Development of a Simulation System for Assessing the Layout of Pseudolites in Urban Environment

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ABSTRACT

Since the launch of the first Global Positioning System satellite, the demand for higher accuracy and wider applicability has been continuously increasing. In particular, personal navigation stresses requirements on "seamless" or continuous positioning with higher reliability are needed in urban areas. Unfortunately, urban canyons causing shadowing and multipath represent an adverse condition for Global Navigation Satellite System (GNSS) signal reception, thus leading to poor satellite visibility and low positioning accuracy. In order to overcome such problems, pseudolites can be set up to provide additional ranging signals and aid the carrier phase ambiguity resolution which is crucial for utilizing the full accuracy and wide range capability of GNSS. Pseudolites, which are ground-based instruments that transmit GPS-like signals, can improve the satellite-receiver layout and be used as additional range observations to improve the performance of a GPS-based deformation monitoring system. However, due to economic and environment constraints, the number of pseudolites that can be installed will be limited. More importantly, in order to reduce the areas affected by multi-path of pseudolite signals, locations and antenna pattern of pseudolites have to be carefully examined.

This paper shows the development of a simulation system for evaluating the appropriateness and economics of installing pseudolites using precise orbital information of the satellite and a three-dimensional digital map.

1. INTRODUCTION

The satellite-based positioning techniques, such as GPS, have been widely used in surveying and geodesy in recent years. Moreover, the requirements on the precision of positioning are ever increasing. However, there are still situations where GPS or GNSS will not provide users with desired precision such as in areas between buildings, tunnels, and underground shopping malls or deep open-cut mines because the number and geometric distribution of tracked satellites may not be sufficient for accurate and reliable positioning. These disadvantages can be solved or improved by using pseudolites, which are located on the ground and transmit GPS-like signals, and most commonly transmits a signal at the GPS L1 frequency of 1575.42 MHz. Pseudolites improve the reliability of GPS or GNSS by providing an additional signal to assist in carrier phase ambiguity resolution. It is well known that, the accuracy, availability and reliability of the satellite-derived position solution improve with the number of tracked satellites or pseudolites [1]. However, due to economic and environment constraints, the number of pseudolites that can be installed will be limited. Therefore, in order to install the pseudolites, the locations and antenna pattern of pseudolites have to be carefully examined.

This paper present the development of a simulation system for assessing the layout of pseudolites in urban environment and focuses on the evaluating of appropriateness and economics of installing pseudolites using precise orbital information of the satellite and a three-dimensional digital map. Accordingly, using this simulation system, it is possible to estimate the ideal numbers and positions of pseudolites by simulation, without the need of actual observations.

2. INTEGRATED GPS-PSEUDOLITE POSITIONING SYSTEM

Pseudolites can be considered as ground based radio navigation satellites. This means that they transmit signals, which are similar in structure to GPS signals and that they are easy to install. So, pseudolites can be used either to augment a GPS or set up as a stand-alone pseudolite positioning system.

There are several reasons to augment a GPS with pseudolites. A general reason is to improve the precision of positioning. Pseudolites may even be indispensable when satellite signals are blocked, for example in urban areas or in open pit mines. Furthermore, pseudolites may be used to improve the geometry of the positioning system, because of their low elevations. Lastly, the use of pseudolites achieves a considerable geometry change for roving receivers, even within a short time span. This allows for fast carrier phase ambiguity resolution [*Lawrence et al.*, 1995], because the baseline coordinates are easier to separate from the ambiguities. The design of an integrated GNSS-pseudolite system has been studied for a number of particular applications, cf. [*Elrod and Van Dierendonck*, 1996] and [*Cobb*, 1997] for an overview [6].

3. DESCRIPTION OF SIMULATION SYSTEM

This simulation system consists of a three-dimensional digital map, a model of GPS satellite orbit and a model of Quasi-zenith satellite orbit. This system was developed with JAVA, and each GPS satellite and map data are all implemented as individual classes. Figure 1 shows the three-dimensional digital map of Shinjuku area in Tokyo used in this simulation.

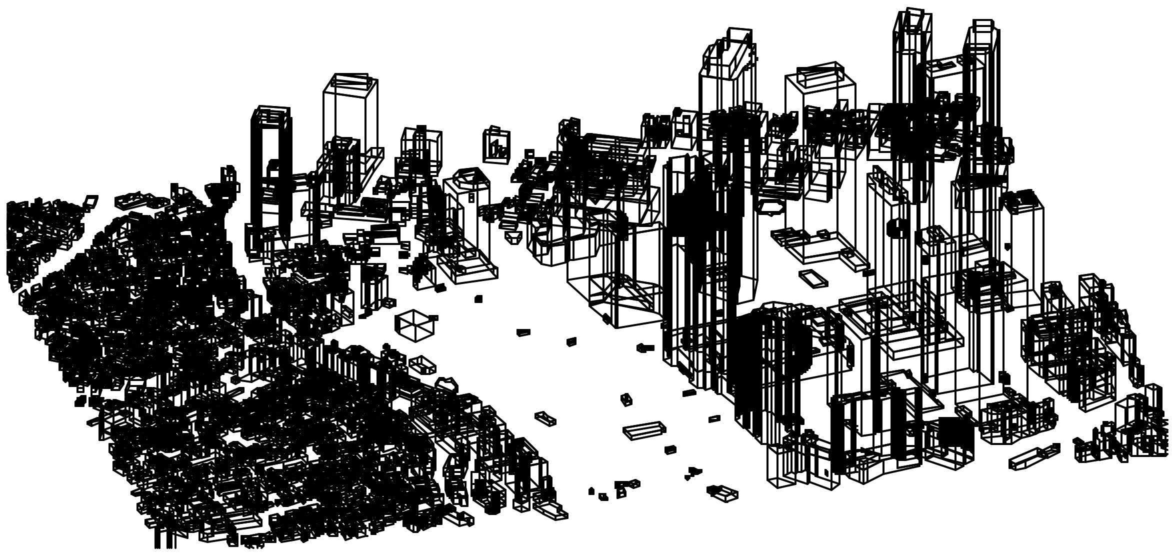


Figure 1. Three dimension digital map which used in this simulation (DiaMap by Mitsubishi Corporation)

The test area is divided into the grid cells, and this simulation system estimate whether the line of sight from the center of each grid cells to each GPS satellites intersects any object or not. Then the numbers of visible GPS satellites are computed for each grid cells. If four or more of the tracked satellites are at a particular grid cell, this simulation system recognizes that the cell is available for a positioning. Figure 2 shows the concept of the developed simulation system to estimate available area of GPS and pseudolites.

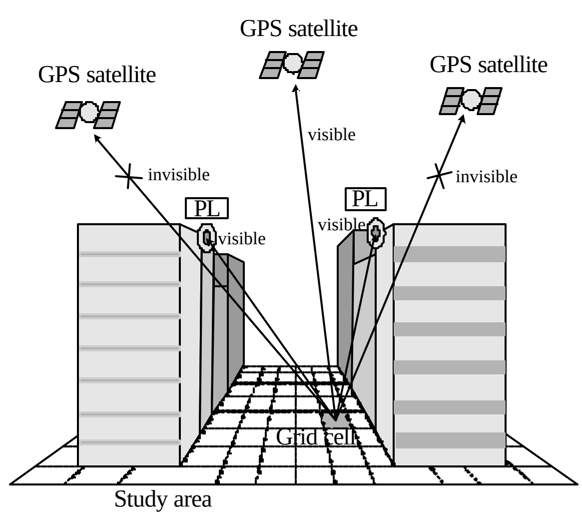


Figure 2. Concept of available area estimation

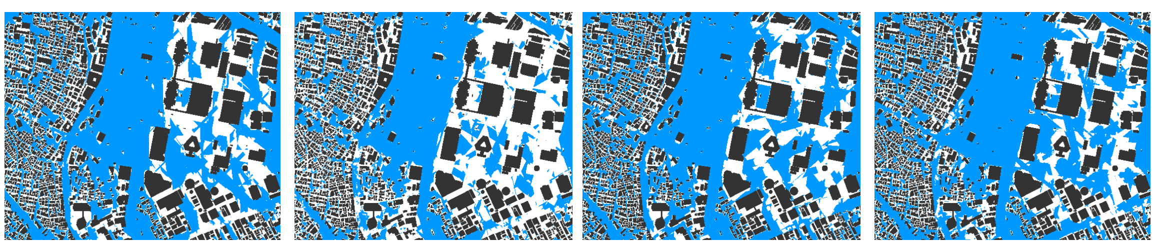
Furthermore, this simulation system can calculate the Dilution Of Precision (DOP) and the error distribution using precise orbital information of the satellite and the 3-Dimensional digital map. This simulation system may also be applicable when estimating the number of visible GPS or pseudolite transmitters and installing new positioning satellites system like Galileo or Quasi-zenith satellite system.

4. SIMULATED MEASUREMENT SCENARIOS

The goal of this research is to evaluate the appropriateness and economics of installing pseudolites through the developed simulation system when GPS is integrated with pseudolites. First of all, it is necessary to investigate the available area of positioning for the case when only-GPS satellites are utilized in order to find out the number and geometric distribution of tracked satellites. The conditions under which this simulation was performed are listed as follows.

- Estimate process at every hour from 0 o'clock on 1st August 2002 to 0 o'clock on 2nd August 2002, that is, 25 steps as total.
- Estimate GPS satellite orbit by using the actual satellite orbital elements around 31 May 2002.
- Use the simplified 3-dimensional digital map of the Shinjuku area (1,058,000 m^2) of Tokyo in Japan as a study area.
- The study area is divided into grid cells of regular tetragons with widths of two meters.

The graphical output is shown in Figure 3, which estimate s the available area of the positioning using only GPS satellites through simulation. At every six hour over a period of 24 hours from 0 o'clock on 1 August 2002, the result of the four steps was sampled from all estimated 25 steps representatively. This result is defined as the set of the grid cells where four or more GPS are visible base on the concept shown in Figure 2.



(a) 00:00 (b) 06:00 (c) 12:00 (d) 18:00

Legend : building available not available

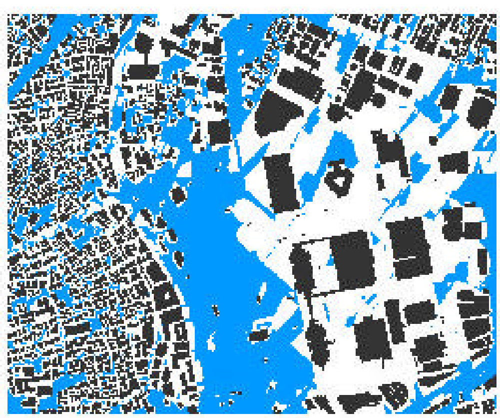
Figure 3. Result of available area of the positioning when using only-GPS satellite transmitters

As shown in Figure 3, there are still situations where GPS cannot provide users with positioning services when only GPS satellites are utilized such as in areas between buildings. In this research, to cover these poor satellite visibility and low positioning accuracy, the integrated GPS and pseudolites were applied. Among the results from the available area of the positioning when using only-GPS satellite transmitters, the result at the time of 19:30 on 1st August (Figure 4 (a)) is used for comparison, which is the worst satellite coverage during the day along of the simulation. During comparison, the same satellite configuration and satellite observation model are applied in their simulations.

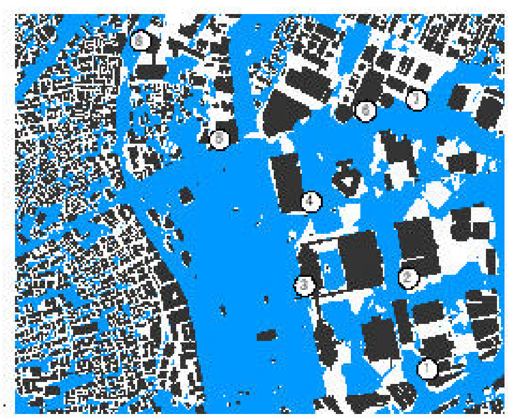
First of all, we installed the pseudolites at the buildings which caused shadowing for a GPS signal reception through the 3-dimensional digital map. In general, the accuracy of positioning is affected by number of the constellation transmitter. However, it is almost impossible to install the pseudolite unlimitedly because of economic and environmental limitation. Accordingly, we try to achieve a maximum efficiency with minimum number of pseudolite. Especially, in this simulation, the transmitters of pseudolites were installed one meter outside the walls of buildings in order to ruduce the multi-path effect, which is caused by reflecting surfaces near the receiver. Subsequently, we calculate the distribution of DOP (Dilution of Precision), which is a measure of satellite geometry with respect to the observing site. The geometry of the visible satellites is an important factor in achieving high quality results especially for positioning.

5. SIMULATION RESULTS

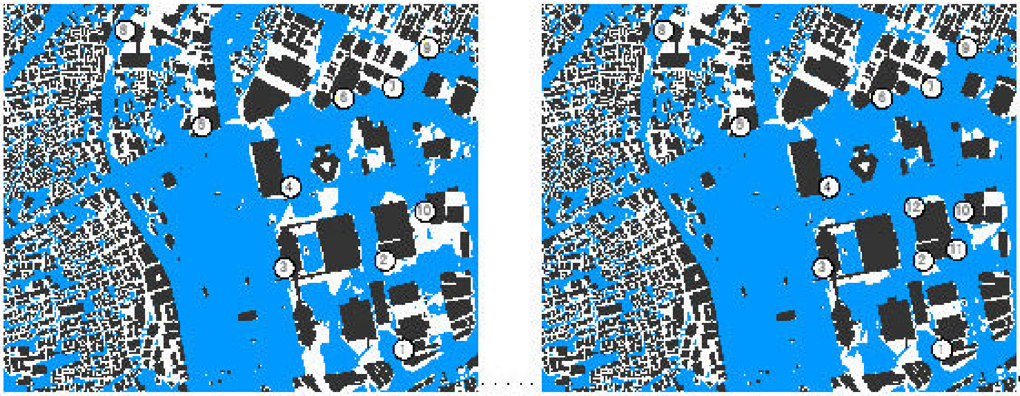
In this section we present the simulation results for the different number of pseudolites as described in the preceding section. The results of the simulation are given in Figure 4, which shows the cases when 8, 10, 12 pseudolites were utilized compared with the only-GPS case. As shown in the Figure 4, the available areas of positioning are gradually increased with the number of pseudolite transmitters. The percentage of available area of the positioning is 38.5% in case of only-GPS, 64.4% in case of 8 pseudolites, 66.3% in case of 10 pseudolites, and 70.2% in case of 12 pseudolites in the study area. Summarizing, it can be concluded that 12 pseudolites will be able to cover harsh observing conditions such as in urban canyons and roads for seamless positioning. Moreover, Figure 5 shows the result of distribution of DOP for the only-GPS case and integrated GPS and pseudolites case. The upper figure shows the HDOP, and the lower figure shows VDOP. The more satellites we deploy, the higher accuracy we have.



(a) Only-GPS satellite transmitters



(b) Integrated GPS satellite and 8 pseudolites



(c) Integrated GPS satellite and 10 pseudolites (d) Integrated GPS satellite and 12 pseudolites

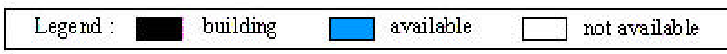
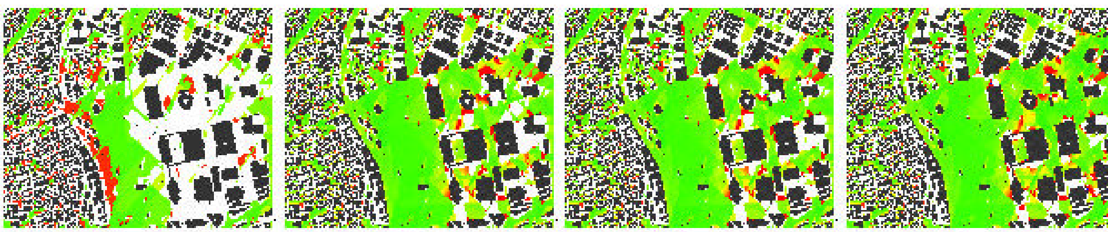
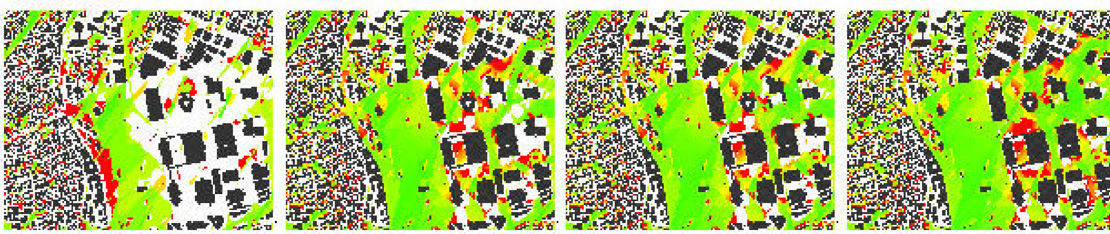


Figure 4. Results of available area of the positioning when using integrated GPS and pseudolites



HDOP : (a) Only-GPS (b) 8 pseudolites (c) 10 pseudolite (d) 12 pseudolite



VDOP : (a) Only-GPS (b) 8 pseudolites (c) 10 pseudolite (d) 12 pseudolite

Figure 5. Results of Dilution Of Precision (DOP) by increasing number of pseudolites

6. LUSIONS AND FUTURE WORKS

Satellites orbiting in space are not under users' control. In contrast, pseudolites are ground-based transmitters, which can be easily installed wherever needed. They therefore offer great flexibility in precise positioning applications. However, the choice of the number of pseudolites and their locations are especially important due to economic and environment constraints.

It has been shown that it is indeed possible to evaluate the appropriateness and economics of installing pseudolites through this developed simulation system without the need of actual observation. Consequently, the results from a simulation system have been presented, which demonstrate the appropriate locations and number of pseudolites in improving the performance of precise positioning system.

As for the future works, we plan to develop a tool to aid the optimization of positioning the pseudolite automatically. Moreover, it is necessary to develop a radio wave propagation model to deal with multi-path problem, which is caused by reflecting surfaces near the receiver, and also develop an additional function to estimate positioning accuracy with evaluation of multipath propagation.

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