INTEGRATION OF GPS AND PSEUDOLITE FOR SEAMLESS POSITIONING : Fundamental Verification Experiment and Results

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ABSTRACT

The Global Positioning System, GPS 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 space or inside of buildings, it is really hard 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 wider area without replacing existing GPS receivers. On the other hand, to adopt pseudolites at larger scale, it is necessary to verify how the pseudolites can complement the existing GPS-based positioning.

In this paper the authors present the detail of experimental investigations 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 and discuss about the influence on GPS receiver by pseudolite signal. 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.

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 the valley between buildings, tunnels, underground shopping malls or in 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 exiting GPS-based positioning. This paper also introduces the technical problem of pseudolite such as near/far problem and multhpath effect.

1.2 Objective

In order to adopt the pseudolite technology for some large-scaled projects such as infrastructure development program, it is really important and necessary 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 circumstances such as urban canyons for seamless positioning. This paper describes that the overview of experimental system and the results of accuracy from the dynamic and static navigation experiments, and discuss about experimental results and future works.

2. PSEUDOLITE

2.1 Pseudolite Concepts

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.

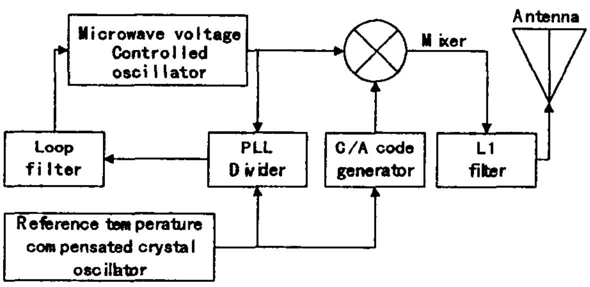

Figure 1: Block Diagram of the Simple Pseudolite

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 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 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 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.

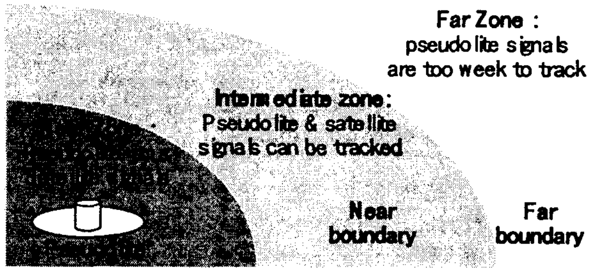

Figure 2: Near -far problem

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 3 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.

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

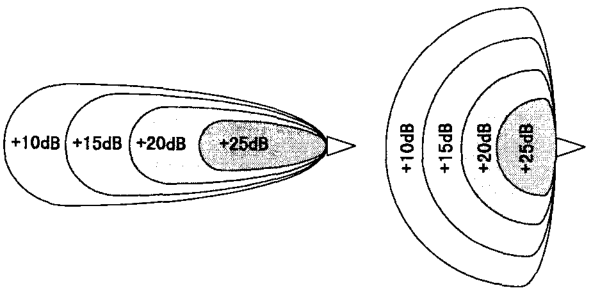

Figure 3: Antenna diagram shaping

3. EXPERIMENT DESCRIPTION

3.1 System Overview

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

Figure 4 shows the composition of pseudolites.

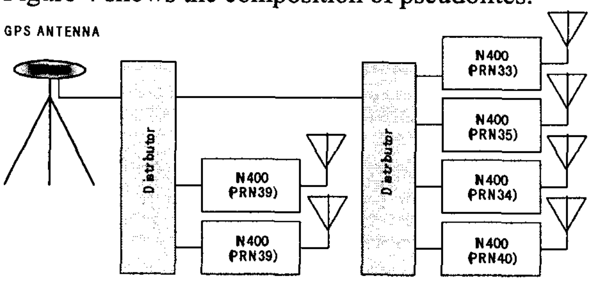

Figure 4 : Composition of Pseudolites

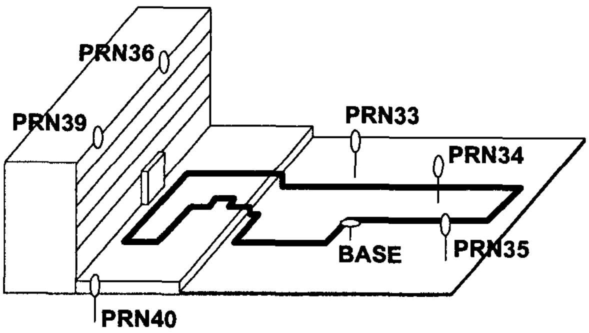

Figure 5 : Distribution of Pseudolites

Figure 5 shows the distribution of pseudolites. Four pseudolites and transmission antennas are located on the ground and two pseudolites are located in the rooftop. The base station is also located on the ground, and the rover moves along the test line. The pseudolites, which we used in this experiment, are manufactured by IntegriNautics.

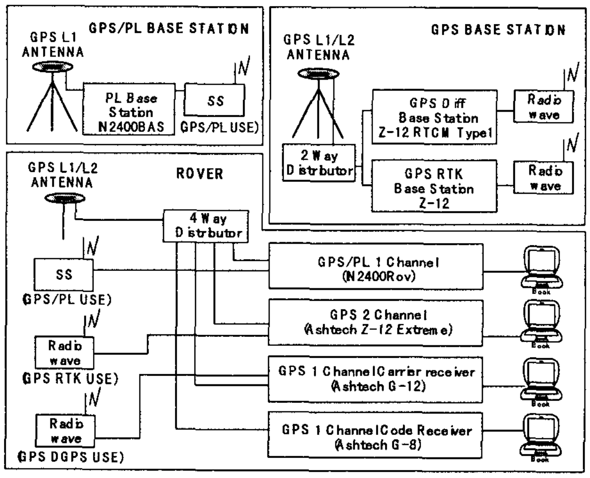

Figure 6 : Composition of Receivers

Figure 6 shows the composition of receivers. This is composed of three parts; GPS/PL base station, GPS base station, and rover.

3.2 Methods and Procedure

3.2.1 Dynamic positioning

In this experiment, we have set the signal power of pseudolite transmitter as two types of level. The arrangement and the combination of the number of pseudolites have been assumed five types kind of circumstances, therefore dynamic navigation experiment was done under ten types of circumstances.

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	No use	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	No use	0

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

3.2.2 Static positioning

In this experiment, we have set the signal power of pseudolite transmitter as two kinds of level. The arrangement and the combination of the number of pseudolite also has been set two kind of environment. Like as Table 2, static positioning experiment was done under three types of environment that is change of observation point and Level of signal power.
Table 2 shows the arrangement of the pseudolites and each item 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 : Middle of experimental area.
*Position B : Beside of the building.

4. RESULTS AND DISCUSSION

4.1 Results of Dynamic Positioning

Figure 7 and Figure 8 show the horizontal result of the dynamic positioning experiment which performed under the each condition of using no pseudolite and using all pseudolites, and Figure 9 and Figure 10 show the vertical positioning result of each experiment, and shows differences between measurement positioning and real positioning vertical, DOP(Dilution of precision), The number of satellites.
As shown in the horizontal results, it can be easily compare the differences of accuracy between the case of using no PL and all PL, especially, the deviation from the real position is seen more clearly near the building.
In this analysis, the standard deviation of the errors σ is calculated considering observation error σo and the influence of antenna shake σa, because the antenna shakes slightly during the experiment.

$$\sigma = \sqrt{\sigma o^2 + \sigma a^2}$$

As shown in Table 3 and Table 4, the standard deviation of errors is about 4cm same as horizontal ingredient and vertical ingredient experiment under the condition of using all pseudolites.

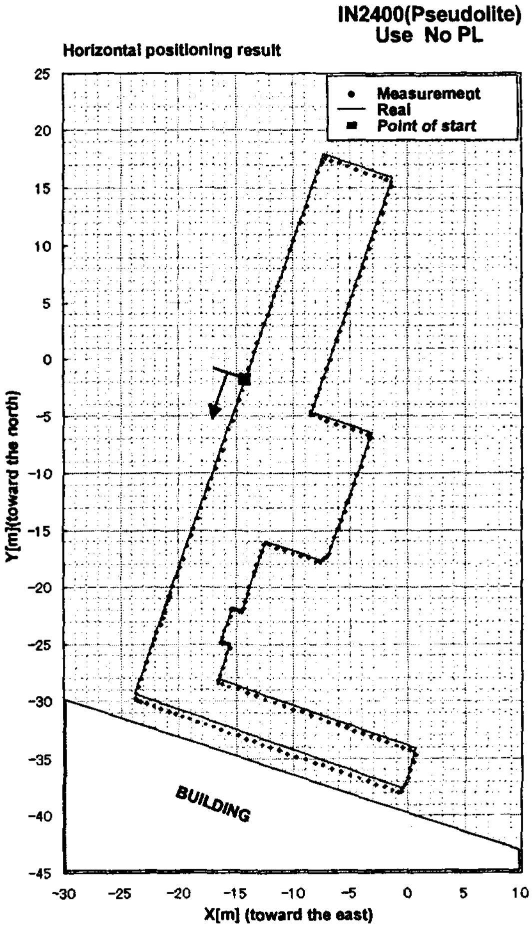

Figure 7 : Horizontal result of using No PL

Here we can see that this value is the maximum of the observation error. These values will be smaller than that of Table 3 and Table 4, because these values contain the influence antenna shake.
Table 3 and Table 4 show the deterioration of observational errors compared with the values, which obtained from case that using all pseudolites under condition of low and high signal power of pseudolite. In this table, minus values mean more accurate values better than that obtained from the case which use all pseudolites, we can guess the reason of these minus values is according to observational circumstances. Table 5 and Table 6 show that errors of vertical position are bigger when using the pseudolite only in parts compared with the case of using all pseudolite.

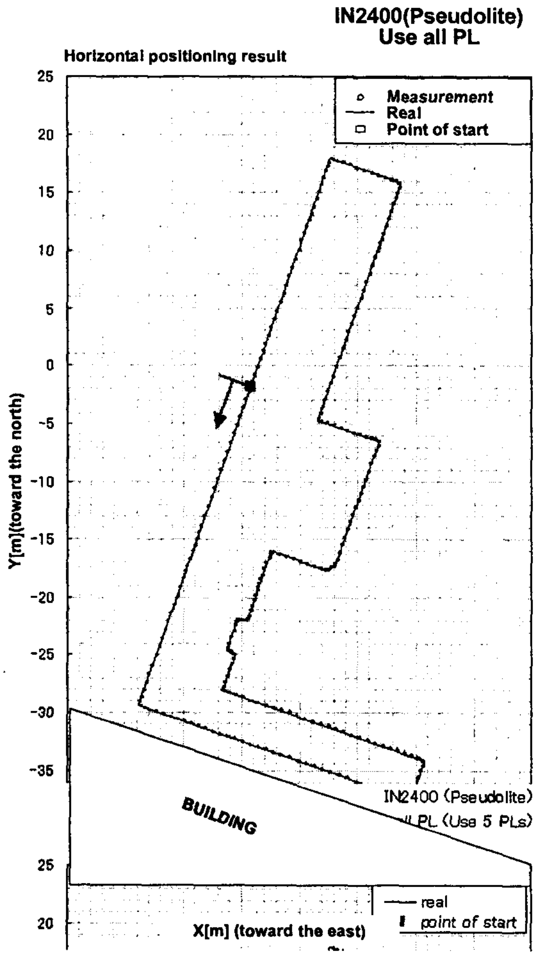

Figure 8 : Horizontal result of using All PL

Table 3 : The 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 : The 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

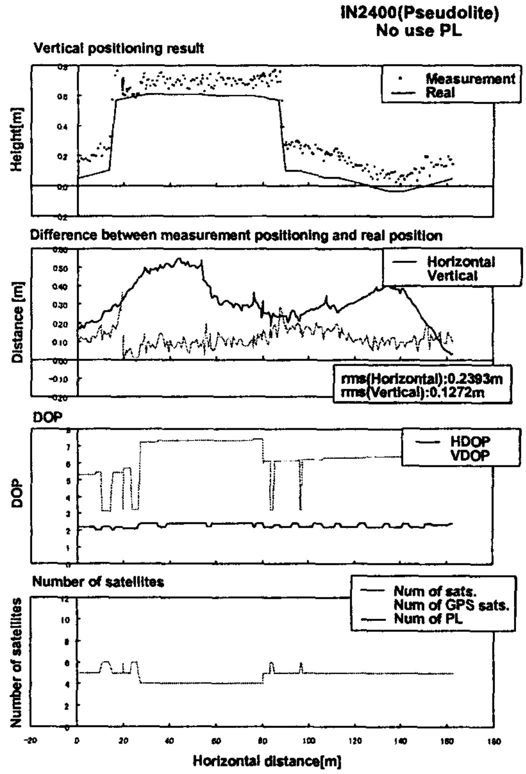

Figure 9 : Vertical results of using No PL

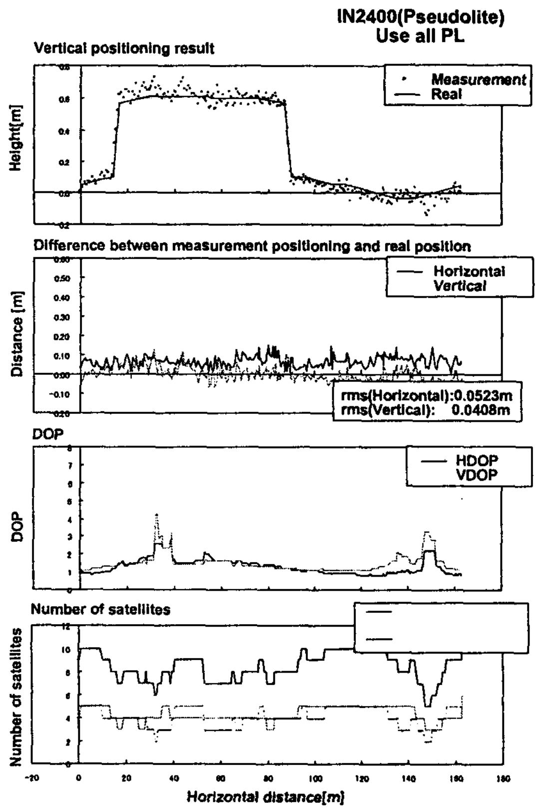

Figure 10 : Vertical results of using All PL

Table 5 : The deterioration of observational errors compared with the values of using all PL 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 : The deterioration of observational errors compared with the values of using all PL 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 the normal manner because the receivers and pseudolites are 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, used IN2400 receiver, it takes much time to get the accurate value because there are some wrong data for several hours among the total period of time, while the calibration value approached the true value gradually. We can guess this problem is caused by the peculiar trouble of IN2400 in itself.

The values of Table 7 are obtained from the last one hour among the total measuring period of time, which is considered to be the states when the observational values approached the true value and stabilized. From these results, we can see that the observational errors when we use all the pseudolite 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.

Table 7 : The 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, Open sky.
*Case B : High signal power, Beside of the building.
*Case C : Low signal power, Beside of the building.
*Case D : High signal power, Open sky.

Moreover, the place such as beside of the building, it is hard to navigate with general GPS receiver because of the limitation of tracked GPS satellites, but, by using pseudolites, it can be possible to navigate even such harsh observing circumstances. Figure 11 shows the results of static positioning and DOP, Number of satellites.

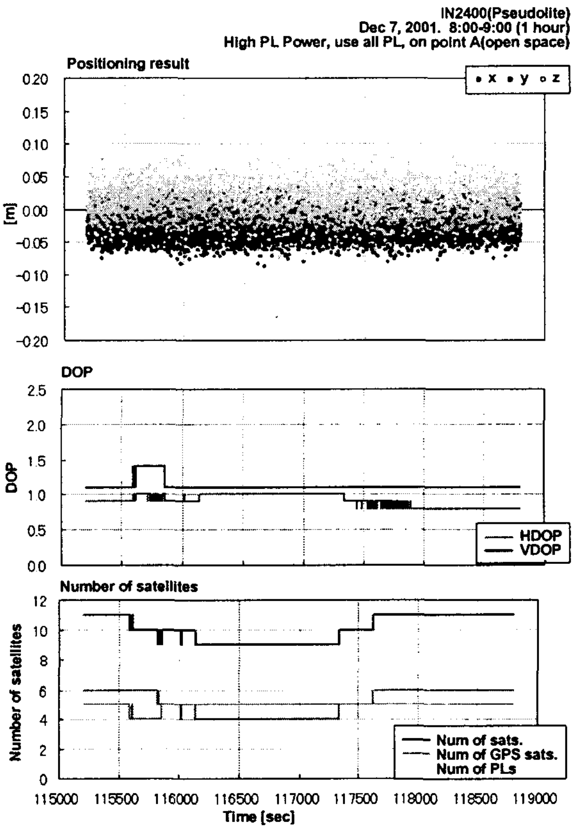

Figure 11 : The results of static positioning

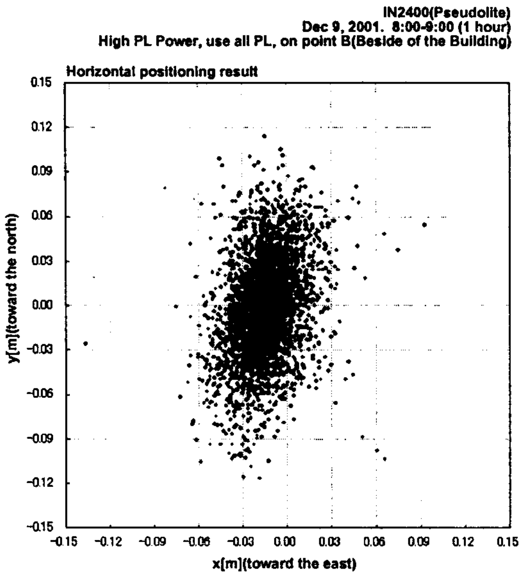

Figure 12 : the horizontal results in static positioning (High PL Power, use all PL, IN2400)

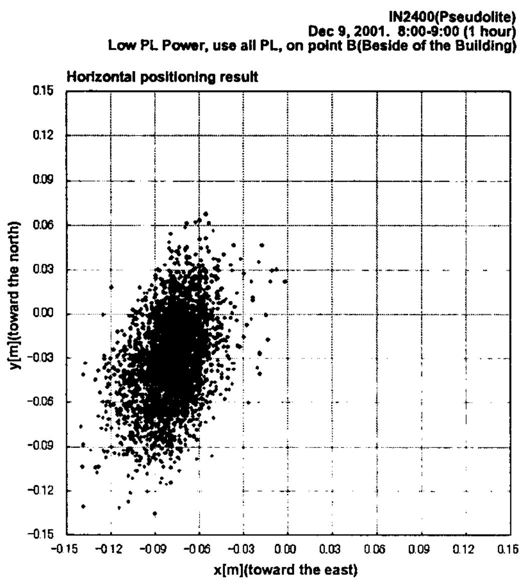

Figure 13 : the horizontal results in static positioning(Low PL Power, use all PL, IN2400)

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

4.3 The influence on GPS receiver by pseudolite signal

Signal from the GPS satellites are extremely weak, because of that reason, pseudolite signal influence GPS receiver. Sometimes, the fall of S/N ratio make it impossible to navigate. Figure 14 shows that the transmitter of RTK-GPS is extremely week to the exterior signal. We can guess these results are much related to the number of used pseudolite and signal power.

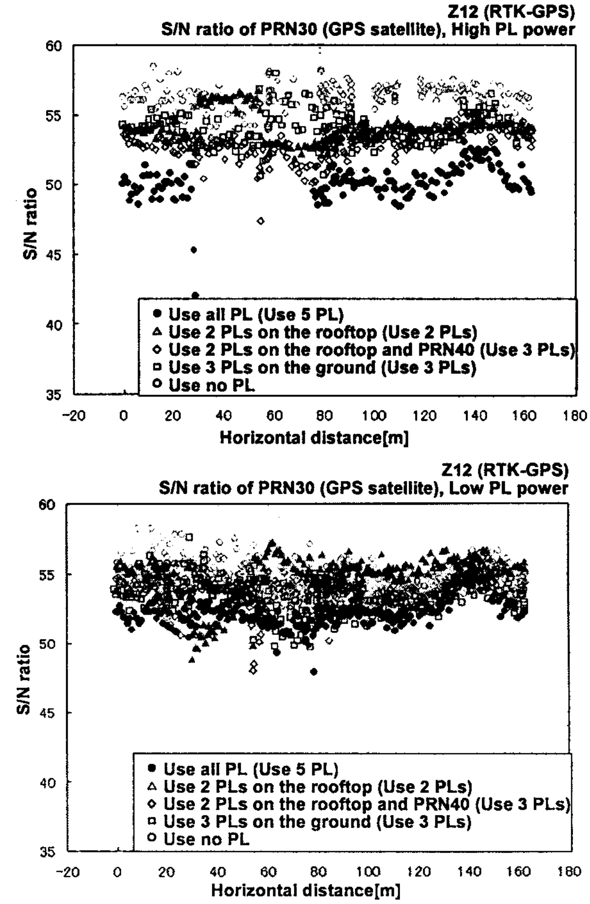

Figure 14 : S/N ratio of PRN30(GPS satellite)

5. CONCLUTIONS AND FUTURE WORKS

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

In this paper, we verify the accuracy and efficiency of the integration GPS and pseudolite through the dynamic and static positioning experiment. The experimental results indicate that the accuracy of the height 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.

As the future works, it is necessary to investigate pseudolite multipath and the mitigation of the systemic errors identified in the pseudolite measurement. And the proper arrangement of pseudolite transmitters through previous three-dimensional simulation is also a challenging issue for future investigation.

ACKNOWLEDGEMENT

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