DIGITAL TERRAIN MESHES FROM GPS IN URBAN AREAS

A Practical Aid to City Modelling

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Abstract. The work presented here brings together two core interests that have been developed by the first two authors over recent years. The first is the development of city models for use in a range of applications where different data sets and different levels of detail may be appropriate. The second is the development of low cost systems that can deliver useful tools to help address Computer Aided Architectural Design problems. In addition the involvement of a colleague in Electrical Engineering and Electronics reflects a long standing belief in the benefits of cross-disciplinary and interdisciplinary work between architecture and parallel research fields. The product of the collaboration is a system that can aid in the production of terrain models that, in our case, are particularly important as the base for a city model (Brown et.al, 2005).

1. Context

One of the problems in creating 3D city models is obtaining a suitable digital model of the terrain. Some terrain models can be purchased commercially, but apart from the expense the form and density of the data may be inappropriate. This may require time consuming data manipulation or algorithms to strip the data to an appropriate level of detail. Also as cities undergo major development new interventions may change the levels in the terrain. Consequently, this paper describes a method for the collection of data and the creation of a CAAD 3D terrain model from a low cost GPS system.

For several years there has been an appreciation that providing City Models in a form that can be accessed via internet connection can have numerous productive applications. An early example of this was by Maver et.al. (2000) who showed that basic geometric data describing the city could be enriched by layers of supplementary textual information, or alternative graphical information such as vrml.

A number of researchers have shown the potential benefits and applications for such models. For instance Fukuda et.al. (2002) and Arup (2005) have shown how local communities can be drawn into the planning and development process through the use of, and interaction with, a digital representation of the city. However, a fundamental starting point is the ground plane on which the model of the city is constructed. In a number of cases a flat ground plane is assumed and such an approximation may be valid in certain cases. There are other cases, though, where the topography is inextricably linked to the buildings and infrastructure of the city. In these cases a reasonably accurate ground model is important in city modelling applications.

The conventional way of creating a 3D terrain model is through the use of aerial photogrammetry or physical survey. However in larger scale urban areas this is either difficult, costly or insufficient information is available. The method proposed here involves the use of a vehicle mounted GPS system which is driven around the roads of the urban area. From the raw GPS data, the horizontal and vertical components are extracted and converted to X,Y,Z data which can be easily read by a CAAD package. From this data, a conventional terrain mesh is created, with the horizontal GPS data being used for accurate location and checking for accuracy against spot-height data from conventional digital maps.

2. Background

GPS in its most basic form calculates position from time signals received from orbiting satellites. Before 2001, the accuracy of GPS systems was limited to approximately 30m due to 'Selective Availability', an error built into the system to degrade the performance for non USA military users. With Selective Availability removed the accuracy has improved to approximately 10m. This is in no way accurate enough for the proposed use, particularly given the problems that GPS systems may encounter in urban areas. These problems may vary from building blocking the view of the sky and hence the signal, to signals bounced off building obstructions giving erroneous readings.

Whilst the calculation of horizontal (X,Y) positioning is relatively accurate, the vertical (Z) is more problematic. As the Earth is not a convenient perfect sphere but an irregular and complex biaxial ellipsoid, a theoretical 'best fit' model is used to represent the earth. GPS uses height above the reference ellipsoid whereas traditional, orthographic height is calculated as the height above a different theoretical surface, the Geoid, which is determined by both the earths gravity and an approximated Mean Sea Level. The difference between these two figures is the Geoid height. The figure below illustrates this.

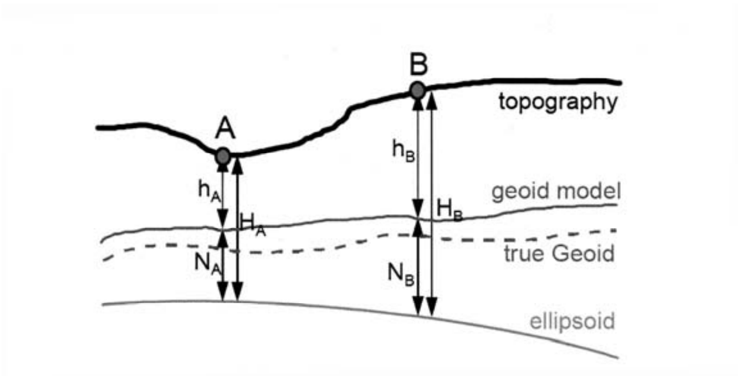

Figure 1 Geoid height

Enhancements to 'standard' GPS have been developed which significantly improve accuracy, the trade-off being increased cost and complexity.

2.1 DIFFERENTIAL GPS

The accuracy of both horizontal and vertical positioning can be improved through the use of Differential GPS (DGPS), which uses a known fixed base station to determine the errors in the pseudorange measurements of each of the satellites in use. These pseudorange errors are then transmitted via a real-time data link to the rover which uses the know errors to increase the accuracy of the estimated position. This correction factor is necessary because in 'standard' GPS, a receiver uses at least four satellites to establish a position but small transmission timing errors can influence accuracy. Using DGPS, the accuracy can be improved (if the mean position is calculated) to within 700mm. Problems can arise in urban areas if the receiver cannot see a minimum of four satellites.

Where no real-time communications link is available, post processed differential GPS can be implemented. In this scenario both the base station and rover record the pseudoranges of the satellites. This data, together with the satellite ephemeris data can then be processed to give an accurate location of the rover with respect to the base station.

2.2 REAL TIME KINEMATIC GPS

An advance on this is the use of a Real-Time Kinematic (RTK) GPS system can significantly improve on this accuracy. Similar to DGPS an RTK system uses a static GPS receiver as a reference system located at a known point, (in this case the roof of a Dept. of Electrical Engineering building) and a second receiver is used as a rover which can move and record any points of interest. Both receivers record GPS signals simultaneously and a radio modem link between the two receivers allows data to be sent from the reference station to the rover for the calculation of coordinates. The increased in positional accuracy is by using phase information from the signal carrying the satellite information.

The system proposed in this paper is for use in an urban environment and uses low-cost OEM GPS systems with a methodology that combines some of the advantages of high end (i.e. high cost) and trades this against the cost advantages of cheaper systems whilst still retaining a reasonable level of accuracy.

For illustration, a high end Real-Time Kinematic (RTK) differential mode system with a real time link between the moving survey vehicle (the rover) and the base station might cost in excess of £10,000 (17,000 US$). This should be capable of an accuracy of 15 mm horizontally and 20 mm vertically. This method relies on a continuous radio link between the rover and base constantly applying a correction to the received data.

The next level down would be a system using a DGPS base station and rover with real-time data link costing in the region of £3000 (5,000 US$) giving approximately 3 m accuracy.

The cheapest solution is a consumer level WAAS receiver that gives an accuracy of the order of 5 m. This is not considered accurate enough for the proposed use.

3. The system

The DGPS system proposed here uses two identical sets of equipment made up of a Motorola M12+ GPS receiver. These are each connected to a standard PC laptops. The total cost of this system (excluding laptops) is approx £200 (350US$). The Motorola M12+ GPS receivers allows the pseudoranges of any of the satellites in view to be read when using the Motorola Binary Format. With extra hardware this allow the M12+ to be configured as a low cost DGPS base station.

For the test case, the University campus and surrounding area was used. A digital map was used both to establish the route and provide a check on data points recorded. In common with other urban areas, the digital maps of the areas have a number known benchmark heights which can provide checking and reference points, but there are not sufficient in number to allow for the creation of an accurate terrain mesh.

3.1 TEST PROCEDURE

Firstly, both the base station and the rover were calibrated by letting them run at known locations for 12-24 hours. Then at a known time, positions were recorded on both the base and rover. One the units had been calibrated, the rover unit was mounted in a car. The methodology for determining the collection of GPS points was very simple. Being mounted on a car, the route was restricted to main roads with good sky visibility. The more roads that were covered the more data that would be collected.

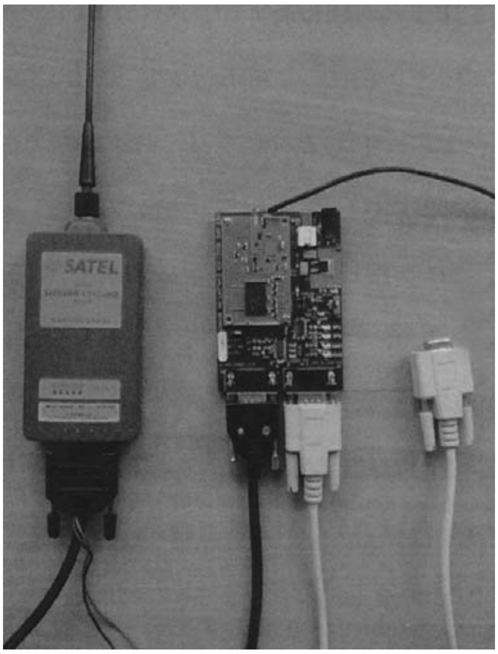

Figure 2 - the rover system

Once the data had been collected, it was post-processed using ephemeris data for the exact time of the reference measurement from US National Geodetic Survey. This corrected data gave accuracies shown below.

	X	Y	Z
Base Reference pos	3805898.598	-197000.012	5097379.145
Rover reference pos	3805445.333	-197112.931	5097734.789
Corrected rover position	3805441.007	-197114.167	5097734.463
Corrected distance	4.326	1.236	.326
Improved accuracy	4.3-5.3	6.5-7.7	0.5-0.8

Figure 3 - the route for data collection

As the native format for any GPS receiver is the World Geodetic System (WGS84) expressed in latitude, longitude and ellipsoidal height, the data collected has to be converted into a set of coordinated compatible with the local map format. In the UK, the Ordnance Survey uses a system of Eastings and Northings based upon the National Grid which uses a UK only system - OSGB36. A complex series of transformation calculations are necessary to convert from one system to another in order to use them with the digital maps. Luckily, the Ordnance Survey make conversion programs freely available through their website to ease the process. Whilst this does not improve the accuracy of collected data, it does at least ensure that no additional error is compounded in the transformation.

Once a set of coordinates has been collected and transformed it is ready to be put into a CAD system. Initially, this has been done using AutoCAD, but the X,Y,Z format will allow input into virtually any 3D CAD system. Initially 3D Surfaces were created manually as a proof of principle. The height information on the underlying digital map was also used as a check for accuracy

We are in the process of writing an scripted system for use with Rhinoceros (3D modeling software) which will allow a much quicker visualisation and checking of results.

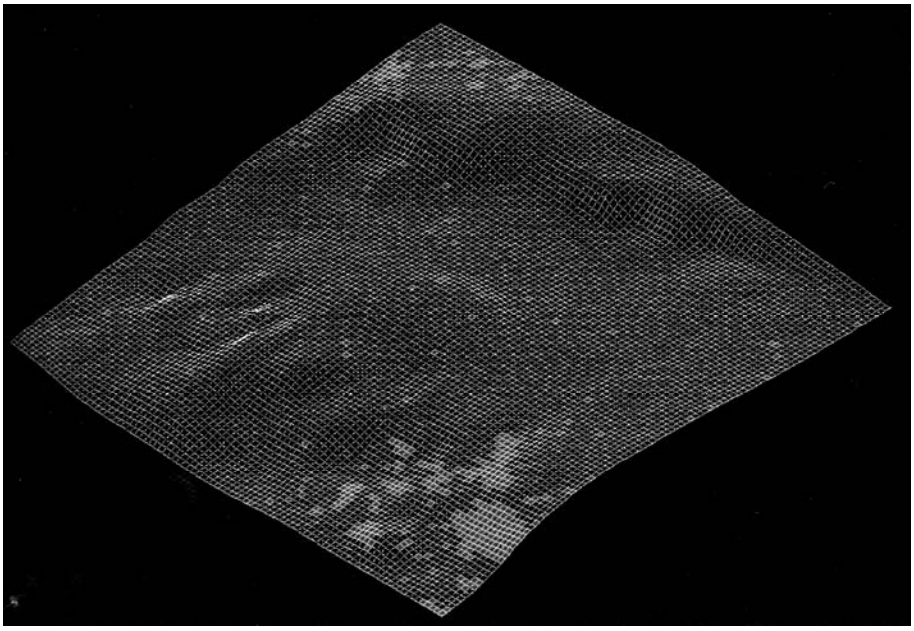

Figure 4 - final mesh

4. Conclusions

The initial results are promising in the areas of relative ease of collection of data and cost and show an acceptable level of accuracy for large scale urban modeling for the creation of city models.

The level of accuracy achieved is not suitable for detailed site modeling for which either more accurate (i.e. expensive) GPS techniques could be used or more traditional(i.e. aerial photogrammetry or 3D laser scanning). What has been achieved is a good price/performance balance with a system that is capable of further refinement and, as GPS technology improves, increased accuracy and wider availability will lead to greater usage. It is intended to further refine the system is several key areas.

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