DEVELOPMENT OF A SIMULATION SYSTEM TO ESTIMATE AVAILABLE AREA OF GPS AND PSEUDOLITE

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ABSTRACT
Recently, the Global Positioning System, GPS has been widely used in positioning. It is well known that the accuracy, availability and reliability of the positioning results are heavily dependent on the number and geometric distribution of tracked GPS satellites. Because of this limitation, the integration of GPS with the pseudolite technology has been proposed. With this pseudolite technology, it is expected that seamless positioning service can be provided in wider area without replacing existing GPS receivers. On the other hand, to adopt pseudolites at larger scale, it is necessary to evaluate how the pseudolites can complement the existing GPS-based positioning. Therefore, in this paper, we developed a simulation system which can estimate the availability of the positioning service using GPS and pseudolites at a given location and at a given time. This system consists of a three dimensional digital map, a model of GPS satellite orbit and a model of pseudolite. And, this system can estimate how the available area will change as the number and geometric distribution of tracked GPS and pseudolite change. As the results, it is expected that this system can contribute to determining the allocation of the pseudolites and estimating the effects of pseudolite installation in terms of the positioning service availability.

1 INTRODUCTION

1.1 Background

Recently, the Global Positioning System, GPS has been widely used in positioning, for example, car navigation system, surveying, automatic controlling and so on. It is well known that the accuracy, availability and reliability of the GPS-based positioning services are heavily dependent on the number and geometric distribution of tracked satellites.

However, in some situations, such as in the valley between buildings, underground shopping malls or in deep open-cut mines, the number and geometric distribution of tracked satellites may not be sufficient for accurate and reliable positioning. Because of this limitation, the integration of GPS with other technologies has been extensively investigated in order to improve performance of the GPS-based positioning. In this paper, we focused on the pseudolite technology which is one of the most promising technology to complement the GPS-based positioning.

But especially in urban area, the availability and reliability of the pseudolite technology are so seriously affected by the number and distribution of the pseudolites. To adopt the pseudolite for some large-scaled projects such as infrastructure development program, it is necessary to evaluate how effectively the pseudolite can complement the existing GPS-based positioning with how much cost. Therefore, it is strongly demanded to develop a simulation system to estimate the installation effects of the peudolites.

1.2 Objective

The objective of this paper is to develop a simulation system which can delineate available area of the positioning system using GPS and pseudolite. The system consists of a three dimensional digital map, models of GPS satellite orbits and of pseudolites, and it must be able to estimate how the available area will change as the number and geometric distribution of tracked GPS and pseudolite change.

2 PSEUDOLITE

2.1 What is Pseudolite?

The idea to use pseudolites is older than GPS itself. Before the U.S. Department of Defense launched the first GPS satellites, it tested the system concept with ground-based transmitters called “pseudo-satellite”, which was shortened to pseudolite. In 1984, Dale Klein and Bradford Parkinson were the first to point out that pseudolite could be a useful complementary technology for GPS operations, improving navigation availability and geometry accuracy. And now, one of the most attractive characteristics is that the user’s GPS receiver already contains all the hardware necessary to tune and demodulate the pseudolite’s signal; it requires only a software upgrade.

A pseudolite transmits a signal with code-phase, carrier-phase, and data components with the same timing as the satellite signals and with nearly the same format. A GPS receiver acquires this signal and derives code-phase pseudo-ranges or carrier-phase measurements to be used in a navigation algorithm. The major differences are that a pseudolite typically does not contain a high-accuracy atomic clock and that the pseudolite’s position must be described in geographical terms rather than in orbital elements.

2.2 Technical Problems

2.2.1 Near-Far Problem

GPS’s designers assumed that all transmitters would be aboard satellites at a large and relatively constant distance from all user’s receivers, consequently generating signal levels at the receivers that would be weak and relatively constant. Pseudolite, of course, violate this assumption. The distance between a user’s receiver and a pseudolite can be large or quite small, so pseudolite’s signal levels at a receiver can vary significantly. Figure 1 shows a concept of this problem called “near-far problem”.

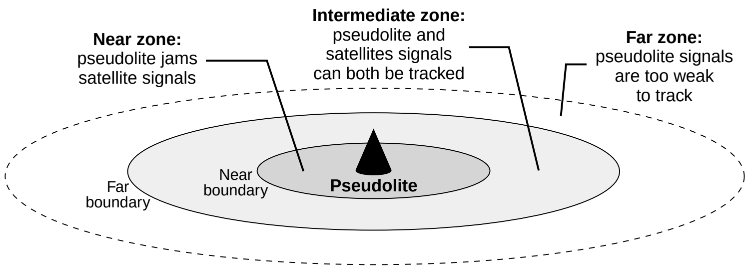


Figure 1: Near-far problem

Relatively strong pseudolite’s signals have the potential to overwhelm satellite signals and jam a receiver, whereas relatively weak pseudolite’s signals may be too feeble to allow receiver to track it. To navigate with both GPS satellites’ and pseudolites’ signals, the receiver must remain in the zone where both sets of signals can be tracked.

As a most reliable solution for the near-far problem, signal pulsing method was proposed. The near-far problem is minimized if the pseudolites transmit their signals only in short pulses with a low duty cycle. Such a pseudolite can interfere with the GPS satellites’ signals only while it is transmitting. If the pseudolite transmits only 10 percent of the time, it interferes only 10 percent of the time. During other 90 percent, the receiver hears the GPS satellites’ signals without interference.

2.2.2 Multipath Effect

Multipath is always a problem with GPS positioning, and is also certainly the enemy of pseudolite operations. As the strength of the pseudolite’s signals is much greater than that of the GPS satellite’s signals, the former is much more sensitive to multipath disturbance than the latter. It has been found that the mitigation of positioning result affected by multipath is absolutely important for accurate positioning with pseudolites.

One of the most effective approach to overcome the limitation of the large error due to multipath propagation is the adaptation of the antenna diagram to the pseudolite’s environment.

Figure 2 illustrates how the available area of a pseudolite can be extended by means of the antenna diagram shaping. The right side displays an antenna diagram which is typical for medium gain antennas like patch antennas in combination with choke rings. The left side shows an operation area which occurs with a high gain antenna.

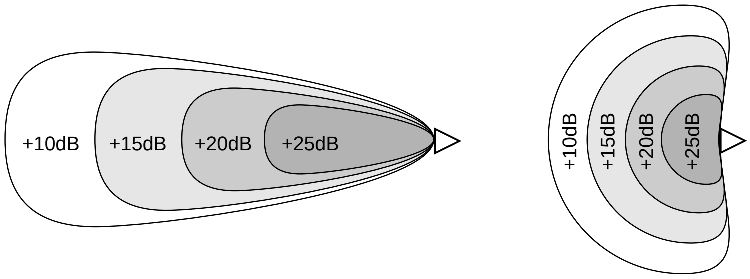


Figure 2: Antenna diagram shaping

The advantage of shaping the antenna diagram is that the illumination of the pseudolites' working area can take into account possible reflectors.

3 SATELLITE ORBITAL ESTIMATION

To estimate the number and geometric distribution of tracked GPS satellites at a particular time, the satellite orbit must be simulated. The GPS satellite orbit can be estimated with Keplerian model and satellite orbital elements which can be acquired from some WEB sites, for example, CelesTrack WWW (`http://celestrak.com/`).

3.1 Keplerian Orbital Elements

Seven numbers are required to define a satellite orbit. This set of seven numbers is called satellite orbital elements, or sometimes Keplerian orbital elements. These numbers define an ellipse, orient it about the earth, and place the satellite on the ellipse at a particular time. In the Keplerian model, satellite orbit in an ellipse has a constant shape and orientation. The Earth is at one focus of the ellipse, not the center; unless the orbit ellipse is actually a perfect circle. The basic orbital elements are listed as below.

t **: epoch** A set of the orbital elements is a snapshot of the satellite orbit at a particular time. Epoch is simply a number which specifies the time when the snapshot was taken.

i **: inclination** The orbit ellipse lies in a plane known as orbital plane. The orbital plane always goes through the center of the earth, but may be inclined any angle relative to the equator. Inclination is the angle between the orbital plane and the equatorial plane.

Ω **: right ascension of ascending node (RAAN)** The above inclination and this RAAN can orient the orbital plane in space. After the inclination could be specified, there are still an infinite number of possible orbital planes. If we specify where along the equator the line of nodes pokes out, we will have the orbital plane fully specified. The line of nodes pokes out two places, but we only need to specify one of them. One is called the ascending node (where the satellite crosses the equator going from south to north), and the other is called the descending node (where the satellite crosses the equator going from north to south).

ω **: argument of periapsis** The major axis passes through the center of the earth, and another line passing through the center of the earth, the line of nodes, was already identified. The angle between these two lines is called argument of periapsis.

e **: eccentricity** In the Keplerian model, the satellite orbit is an ellipse. Eccentricity tells us the shape of the ellipse.

n **: mean motion** Refer to the next paragraph 3.2.

M **: mean anomaly** Refer to the next paragraph 3.2.

3.2 Keplerian Model

Keplerian orbital dynamics problem is defined by the differential equation

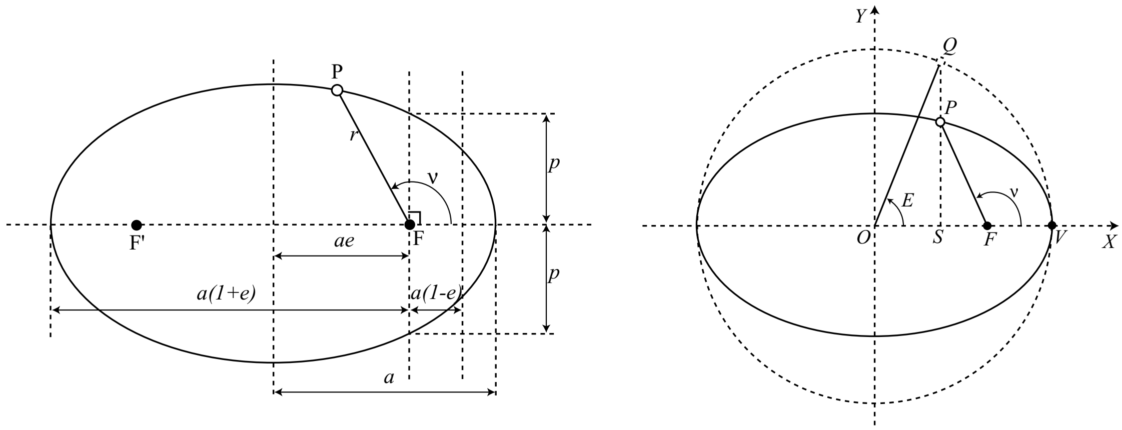
$$\ddot{\mathbf{r}} = -\mu \frac{\mathbf{r}}{r^3} \tag{1}$$

where $\mathbf{r}$ is the position vector of the satellite and r is the magnitude of the position vector. The gravitational parameter, μ, is a physical constant dependent upon the mass of the central body.

From equation (1), the orbital equation and the Kepler's equation can be formulated. equation (2) shows the orbital equation, and equation (3) shows the Kepler's equation.

$$r = \frac{p}{1 + e\cos\nu} \tag{2}$$
$$p = a\left(1 - e^2\right)$$
$$M = n(t - T) = E - e\sin E \tag{3}$$
$$n \equiv \sqrt{\frac{\mu}{a^3}}$$
$$\cos E = \frac{e + \cos\nu}{1 + e\cos\nu}$$

Where p is semi-latus rectum, a is semi-major axis, e is eccentricity, ν is true anomaly, M and E are mean anomaly and eccentric anomaly, n is mean motion, T is time of periapsis passage, t is a particular time, and the orbital parameters are illustrated in Figure 3.



(a) Parameters of an orbit ellipse

(b) Relationship between an orbit ellipse and the auxiliary circle

Figure 3: Orbital parameters

With Newton's law, eccentric anomaly E can be computed from known value, which is mean anomaly M, and then ν also can be computed. Therefore, with some conversions of coordinates, the satellite orbit and satellite position at a particular time can be computed.

4 AVAILABLE AREA ESTIMATION

This simulation system consists of a three dimensional digital map, a model of GPS satellite orbit and a model of pseudolites. In this paper, the model of pseudolite has only the position of pseudolite. This system was developed with JAVA, and each GPS satellites, pseudolites and map data are all implemented as individual classes. Figure 4 shows the concept of this simulation system developed to estimate available area of GPS and pseudolite.

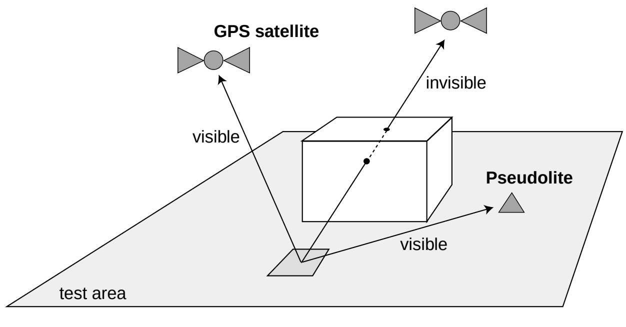


Figure 4: Concept of available area estimation

The test area is divided into the grid cell, and this simulation system estimate whether the line of sight from the center of each grid cells to each GPS satellites or pseudolites intersects any objects or not. Then the number of visible

GPS satellites or pseudolites are computed for each grid cells. Then if the number at a particular grid cell is four or over, it means that the positioning system using GPS and pseudolite will be available in the grid cell.

5 EXAMPLE OF SIMULATION RESULT

An example of simulation result which estimate available area of the positioning system using GPS and pseudolite is illustrated in Figure 5 and Figure 6.

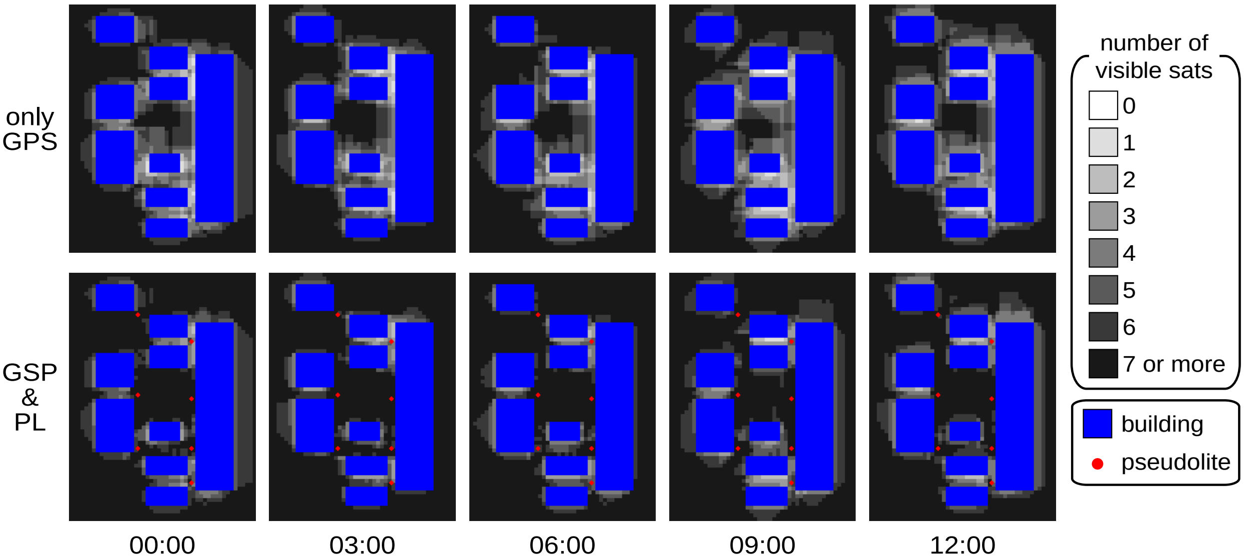


Figure 5: Number of visible transmitters; GPS satellite and pseudolite

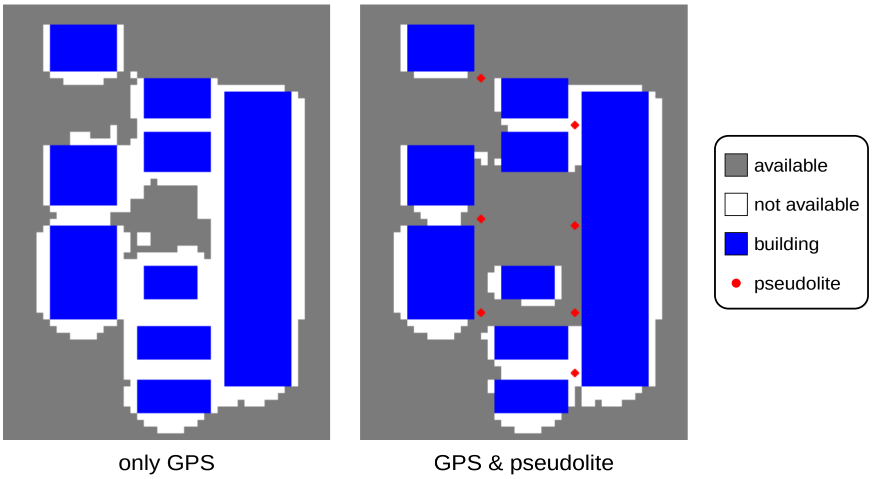


Figure 6: Available area of the positioning system using GPS and pseudolite

The conditions of the simulation is listed as below.

- Do the estimation process at every one hour from 00:00 August 1 to 00:00 August 2, 25 steps as total.
- Estimate GPS satellite orbit by using the satellite orbital elements around July 31.
- Use simplified three dimensional digital map of Komaga campus, Institute of Industrial Science, University of Tokyo, Japan, and hight of all buildings are 20 meter.
- The test area is divided into grid cells whose length of side is one meter.
- Each pseudolites are assumed to be located at the roof of buildings.

Figure 5 shows the number of visible transmitters at every three hour from 00:00 August 1 to 12:00 August 1, 5 steps as total, sampled from all estimated steps; upper five figures show the number of visible GPS satellite, and lower five figures show the number of visible both GPS satellite and pseudolite.

And, Figure 6 shows the available area which is defined as sets of the grid cells where four or more GPS satellite and pseudolite are visible. The left figure shows the available area of positioning system using only GPS, and the right figure shows the available area of positioning system using both GPS and pseudolite. We can clearly find out that the available area is extended efficiently by pseudolite.

6 CONCLUSIONS

We developed a simulation system which can delineate available area of the positioning system using GPS and pseudolite. This system can estimate how the available will change as the number and geometric distribution of tracked GPS and pseudolite change.

As the future works, it is necessary to develop a radio wave propagation model to deal with near-far problem, multi-path problems and antenna diagram shaping for the pseudolite, and develop an additional function to estimate positioning accuracy with evaluation of multipath propagation. Then, to develop an assistant tool to estimate the most suitable number and geometric arrangement of the pseudolites may be the useful and expected next target of this study.

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