Integration of LiDAR and stereoscopic imagery for route corridor surveying

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ABSTRACT:

Transportation networks are, typically, one of the most economic valuable resources for any nation requiring a large percentage of GDP to build and maintain. These route corridors attract their own unique set of spatial information requirements in terms of overall management including planning, engineering and operation. Various disciplines within a road management agency require high quality, spatial data of objects and features occurring along these networks from road infrastructure, sub-surface pavement condition through to modelling noise. This paper examines the integration of relatively novel sensor data against some pressing spatial information requirements for a small European road management agency.

LiDAR systems are widely available and now used to record data from both aerial and terrestrial survey platforms. One of the chief LiDAR outputs are X,Y,Z points enabling a reliable 2.5-D geometric surface to be produced. Stereoscopic imagery is also collected from similar airborne and terrestrial mobile platforms. Both provide different datasets in terms of their respective optical and geometric properties. For example, stereoscopic cameras mounted on a survey vehicle record different data compared to LiDAR mounted near vertically on an airborne platform. Airborne LiDAR provides a more comprehensive geometric record whereas stereoscopic imagery can be used to provide a more comprehensive visual descriptor of the immediate route corridor. Acquisition systems for both sensors are relatively well understood and developed. Both systems collect large volumes of data that require a significant amount of data processing in order to produce useful information. A more efficient result can be achieved by integrating these two datasets within a GIS. The preliminary results of integration of airborne LiDAR with ground based stereo imaging systems are presented. How well this integration satisfies the growing spatial information requirements of the road agency are also examined.

Background

The importance of transportation networks including road, rail, air and water in most economies is underlined by the statistics for historic and forecast spending and national and international level (DOT, 2007; DFT, 2007 and DGEAT, 2007). The popularity of roadways, as one of the chief transportation conduits, has resulted in continued government investment in designing, building and maintaining these ever expanding networks (DGEAT, 2007). A broad spectrum of information is required to manage various activities that occur along these transportation corridors including infrastructure and asset data. This information is required for a variety of activities including; road maintenance, pavement condition, street furniture upgrade, safety analysis, road user charging and noise modelling, This is borne out by recent compilation of specialised base mapping datasets for the transportation industry for example, Ordnance Survey, the UK national mapping organisation (ITN, 2007), national standards for populating route corridor asset registers (HAPMS, 2007) as well as upsurgence of specialist road network asset inventory software (Exor 2007, Symology 2007). Data can be collected by a variety of remote sensing methods including spaceborne, airborne and terrestrial sensor systems. Terrestrial based systems include stereoscopic cameras mounted on road survey vehicles and airborne systems include LiDAR. Stereoscopic camera systems, usually mounted orthogonal to direction of travel, collect image data enabling 3-D in-frame measurements to be extracted. These together with any visual data for example, road sign damage can be stored in a database. Airborne LiDAR system acquires XYZ point data, using a vertically pointing sensor, along the route network enabling a high resolution 2.5-D mesh of the route corridor to be constructed. These two approaches result in different spatial content with associated strengths and weaknesses in terms of spatial information recorded. It has been demonstrated that a GIS is the most efficient and cost effective system for handling route corridor infrastructure assets (Husone et al., 1997). Therefore, a more comprehensive record can be achieved by integrating the two sources of data within a GIS. This step paves the way for examining data fusion methods using multi-platform, multi-temporal LiDAR, imagery and indeed other sensor datasets.

Mapping Systems

Survey vehicle stereoscopic mapping system

Ohio State University's centre for mapping was one of the first research groups to pioneer the development of dynamic stereoscopic image mapping systems for route corridor mapping back in the mid-1990s (Blaho and Toth, 1995; Bosler and Toth, 1995 and Bosler and Toth, 1996 and Jeyapalan, 2004). Developments extended beyond stereoscopic image collection and measurement to automatic feature extraction (Habib et al., 1999; Habib 2000; Tao 2000; Tau 2001 and Toth and Grejner-Brzezinska, 2004). Mobile stereoscopic image mapping technology is now reasonably well established with a number of companies offering this as a commercial service (Lamda, 2007; Geo3-D, 2007; Omnicom, 2007 and Romdas, 2007). The author (more recently based at NCG) has been involved designing one particular variant; RouteMapper UltraX (RouteMapper, 2007). The underlying objective for RouteMapper UltraX was to design a *fit for purpose* mobile mapping solution which could be easily replicated and transported for mobile mapping. Installation, calibration, operation and support had also to be relatively straight-forward, reducing this to a one man operation.

RouteMapper UltraX stereoscopic mapping system: Four progressive scan cameras (1392*1024) are connected to a dual Xeon 3.6 MHz datalogging PC via CameraLink. Synchronisation and triggering functions are provided using a industry standard module including a high speed GPS timing unit. Standard real-time, corrected DGPS is used as primary navigation module while various configurations of sensors can be used for secondary navigation depending on operating environment including optical distance measurement instrument through to full inertial measurement unit. Camera calibration is carried out each time cameras are moved, this is designed to be carried out in the field. A number of 3-D control points are set out directly in front of the cameras usually extending out to about 50m range and 7m in height. The resulting transformation handles camera model as well as exterior orientation with respect to a datum point on the survey van. This enables 3-D measurement to be carried out, using the DGPS antenna as the local datum point. All stereoscopic 3-D measurements are calculated with respect to this datum point. A secondary transformation is carried out to rotate this vector into local map grid coordinates. All measurements are usually carried out in the same plane as the survey van. Platform orientation, using an IMU is required for *out of plane* measurements. If there are two pairs of stereo, then two sets of calibration are performed.

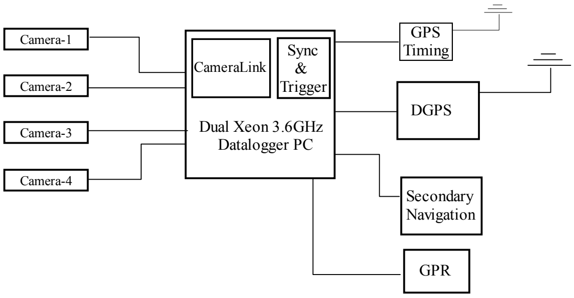

Figure 1. Road stereoscopic image mapping system

The system is powered-up at the start of survey. Self checks are carried out ensuring correct camera initialisation, adequate navigation operation and sufficient disk space. The progressive scan cameras are fitted with auto iris-lens enabling sections of route corridor to be surveyed under varying illumination.

Figure 2. Front seat view of Routemapper_UltraX datalogging system on left and moving map display on right.

The present system handles four cameras but has the ability to handle more using a simple client-server architecture. These are positioned and orientated ontop of the survey van depending on mapping requirements. The frame capture rate also depends largely on mapping requirements and associated vehicle speed. Typical capture rates vary between 3 frames per second and 8 frames per second. Over 1.2kW of power is provided using split chargers, deep cycle batteries and sine wave inverters. A stable power supply is one of the key ingredients to successful day to day operation of these systems.

Figure 3. Rear survey vehicle view of Routemapper_UltraX datalogging system displaying main datalogging PC, primary & secondary navigation and associated power module.

The navigation, timing and image datasets are processed after survey. The prime function is to ensure that the correct navigation record is assigned to the correct image set. Secondary navigation is back interpolated where the primary source has failed. Additional sensor data such as ground probing radar (GPR) can also be integrated. The sampling rate can be set to match any sensor using standard interpolation techniques. The final step of data processing is to produce metadata for all survey datasets. This enables a large number of surveys to be rapidly accessed by the browser in a structured fashion

Figure 4. Close-up of one of the cameras on top of the survey vehicle

The browser software comprises image, map and database displays together with associated toolbars and drop down menus. The user to navigate through the recorded data using interactive image controls or via the mapping interface. The user can click play and view all four cameras whilst position of survey van updates dynamically in a moving map display. 3-D in-frame measurements can be carried out, recording both dimensional as well as positional information. This together with any additional attribute can be stored in survey database. Standard GIS functionality is available including spatial and aspatial query. The browser is lightweight and designed so that users can learn basic functions in a very short time. Presently, 3-D line measurements require four separate operators mouse clicks. This is a task that could be more efficient with automated pattern matching.

Figure 5. Browser depicting imagery and map displays

Additional modules have been developed to enable specialist asset register construction. A wider audience can access this data over a recently developed, easy to use Internet browser plugin. This can be particularly useful if an organisation comprises many departments such as road planning, maintenance and operations.

Airborne LiDAR

Airborne LiDAR has been available since the late-1990s (Hill et al., 2000) has been accepted as an accurate, effective method for data collection (Iavarone, 2005). This high resolution XYZ point data can be collected during the day or night onboard survey aircraft. LiDAR data acquisition has been well documented for a range of applications (Kidder et al 2004 and Veneziano et al., 2002). Very fast scanning technology at rates of upto 150kHz enable reasonably large swaths of ground to be surveyed in a short time for a variety of end user applications including flood-plain mapping, utilities, transportations and municipal surveying (Hill et al., 2000). Some of the negative points include requirement for rigorous ground control and *data holes* due to absorption by certain ground target material (Hill et al., 2000), false readings due to reflection from water bodies (Veneziano et al., 2002) and *noisy* data due to aerial water droplets such as clouds and mist (Hill et al., 2000). Data processing still demands a reasonable amount of manual input evidenced by one of the chief outputs; automated production of *bare-earth* digital elevation model (**DEM),** been described as still "in it's infancy" (Chen, 2007). The information content is also quite high for example, upto five levels of data processing resulting in five distinct data products have been identified (Flood, 2002). Data volume also needs to be taken into account with a typical 20km X 12km survey resulting in 25 million XYZ points (Kidder et al., 2004). Airborne LiDAR has also been used for route corridor design (Uddin 2002 and Veneziano et al., 2002) and route inventory (Shamayleh et al., 2003). In all cases, LiDAR has been found to increase mapping efficiency whether it's for planned routes or mapping out existing infrastructure.

Airborne LiDAR dataset was provided for this initial study by Ordnance Survey Ireland, (OSi, 2007) using a Leica ALS50 150kHz airborne scanner (Leica, 2007) flown onboard a twin-engined aircraft at 4000' AGL. The test section, acquired in September 2006, was over the N25, a small section of national roadway about 8km East of Cork city, Southern Ireland. Average dZ was reported to be better than 0.20m when checked against ground control. The data was processed to produce three separate products; digital surface model (**DSM)**, vegetation layer and buildings. Building outlines from orthophotos were used to automatically segment geometry from XYZ point cloud data.

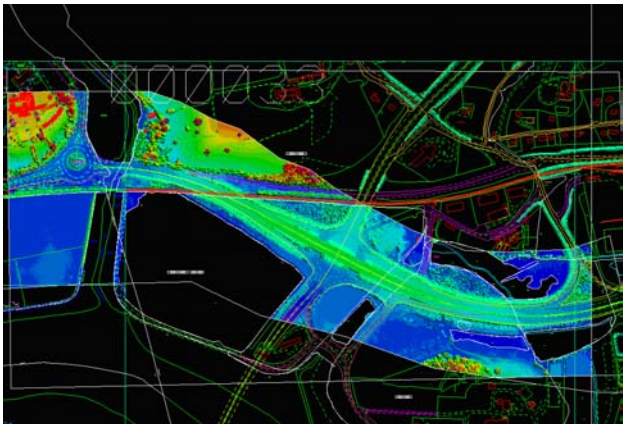

Figure 6. LiDAR (all layers) data from OSi aerial survey at 4000' AGL.

Integration of stereoscopic imagery and airborne LiDAR

A number of researchers have examined the advantages of integrating LiDAR with other datasets within a GIS. Kidder et al (2004) carried out an evaluation of methodologies employed to make LiDAR compatible, consistent and useable within a GIS. These focused on data handling, error detection and geodetic transformation. One of the chief conclusions centred on understanding the errors in LiDAR data and advised further research before wholly relying on this dataset for certain applications. Kressler et al. (2006) integrated LiDAR, image data and spatial databases to produce a higher resolution building/land classification map. Rottensteiner et al. (2003) used aerial imagery to aid building outline extraction and recommended further examination of GIS datasets for assessing data quality. In all cases, GIS was perceived as useful whether as a spatial repository, aiding LiDAR processing or an environment for checking data quality.

This research project focused on bringing together two data types that have been recently developed over the past decade and integrate these within a GIS with specific interest in route corridor mapping. Spatial information is required by Ireland National Road Authority (**NRA**) for various uses including; Noise modelling, Asset mapping, and Safety. Some of the various features and objects are listed below, Table 1. There are, of course, a multitude of additional phenomena, features and objects, occurring along the route corridor, at various levels of detail that are of interest to NRA but are not dealt with here.

Feature/Object	**Dimensions**	**Location (Road Centre Line)**
Infrastructure		
Roadside Kerb	10cm (continuous)	<50m
Road centreline/Central	10cm – 10m (continuous)	<5m

reservation		
Safety barrier	10cm (upto 250m)	< 75m
Bridges	30m X 100m X 8m	<75m
Embankments	30m X 500m X 50m	<150m
Walls	50cm X 15m (continuous)	<150m
Street Furniture		
Street lamps	20cm X 15m	<75m
Traffic signs	50cm X 5m	<75m
Road surface signs	6m X 10m	<75m
Traffic lights	50cm X 3m	<75m
Milepost markers	10cm X 75cm	<75m
Telecom points	50cm X 2m	<75m
Drainage	50cm (continuous)	<75m
Road stud reflectors	15cm X 15cm	<75m
Engineering		
Sight line	Upto 5km	<75m
Slope/Grade	+/- 45-degrees	<75m
Camber	+/- 10-degrees	<75m

Table 1. Features and objects occurring along a route corridor

The main stereoscopic browser engine was modified to include stereoscopic image display, LiDAR display and conventional map display. The latter was populated by simple plan view of elevation data. The LiDAR display was provided by a Microsoft .NET compatible SDK (ScienceGL, 2007) to enable preliminary integration of LiDAR with Stereoscopic imagery. DSM was exported as ASCII point cloud, this file was read by the LiDAR SDK on start up and displayed as a textured mesh ranging in colour from blue to red, classified on height value. The test dataset covered a 5km section of route corridor.

The current position could be set, in the browser so, that the user was occupying the same position in all three display; stereoscopic, LiDAR and map at any instant. The user could control navigation through the data in any of the three display environments using mouse controls or toolbar buttons along tool bar. Pre-stored objects in the underlying database could be chosen from a table. This enabled the browser to update all three display environments wand displayed the stored data. Measurements could be carried out in the stereoscopic or LiDAR windows with the resulting point or line plotted in all three displays. Volume measurements, including embankment and cutting estimates could be computed in LiDAR display.

Results and Discussion

Initial results to date are confined to the qualitative aspects of integration. These findings are presently being used to refine integration approach. There were a number of issues arising from preliminary integration of these datasets firstly, stereoscopic imagery, acquired from survey-vans, results in a very high resolution dataset where 5cm text can be read from street lamps even from survey speeds of 100km/hr. This data is collected orthogonal to direction of travel so, full driver view geometry is possible including road signs and underneath bridges. The disadvantage is that this field of view is fixed so, it's impossible to inspect far side of walls or buildings. Resolution and associated measurement accuracy decrease with range. Measurements out to 30m can made carried out at the decimetre level but long range measurements (100m to 1km+) cannot be carried out at this same decimetre level. Large embankments and bridges are difficult to measure and sometimes obstructed by camera field of view (nominally 50^{o}). Digitising using stereoscopic imagery acquired from survey vans can be a quite slow. In a recent exercise, an average of 15km per day was achieved where operators were tasked with digitising embankments, walls, bridges and buildings along a route corridor for noise modelling.

LiDAR records XYZ geometry over the entire route corridor, collected from plan view. This allows the user to measure large features such as embankments as well as small features such as drainage gullies. Measurements can be carried out relatively quickly since all mouse clicks take place in the one display. These is no need to click on the same feature twice in two separate displays. The synoptic coverage of LiDAR enables features and objects behind walls such as building height to be measured. Road incline & camber angles can be recorded as well as line-of-sight measurements.

Figure 7. Browser depicting stereoscopic, mapping and LiDAR display, off ramp to the left

However, objects like road signs, traffic lights cannot be easily classified as to state of repair or indeed, in some cases, object type. Obstructions such as tree canopy, tunnels and bridges result in holes in the data or missing sections. Integrating both datasets resulted in a more comprehensive digital record of the route corridor and allows all features listed in Table 1 to be classified, measured and stored. The ability to measure 3-D features at a location as well as more synoptic road measurements using LiDAR, all within a single display, increased productivity. Having stereo imagery integrated with LiDAR meant that objects and features could be classified with additional descriptor information and with greater certainty.

This preliminary study has also raised a number of issues including Geometry, Temporal, Architecture and Interface that need addressing when integrating these two datasets, Table 2. The view-shed of LiDAR and stereoscopic displays should match in terms position, orientation, vertical and horizontal fields of view (FOV$_{h}$, FOV$_{v}$) & range. Dataset resolution should be similar so, that differences between scale, dimension and detail are minimised. Time interval between data acquisition of either imagery or LiDAR should be kept to a minimum so that scene information is similar. It is likely that long route corridors will result in very large data files. These should be stored in smaller files and smart preloading techniques used to manage their retrieval and display. The browser interface needs to be easy to use and intuitive with a logical in terms of work flow so, that the user can easily retrieve, measure and record data along the route.

Type	Item	Comment
Geometry	View shed	Coincident in terms of position, orientation, FOV_h, FOV_v & range
	Resolution	Similar resolution so that scale/dimension/detail appears approximately the same
Temporal	Data Acquisition	Minimise time difference between acquiring two datasets
Architecture	Smart Route segmentation	Logically store a route as a number of smaller models and use pre-loading techniques to load/flush sections as user moves through the data
Interface		
	Displays	User-switchable between *locked* and independent. Independently re-sizable.
	Navigation	Intuitive mouse and buttons
	Orientation	Overview map showing user position
	Measurement	Concurrent display of measurements in all displays (where possible)
	Work flow	Logical order enabling user to view data and carry out measurements.

Table 2. Issues to be considered when integrating stereoscopic imagery with LiDAR within a GIS

A number of researchers have investigated various integration and more advanced data fusion techniques. Elementary integration of LiDAR and stereoscopic imagery was developed by Yamuchi (2006) for automated guidance. Fusion of LiDAR and aerial imagery especially, when acquired from different platforms, is not a trivial exercise. Elstrom et al., (1998) developed stereo based method for integrating colour imagery with LADAR. Habib et al. (2005) investigated registration of aerial LiDAR and imagery to a common reference frame using straight line features. Zhang et al. (2006) investigated potential of integration of aerial imagery and LiDAR using simulation, Habib et al. (2004) examined integration of LiDAR and photogrammetry for close range application. Iavarone (2005) describes the results of fusing aerial and terrestrial LiDAR data sets.

Dynamic terrestrial LiDAR survey systems have been developed commercially to collect route corridor data from moving survey vehicles (Geospatial, 2007; 3DLaserMapping, 2007). The 3DLaserMapping system can collect upto 40,000 points per second with a positional accuracy of better than 1m whilst the point to point accuracy is better than 3cm within the point cloud. These developments indicate that data fusion using multiple, cross platform imagery and LiDAR datasets is attainable in the near future.

Conclusions

Stereoscopic imagery collected form road survey vehicles and airborne LiDAR have developed considerably over the past decade. Both have a significant role to play in mapping and recording route corridor infrastructure. Integration of these two datasets results in much more efficient approach to providing the diverse spatial information required by national road agencies.

A number of key issues need to be addressed in designing an integrated stereoscopic and airborne LiDAR GIS. These revolve around geometric and temporal characteristics of data together with system architecture and interface.

Advances in data fusion methodologies using cross platform LiDAR as well as LiDAR & imagery is evident in the literature. Terrestrial LiDAR systems mounted on survey vehicles are now available commercially. These developments point to greater cross-platform sensor integration and richer data fusion outputs in the very near future.

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