PhD Showcase: Haptic-GIS: Exploring the Possibilities

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ABSTRACT

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 through a device. Haptic enabled devices have recently gained much publicity in the computer games industry due to their ability to provide a more immersive experience. The use of haptic in the context of GIS and navigation assistance has not previously been considered. We present an overview of Haptic technologies and provide a commentary on how GIS and haptics may crossover and integrate. To demonstrate the potential of haptics for navigation assistance a simple case-study of using haptic feedback as a navigational assistant in pedestrian route planning software is presented. This case-study uses the OpenStreetMap(OSM) database and Cloudmade routing API.

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: Haptic I/O; H.5.1 [**Multimedia Information Systems**]: Artificial, augmented, and virtual realities

General Terms

Human Factors

Keywords

Haptic Feedback, Pedestrian Navigation, OpenStreetMap

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1. INTRODUCTION

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. Simple haptic devices are now commonly found on computer and video game controllers, in the form of force-feedback joysticks and steering wheels. In reality haptics have been employed mostly in a relatively unsophisticated manner ranging from rumbling video-game controllers and to vibration alerts on cellphones. Haptics has a broad and expansive range of potential applications: from handheld electronic devices to remotely operated robots. Yet outside of the haptic research and engineering community it is a virtually unknown concept [21]. The aim of any haptic system is that a user feels and interacts with a virtual model of their current environment. The potential of haptic technology has only recently started to receive the attention of the research community. This slow uptake can be attributed to two factors. Only recently has it been discovered that the human haptic sense is equally good at perceiving properties such, for example roughness, as the visual system [26]. Secondly the development of small scale wearable haptic enabled devices on which algorithms can be implemented are only starting to become available [31, 9].

In this paper we describe work in progress from PhD research into exploring the possibilities of integrating haptics into GIS. The last decade has seen GIS data and mapping move from the desktop application and desktop web-browser to the dynamically located mobile device with high expectations regarding user interfaces, query response times, and visualisation. We explore the possibilities for extension or redevelopment of GIS user interfaces to include haptics. This raises the question of whether popular location-based services (LBS) applications such as: pedestrian navigation, map visualisation, city exploration and assisted navigation can benefit or be enhanced by haptics. A case-study application is described for haptic-assisted pedestrian navigation for visually impaired pedestrians. State-of-the-art mobile phones are haptic enabled. This makes developing haptic-enabled software easier as there is a well understood testing environment. The primary source of haptic feedback on mobile phones is vibration. Despite the falsely perceived limitations of vibrations many mobile devices have the ability to create complex pulsing vibration patterns, not just continuous vibrations. Pulsing techniques allow for a richer display of haptic effects and add another dimension to convey information [30].

The paper is organised as follows. In section 2 we give an overview of the literature on haptics where GIS or spatial data and interaction is explicitly stated or studied. In section 3 we describe the motivation for the development of a pedestrian navigation assistant application which uses haptic-feedback. In this section we describe a model for the haptic-interaction process using spatial data. The pedestrian navigation assistant application is described in detail in Section 4. The paper closes with Section 6 where we outline some discussion and concluding remarks.

2. LITERATURE REVIEW

The literature on haptic-related research is very broad as it usually integrates cross-disciplinary research including: engineering, user-interface design, telecommunications, robotics, and intelligent systems. While research into using the sense of touch to communicate has been ongoing for decades the development of haptic-based devices was hampered by the availability of only "bulky or very non-discrete instruments" [28] such as head-mounted devices and backpacks (wearable devices) [31, 9]. Advances in mobile phone technology and design has seen the state-of-the-art mobile phones integrated with multiple sensors [10]. Hoggan and Brewster [10] comment that this "makes it an easier task to develop simple but effective communication techniques on a device as handy as a mobile phone". They describe the integration of actuators (a mechanical device for moving or controlling a mechanism or system) along with the mobile sensors for haptic feedback in a multi-modal interface. When combined with high resolution in-built cameras, on-board GPS, digital compasses, orientation sensors, and an accelerometer the mobile phone is equipped with the tools to support advanced haptic feedback interfaces. In Dai *et al* [7] the authors have demonstrated how a haptic-enabled mobile phone can be used as a drunk driving detection system. Their system works by reading values from a Google Android phone sensors (accelerometer and orientation sensor). Deviations in signals from the accelerometer and orientation sensor according to that of a normal driver are used to detect a potentially DWI (Driving While Intoxicated) driver. Spatial information analysis and handling requires the use of three cognitive spaces: haptic, pictorial, and transperceptual. Currently Geographical Information Systems interfaces do not yet integrate these three spaces in the same working environment [16]. Knowledge about designing haptic interfaces is still a young field and some key issues and challenges encountered have been outlined in the literature [15, 11].

We believe that the introduction of haptic technology into GIS would be of great benefit. In particular this work focuses on haptics in the context of navigation which is a central topic in GIS. Paneels and Roberts [21], who provide the first broad overview of the haptics field, describe some virtual map reading applications where electronic maps of US states are made tactile on screen - for example users could feel subtle bumps for county boundaries, large bumps for state boundaries, and a constant vibration on cities. Cervantes et al. [25] realized a tool for navigation in 3D virtual environments using the Novint Falcon haptic device. This technology is developed by the company Novint and has previously been exclusively used in the domain of computer game technologies. Cervantes et al. [25] showed that navigation could be greatly assisted in a virtual 3D environment through the use of haptics. This method was implemented on a large scale desktop device. The authors are unaware of any studies which evaluate the usefulness of haptics in a real environment using small scale devices. Ren *et al* [14] describe the development a multi-modal 3D GIS with a haptic interface which allows users to move through 3D representations of thematic maps. As variables such as temperature or humidity increase or decrease vibration feedback is given to alert the user. Newcomb and Harding [17] discuss the need for a multimodal interface in order to improve the human-computer interactions which is less in the traditional map interfaces due to information overload and emphasized on the need of audio, haptic or sonification. Hagedorn [8] investigates and assesses the functionality and viability of a novel multi-modal audio-haptic computer interface intended for non-visual geographic information retrieval. It has been shown that haptic clues allows individuals to build haptic mental models for better navigation skills in 3D virtual environments [25].

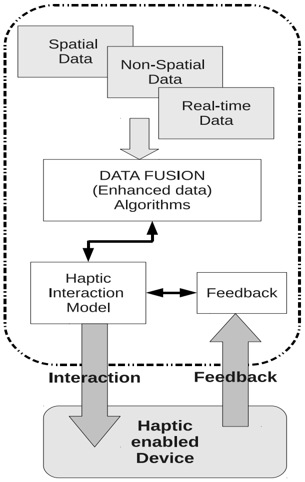

Figure 1: The haptic-interaction process using spatial data

3. HAPTIC-ASSISTED NAVIGATION

In this section we provide motivation and justification for the use of haptics in pedestrian navigation. Van Erp [29] argues that current popular navigation techniques are not "reasonable" or possible at all times. For example pedestrians use a "neck-down" approach and take their vision off their current environment. This has serious consequences like not paying attention to traffic in a busy street or not looking out for dangerous edges at the side narrow trail in the case of the hiker. Several authors [29, 24] discuss design of wearable haptic devices for assisting user for navigation and outlines about how the vibration alert can be used in conveying direction and deviation cues to the user in a way where it does not obstruct the users main activity. As stated above there are false perceptions about the limitations of vibrations as a feedback mode. Many mobile devices have the ability to create complex pulsing vibration patterns and not just continuous vibrations [30]. LoroDux [20] and HaptoRender [19] are two projects started by Lulu-Ann in 2009. The Haptorender project was to help map features for the visually impaired on OSM and then make it available for for users to navigate using a mobile device through the LoroDux project.

3.1 Motivation and Justification

One of the many difficulties experienced by those with vision impairment emerges from the communication barriers that prevent non-visual access to highly pictorial cartographic products and geographic reference sources. Without access to spatial information, the capacity for independent mobility, geographic learning, and communication concerning spatial concepts may be significantly reduced for anyone who cannot utilize traditional visual maps [13]. Crossing the street or the road, as a pedestrian, is a risk-laden task. This task becomes even more difficult for those pedestrians with visual impairments. There are a number of well-documented problems for pedestrians at the typical signalized crossings that are provided in most countries. These problems are: the fact that pedestrians are supposed to register their demand manually by pushing a button, but frequently do not do so; inadequate crossing time duration for slower pedestrians; insufficient responsiveness in the signals, so that the pedestrian stage is only available at a certain point in the signal cycle, regardless of demand [3]. In poor weather, pedestrians were more likely to walk against a "Flashing Dont Walk" or steady "Dont Walk" signal. The proportion of pedestrians obeying the traffic signals at this two-stage crossing was only 13% and it dropped to 3% when it was cold and snowing. The alarming low compliance rate at this crossing questions the effectiveness of staged crossings with pedestrian refuges at signalized intersections, especially in inclement weather [32].

In this paper our target user group are visually-impaired pedestrians. Several studies [27, 4] show that the usage of mobile devices for navigation amongst the visually impaired is high. While the cane and guide-dog are the oldest navigational assistance methods for the visually impaired the "most effective available mobility aid for visually impaired people is using a mobile phone device as it provides a fully supportive and stress free guidance" [4]. Visually-impaired pedestrians cannot use vision-based feedback systems. Studies also show that visually impaired pedestrians are less like to take the risks of "crossing while red" than other pedestrian road users take. A haptic-feedback approach is considered in this paper where feedback can take the form of audible commentary from the mobile device or vibration of the device. Audible assistance is available at many traffic signals where traffic signals emit a series of sounds to assist blind pedestrians and have been in operation in many countries for several decades now[23]. In Ivanchenko *et al* [12] the authors describe a novel camera phone-based system for helping visually impaired pedestrians to find crosswalks and align themselves properly before they attempt to cross. This application searches an image for crosswalk zebra stripes. Amemiya and Sugiyama [1] build a mechanism for creating a pseudo-attraction force designed for provide a haptic direction indicator. The device was used to assist visually impaired users to navigate on a pre-defined walking route. However, traffic signal detection was not considered.

3.2 The haptic-interaction model

In Figure 1 we extend the haptic visualisation process model of Paneels and Roberts [21] to describe a haptic-interaction model which relies heavily on spatial data to drive decision making. In our case-study application in section 4 we use OpenStreetMap as our source of spatial data. As described in Figure 1 this spatial data can be fused with other sources of data including non-spatial data and real-time data such as weather forecast reports, pollen counts, environmental information. The Data Fusion component provides the spatial decision making for the haptic model. In our case this the data fusion component is made up of the shortest path routing algorithms and the parsing and understanding of the computed route. The haptic interaction model component is where haptic actions, signals, or interactions are produced based on output from the data fusion component. The interactions can take any of the haptic forms mentioned above including vibration, pulsing, sound, text, or graphics. Using the software API on the haptic enabled device hardware the interaction is delivered to the device. This instructs the user to take some action. Feedback is then provided by the user. This can take many forms depending on the application. These forms include: movement of the device, pressing or touching the device, voice commands, or selecting a user-interface component from the screen.

4. APPLICATION OVERVIEW

In this section we give an overview of our application and will outline the various components of the application including the data, routing algorithms and mobile phone sensors.

- **Spatial Data Source: OpenStreetMap** OSM [18] is a very popular source of Volunteered Geographic Information (VGI). The OSM data model is very flexible and we have mapped our university town to include a great deal of spatial richness. To improve the web-based query performance of our application we maintain a local copy of the OSM database for Ireland (in PostgreSQL PostGIS - as described by Ciepluch *et al* [5]). We have extended the OSM tag/metadata ontology to include height information about traffic lights and lamp-posts. Tactile pavement areas and other physical features on paths and streets which assist visually impaired pedestrians are mapped, tagged and included in the OSM database.

- **Routing: Cloudmade routing API** The Cloudmade Routing API[6] uses OSM spatial data to provide powerful web routing services which delivers turn-by-turn directions. For this project we needed access to each of the nodes in the navigation path between the source and destinations points of a route. Using standard HTTP GET methods the coordinates of the user's start and destination points are sent to the Cloudmade Routing API. In this API shortest paths can be generated for: pedestrians, automobiles, and bicycles. The Cloudmade API is dependent upon a very rich OSM representation of the current location of the user. Provided geographical features in the OSM database are correctly annotated with "tags" the API can find realistic and accurate routings. The routing algorithm (most probably Dijkstra's algorithm) in the API can route pedestrians also through indoor paths provided these features are in the OSM database and correctly annotated to indicate a pedestrian thoroughfare.

- **Sensors: GPS and Orientation:** The Android phone

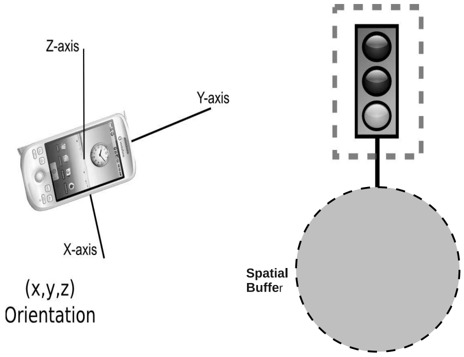

Figure 2: Extrinsic camera parameters in traffic light detection model

software provides API access to the sensors on the phone. We can obtain the user's current location in (latitude, longitude). The orientation of the phone is also accessible from the orientation sensor. This returns the angles for yaw, pitch, and roll. Here yaw is the rotation around the z-axis, pitch and roll represents the rotation around the x and y-axis respectively. The method `addProximityAlert()` is used so that we can alert the user when he has reached within a particular radius of a point. We use this so that we can alert the user with a different frequency of vibration that he has reached a way point or near the pedestrian crossing. These parameters allow us to calculate the extrinsic camera parameters. This is described in Figure 2. The spatial buffer is used to alert the user that they are in the correct location and now must hold the camera at the correct orientation so a picture of the traffic light may be taken. The positions and heights of all traffic lights in the town are stored in OSM.

- **Vibration Alarm:** The vibration alarm in the phone is the most important component of navigation in our work. The vibration alarm class in the Android is used in our work to provide the haptic feedback to the user. We can specify the duration of the vibration by accessing the API method `vibrate(long 2000.0)` to make the phone vibrate for 2 seconds. Vibration to a given pattern is possible by using `vibrate(long[] pattern, int repeat)` where "pattern" is an array storing times at which to turn on and off the vibration alarm and "repeat" holds the index for the pattern where the repeat begins and ends. Different patterns of vibration are used to provide haptic feedback to the user for: (1) path following ; (2) signalling a change of direction in the path; (3) alerting the user that they have reached an area which includes a tactile pavement near a pedestrian crossing; (4) to alert the user that he is pointing towards the traffic light post and can take a picture; and (5) to give feedback after the template matching of the picture of the traffic light to indicate to the user if it is "green to go" or "red to stop".
- **Camera** The camera in the phone is used to capture an image of the traffic light. We developed a simple template matching algorithm which matches the captured image with a set of template images of traffic lights [2]. If template matching returns a high correlation with a "red" signal template the user is given a pattern of vibration to indicate *stop*. On the other hand if template matching returns a high correlation with a "green" signal template the user is given a pattern of vibration to indicate they may proceed to cross the street. A set of template images are used to ensure that all styles of traffic light signal structures found in this environment are available for matching. An example of the template matching is shown in Figure 3

(a) (b) (c)

Figure 3: The template in (a) is searched for in the image (b). A visualisation of the corresponding correlation values are shown in (c). A high correlation value is found in the lower center of (c) indicating the presence of the template in question.

5. EXPERIMENTAL ANALYSIS

Experiments were carried out in fairly open areas and around low rise buildings. Two visually impaired participants assisted us in our experiments. A route within the university area was generated and traversed by the users. We selected this route as it consisted of a mix of both walkways on campus and a foot path beside a public road. Traffic light signal locations have tactile pavements near the crossing location. To check the accuracy of GPS we recorded the lat/long values at various points in the path by collecting them using the phone and compared it, by map matching, with the lat/long values of the OSM database. Less than 3% deviation was recorded between the values collected from the GPS and matched to the path or walkway objects in the OSM database. We tested the template matching algorithm by capturing different images (photographs of the traffic signals) at different times of the day. By setting a very high matching threshold value (0.95) for correlation we successfully filtered out the majority of False Positives(FP) and False Negatives(FN). In Table 1 we present the results of testing of the template matching component to automatically detect traffic light colors: (R) Red, (Or) Orange, (G) Green and (NL) No Light. There were 50 samples taken for each colour. If the returned correlation value of the template matching algorithm is not $\geq .95$ we return the decision as "No Light". This helps to eliminate cases of incorrect classification of a Red light and prevent the situation where the pedestrian is advised to proceed with crossing under a Red light. From the 50 test samples taken for each traffic light state the system responded correctly in at least 70% of cases. The remaining cases were usually an "NL" response which is provided for the safety of the pedestrian. In Table 2 we present the results of the actions of the user based on a particular suggestion from our system. In all cases the user was aware that it was a trial situation. From the 20 times the system directed the user to "wait", the users did

Table 1: The responses of the Traffic-light component

		Actual			
		R	**Or**	**G**	**NL**
Predicted	**R**	36	0	0	0
	Or	0	38	0	0
	G	0	0	42	0
	NL	14	12	8	50

Table 2: User response to the Camera component

		System	
		Cross	**Wait**
Action	**Cross**	11	0
	Wait	9	20

so. However in the case of the system directing the user to "cross", out of 20 trails the the users actually waited on 9 occasions and did not cross. When directed to cross the user did supplement the advice from our system by listening and attempting to gauge the reactions of other pedestrians. From the 11 times where the user crossed based on directions from the system, 3 of these were occasions where the audible sound signal at the crossing was clearly audible with no other distracting noise of vehicles. We feel that the visually impaired users are incorporating environmental awareness skills of their own with the advice from the system to make the decision about crossing.

6. CONCLUSIONS

In this paper we have presented a case study describing how haptic feedback in mobile phones can be used as a means for localization and navigation. Scalability of the application to work in new areas depends on the availability of OSM data in those regions. Other research has been found that blind people use both hands while using a cellphone as they hold the phone in one hand and use the fingers of the other hand to explore the phone [22]. One key advantage of our application is that the visually impaired pedestrian is not burdened with carrying another device. Our test participants remarked that navigation using a cane in one hand and the mobile in the other is a likely combination provided effective communication can be provided using different vibration patterns on the phone. The image processing component used in this system will remain as a "pluggable" component which by default is turned off. Our participants commented that they would like to maintain their independence at traffic lights by crossing themselves. In order to provide the user with instantaneous and current information the image processing algorithms must be of low computational complexity for successful implemention on the mobile device for this application. We found from the experimental trials that the participants sometimes ignored the indications from our application and went with their "instinct" while taking a decision making to cross. Using other environmental awareness skills (sound, detection of movement) our participants either waited for a longer duration or "went with the flow" of other pedestrians crossing at the same location.

When developing a non-visual method for exploring geographic data we feel that richer and more meaningful sensory feedback can be obtained from a system that enables intrinsically spatial tactile user interactions. Unfortunately, non-visual map exploration is a mentally demanding activity. In instances where a blind user is exploring a map on a conventional personal computer or mobile device, a standard mouse, pointing device, or the user's finger are the input devices most often used to both explore and manipulate the map scene. While this case-study used an example of the pedestrian navigation for visually impaired users we shall be working to extend this to a multimodal location and navigation system. The use of the full range of haptics cues will be considered including audio feedback and image assisted navigation for fully sighted users. More testing will be carried out in dense urban environments. Given the distractions and noise of busy urban centers how effective will vibration alarms be? To develop a Haptic-GIS the GIS community must think beyond the "slippy-maps" and AJAX-driven interaction and feedback models of web-based GIS and location-based services on mobile devices. The recent changes made to the Android API classes for location and orientation of the mobile phone will be incorporated into our work.

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