wait time to be longer than their measured wait time. Watkins et al [2] found in their study that mobile real-time information reduces not only the perceived wait time but also the actual wait time experienced by customers. Real-time information users in the study wait almost 2 minutes less than that arriving using traditional schedule information. Mobile real-time information has the ability to improve the experience of transit riders by making the information available to them before they reach the stop. The *UniShuttle* application [16] tracks public transport vehicles in a ticketless and partially unscheduled bus network. Passengers have the ability to view bus schedules in real-time. Koskinen and Virtanen [3] present concepts and experiences of using public transport real time information in personal navigation systems. The information needs are discussed from a point of view of the visually impaired. Three cases are presented: (1) using real time information about the bus to help the visually impaired to board and leave a bus at the right stop, (2) boarding a train and (3) following a flight status. The research has been done in a national NOPPA (Personal Navigation and Guidance for the blind) project piloting a guidance system for the visually impaired. The goal of the project has been navigation without additional installations to physical infrastructure. Zenker and Ludwig [17] describe a system that calculates a route to the next best public transport stop, which means of transportation to take, where to change transportation, and how to walk from the last stop to the goal location. Departure times are displayed to the user and they are informed, i.e. if they have to hurry to catch a bus.

2.3 Multimodal communication techniques

Researchers have investigated multimodal communication with users of public transport. TravelMan [19] is a multimodal mobile application for serving public transport information in Finland. The application includes different kinds of input and output modalities (speech input and output, a Graphical User Interface (GUI), and contextual predictive text input). The main design principle of the TravelMan application was to ensure that different modalities can function in tandem with each other and support multiple, simultaneous or alternative modalities. The main output modalities used here (speech and GUI), were designed to work independently or simultaneously. Results from their related work [20] suggest that speech input outperforms other input methods, even with high error rates and slow response times. The authors however find that contextual predictive text input was the preferred method. Mobile devices, such as smartphones and personal digital assistants, can be used to implement efficient speech-based and multimodal interfaces [6]. The authors state that for special user groups (such as visually impaired people) to access specific information when using public transport, speech-based mobile applications is the only possibility. Their system offers services such as route guidance and service disruption information (e.g. roadwork information). The system is designed to function as an information aid for visually impaired people in everyday life and it contains several other services and features in addition to public transport information services. The external routing system and database returns, for each complete query, a detailed set of route information in XML format. The MUMS system, describedby Hurtig and Jokinen [18], is a mobile PDA-based route navigation system which allows the user to query public transportation information using spoken language commands and pen-pointing gestures on a map. The system responds with route information in speech and graphical output. The authors find that tactile systems such as input and interaction systems can benefit from speech in different ways: their main interaction mode is not regarded as language-oriented communication so speech can provide an additional value for the tactile interface users. The evaluation results of a multimodal route navigation system that allows interaction using speech and tactile/visual modes are presented. Various functional aspects of the system were studied, related especially to the I/O-modalities and their usage as means of communication. The authors compared the users' expectations before the evaluation with their actual experience of the system, and found significant differences among various user groups. Multimodal systems are usually considered advantageous over unimodal systems as they provide flexibility and give a more natural feeling to interaction. All the users, however, responded unanimously that a system with both speech and tactile/visual I/O-possibilities is preferable to a unimodal one [22]. The aim of the RAMPE project [23] was to design and experiment a system based on a light hand-held device for the assistance and information of blind people so that they can increase their mobility and autonomy in public transport. This system offers detection abilities and guidance in the spatial area surrounding the stop point and delivers relevant information using Wifi from these fixed stations to the mobile device of the user. Hurtig [24] describes a system that provides route information and navigational instructions via synthetic speech and map graphics. Users are free to use any chosen combination of input and output modalities, resulting in flexible and efficient task-based interaction. Hurtig [24] states that multimodality seems generally to improve performance, but mainly in spatial domains, such as map and navigation applications. Following on from this Hurtig and Jokinen [25] demonstrate a Multimodal Route Navigation System which combines speech, pen, and graphics into a PDA-based multimodal system [25]. Accessibility information for public transport users have also been an area where interesting research has been seen [26,27]. When people with reduced mobility (e.g. due to a disability, luggage, frailness) want to use public transport they face the problem of finding barrier-free travel that correspond to their special needs (eg: wheelchair access, ramps etc) [28]. An approach to adaptive route directions based on a combination of turn-by-turn directions and destination descriptions is presented in the work of Richter et al [29]. Work towards non-static, adaptive route direction services is provided here where instead of relying on information on a wayfinder's previous knowledge, here a wayfinder can adjust the type and detail of the presented information via dialog. The BAIM plus by Buhlet et al [30] is a system that provides information about schedules, vehicles and stations. This journey planner has a query interface with different user profiles (e.g. no limitation, wheelchair user, restricted in walking) which can be chosen in order to get customized suggestions for barrier-free travel connections as well as information about the accessibility of facilities to be used during the journey. Goto and Kambayashi [1] have developed a passenger support system for the public transport system based on information integration and dynamic personalization in multi-channel data dissemination environments for the visually impaired. Foth and Schroeter [31] investigates opportunities to enhance the experience of commuters in all aspects of their journey (planning the trip, waiting at bus stop, payment before journey, in journey activity, post journey feedback. Instead of focusing on efficiency and speed of each of these steps their focus is on making the public transport experience more enjoyable and meaningful, in particular through the innovative combination and interaction of technologies such as mobile devices and urban screens, real-time data and sensor networks, as well as social media and Web 2.0. Bantre et al [21] describes an application called "UbiBus" which is used to help blind or visually impaired people to take public transport. This system allows the user to request in advance the bus of his choice to stop, and to be alerted when the right bus has arrived. Turunen et al [33] meanwhile presents approaches for mobile public transport information services such as route guidance and push timetables using speech based feedback.

2.4 In-transit information systems

Darren et al [10] focuses on 'in-transit' information provision, which could provide benefits to a wide range of user groups (eg: visually impaired, tourists). This work deals with the encouragement and promotion of the use of buses in Edinburgh, especially among visually impaired users and tourists / migrant workers. The authors report the key issues these groups encounter when using buses, and introduces Visual and Vocal Information Platform (VVIP) as a solution. VVIP is a dynamic location based system which offers passengers a visual and auditory display of where the bus is in relation to its next stop facilitating and improved bus travel experience. The Scottish Executive published research on how to improve public transport for disabled [32]. The most interesting finding was from the research carried out with visually impaired individuals who suggested that information in Braille or audio may encourage the use of public transport, and one of the main issues was "*bus drivers forgetting to inform passengers that they have arrived at their destination stop*". Thus the importance of providing certain user groups with information about current location and time to next bus stop was important.

Thus there is the need to have a system that provides these user-groups with information about current location and time to the next stop. The system should also ensure that it gives information/feedback to the passengers and give them sufficient time to disembark from the vehicle [10]. To achieve this, the authors use an auditory display that would give information about what the next stop is and length of time to next stop, therefore, making bus use as easy and comfortable as possible for the visually impaired. The authors [10] introduced localized visual interfaces in the buses that could assist passengers who have hearing disabilities (auditory problems) and also by supplying the same information using audio feedback. Information on tourist attractions, which are in close proximity of the bus location were displayed so that it could also be beneficial to different user groups/tourists. This research suggested that continuous auditory updates would "annoy the 'average' bus user" [10]. Darren et al

[10] conclude in summary that there are some very obviously negative aspects of auditory systems along with benefits. The key benefits of multimodal services listed by Hurtig and Jokinen [18] are - interpretation accuracy can increase since information is encoded in redundant or complementary modalities (e.g. combing text with tactile/ gestures), and different modalities bring in different benefits (e.g. combination of map with audio). The authors go on to state that although the differences may not be always pinpointed down to prior knowledge, predisposition, age, or gender differences, it is important to notice that the goal of building one single practical system that would suit most users is not reasonable. They stress that “a multimodal notification/alert system would be an important addition to scientific research in the field of public transport user and services” [35].

2.5 Use of haptics to provide useful information

We look at how location based haptic feedback can be integrated to public transport users [13] via GPS enabled mobile devices to provide alerts/notifications to the users about destination bus stops. Lee and Starner [34] present two experiments to evaluate wrist-worn wearable tactile displays (WTDs) that provide easy to perceive alerts for ``on-the-go users''. Their results indicate that when visually distracted users' reactions to incoming alerts become slower for the mobile phone but not for the WTD. Srikulwong and O'Neill [36] investigate using haptics to alert users about landmarks in a town or city. With training, participants were able to haptic signals for distinguish landmarks from directional signals and recognized over 80% of learned landmarks. They also found that participants did not show high rates of ``forgetting'' the haptic signals they had learnt. Amemiya et al [37] developed a novel handheld kinesthetic force-feedback device is based on the characteristics of human perception. It convey a sense of pulling or pushing the user towards a specific landmark or object and can be used to alert users that they are ``near'' a specific POI. This haptic direction indicator would help blind pedestrians intuitively and safely escape from dangerous area by means of haptic navigation.

In our paper we introduce 'haptics' as a modality to deliver spatial information (eg: near POI/landmark, arrival at bus stop etc) to mobile devices of public transport users. This work integrates user location (via GPS) and a spatial database along with feedback (alerts/notifications) in the form of visual (text and color coded buttons) and haptics (vibration alarm with varying frequency) about important POIs, landmarks, or tourist locations.

3 HAPTIC INTERACTION MODEL

In this section we describe the user interaction model of our system.

3.1 HapticTransit System

The HapticTransit system described in Figure 1 provides assistance to the user to indicate when their bus-stop is approachingwhen they are in the bus on a journey. Rather than providing the user with an outline of the travel time to their stop they are informed by haptic feedback, in sufficient time, when their stop is approaching [13]. The user selects their destination and the desired information mode: – destination only (no addditional information) while tourist mode provides with information and alerts about POIs along the way. The bus arrival time prediction algorithm forms an important system. The bus location and arrival time at bus stops are calculated using either direct extraction of information from timetables or by bus arrival time prediction algorithms. The broker service running on the server is responsible for calculating the proximity of the user to their desired stop. Time and distance information is also provided visually on the device. The system computes the proximity to the user's destination stop and provides a subtle alert about the approaching destination by providing a low frequency vibration feedback when the user has reached the stop just before the destination stop. This enables the user to prepare to disembark the bus when the next stop is reached. The intensity of the vibration alert on the mobile device increases as the bus is approaching the desired stop. A simple colour-coded visual display is also used to represent far, close, and very close using green, red, and amber colours respectively. An amber button displayed indicates that the user is very close to their destination stop. A red button indicates that the user has reached the penultimate stop. Green indicates that the user still has some distance to travel. The model incorporates additional feedback along the route to improve the 'in-bus' interaction. If the user has selected "tourist mode" then the user is alerted by a unique vibration feedback pattern about a landmark/POI along the route. In combination with the haptic feedback here they systemalso provides visual feedback with the name and description of the landmark/POI currently in the proximity of the user.. The real-time bus arrival time algorithm computes the arrival time of buses at various bus stops [5]. The use of the haptic feedback ensures that the user is not required to be interacting or looking at the mobile device at all times for assistance. The user instead enjoys the trip and will be informed about destination stop and/or important landmarks/POI along the route through tactile feedback.

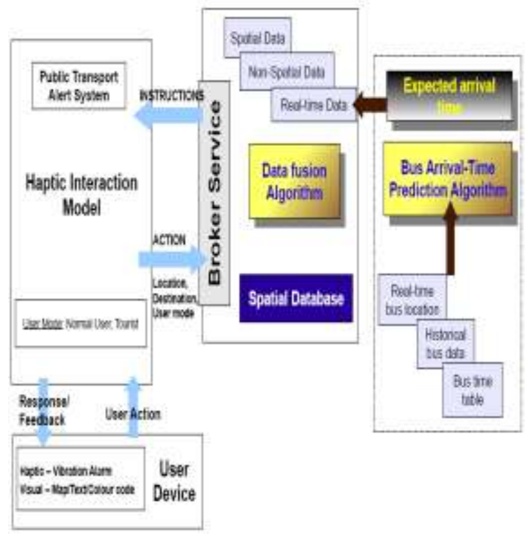

Figure 1. HapticTransit Model

The model of the route is stored in the spatial database. Each route *R* is an ordered sequence of stops *{ds, d0, ..., dn, dd}*. The departure stop on a route is given by *ds* and the terminus or destination stop is given by *dd*. Each stop *di* has attribute information associated with it including: stop number, stop name, etc. Using the timetable/real-time bus arrival information for a given journey *Ri* along route *R*, we store the timing for the bus to reach that stop. This can be stored as the number of minutes it will take the bus to reach an intermediate stop *di* after

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departing from *ds*. This can also be stored as the actual time of day that a bus on journey *Ri* will reach a stop *di* along a given route *R*. This is illustrated in Figure 2. This model extends easily to incorporate other modes of public transportation including: long distance coach services, intercity trains, and trams.

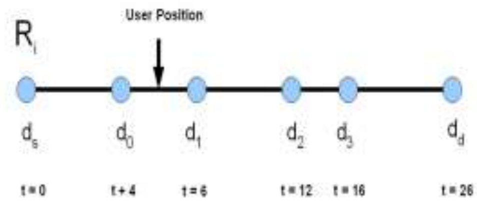

Figure 2. An example of our route timetable model for a given journey Ri.

The number of minutes required for the bus to reach each intermediate stop is shown as *t.*

3.2 Implementation of the system

Our software implementation of the prototypes use well known components. The Android mobile operating system was used to develop and implement this model. A PHP script running on the server acts as the software broker service. While any source of spatial data could be considered we have used OpenStreetMap (OSM) as the main source of spatial data. OSM offers a very detailed street and road network it also provides a very rich database of POI and landmarks. PostgreSQL (PostGIS) is used as the spatial database. The PHP broker service is easily configured to extract spatial information from alternative sources of spatial data. This is outlined in flowchart format in Figure 3 where we see that in the web server the broker service and the database interacts and obtains input about arrival time at destination bus stop.

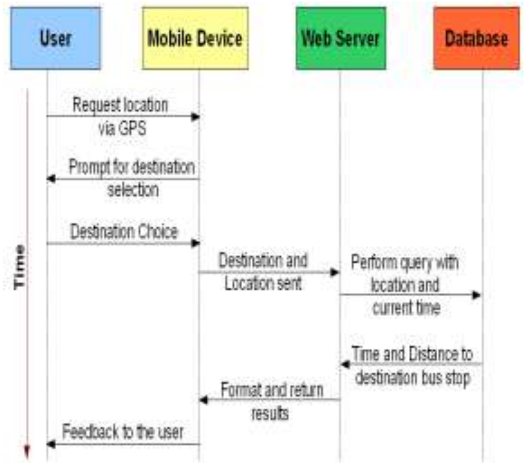

Figure 3. Flowchart depicting the flow of information with time.

On entering the bus or just before boarding the bus the user runs the application on their mobile device and selects the destination.

4 SURVEY AND FINDINGS

To quantify motivation for this work we conducted a survey on public transport usage. We contacted 50 people for the survey and received 45 responses. There are a number of important results from this survey, which was conducted online, which show that there is a need for an alert system similar to the one we have described in this paper. The majority (40 respondents) felt that the feedback from the in-bus displays is useful. Figure 4 gives a list of techniques that users said they would do to keep track of destination bus stop. We see that the majority of respondents 'ask the driver to alert them' or 'look for landmarks' to notify them about arrival at their expected destination bus stop. A small percentage of users said that they would use journey planner software before the trip and that these people would then carry a map or printed version of the route itinerary when they are on their bus. Figure 5 displays a summary of the types of “in-bus” activities that users indicated they are normally involved in. The majority of these users said that they would listen to music or just look out of the bus window.

Figure 4. User activity to know the destination bus stop

The respondents of the survey reported that if they are traveling with a friend or family member(s) they would normally be in conversation with their travel companion. 33 of 45 respondents reported that they had missed their stop while traveling by bus at some stage in the past.

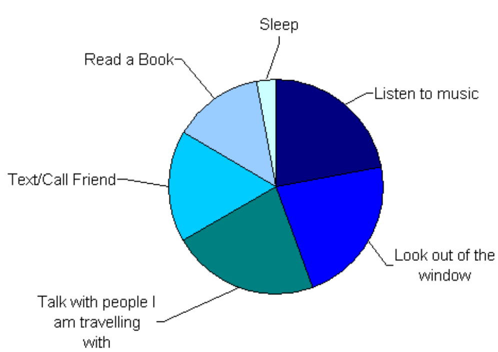

Figure 5. In-bus activity during a bus trip

The most commonly cited reason for missing a stop was attributed to darkness and traveling in hours of darkness. as since it was dark outside the users found it difficult to recognise (using landmarks and POIs) that they had reached their destination. The second most commonly cited reason for missing a stop was a result of the passengers falling asleep on the bus. The survey participants were also asked what form of alert feedback they would most prefer. From the survey ‘displaying user position on a map’ and ‘vibration alert to inform them of the bus stop’ were the most popular responses. In providing the reasons for choosing the vibration alert feedback the 30 out of 45 respondents explained that they chose this since they don’t need to devote all of their attention to the phone screen. The participants explained that since the phone is in their pockets/bag most of the time, the vibration alert would be a suitable form of feedback. Our system provides three kinds of feedback to the user with regard to arrival at destination stop: textual feedback, the color coded buttons and haptic feedback. The textual and color coded feedback requires the user’s attention. The user needs to have the screen of the application open to ensure he/she sees the information that has been provided. Thus the user will miss this information if they are involved in any other activity like listening to music, sending a text, or browsing through other applications in the phone. If the user is traveling with friends, it is very unlikely the user will have his attention on the phone [39]. Amongst the respondents, haptic feedback is the preferred mode for providing feedback to the user regarding arrival at destination stop. Haptic feedback ensures that the feedback is not distracting or embarrassing like voice feedback and it also lets the user engage in other activities in the bus. Haptic feedback can be used by people of all age groups and by people with or without visual impairment. It provides a very suitable modality for information for passengers who are unhappy with the use of continuous audio feedback modality [10].

5 DISCUSSION AND COMMENTS

This paper has given an overview of a haptic-feedback based system to provide location based information for passengers using public transport (specifically buses). The main benefit of this system is that passengers can use the system on their mobile devices to reduce the anxiety about missing their stops. The system is aimed at users who are unfamiliar with a particular bus journey or network. The vibration alarm provided by the system helps alert passengers about the bus as they approach their destination. The system also notifies them about POIs along their travel route for further information if they choose to have this provided to them. This assists in enhancing the in-bus' experience of the user, it involves less interaction with visual/audio notification system on the mobile device, and the passenger can enjoy the trip and be involved with other activities. Tourists, who normally find taking buses in a new location rather daunting, can use this system as an assistant while they absorb the city environment from the window of the bus. Another aspect of public transportation related to this work is theft on public transport. Several authors report an increase in smartphone theft in public transport vehicles [40, 41]. Using our system with haptic feedback drastically reduces the amount of time a user needs to have their phone out on display. With the vibration feedback to alert passengers of their stop location it is hardly necessary at all to have the phone device displayed in public throughout the journey. As some of our participants in our user trial put it: "we can look like locals rather than toursists". The real-time bus arrival time sub-system within our model provides more accurate expected arrival times for buses. To make the system software more generic we intend to extend the design of the timetable important functionality to consume XML, KML, etc. This would allow automated import of standards-based public transport schedules rather than manually storing the timetable into a database. This will provide quicker and more efficient extension to public transportation routes in any region. The final two aspects of future work are focused on user trials and energy consumption of the application. To demonstrate the success and use of our application in the real-world more extensive user trials will be carried out with a wider range of participants. The results of these trials will be published in a suitable journal. The continuous use of the vibrate function, GPS sensor, and data transfer to the server can drain battery resources rather rapidly. Consequently, our software for this application must be developed with battery efficiency in mind. Some authors have shown that when applications cause drain of the battery this can cause distress and potential annoyance for the user [42].

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What's up that street? Exploring streets using a Haptic GeoWand.

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Abstract. In this paper we describe a Location-based Service (LBS) 'point to query' system called *Haptic GeoWand* where we use the orientation of the user to retrieve information for the user along a given street. With the textual description of query results we use the vibration alarm to provide haptic feedback to the user about the availability and distance to their desired points of interests along a particular path or street. To test the usability of *Haptic GeoWand* we developed two mobile prototypes. We tested two different types of queries - 'Tell me what comes along my street and where it is?' and 'From this intersection/junction which is the best path to take?'. With our system we demonstrate that the user can point and query the availability of objects along the street which are not directly visible to them but is along the path he/she intends to take. After selecting a Point of Interest (POI) type the user can engage in his/her physical activity without increased cognitive burden. The user is not required to constantly look at the mobile screen. . Haptics has proven to be powerful notification technique used to convey quantitative information. We integrated this system with OpenStreetMap as the spatial data source. *Haptic GeoWand* provides the user with location, orientation, and distance information using varying vibration patterns which helps to reduce the visual mobile interaction required from the user.

Keywords. orientation, haptics, gesture, pointing, GeoWand, GPS

1. Introduction

With the growing number of mobile phones with GPS receivers combined with affordable internet access on these devices have lead to a rise in location based services .With the development of micro sensor technologies most smartphones these days are equipped with sensors like the orientation (magnetometer) , tilt sensors (accelerometer), and of course GPS receivers. So apart from the location information about the device we now also have the orientation of the phone providing application developers with the ability to understand which direction the user is facing. It is now possible to integrate the output of these sensors to provide a more location and orientation-aware interaction based system instead of the standard location (only)-based interaction on mobile devices.

Over the last decade research work has been carried out on integrating the orientation component and the location information. In 1999 Egenhofer (1999) predicted that various 'Spatial Appliances' will appear in the future that can be used with gyroscopes and GPS receivers to use both location and orientation information for knowledge retrieval. In early 2000 some interesting applications appeared that included orientation information integrated with other types of sensors such as the AudioGPS (Strachan et al. 2005) and M3I (Wasinger 2003).

Haptic technology, or haptics, is a tactile feedback technology that takes advantage of our sense of touch by applying forces, vibrations, and/or motions to the user. Several important pieces of research work has been carried out by a number of authors using haptic feedback as an alternative mode for providing user's with location and/or orientation information for use in navigation assistance: Erp et al (2005), Elliott et al (2010) ,Jacob et al (2010), Amemiya & Sugiyama (2008), and Robinson et al (2010) in. The key advantage of haptic feedback over other map or audio based assistance is that it does not require the user's constant attention and alertness.

In this paper we describe the development of a point to query system for specific queries along a street/path. We integrate haptic feedback with the point to query system using the GeoWand concept. The OpenStreetMap dataset is used to test the system. The vibration alarm in the phone (controlled using the Android API) is used to provide haptic-feedback based on location/orientation information in order for the user to use their mobile device to obtain information like: availability of a feature(s), distance to a feature, ideal path to take from a road junction (intersection) based on user needs, etc.

Our paper is organised as follows. In section 2 we provide an overview of related literature. This focuses on orientation-aware devices and applications. This also helps us motivate haptic-feedback as a modality. In section 3 we provide details of the system implementation for both prototypes. Section 4 discusses the results of some trials of the system in Ireland using the OpenStreetMap database. In the final section we provide a review of the advantages offered by our approach and discuss some issues for future work.

2. Background

In this section we review literature where orientation aware interaction systems have been tested or used. Researchers have focused on retrieving information about a feature the user can see or is within his/her line of sight. It can be seen that authors are now beginning to integrate haptic feedback as a modality for navigation assistance in way finding and route planning.

2.1. Orientation-aware interaction

One of the most interesting applications listed by Egenhofer (1999) was the GeoWand. A GeoWand is an intelligent geographic pointer, which allows users to identify remote geographic objects by pointing to them (Egenhofer 1999). Many researchers Carswell et al (2010), Simon et al (2007), and Robinson et al (2008) have used this concept in their work. In Gardiner et al (2003), their approach restricted the search space to a user's field-of-view (FoV) using the concept of an observer's two dimensional query frustum to determine what the user can actually see from their location in the environment. The framework used by Simon et al (2006) relied on a 2.5D environment block model. For performing the query they use a basic scan-line algorithm to compute a 360-degrees line of sight. Similar work has also been carried out by Gardiner (2009) for their system called -EgoViz which is a mobile based spatial interaction system. Carswell et al (2010) focuses on directional querying and the development of algorithms for mobile 2D and 3D spatial data interaction. Simon et al (2007) developed a system around the concept of 'GeoWand' (Egenhofer 1999) which implements a *Point-to-Discover block model using a* *mobile* device. Here the user points the mobile device at a building and based on the position and direction, the address and other information about the building is obtained. Here with the help of location direction and orientation information, directional queries in the real world are performed on a mobile device. The ‘quality of the sensor data’ determines the quality of results returned from the query and thus becomes the most important aspect of directional queries. Simon et al (2008) has investigated GPS inaccuracy and compass error. They commented that these factors can be the deciding factor for systems returning accurate query results. Strachan and Murray-Smith (2009) have demonstrated an audio based system for using gestures and user orientation.

Robinson et al. (2008) demonstrates how a user can record interesting locations along the path by pointing and tilting a mobile device. Points of Interests (POIs) along the path of the user that was recorded can then be downloaded and viewed and blogged about. The authors use lightweight approaches for gathering location-orientated material while the user is mobile; the sensor data is used here both to collect and to provide content; and, integrating map visualisation is used as the basis of the journey record. Costanza et al (2006) introduced a novel notification display embedded in eyeglass frames. The device delivers peripheral visual cues to the wearer without disruption to the immediate environment. The display is designed to take advantage of the visual field narrowing phenomenon, so that it tends to become less noticeable under high workload. (Wasinger 2003) developed a location based interaction system where the user could ask 'What is that?' by pointing the device in that direction. The platform here combines 2D/3D-graphics and synthesized route descriptions, with combined speech and gesture recognition.

2.2. Haptics as a modality

Research from Erp et al (2005) and Robinson et al (2010) have shown how haptics can assist where one would not want their visual and/or sound channel interrupted by interaction with mobile. Haptic feedback has been integrated into orientation aware navigation systems such as: Erp et al (2005), Elliott et al (2010), Jacob et al (2010), Amemiya & Sugiyama (2008), and Robinson et al (2010). Elliott et al (2010) validated the use of haptic navigation device and found promising results. The device was a torso-based eight-tactor belt that is used to provide direction information. The authors find that the system is viable and found it effective in extremely demanding conditions. Tactile displays enabled the user to more easily make a detour from the straight routes when terrain circumstances made this advantageous. Jacob et al. (2011) describes a system that integrates haptic feedback into pedestrian navigation applications that uses the OpenStreetMap database with the routing service provided by Cloudmade API. In the system the authors use orientation information along with location for navigation assistance. Haptics feedback has been used in various other systems including: to alert passengers using public transport of the arrival at their bus stop using the GPS sensor on the user's mobile device, feedback was provided using the vibration alarm in the phone (Jacob et al. 2011a).

This overview of the literature has shown that haptics has been demonstrated as an effective way of giving feedback to users in a more subtle way. It provides an alternative to the traditional “neck-down” approach required by the user of most mobile devices. To motivate our work let us provide a real-world example:

Raj is visiting Vienna for the first time, and it about 12:30pm. He wants to find a restaurant for a meal. At present he is at a road intersection/junction where he cannot see the shops/restaurants along the street(s) ahead of him. If possible he would like to avoid walking down each street to see what his options are for eating out. Using his mobile device, running our Haptic-GeoWand application he selects 'food/cafe' as his choice of place to search and runs the application. He now scans the area quickly by holding the phone almost horizontal to the ground and moving it around him along each of the road starting from there. He is alerted via the vibration alarm about the availability of places to eat. Upon recieving the alert he checks his mobile screen trying to see the list of options available and the distances to those locations from where he is standing. Consequently he can quickly make decisions about where he wants to go on the streets directly infront or around him. The alternative is running a circular region query and the potential for being overloaded with options of all restaurants around him which could make it it difficult for him to take a decision.

Our paper argues that assuming that an application can have the full attention of the user on his/her mobile device while moving can be impractical at various times. In a busy city,with large number of pedestrians, it is very difficult to stand at a particular spot trying to make decisions (based on feedback provided on the mobile device) about which way one needs to move from the current location or somewhere nearby. A familiar sight in many cities is one of tourists standing at street junctions and intersections with toursist-orientated paper maps attempting to orientate themselves with their current location. . In all of these cases a haptic-based system with a visual interface can help users make decisions more quickly and without feeling under pressure from the busy streets around them. . A point and query system as described in this paper, with haptic feedback as a feedback modaility, could be very useful in these real-world situations. The literature on haptics has shown that using haptic-feedback can reduce the overhead of looking into the screen at all times while walking and allows users more time to interact with the real world around them. In the next section we describe the system design of the Haptic-GeoWand application.

3. System design

The *Haptic GeoWand* is a system that allows users query geo-tagged data along a street or streets by using a point-and-scan technique with their mobile device. Implementation was performed on the Android operating system running on a HTC-Magic smartphone.

For testing the *Haptic GeoWand*, we have built two prototypes that uses a point and query technique using haptics for feedback. The first system – *whereHaptic* provides the user with functionality allowing them to select a place/feature they want to go to. As the userwalks along a streetthey can query points of interest (POI) that are approaching along the path. They will be alerted via a vibration alarm when they are within a specific pre-defined distance of that feature. Along the path the user can obtain a list of features (and the distances to these features) by pointing the phone in their walking direction. This also includes features that the user most probably cannot physically see (50 metres or more) but are ahead of them along the street. The second system is called– *whichHaptic.* In *whichHaptic* the user is provided with the following functionality. Suppose the user is at a road/street intersection. The user selects places that they would like to visit: a restaurant, gift soft, pub, cafe, etc. They need assistance in decidingwhich road/street they need to travel on (based on the place(s) they want to visit and their avilability). The *whichHaptic* system provides vibrotactile feedback using patterns of vibration, which vary in frequency and intensity, to inform the user about: how close they are to a given feature or if a given feature (pub, art gallery, etc) is actually available or present in the immediate viccinity of where they are currently located. .

3.1. Implementation

For developing our prototypes we used a HTC magic smart phone running on the android Operating System. The phone comes with a GPS sensor, digital compass and an accelerometer. The vibration alarm in the phone provides the physical haptic feedback used in our system.

In our system we log a number of important variables: the location, the oritenation of the user's phone, and the accelerometer reading is logged at all times. These log files are retained and user for further analysis. The ability to integrate all the sensors into an off-the-shelf smartphone has allowed quick development and implementation of the system. The geographic data used to test the system was –OpenStreetMap. Aversion of the Ireland OpenStreetMap database was stored locally on our server in a PostGIS database. The OpenStreetMap provides us with a rich dataset to test the application. However, we have designed the application with flexibility to access other sources of vector spatial data, if available.

3.2. Prototypes

In this section we provide more details on the two prototypes designed to test the *Haptic GeoWand* system.

whereHaptic – In this prototype the user starts the application and points their mobile device toward the street that they wish to travel down. The **whereHaptic** application querires the spatial database and returns the POI along this street, in order of their distance from the user's current location. The user can then select the POI(s) that they are interested in from the list presented to them.

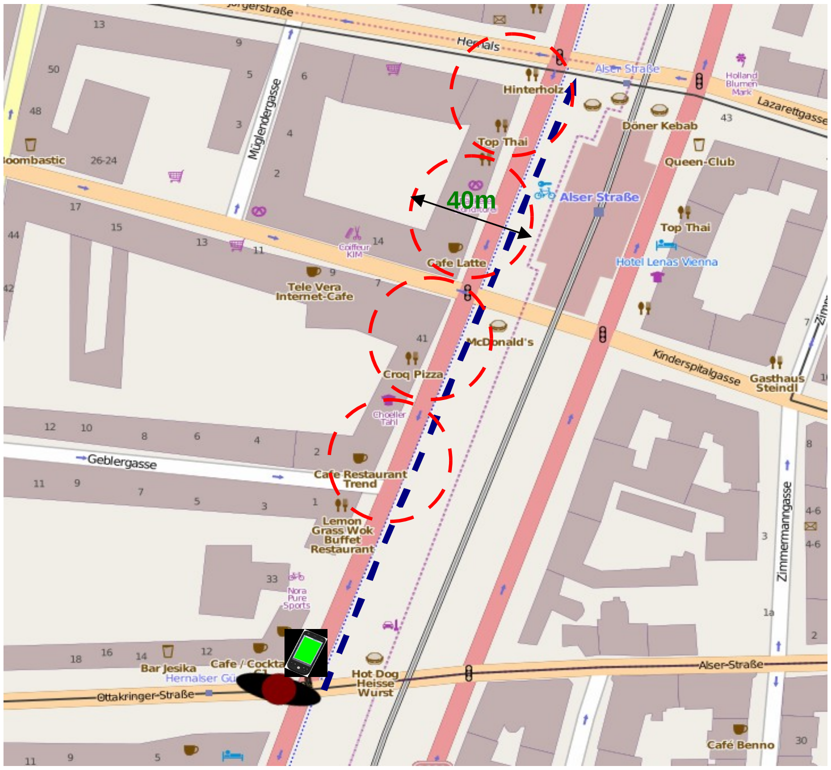

Figure 1. Prototype 1: whereHaptic querying along a path and being alerted when near a feature.

The usage of **whereHaptic** is described in the example in Figure 1. Figure 1. represents the how the system queryies the database along a road/street for features like: restaurant/cafe/fastfood/bars by performing a 'look ahead' query along the road/street from where the user currently is. This provides an alternative to the user performing a circular window query where all POI with a particular radius of their current location is returned. It also prevents the user having to walk along the street/road looking for a certain type of POI without knowledge if that POI is actually on that street/road. . The blue line in Figure 1. represents the direction the user is moving. The system will query for features with matching data type(cafe/food in this case) in the direction the user intends to walk with a buffer radius of 20 metre around points along the path. So for the example shown in Figure 1., the system would query for the feature f (=cafes here) along the path from distances x0, x1,...,xn where xn refers to a maximum distance the user intends to walk along a straight path. Here x0 is set to 50metre and every subsequent 50m. These parameters are configurable. For the case of the example here the application will return the cafes and the distance from the current point in ascending order.

whichHaptic – In this prototype the user can have a list of places they wishe to visit. They are, again, situated at a road/street intersection. They areunsure which street/road to take. Using the whichHaptic application on their smartphone they now scan the area. Using the same function as whereHaptic the application returns a list of POIs. The user can select 1 to N of these POIs in the order they would like to visit them.. The application then uses this information to return haptic-feedback in the form of the vibration alarm. Different frequencies and intensities are used to inform the user: how many of each POI they selected are available within the vincity and if they are approaching one of these POI. The user can stroll along the street without the need to constantly look at the mobile device screen for a map/text. The frequency/intensity of the haptic feedback patterns are used to inform the user on the number of each POI and the distance to each of these POI. The user can look into the screen for additional details when they recieve the haptic feedback, if they wish. The additional detail can include information taken from the spatial attributes (metadata) for the POI – for example: for a cafe this could include opening hours, Wifi availability, menu, etc.. The integration of the haptic-feedback provides the user with an opportunity to explore and enjoy the stroll along the street/road. It also reduces the amount of time required of the user to have their „head-down“ looking into the mobile screen to read directions and/or information. Figure 2 shows an example from Dublin city. The user requires an automated teller machine (ATM) and a cafe/bar. There are two streets available as options.

Figure 2. Prototype 2: whichHaptic querying to see which street is ideal to take.

As stated above the Android operating system is the test environment for this work. The Android SDK is a freely available software development kit that enables developers to create applications for the Android platform. Applications are written using the Java programming language. The SDK allows simplified programmatic access to the various sensors on the mobile device. This allows us to develop intelligent „back-end“ logic based on the results of spatial queries which can be transformed into haptic-feedback. The vibration alarm on the mobile device can be accessed using the 'android.os.Vibrator' class.

The three methods providing control of the vibration of the device are

public void cancel()

public void vibrate (long[] pattern, int repeat)

public void vibrate (long milliseconds)

By using the method *public void vibrate (long[] pattern, int repeat)*, we can make the phone vibrate to a given pattern. To reduce the cognitive burden on the user we minimise the number of vibration patterns that they have to “learn“ before they can use the application correctly. Vibration patterns are generate for the key signals that must be provided to the user: approaching a POI, distance from a POI, abundance of a particular POI in their current location.

As stated above the SDK code greatly simplifies the process of developing code for this application. The following two lines of code will make the phone vibrate for 1 second.

```
Vibrator vibrator = (Vibrator)getSystemService(Context.VIBRATOR_SERVICE);

vibrator.vibrate((long) 1000.0);
```

In the next section we provide some results of the system in operation and provide a discussion of the results.

4. Results and discussions

Using the Ireland OpenStreetMap database we have tested the applications in Dublin, Galway and Maynooth Ireland. As a means of ground-truth comparison we checked the results returned to the applications manually by walking down the streets ourselves. Overall the application returned accurate information based on POI and streets where spatial data corresponding to these features were available in OpenStreetMap. One issue in using OpenStreetMap for this application is data completeness. For example O'Connell Street in Dublin is the most famous street in Ireland and very popular with tourists and locals. However the O'Connell Street area is sparsely represented in the OpenStreetMap database. Regardless this is not a disadvantage of our application. We have designed our spatial query functionality such that we can access other sources of vector data if available. The system does not rely exclusively on OpenStreetMap.

For each of the test locations we took digital photographs of the „viewpoint“ of the user from the spot where they performed the scanning with their mobile device. Figure 4a shows what can is actually visible to the user when looking along a street from a particular point and how our system helps them see beyond that.

As is visually apparent from Figure 4a – the view of the user is quickly obcured by trees and other street infrastructure (lamp-posts, signs, etc). Our system allows the user to „see beyond“ their visual field of view. The user can choose the distance range for the query.

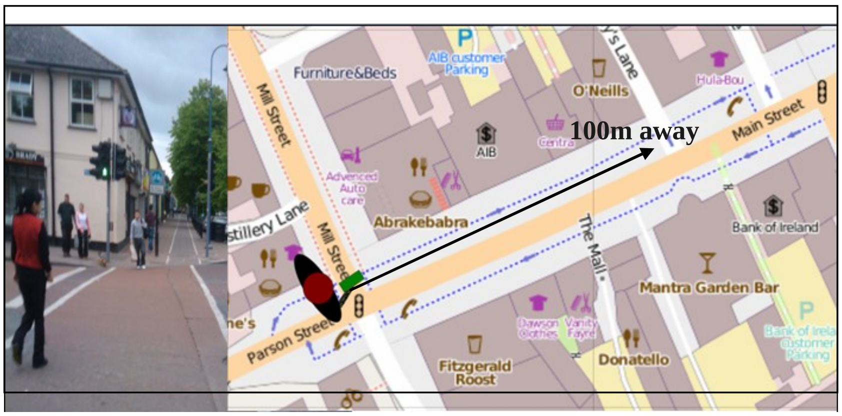

Figure 4a. User querying along a street in Maynooth to see what is available and where it is.

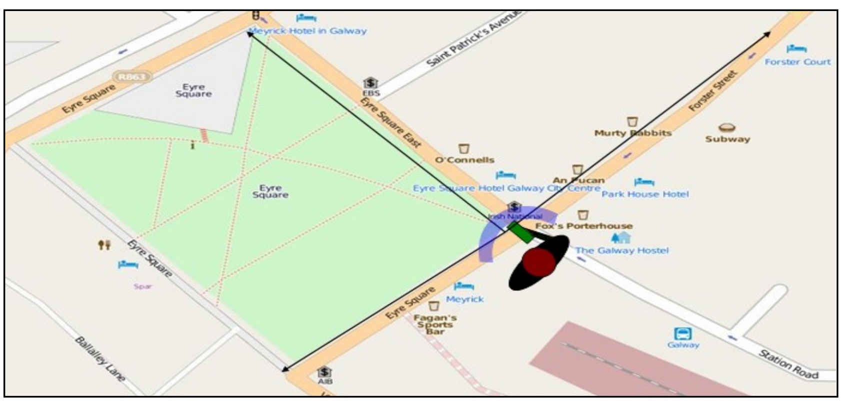

Figure 4b. User querying to see which street to take in Galway.

In Figure 4b we have a user querying for Hotels and pubs along each of the streets from the road intersection near the train station in Galway, Ireland. The user obtains haptic and text feedback based on availability and distance to pubs and hotels. From their current position they are unable to see beyond a few buildings along each of the three streets. They can query to investigate which road should be taken in order to find their hotel and then go out to a pub. I

One of the parameters which are logged for further analysis is orientation of the user and their scanning patterns with the mobile device. In Figure 5 we can visualise the orientation pattern of the user by viewing his trip log. The polar graph below shows periods of scanning through a wide angular range. The horizontal is time from the beginning of the journey to the destination. The times when the user was heading in a straight line is shown by the concentration of orientation values between 0 and 45 degrees. Using the accelerometer data we can perform analysis on where and for how the user paused or was stationary as they following the directions from our applications. This is shown in Figure 6.

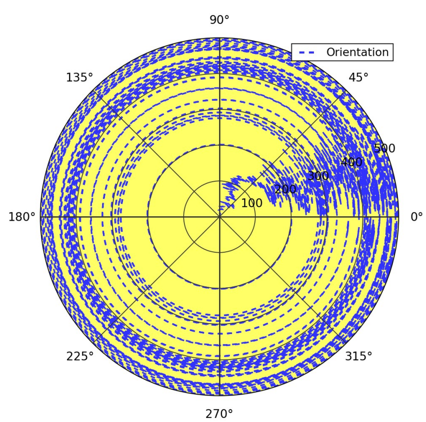

Figure 5. Compass reading of the user for a particular path.

One of the drawbacks of the query functionality in the current implementation is that the system returned POIs in adjacent/parallel streets which were not necessarily accessible from the street along the user path. Some further work is necessary to investigate if this is an issue that can be resolved by development of more complex spatial queries or if it is an artefact of how OpenStreetMap mapping is performed. Building outlines are often traced from poor resolution aerial imagery and uploaded to the OpenStreetMap database. This approach could allow poorly constructed and represented polygon shapes be uploaded to OpenStreetMap which are not very similar to the real-world building footprint of the building.

Currently our application is restricted to look ahead at adjacent streets/roads at the current location and the street “ahead” of the user. In the future development to this system we will provide a deeper look-ahead function allowing streets/roads which branch off the current street “ahead” to be listed in the results. This could potentially introduce additional learning for the user of the application. It could also require the user be provided with shortest route information. These issues will be carefully considered before this functionality is integrated into the prototypes.

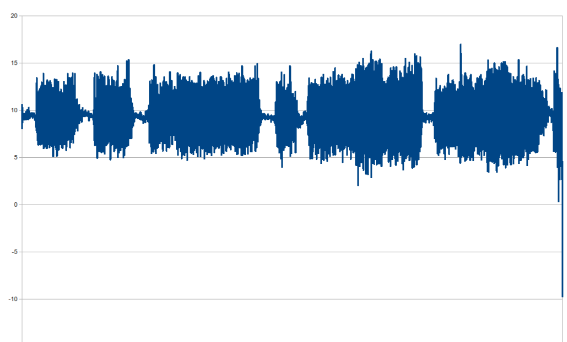

Figure 5. Accelerometer reading of the user walking.

The geo-wiki spatial data source like OpenStreetMap is used as a source of rich and timely spatial and non-spatial information. In terms of providing detailed information to users of our system – some featurs in OpenStreetMap are tagged with add additional information like opening hours, price of food/drinks, reviews/testimonials etc which can be provided as additional information to another user before making decisions.

Our multimodal point and query tool is benificial when the user is in a physical environment where it is not ideal to use a visual or sound based system. The user can choose the haptics based interaction areas with a high density of pedestrians such as well known tourist streets or tourist attractions. AIf they wish they can take advantage of the vision based when system (mostly text and hyperlinks) when they are on less crowded streets.Previous works (Erp et al 2005, Robinson et al 2010, Jacob et al 2011) in the field of haptics to provide distance, direction or location information for navigation has shown that it is possible to provide meaningful information to the user where a neck-down approach of interaction needs to be avoided or is in-appropriate. However further research is required. Heikkinen et al (2009) mentioned that the use of haptics in human-coumputer interaction using mobile devices is still very limited and they conducted user trials to understand user-expectations in such systems. Privacy, spontaneity and providing easy to understand information were key points dicussed. The *Haptic GeoWand* described here using two prototypes have shown how a haptic based 'point and query' system can be used in city environments.

5. Conclusion

As outlined above in the literature review section of this paper haptic-feedback based Location-based service applications are begining to appear. A multimodal system for user interaction brings the added advantage of choosing one modality over the other when either one is not-appropriate. In our Haptic-GeoWand the user can choose either haptic-feedback or more traditional text-based feedback. We have purposely avoided using maps in this implementation but are carrying out research into the best way to integrate mapping without reducing the opportunities for the user to choose haptic-feedback. We can now see a trend which looks beyond the location-aware system to a more orientation and context aware interactive applications. *Haptic GeoWand* integrates haptic feedback to provide a 'point to query' scanning application which reduces the visual interacion required with the mobile device. Scanning the immediate area around the current location is a very simple physical task. There is a reduction in the overall time the user must be attentive to the mobile screen for information. They are only required to "look down" into the screen when there is some relevant, additonal, information displayed. The user in the meantime can be attentive to his actual physical environment. In the coming weeks we will be carrying out additional user testing of our application in busy urban environments. The applications , obviously, relies heavily on GPS signal accuracy and continuity. We will also test the application in „street canyon“ locations within Dublin city. The updated results of our user-trails and additional spatial query functionality will be reported in the final version of this paper.

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