MOBILE MAPPING IN GPS-DENIED AREAS: A HYBRID PROTOTYPE

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ABSTRACT:

This paper describes research undertaken to develop and test a prototype system to readily capture and/or map 3D information of objects of interest in GPS-denied areas. The captured information of objects in the field is automatically determined and then sent electronically to an office environment where it interacts with GIS and CAD software. This portable mapping system combines the theory of photogrammetry, the principles of conventional land surveying and the techniques of dead-reckoning. The resulting hybrid technology has been consolidated into a device which geo-references points of interest located over any object of any size within a global or common reference system, without the need for a network of control points. The components of the single unit prototype device include: a digital compass, a medium-range laser range finder, and a GPS-enabled Smart-Phone (incorporating a digital camera and a Personal Digital Assistant with on-screen digitising facilities). The result is a portable unit that allows for automatic geo-coding of points of interests shown in the photos. In this study, the mobile unit was tested and used to determine the position of selected points located in Australian national parks (such as trees, landscape areas, public facilities and/or structures), where dense tropical rainforest vegetation and narrow valleys often obstruct GPS signals. Limitations in quality, precision and performance of the proposed system have been assessed and the architecture of the software environment is currently being improved in order to synchronize the functionalities of the proposed system and facilitate user interaction. The paper concludes with an evaluation of the system's potential for real-time operations along with the factors that present a challenge to its universal implementation today.

1. INRODUCTION

With the continuous development and miniaturization of mobile telecommunication systems, information can be distributed universally to end-users anywhere and at any time (Blumer, 2004; Novak, 1995). This reality has contributed to the expansion of portable multi-sensor systems, allowing for the development of a variety of mobile mapping services based on the idea of combining or integrating in general the following functions or components:

1. Image capture
2. Coordinate measurement
3. Temporary data storage devices
4. Network connection
5. Screen display
6. On-screen digitising
7. Automatic orientation

A common feature of present hand-held mobile mapping systems for geo-coding points or features of interest such as government or public assets, is the use of the Global Positioning System (GPS), which has also become established as the preferred method for outdoors position sensing for wearable computers and mobile computing in general (Ladetto and Merminod, 2002).

Some of the disadvantages of portable GPS units are the loss of signals due to obstruction by tall buildings in urban environments and the attenuation of signals by foliage of tall trees in densely vegetated areas. Erroneous signals due to multi-path effects commonly caused by ‘urban canyons’ and poor accuracy in relation to the scale of the measured locations are other factors which limit the direct use of mobile GPS based units.

These drawbacks related to poor satellite ‘visibility’ and signal interference can be averted in most situations by combining the GPS receivers with other measuring devices such as laser range finders, digital compasses and imaging sensors to mention some. In this way the user may move the GPS unit away from the source of signal disruptions while still being able to remotely map objects of interest and their attributes in the challenging settings.

In this context, this paper proposes and tests a conceptual framework for a mobile mapping device which was experimentally used for geo-referencing government assets located in national parks surrounding the city of the Gold Coast in Queensland, Australia. These assets range from landscape areas, water features, utility poles to points of heritage or archaeological significance and other recreational facilities such as picnic areas and public venues. The location of these assets may be found in narrow valleys of forest areas or in reserves characterized by tall eucalyptus and coniferous trees. Figure 1 gives an indication of this type of environment.

The proposed measuring device was conceived to readily acquire and transfer 2D and relative 3D spatial and imaging information via the Internet. Its components include a GPS-enabled smart-phone with image capture capabilities and a Personal Digital Assistant (PDA) component featuring on-screen digitising facilities and an Internet connection. An external digital compass and a laser range finder are also attached to the telephone unit.

Figure 1. Densely vegetated area can attenuate GPS signals

The combination of these components allows the system to capture and geo-reference spatial information of objects of interest located in GPS denied areas to a specific control network or coordinate system. This captured information can then be used either in the field as required or sent electronically to an office environment where it can interact within GIS, visualization or CAD programs thereby assisting data validation while also improving the speed of communication.

A controlled field experiment is described to demonstrate the capabilities of the system. This experiment is not intended to be exhaustive, but it gives useful results which can be taken as typical indicators of the accuracy to be expected from the proposed measuring tool.

This was ascertained by evaluating and comparing statistically the coordinate values obtained during the test phase and the coordinates values of the same objects and their attributes as captured with what was considered to be more accurate land surveying techniques. These techniques make use of sophisticated electronic total stations combined with embedded GPS instrumentation, with all measurements linked to stable control stations situated outside the areas of poor satellite signal reception.

2. COMPONENTS OF THE PROPOSED SYSTEM

Figure 2 illustrates the overall architecture of the proposed prototype hybrid system. The four major components include the *i-mate™ JASJAM* mobile phone (1) which is GPS enabled by a wearable GPS receiver (2) (the *Foretrex 100* by Garmin) via its serial cable. The positional accuracy in 2D (i.e. X and Y) of a single point determination using this receiver is reported by the manufacturer to be in the region of +/- 7 m. For applications demanding greater accuracy, the GPS unit is capable of receiving a data stream from external GPS devices or systems.

The Mobile phone is comparable in size to traditional mobile phone handsets. In addition to GSM/GPRS features, the *i-mate™ JAZJAM* incorporates PDA functionality using the Windows Mobile 5.0 operating system which supports Microsoft Office formats (Word, Excel, PowerPoint). This telecommunication device uses a processor operating at 400 MHz and includes 128MB of Flash RAM and 64MB SDRAM memory, which can be used to save and/or create applications and files. The *i-mate™ JASJAM* also incorporates a 2 MPixel CMOS (Complementary Metal Oxide Semiconductor) camera. A simplistic image processing software for Pocket PCs, namely the *Spb Imageer 1.5,* was downloaded as freeware from the Internet with the purpose of processing the pictures taken with the camera if required as well as to facilitate the digitisation of selected points of interest on the LCD display of the mobile phone.

The third component of the system is a digital magnetic compass (3) by *Sherrill compasses*. The sensors of this instrument can define the three orientation angles which correspond to the three standard photogrammetry angles (Fiani and Pistillo, 2004). The nominal accuracy of these angle measurements is +/- 0.5^0. In addition, the compass features a digital clock and a dedicate mounting bracket so that the compass and the camera of the mobile phone can be synchronized at the time of taking pictures while the bracket allows for the compass to be attached with pads to the back flat surface of the telephone unit.

The compass can also warn about the presence of conditions that adversely affect the azimuth reading. This may be the case of subterranean ferromagnetic deposits, large metal objects, or anything capable of generating a magnetic field, which will pull the azimuth reading out of an acceptable range of accuracy. The magnetic azimuth can also be corrected by giving an appropriate declination angle.

The final component of the system is a laser range finder (4) (the *Disto A3*, www.disto.com.) with a typical measuring accuracy of +/- 3mm up to 30 m (2 sigma standard deviation) as per manufacturer specifications. Laser range finders have been extensively used in mobile mapping projects. Some interesting applications and functions of these measuring devices can be found in Kim et al. (2004), Shrader (2006) and Yuichi et al. (2007).

Figure 2. The components of the system

3. DESCRIPTION OF THE PROTOTYPE

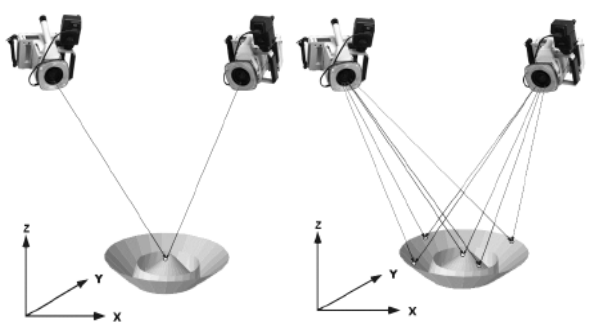
As illustrated in Fig.2, the digital compass is attached to the structure of the phone using a dedicated mounting bracket. This plastic bracket was attached so that the LCD screen of the compass was aligned with the plane defined by the image sensor of the camera and was positioned to avoid the magnetic interference emanating from the Lithium batteries of the phone and the speakers' magnets.

On the other hand, the laser range finder was clamped to be perpendicular to the imaging plane thus providing for correct linear measurements to a specified target. All relative distances between the imaging sensor of the camera, the compass and the laser range finder were determined to the millimetre using an electronic digital calliper. This was possible by following the design features of the instruments as per the specifications in the respective instruction manuals.

As previously mentioned the system was conceived to measure points of interest by way of well known remote measuring techniques or procedures which could be used in combination or individually depending on the characteristics and location of the objects of interest. These techniques are:

1. Close Range Photogrammetry
2. Land surveying
3. Dead reckoning

Photogrammetry uses the basic principle of triangulation, whereby intersecting lines in space are used to compute the location of a point in all three dimensions. However, in order to triangulate a set of points the camera position and aiming angles (together called the orientation) for all the pictures in the set must be known.



Single point triangulation   Multiple point triangulation

Figure 3. The photogrammetric concept (www.geodetic.com)

Triangulation is the principle used by both photogrammetry and conventional surveying techniques to produce 3-dimensional point measurements. By mathematically intersecting converging lines in space, the precise location of the point can be determined. However, unlike land surveying instrumentation (i.e. total stations), photogrammetry can measure multiple points at a time with virtually no limit on the number of simultaneously triangulated points.

In the case of a total station, two angles are measured to generate a line from each observing point to the object. In the case of photogrammetry, it is the two dimensional (x, y) location of the target on the image that is measured to produce this line. By taking pictures from at least two different locations and measuring the same target in each picture a "line of sight" is developed from each camera location to the target. If the camera location and aiming direction are known, the lines can be mathematically intersected to produce the 3D (i.e., X, Y and Z) coordinates of each targeted point.

In order to triangulate the location, accurate estimates of camera external geometry (position and orientation of the camera), and internal geometry (lens distortion, focal lengths, optical centres) must be calculated. This is necessary to relate camera information expressed in pixels to the external world coordinate system expressed in meters (Wolf and Dewitt, 2000).

This process is referred to as *camera calibration*. Camera calibration defines the parameters which are used to remove distortions caused by tilt, relief and perspective. These distortions usually generate a shift in the location of a projected point onto the image plane. The calibration parameters of the camera component of the phone used in this study were defined by using the camera calibration process of a conventional close–range photogrammetric software, namely Photomodeler by EOS systems. For in-depth information on camera calibration the reader is referred to Fryer (1996).

The basic land surveying practice employed here combined the laser range finder and the digital compass for measuring a series of straight lines or segments along a route or path of interest. By knowing the length and direction of each segment of the route it is possible to compute the position of changing points relative to a given starting or initial point (i.e. as provided by the GPS unit of the system).

This process is similar in principle to a dead reckoning technique whereby the estimate of a present position is a function of projecting heading, distance and/or speed from a known past or fixed position (Kim J. W. et al., 2004; Ladetto and Mernimond, 2002).

4. HOW THE SYSTEM WORKS

This section describes the photogrammetric process of the proposed device. Aspects related to the functioning and applications of the laser range finder and the digital compass, as auxiliary tools of the overall measuring process, will become self-evident in the ensuing section which gives the details of the field experiment.

When the camera generates an image the compass simultaneously measures the three orientation angles of the camera. This angular information is fed to a set of dedicated functions programmed in an Excel file hereby referred to as *data.xls*. This Excel file is embedded in the PDA of the *i-mate™ JASJAM* and it also contains the camera calibration parameters and the known geometric relationships, that is, the offsets and angles separating the components of the device in Fig. 2.

Once a stereo pair of images is taken (see Fig. 4), the user selects and digitises with a stylus on the LCD screen of the phone the desired target points on both images. For example, selecting Point 4 on Photograph 1 and selecting its corresponding Point 4 on Photograph 2. These photographs are stereo images of a scene taken from two converging angles where the camera positions and relative distances and orientations between them were defined by the laser range finder and the digital compass.

The digitisation of the selected points and their relative coordinates within the images (pixel position) is carried out using the image editor for pocket PCs mentioned in section 2. Upon completing the digitisation of the selected points of interest that information (the pixel coordinates) is forwarded to a second *.xls* file (*process.xls)*, where it interacts with the data from *data.xls* in order to compute the 3D coordinates of the chosen points of interest relative to the position of the cameras at the time of taking the photographs.

Photograph 1 Photograph 2

Figure 4. Converging images to the objects of interest

When all the selected points have been digitised, the results of the individual computations for the X and Y coordinates of these points and their relative elevation (Z) are recorded automatically in a tabular format in an additional file called *results.xls* in which the data is then transformed relative to the initial or original fixed GPS station. All the *.xls* files are linked using dedicated scripts programmed with visual basic for pocket PCs.

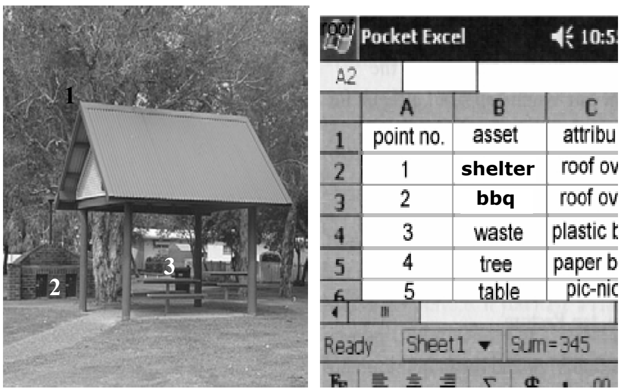


Figure 5. An example of data ready for export

The file *results.xls* containing the X, Y and relative Z computations together with one of the images showing the points of interest, each with a designated point number, is now ready to be used in the field if required or to be exported to an external location via the Internet connection capability of the *i-mate* ™ *JAZJAM* (as illustrated in Fig. 5). The attributes are inserted manually in the appropriate cells of the Excel file to correspond to the objects photographed. Excel is a standard that is easily recognized and adapted by various GIS and CAD popular programs such as MapInfo or AutoCAD.

5. CASE STUDY

The plan was to measure a line of five adjoining segments through a forest trail of an area of the Springbrook National Reserve (Queensland, Australia) until reaching the desired destination, that is, a public picnic area where the picnic tables, barbeque units and other recreational facilities were to be mapped together with their attributes (type of asset, material, function, life span etc.).

Local government directorates routinely carry out periodic surveys of public assets in order to update and monitor the state of these public facilities for planning capital expenditures and safety purposes. At present the mapping process in GPS denied park areas such as the one herein considered are carried out by way of Electronic Total Stations instruments using conventional land surveying techniques.

This surveying instrumentation can yield positional accuracies in the order of +/- 10 mm but the techniques involved can be very time-consuming, usually require additional personnel and is more expensive to carry out as compared to procedures which make use of hand held GPS receivers operated by one person alone.

However, the consistency and accuracy of results of this more precise form of survey formed the basis for an overall statistical analysis as the results obtained from the proposed system (in terms of coordinates values) could be directly compared with the coordinates results obtained with these more accurate surveying methods.

The field test was carried out on a relatively uneven terrain so that the influence of vertical elevation changes could be taken into consideration. An initial or starting station (station O in Fig. 6) was established in an area of clear sky visibility to avoid signal interference and was computed by averaging 20 GPS fixings from the receiver of the *Foretrex* unit using the signals from at least eight satellites with an elevation angle greater than 30^o.

In most cases positional accuracies of approximately +/- 1.0 can be achieved with this averaging method as compared to the nominal positional accuracy of the GPS unit, that is, +/- 7m. This relatively time consuming procedure was adopted in this testing phase to improve the positional accuracy of the starting station because all subsequent measurements and results would be based on this initial point.

Starting from station O the distances and directions to the next points were measured in progression. These points, or turning stations (A, B…etc in Figure 6), were well-defined natural features such as trees or rocks with contrasting patterns and located at distances estimated visually to be about 30 meters in a direction that was suitable in terms of clear visibility and access.

In order to avoid any confusion in identifying the changing stations a picture was taken in order to clearly identify the projection of the laser beam over the selected turning point and thereby create a visual record of every turning station involved in the fieldwork. The specific distance of 30 metres was chosen for maximizing the accuracy of the laser range finder as per manufacturer specifications.

At each turning point the compass was also turned to the previous changing point so as increase the accuracy and reliability of the measuring process. An error propagation analysis of the measuring scheme shown in Fig. 6 determined an overall cumulative positional error for the last turning point

(point E) of 0.3 metres in relation to the initial station or point O in Fig. 6.

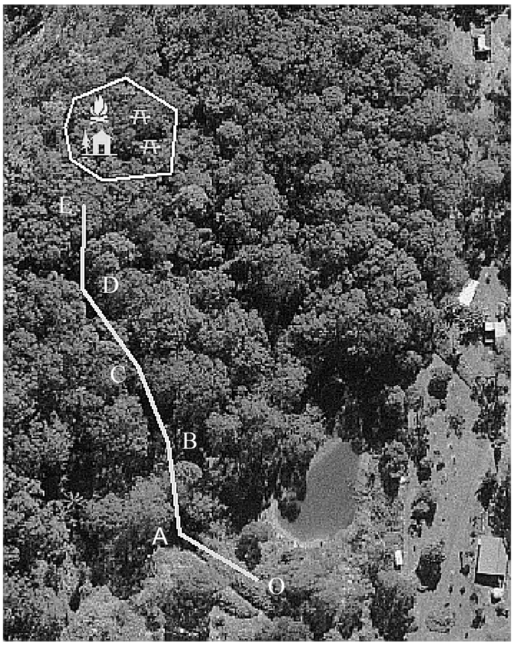


Figure 6. The measuring scheme

This level of error seemed acceptable in view of the experimental nature of this proof of concept field test, and was encouraging enough to warrant the continuation of the experiment. All observations and computations of this process were recorded within a Excel file referred to as *surveying.exl*. Simple trigonometric formulas were programmed in order to convert the measured length and directions of each distance to the equivalent changes in X, Y and relative Z coordinates.

Upon reaching the destination two observation stations or viewpoints were established so that the camera could take two converging images from these viewpoints showing all objects of interest to be measured within the picnic area.

The viewpoints for this basic photogrammetric process were determined by applying the same criteria used for establishing the turning points although care was taken to establish an optimal converging angle to the objects of interest (ideally between 30^o and 60^o). The distances from the objects to the positions of the camera were not greater than 30 m.. For further in depth information optimal geometric schemes for close range photogrammetric measurements the reader is referred to Fraser (1996).

In order to allow for a statistical analysis based on this measuring geometry the proposed prototype device was held as close as possible over the observation or camera station when taking pictures. A surveying range pole with an optical plumb was sufficient to ensure that the vertical line from the camera to the centre of the observing base station was within +/- 30mm in any particular direction. This value was considered more than acceptable for statistical purposes because the precision of the proposed unit at present is estimated to be in excess of +/- 1 metre.

Table 1 summarizes the standard errors of the differences of coordinates for 20 test points determined by the surveying total station measurements and those determined using the proposed measuring device. The Z component (difference in elevation) only relates to the positions of the camera.

Direction	Max. Diff.	Min. Diff.	STD
X	1.24	-1.33	+/- 0.89
Y	1.35	-1.22	+/- 0.98
Z	0.49	-0.66	+/- 0.42

Table 1. Directional standard errors (metres) in X, Y and Z

As illustrated above, these positional accuracies were expected as they directly depended on the precision of the various components of the system. How each component precisely influences the final positional accuracy is the subject of ongoing research and improvements in this area are forthcoming.

6. CONCLUSIONS

The proposed framework for the measuring systems presented herein is expected to widen the perspectives as to the exploitation of geo-referenced terrestrial images. It is anticipated that such a tool will promote the use and exchange of 3D information and further stimulate the development of location-based services and other mapping applications. Several external technology issues still challenge a more generalized utilization of this methodology.

1 Ideally the imaging sensor should have a higher resolution
2 The positioning sensors should provide for a better positional accuracy along with higher miniaturization
3 The networking devices should offer faster data transmission
4 Storage memory should be expanded
5 Screen resolution should be enhanced

In addition, the proposed system still requires external components (i.e. the compass and laser range finder) to achieve the desired functionality, thus, at present, detracting from the possibility of making the proposed system a complete, compact and independent unit for data capturing and telecommunication via the web.

Further research is now being undertaken to combine the GPS capabilities of the measuring device with GSM technology to improve the system performance when capturing data inside buildings in city areas where traditional devices cannot operate or receive signals.

In addition, a further application of the system will include rapid scene mapping. In this context experiments are presently being explored which involve the incorporation of two cameras to the phone unit and thereby averting the process of taking two separate converging images to a selected object of interest. This would be of particular interest to forensic investigations, such as in the case of crime, accidents or even disasters. In these cases it is very important to be able to quickly collect geo-referenced terrestrial images to assist in the understanding and documentation of the circumstances and causes of such events.

The preliminary tests carried out until now demonstrated the potential of the proposed system as well as its versatility. Indeed, the system could also be used to remotely geo-reference difficult to reach vertical or occluded objects from vehicles such as cars, helicopters and boats. These enhancements and more are presently being investigated.

7. REFERENCES

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