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High Accurate and Efficient Positioning in Urban Areas Using GPS and Pseudolites Integration

Yong-Cheol SUH* and Ryosuke SHIBASAKI**

Abstract

The Global Positioning System technology has been widely used in positioning and attitude determination. 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, in some situations, such as in urban canyons, underground or inside of buildings, it is difficult to navigate with GPS receiver. Therefore, in order to improve the performance of satellite-based positioning, 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 a wider area without replacing existing GPS receivers. On the other hand, to adopt pseudolites on a larger scale, it is necessary to verify how the pseudolites may complement the existing GPS-based positioning. In this paper the authors present the details of the experiments and the results of the fundamental verification for seamless positioning using integration of GPS and pseudolite. This paper shows that the accuracy and efficiency of integrating GPS and pseudolite through the dynamic and static positioning experiment. The influence of pseudolite signal on GPS receiver is also discussed. The experimental results indicate that the accuracy of the height component can indeed be significantly improved, to approximately the same level as the horizontal component.

Keywords : *GPS, Pseudolite, Seamless Positioning, Near-far Problem, Multipath Effect*

1. Introduction

1.1 Background

GPS has been playing an increasingly important role in geodesy and positioning, for example, car navigation system, surveying, automatic controlling and so on. It is well known that the accuracy, availability and reliability of the positioning results are heavily dependent on the number and geometric distribution of GPS satellites being tracked.

However, in some situations, such as in areas between buildings, tunnels, underground shopping malls or deep open-cut mines, it is impossible to use GPS receivers because the number and geometric distribution of tracked GPS 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, the authors introduce the pseudolite technology, which is one of the most promising technologies to complement the existing GPS-based positioning. This paper also introduces the technical problem of pseudolite such as near/far problem and multipath effect.

1.2 Objective

In order to adopt the pseudolite technology for some large-scaled projects such as infrastructure development program, it is crucial to verify how effectively the pseudolite technology can complement the existing GPS-based positioning. The objective of this paper is to verify the accuracy and efficiency of the integration of GPS and pseudolite under some harsh observing conditions such as in urban canyons for seamless positioning. This paper describes the overview of the experimental procedures and accuracy from the dynamic and static navigation experiments, and gives a discussion on the experimental results and future works.

*Ph.D. Candidate, Department of Civil Engineering, University of Tokyo, Japan (E-mail : suh@iis.u-tokyo.ac.jp)
**Professor, Center for Spatial Information Science, University of Tokyo, Japan (E-mail : shiba@skl.iis.u-tokyo.ac.jp)

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2. Pseudolite

2.1 Pseudolite Concepts

The idea of using pseudolites is older than the 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 geometric 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; requiring only a software's 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.

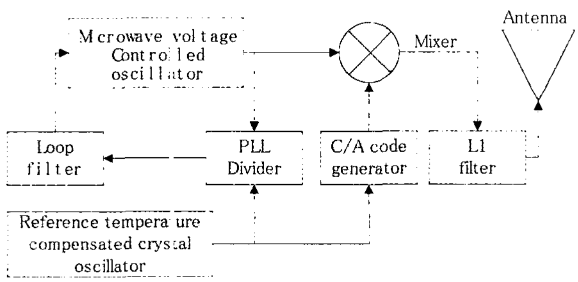

Fig. 1. Block Diagram of the Simple Pseudolite.

2.2 Problems Statement

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, the generated signal levels at the receivers 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. Fig. 2 shows a concept of this problem called "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 the receiver to track it. In order 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, then it interferes only 10 percent of the time. During other 90 percent, the receiver captures the GPS satellites' signals without interference.

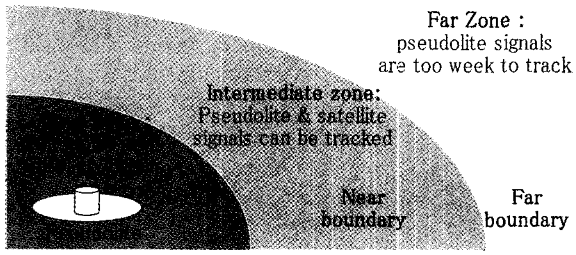

Fig. 2. Near-far problem.

2.2.2 Multipath Effect

Multipath is always a problem with GPS positioning, and is also certainly a hindrance to 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.

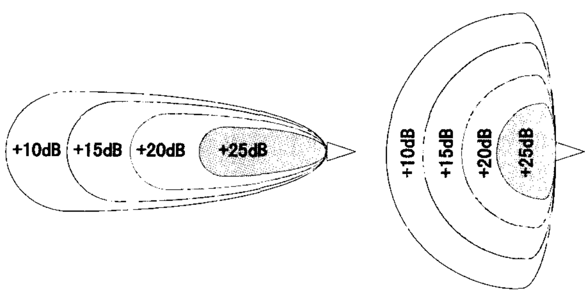

Fig. 3. Antenna diagram shaping.

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.

Fig. 3 illustrates how the available area of a pseudolite can be extended by means of the antenna diagram shaping. The right side of this figure displays an antenna diagram, which is typical for medium gain antennas like patch antennas in combination with choke rings. The left side of fig.3 shows an operation area, which occurs with a high gain antenna.

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

3. Experiment Description

3.1 System Overview

The positioning system implemented for this experiment is composed of six pseudolites and transmission antennas, three receivers and antennas for base station and rover, a wireless modem for data communication, and four notebook computers for calculating and displaying navigation solution.

Fig. 4 shows the constitutions of the pseudolites.

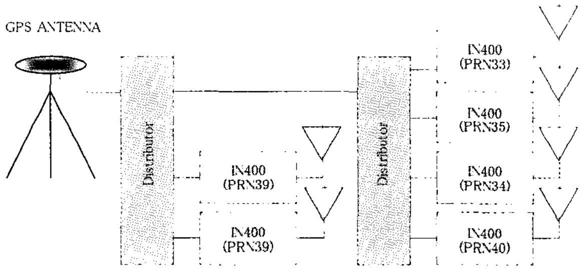

Fig. 4. Constitution of Pseudolites.

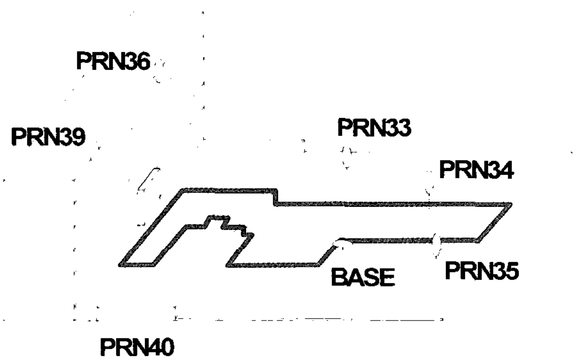

Fig. 5. Distribution of Pseudolites.

Fig. 5 shows the distribution of pseudolites. Four pseudolites and transmission antennas are located on the ground and two pseudolites are located on the rooftop. The base station is also located on the ground, and the rover moves along the test line.

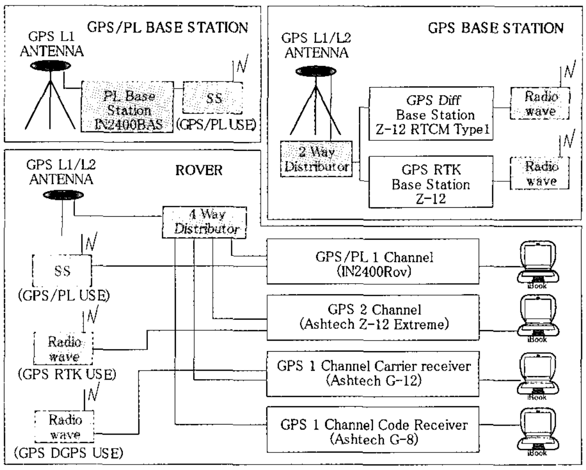

Fig. 6. Constitution of Receivers.

The pseudolites used in this experiment were manufactured by IntegriNautics.

Fig. 6 shows the constitution of receivers. They are composed of three parts; the GPS/PL base station, the GPS base station, and the rover.

3.2 Methods and Procedure

3.2.1 Dynamic Positioning

In this experiment, we carried out the dynamic navigation experiments under ten different conditions; i.e. we set the signal power of pseudolite transmitter to be operated at two different levels each with five different combinations of pseudolite.

Table 1 shows the arrangement of the pseudolites and each item of the dynamic positioning experiments.

Table 1. Arrangement of the pseudolites (Dynamic)

Exp. No	The power of signal	Arrangement of Pseudolite	Sum
D - 1	Low	Using all PL	5
D - 2	Low	Using 36, 39	2
D - 3	Low	Using 36,39,40	3
D - 4	Low	Using 33, 35, 40	3
D - 5	Low	Not used	0
D - 6	High	Using all PL	5
D - 7	High	Using 36, 39	2
D - 8	High	Using 36, 39, 40	3
D - 9	High	Using 33, 35, 40	3
D -10	High	Not used	0

3.2.2 Static Positioning

In this experiment, we set the signal power of the pseudolite transmitter to two different levels while the pseudolites was given two different setups. As shown in Table 2, static positioning experiment was carried out under three different environments which include change of observation point and the level of signal power.

Table 2 shows the arrangement of the pseudolites and conditions of the static positioning experiments.

Table 2. Arrangement of the pseudolites (Static)

Exp. No	The power of signal	Arrangement of Pseudolite	Position
S - 1	High	Using all PL	A
S - 2	High	Using all PL	B
S - 3	Low	Using all PL	B

*Position A : Center of experimental area.
*Position B : Beside the building.

4. Results and Discussion

4.1 Results of Dynamic Positioning

Fig. 7 and Fig. 8 show the horizontal result of the dynamic positioning experiment which was performed under two cases, i.e. using no pseudolite and using all the pseudolites, while Fig. 9 and Fig. 10 show the vertical positioning result of each experiment, differences between measurement positioning and real positioning vertical, DOP (Dilution Of Precision) and the number of satellites used.

From the horizontal results the differences of accuracy between the case of using no PL and all PLs can be easily noticed, especially, the deviation from the real position is observed more clearly near the building.

$$\sigma=\sqrt{\sigma_o^2+\sigma_a^2}$$

The standard deviation of the observations σ is calculated taking into account the observation error σ_o

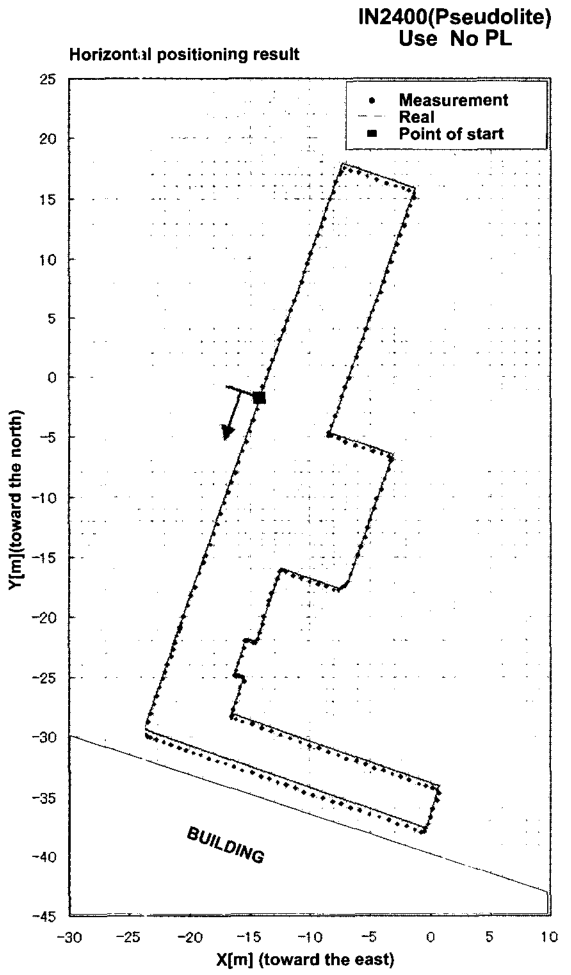

Fig. 7. Result from horizontal positioning using no PL

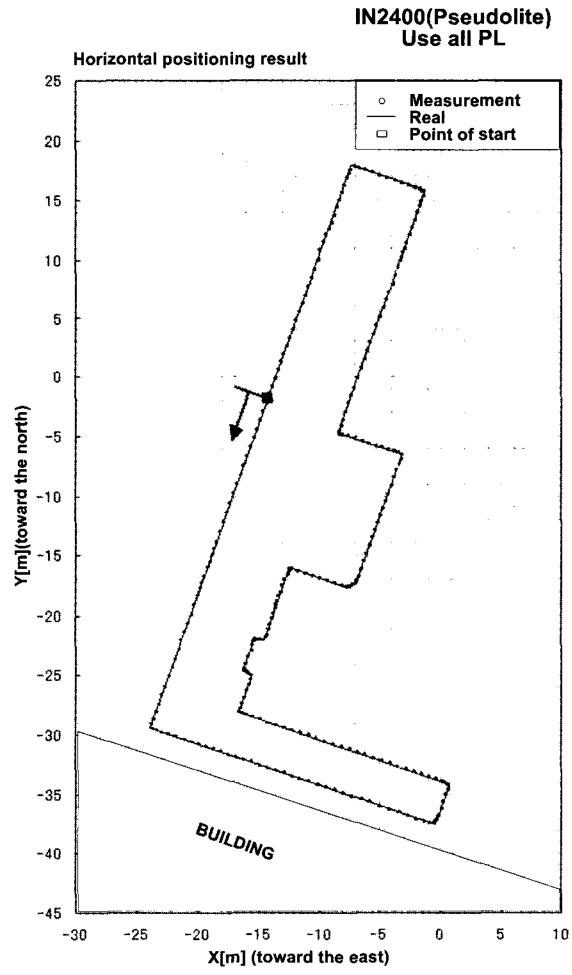

Fig. 8. Result from horizontal positioning using All the PLs

and the influence of antenna shaking σ_a, because the antenna shakes slightly during the experiment.

As shown in Table 3 and Table 4, the standard deviation of the observations is about 4cm in both horizontal and vertical ingredients for the case in which all pseudolites were used. But we should note that this value is the maximum observation error, because it contains the influence of antenna shaking. Thus this error will be a slightly smaller than that of both the tables after reduction of the influence of antenna shake.

Table 3 and Table 4 show the deterioration of observational errors compared to values obtained when using all the pseudolites under low and high signal power condition. Table 5 and Table 6 show that errors of vertical position are bigger when using the pseudolite only in parts than when all pseudolite were used. In this table, negative values imply they are more accurate than those obtained from the case in which all pseudolites were used. We deduce that these negative values are in accordance to their respective observation conditions.

Table 3. Accuracy of positioning IN2400 (Low Signal Power)

Used PL(Num)	Horizontal rms[m]	Vertical rms[m]
All PL (5)	0.052	0.041
Rooftop PL (2)	0.102	0.085
Rooftop+PL40 (3)	0.088	0.032
Ground PL (3)	0.042	0.115
No PL (0)	0.241	0.127

Table 4. Accuracy of positioning IN2400 (High Signal Power)

Used PL(Num)	Horizontal rms[m]	Vertical rms[m]
All PL (5)	0.043	0.042
Rooftop PL (2)	0.091	0.059
Rooftop+PL40 (3)	0.098	0.063
Ground PL (3)	0.042	0.076
No PL (0)	0.159	0.067

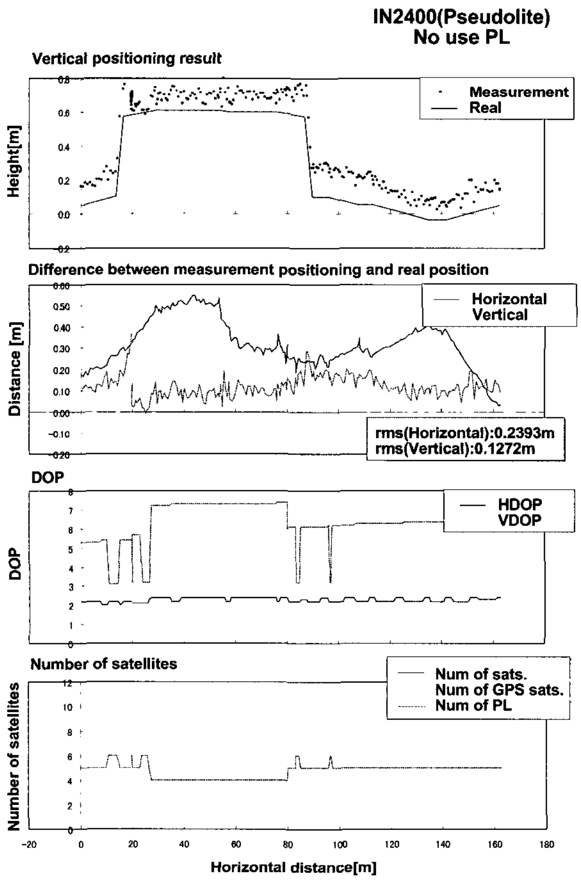

Fig. 9. Result from vertical positioning using no PL

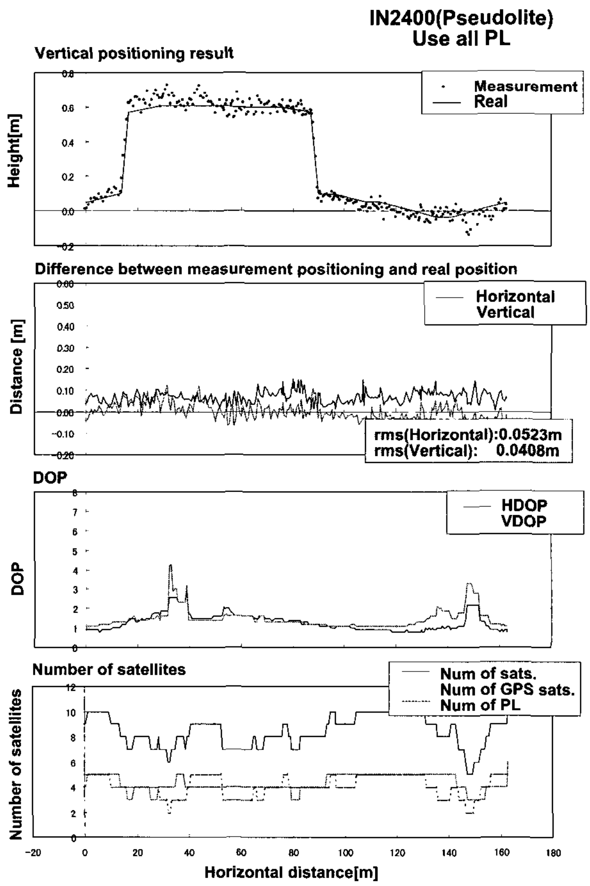

Fig. 10. Result from vertical positioning using All the PLs

Table 5. Deterioration of observational errors compared to the values obtained when all PL were used in IN2400 (Low Signal Power)

Used PL(Num)	Horizontal rms[m]	Vertical rms[m]
All PL (5)	0.000	0.000
Rooftop PL (2)	0.087	0.041
Rooftop+PL40 (3)	0.071	-0.052
Ground PL (3)	-0.067	0.108
No PL (0)	0.236	0.120

Table 6. Deterioration of observational errors compared to the values obtained when all PL were used in IN2400 (High Signal Power)

Used PL(Num)	Horizontal rms[m]	Vertical rms[m]
All PL (5)	0.000	0.000
Rooftop PL (2)	0.080	0.042
Rooftop+PL40 (3)	0.088	0.047
Ground PL (3)	-0.060	0.064
No PL (0)	0.153	0.052

4.2 Results of Static Positioning

Carrier phase ambiguity resolution could not be attempted in a normal manner because the receivers and pseudolites were stationary. The carrier phase processing was conducted by rounding off the double-differenced ambiguity to the nearest integer using the known initial position of the pseudolite. In this experiment, using IN2400 receiver, it took a long time to obtain an accurate value because there were some flawed data for several hours within the total duration of the measurements, while the calibration value approached the true value. It is speculated that this problem is caused by the peculiar behavior of the IN2400 itself. The values in Table 7 were obtained from the last one hour of the total measuring period, which is considered to be the state when the observational values have approached the true value and stabilized. From these results, it can be observed that when all the pseudolites were used, the observational errors are 1cm in horizontal direction and 2cm in vertical direction. Compared with RTK-GPS (Z12), the vertical accuracy is improved by using pseudolites even though the horizontal accuracy is almost same with RTK-GPS as shown in Table 7.

Moreover, in places such as next to buildings, it is difficult to navigate with general GPS receiver because of the limitation of tracked GPS satellites, but by using pseudolites, it is possible to navigate under such harsh observing conditions. Fig. 11 shows the results of static positioning, DOP and the number of satellites.

Fig. 12 and Fig. 13 show the horizontal results in static positioning experiment. These results show that the measuring errors are large in the Northeast direction. The deviation of these values may have come from the location of building, amount of unobscured sky and the arrangement of pseudolites.

Table 7. Accuracy of static positioning

Case		Horizontal rms[m]	Vertical rms[m]
IN 2400	A	0.0145	0.0244
	B	0.0262	0.0381
	C	0.0236	0.0308
Z12	D	0.0056	0.0367

*Case A : High signal power, Unobscured sky.
*Case B : High signal power, Beside the building.
*Case C : Low signal power, Beside the building.
*Case D : High signal power, Unobscured sky.

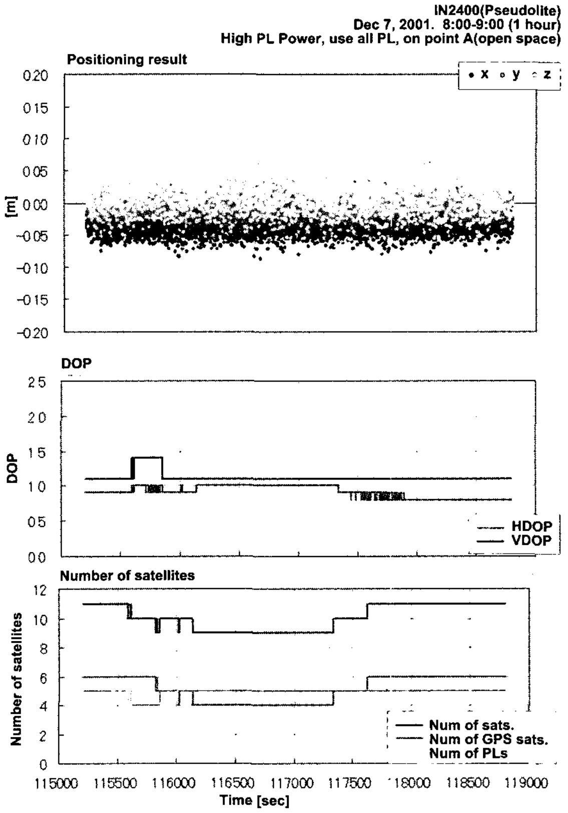

Fig. 11. Results of static positioning.

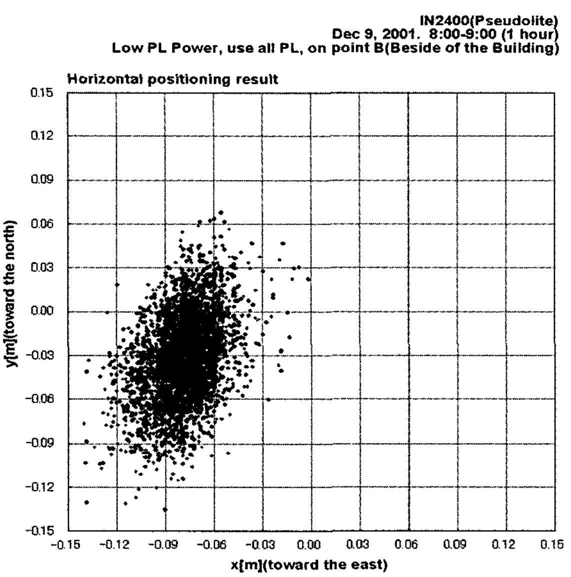

Fig. 12. The horizontal results in static positioning (High PL Power, use all PLs, IN2400).

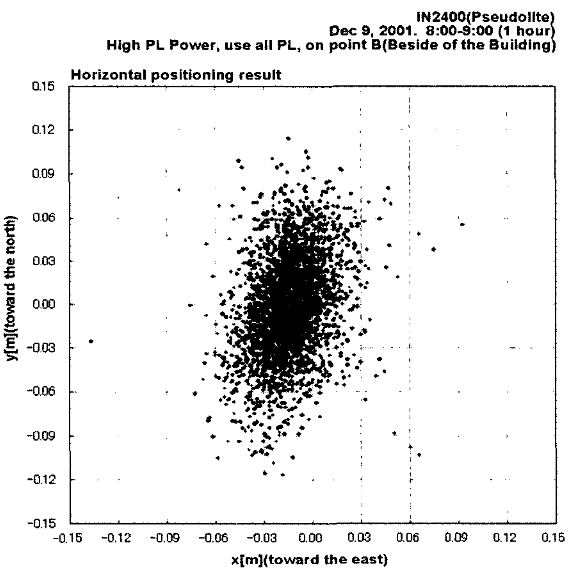

Fig. 13. The horizontal results in static positioning (Low PL Power, use all PLs, IN2400).

4.3 The Influence on GPS Receiver by Pseudolite Signal

The signals from the GPS satellites are extremely weak. Therefore, pseudolite signals influence GPS receiver. Sometimes, the poor S/N ratio makes it impossible to navigate. Fig. 14 shows that the transmitter of RTK-GPS is extremely sensitive to the exterior signal. It is speculated that these results are strongly related to the number of pseudolite used and the signal power.

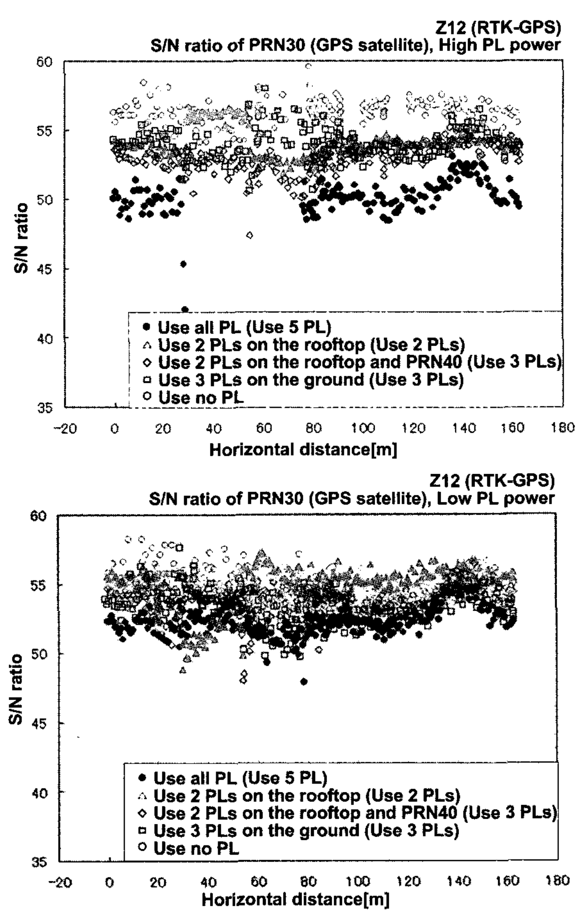

Fig. 14. S/N ratio of PRN30 (GPS satellite).

5. Conclusion and Future Works

The integration of pseudolite and GPS signals is one of the best option for improving system performance, particularly under harsh observing circumstances such as urban canyons for seamless positioning.

In this paper, the accuracy and efficiency of the integration of GPS and pseudolite is verified through dynamic and static positioning experiments. The experimental results indicate that the accuracy of the vertical component can indeed be improved to the same level as the horizontal component. The accuracy, reliability, availability and integrity of the solutions from integrated GPS and pseudolites systems can also be improved.

Development of a simulation system for assessing the layout of pseudolites in urban environment is a challenging issue for future works. 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 multipath of pseudolite signal, locations and antenna pattern of pseudolites have to be carefully examined.

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