Development of a Simulation Tool to Evaluate GNSS Positioning Performance in Urban Area

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Abstract

With the rapid development of spatial infrastructure in US, Europe, Japan, China and India, there is no doubt that the next generation Global Navigation Satellite System (GNSS) will improve the integrity, accuracy, reliability and availability of the position solution. GNSS is becoming an essential element of personal, commercial and public infrastructure and consequently part of our daily lives. However, the applicability of GPS in supporting a range of location-sensitive applications such as location based services in an urban environment is severely curtailed by the interference of the 3D urban settings. To characterize and gain in-depth understanding of such interferences and to be able to provide location-based optimization alternatives, a high-fidelity 3D urban model of Melbourne CBD built with ArcGIS and large scale high-resolution spatial data sets is used in this study to support a comprehensive simulation of current and future GNSS signal performance, in terms of signal continuity, availability, strength, geometry, positioning accuracy and reliability based on a number of scenarios. The design, structure and major components of the simulator are outlined. Useful time-stamped spatial patterns of the signal performance over the experimental urban area have been revealed which are valuable for supporting location based services applications, such as emergency responses, the optimization of wireless communication infrastructures and vehicle navigation services.

Keywords: Global Navigation Satellite System, Location Based Services, 3D Urban Model, Simulation.

1. Introduction

Global Navigation Satellite Systems (GNSS) are a primary positioning technology for a large number of critical industry sectors such as location based services (LBS), maritime, aviation, agriculture, mining, surveying, military, road transport, and personal mobility(Misra and Enge, 2001; Parkinson et al., 1996). GNSS is well on its way to becoming an essential element of personal, commercial and public infrastructure and consequently part of our daily lives. Current generation GNSS is dominated by the US GPS. However, additional spatial infrastructures are becoming available in Europe, Japan, China and India (Breeuwer et al., 2001; Kogure et al., 2003; Sisodia et al., 2003; Wu, 2004; Zhang et al., 2005). The European Union is currently developing its own GNSS, known as Galileo, for deployment starting from 2005 (EC, 2001; Montenbruck et al., 2006). It is anticipated that the next generation GNSS will offer over one hundred satellites for positioning and navigation by 2010.

The applicability of GNSS in supporting a range of location-sensitive applications such as LBS in an urban environment raises a number of problems (Chatre and Ludwig, 2003; Swann et al., 2003). One of the dominating problems is the difficulties related to signal obstructions by features such as buildings bridges and trees, as well as the effects of multipath caused by signal reflections from buildings and other objects. There is no doubt that the combined use of different GNSS will improve the availability, accuracy, reliability and integrity of the position solution. It is known that increasing the number of satellites will result in more satellites in view of the user receiver at any one time. This in turn leads to increased accuracy with much improved availability. However, no investigation has been carried out to accurately quantify and reliably evaluate these improvements in a typical urban context, where most human activities are taking place.

To evaluate the performances of the current and future GNSS in an urban environment, and to characterize and gain in-depth understanding of signal obstruction, and to be able to provide location-based optimization alternatives, a 3D urban environmental model was built, a simulation system based on the urban environmental model was developed, and a comprehensive simulation was carried out in this paper.

The high-fidelity three-dimensional (3D) urban model of Melbourne CBD, built with ArcGIS and large scale high-resolution spatial data sets, was used to support a comprehensive simulation of current and future GNSS performance, in terms of signal continuity, availability, strength, geometry, positioning accuracy and reliability. The design, structure and major components of the simulator were outlined and a comprehensive simulation was carried out in Melbourne CBD. Two types of simulations: spatial simulation and temporal simulation were carried out. The performance of GNSS can be quantified by availability, accuracy, reliability and integrity. Availability and accuracy estimates for GPS are obtained by software simulation. The simulation results are presented using the number of visible satellites (NVS) as a measure of availability and Dilution of Precision (DOP) as a measure of accuracy with spatial and temporal variations. Finally, current status of the project and some preliminary conclusions were given.

2. The Development of a High Fidelity 3D Urban Model

Many 3D urban models have been built for visualisation or virtual reality applications, emphasizing aesthetically appealing criteria for the visual enhancement of the "true" urban settings. To numerically and spatially evaluate the performance of GNSS in typical 3D urban context in terms of integrity, accuracy, reliability and availability, the need for a "high fidelity" 3D urban model arises.

2.1 Methodology

In recent times, focus within photogrammetry and computer science research has been directed at the automatic extraction of building features from aerial photography. The "cost" associated with manual interpretation and digitisation of urban scenes has limited the manual development of such models. Research has focused on reducing the "cost" associated with urban modelling by introducing automatic extraction techniques. In this study, a more labour intensive method is deployed because (Liu et al., 2006).

- Much of the labour intensive photogrammetry had already been performed;
- Extensive editing would be still required for the development of a high fidelity urban model
- With access to high resolution, true ortho-rectified image, the manual interpretation of building features results in high spatial accuracy; and
- Issues associated with supplied data could be identified and rectified in the process.

2.2 Data Set

For the development of the Melbourne CBD model, the Melbourne City Council was approached, and the following data sets were provided (Liu et al., 2006).

- Cadastre data set were provided in both dwg. and shp. formats;
- Large scale aerial photograph captured in October 2002 was provided as true ortho-rectified image with 0.063 m resolution in tiff format;
- Feature data sets provided including polyline data showed building/feature outlines and heights, point data showed building/feature elevations and spot height ground data, in both dwg and shp. formats.

2.3 Data Quality

To ensure high quality and fidelity for the 3D urban model, comprehensive visual investigation has been performed to identify source data quality issues. The ortho-image supplied has a different creation data to that of the feature data set. This creates issues in areas of building development. The true ortho-image also has the following issues (Liu et al., 2006).

- The roofs of building are superimposed onto the bottom of the building and the roofs of the buildings appear twice. This phenomenon is called "ghost image" (Rau et al., 2002), see Figure 1.
- Due to inaccuracy of digital surface model (DSM) used, many small objects weren't true ortho-rectified,and boundaries of buildings were inaccurately ortho-rectified, see Figure 2.
- Feature alignment issues were observed along image seams.
- Insufficient slave images in the refill of the occluded region on the master true ortho-image (Rau et al., 2002).

Many of data issues associated with the true ortho-image were overcome through visual interpretation. Where possible small features not true ortho-rectified due to inadequacy of DSM were digitised by visual interpretation of their bases. This posed a problem only when feature line work was not available; on every other occasion feature line work was used as a guide in the digitisation of buildings.

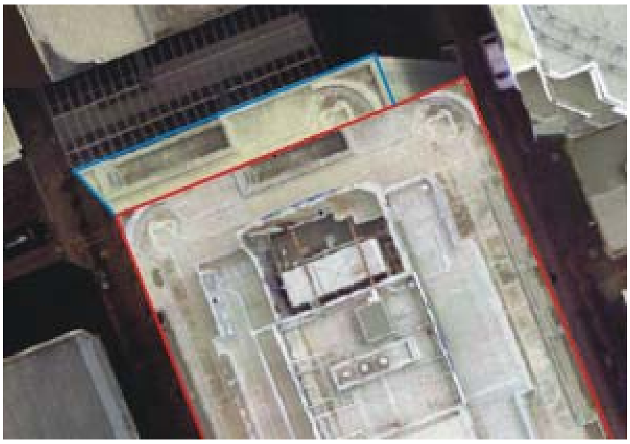


Figure 1. The ghost image of the roof is outlined in blue, the ortho-rectified location in red.

Figure 2. Building roof top has been ortho-rectified although small roof top structures have not.

2.4 Digitising Buildings and Features

The software used for digitising the building features was ESRI's (Environmental Systems Research Institute) ArcGIS suite, in particular ArcMap (ESRI, 2006), the process was labour intensive. The true ortho-image, feature dataset and cadastre data were used to facilitate this tedious task. The building boundaries were digitised according to the following criteria.

- The feature database line work was weighted highest in the digitising process. Where relevant feature line work was available it was used as a template for digitising.
- Where feature line work was not available the true ortho-image was used. Feature line work was often not available for smaller structures on the top of building, e.g. Air-conditioning towers.

The buildings were digitised as a polygon shapefile. The end result was approximately 4000 polygons. Figure 3 shows the finished 3D model of Melbourne CBD.

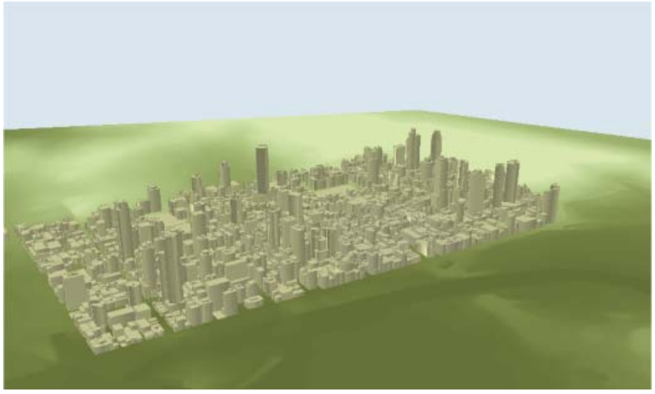


Figure 3. Finished 3D model of Melbourne CBD

2.5 Integrating with Simulation Software

The simulation testing presented in this study was performed on a region of the city where there are no significant 3D modelling issues. The experimental region consists of four city blocks in the south western part of the CBD, see Figures 3 and 5. To integrate the 3D layouts of the buildings into the simulation software, numerical array in ASCII (American Standard Code for Information Interchange) format was used, with the element values representing the heights of the streets or buildings. The building shapefile was first re-projected from Australian Map Grid, Zone 66 (AMG66) to the GPS reference system WGS84, then converted to a raster format which was finally converted to an ASCII format, .using the ArcToolbox within ArcMap.

3. GNSS Performance Simulation

3.1 Simulation System Design

The simulation system consists of three packages, one for 3D model generation, one for satellite position estimation and one for GNSS performance evaluation, see Figure 4. The three-dimensional model generation package is designed to generate a high fidelity 3D urban model. The generation method and data source of a high fidelity 3D urban model have been outlined in Section 2. The satellite position estimation package is designed to estimate GNSS satellite position using Keplerian Orbit Model (Misra and Enge, 2001). The package imports satellite orbit parameter from an almanac, such as YUMA almanac (Navigation Center, 2006), broadcast ephemeris, such as RINEX navigation file. Then the GNSS satellite positions are derived from satellite orbit parameter. The GNSS performance evaluation package is designed to simulate the signal propagation from satellite to receiver, and to evaluate the performance of GNSS in urban areas. Primarily, the package only simulates direct signal, which is not blocked by the three-dimensional terrain and objects. The simulation results are presented using the NVS as a measure of availability and PDOP as a measure of accuracy with spatial and temporal variations.

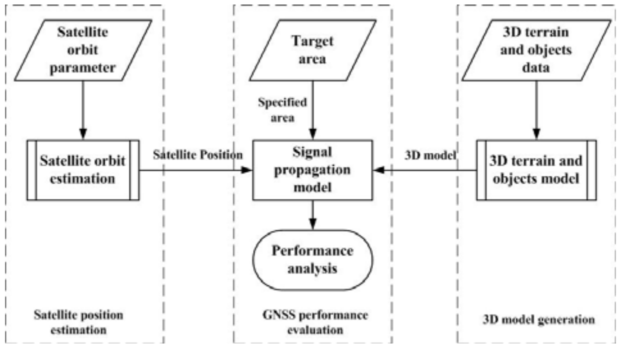


Figure 4. An Outline of the Simulation System Architecture

3.1 Simulation Scenarios

Two types of simulations, spatial simulation and temporal simulation, have been carried out. A GPS constellation with twenty-nine satellites and a Galileo constellation with twenty-seven Galileo satellite constellations are simulated. In the spatial simulation, the receiver-satellite geometries are simulated at 00:00 on April 9, 2006 in the study area, with a sampling grid of 0.5m × 0.5m. In the temporal simulation, the receiver satellite geometries are simulated at the cross point between King Street and Collins Street, Melbourne, Australia from 00:00 April 9, 2006 to 24:00 April 15, 2006. The experimental simulation area and point are shown in Figure 5. The red point is the cross point between King Street and Collins Street. Figure 6 shows the 3D model of the experimental areas.

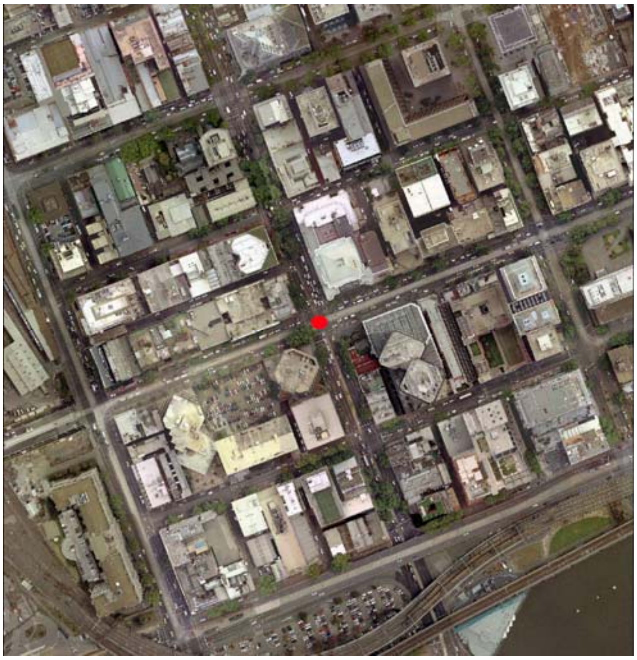


Figure 5. Experimental simulation area and point in Melbourne CBD.

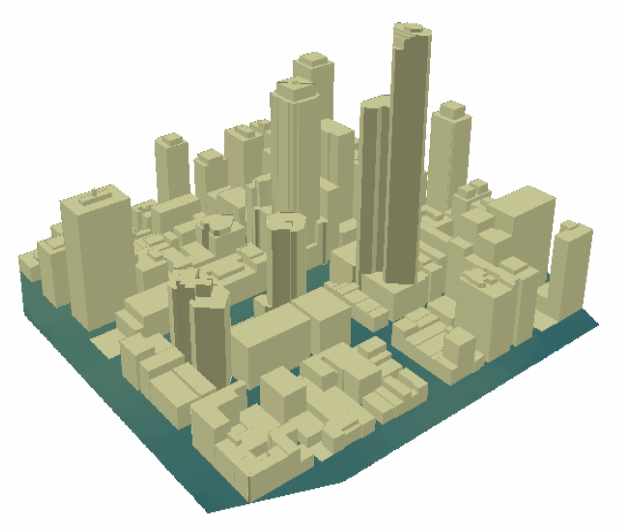
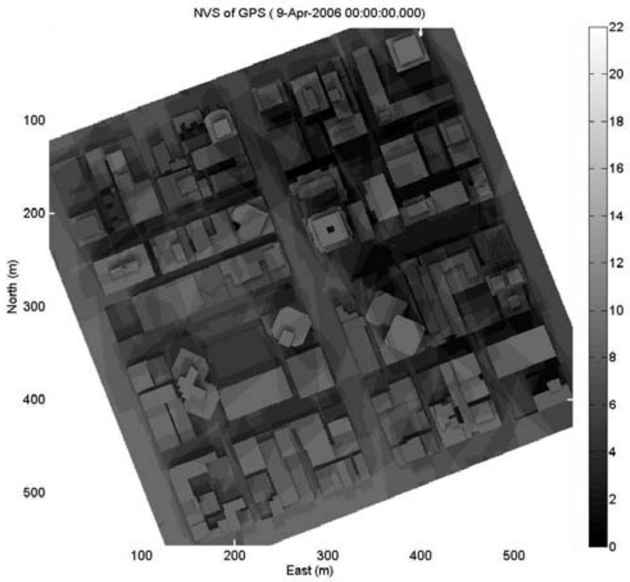
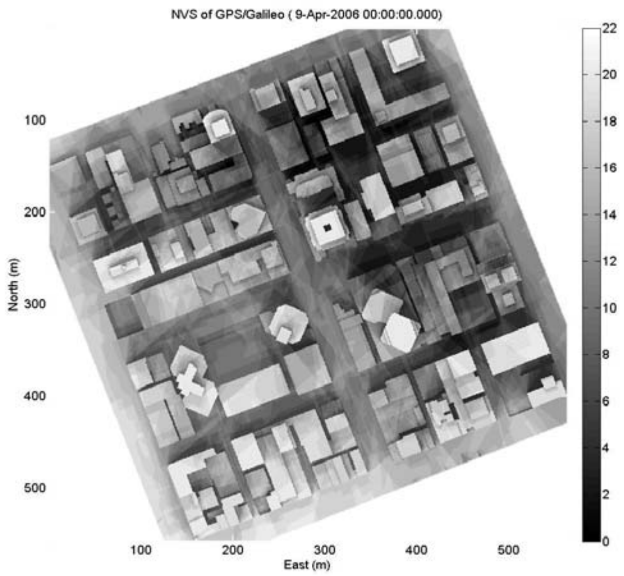


Figure 6. 3D model of the experimental area.

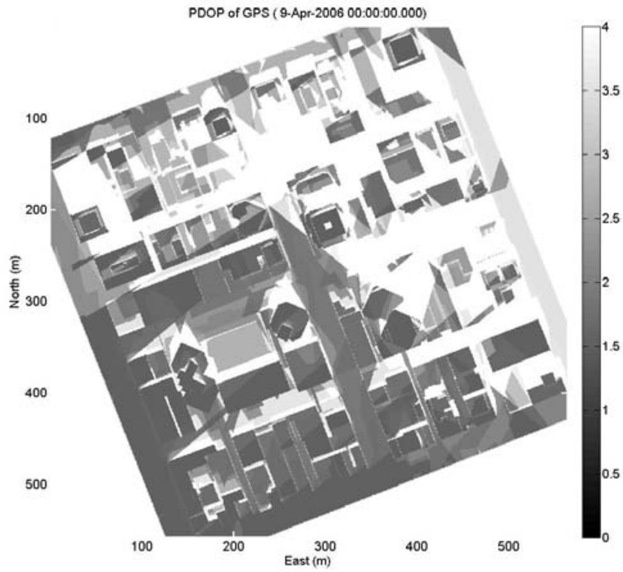


(a) GPS

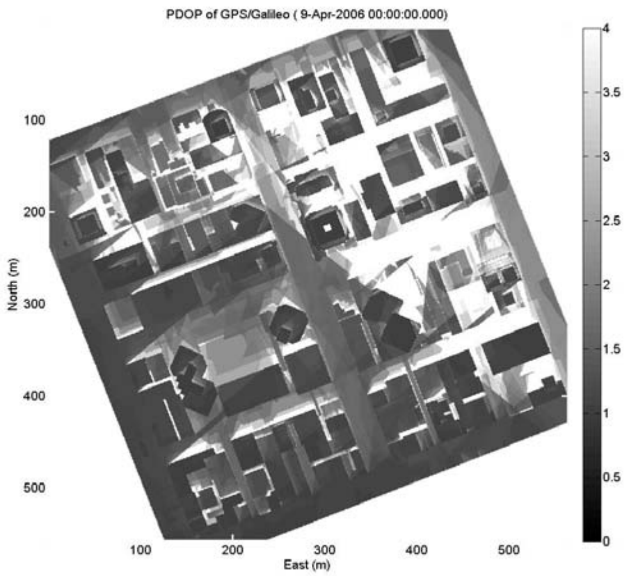


(b) Integrated GPS and Galileo

Figure 7. Spatial variation of the number of visible satellites.



(a) GPS



(b) Integrated GPS and Galileo

Figure 8. Spatial variation of PDOP values.

Figure 7 shows the spatial variations of the NVSs of GPS and integrated GPS/Galileo system in the region of interest. GNSS signals within the specific region are blocked by features, such as high buildings, bridges and trees. This is evident by the low NVS numbers. In some areas GNSS service becomes unavailable, due to non-availability of the required four NVS for GNSS positioning. It has been shown that integrated GPS and Galileo system will improve the satellite visibility and extend the positioning available area significantly.

Figure 8 show the spatial variations of the PDOP of GPS and integrated GPS and Galileo system in the experimental region. Correspondingly the PDOP values are also higher within urban environment areas of the simulation region. The results show that integrated GPS and Galileo system will offer better PDOP and improve positioning accuracy considerably.

Figures 9 and 10 compare the temporal variations of the NVS and PDOP values of GPS, and integrated GPS and Galileo system at the cross point between King Street and Collins Street, Melbourne, with an open sky area. It is evident from Figures 9

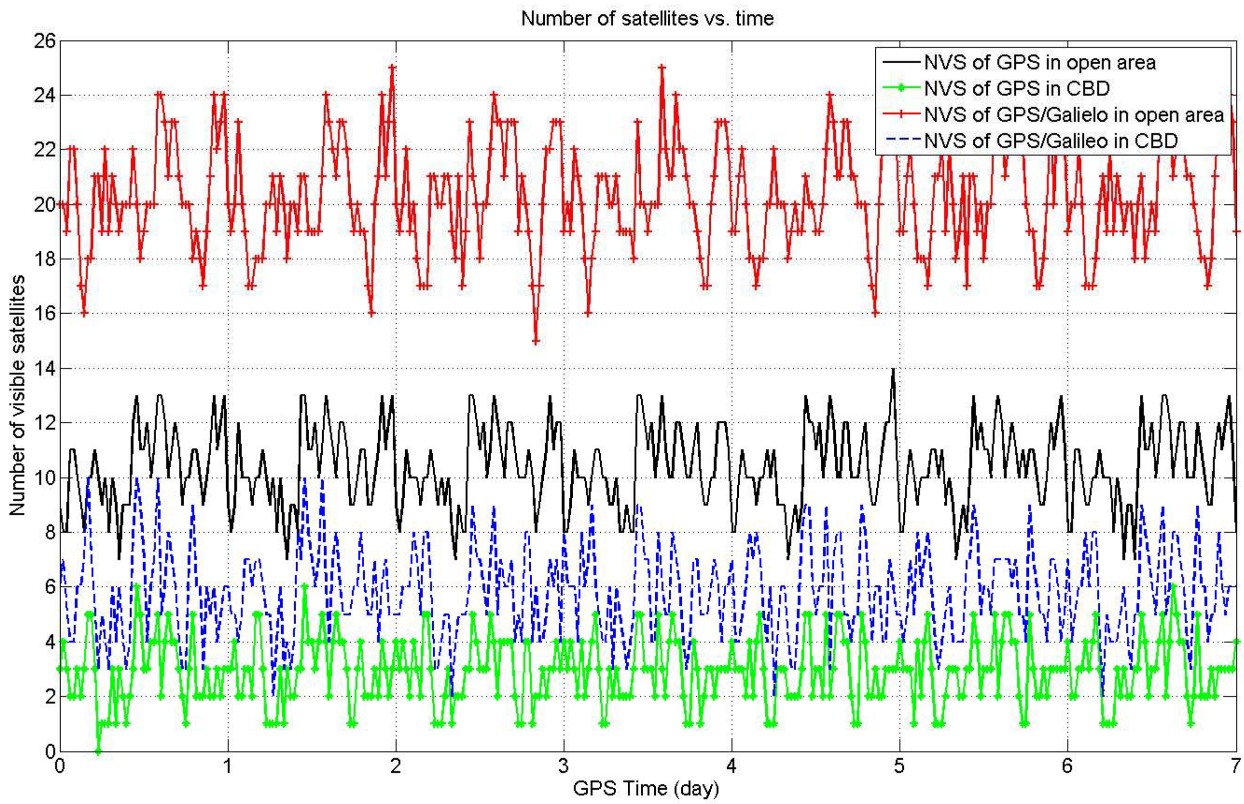


Figure 9. Temporal variation of the number of visible satellites.

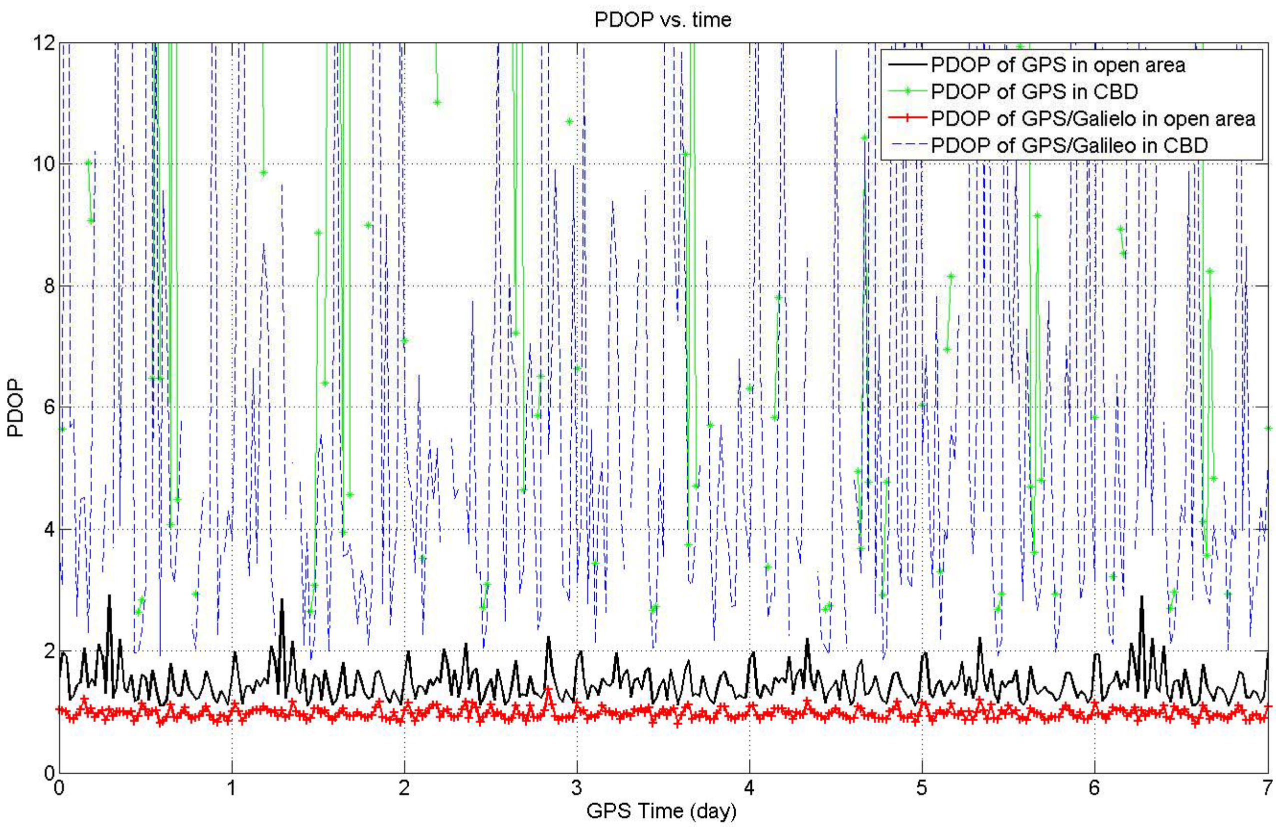


Figure 10. Temporal variation of PDOP values.

and 10, that GNSS service performance is significantly affected by the features of the local urban environment, in this case of Melbourne CBD. The results show that integrated GPS and Galileo system will not only improve the satellite visibility, extend the positioning available time, but also offer better DOP, improve positioning accuracy in urban environment.

4. Conclusion

In this paper, a high fidelity 3D urban model has been built, a simulation system based on the urban environment model has been developed, and a comprehensive simulation has been carried out. A systematic analysis of the detailed results has revealed some useful time-stamped spatial patterns of the performance over the experimental urban area. These time-stamped spatial patterns can be very valuable for supporting applications such as car navigation, tourist information services, emergency responses and the optimisation of wireless communication infrastructures.

The performance of integrated GPS and Galileo system in urban area has been investigated by software simulation. The availability and accuracy of hybrid GPS and Galileo system have analyzed spatially and temporally. The integration of the two systems provides stronger geometry and more availability. These properties allow for higher reliability of the overall system. The increased availability gives better precision in the position domain and can provide improved satellite geometry in the most difficult signal masking environments, such as urban canyons. The simulation results need to be validated with real GNSS data in future work.

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