Preliminary Testing of Pseudolite to Improve GPS Precision

Fang-Shii NING, Szu-Pyng KAO, Chia-Chyang CHANG, Taiwan and Xiaolin MENG, United Kingdom

Key words: key words, theme, etc.

SUMMARY

GPS technique has successfully become a powerful positioning and navigation tool in the recent years. However, there are still some drawbacks to the operations of GPS, such as the view of sky obstructed, causing the positioning precision degraded in some ways. The pseudolite, a satellite-like GPS ground signal generator, is then expected to provide the extra-measurements and to improve the GPS precision, coverage, and availability at the obstructed areas. It has been practically proved by this paper that the use of GPS pseudolite can effectively improve the repeatability of GPS vertical component from 2 cm to 1 cm. It is also encouraged that such level of GPS precision improvement can even be achieved at a trial area where is free of any obstruction to the GPS observation environment. There is really a room to upgrade the GPS effectiveness, especially for cadastral surveys in the urban canyons or monitoring surveys nearby the structural bodies, if the GPS pseudolites are assisted.

This research has proved that the GPS pseudolite combination can promote accurate positioning results, especially when there are no obstacles in the trial area; good repeatability was also obtained in the vertical component. This shows that GPS pseudolite can improve results in areas lacking a good view of the sky, such as in the downtown areas of cities or in valleys. In this study the vertical component precision increased by almost 50%; the improvement in the horizontal component was not significant

Preliminary Testing of Pseudolite to Improve GPS Precision

Fang-Shii NING, Szu-Pyng KAO, Chia-Chyang CHANG, Taiwan and Xiaolin MENG, United Kingdom

1. INTRODUCTION

The use of pseudolite was in the same early stage of GPS development in the late of 1970s. The first model of pseudolite focused on providing range measurements. In 1978, Ground-base GPS signal transmitters were used to test the GPS user equipment at Army Yuma Proving Ground. (Denaro et al., 1978) This team used satellite-like signal's structure but different golden code and data format to produce simulated satellite-like signals successfully. Therefore, people called this GPS transmitter as pseudo-satellite.

In the mid 1980s, the Radio Technical Commission for Maritime Services (RTCM) defined a pseudolite which can receive GPS satellite signals, compute pseudorange and range-rate corrections, and transmit the correction information at 50 bits per-second on an L-band frequency. In addition, the transmitted signal should be GPS like and the signal is designed to prevent interference to GPS and other equipment. The RTCM committee SC-104 ('Recommended Standards for Differential Navstar GPS Service') designated the Type 8 Message for the pseudolite almanac, containing the location, code and health information of pseudolite (Kalafus et al., 1986).

Pseudolite could be appendage of GPS system. It can ameliorate geometry problem. During the past decade, new pseudolite concepts and hardware have been developed for a variety of positioning and navigation applications. Pseudolite can be used as an augmentation tool for space-borne satellite positioning system. This augmentation can improve the system performance because the availability and geometry of positioning solutions are significantly strengthened. Further more, a pseudolite-only positioning system is possible, which can replace the space-borne satellite constellation where the use of satellite signals is not feasible, such as underground and Indoors. (Wang, 2002).

In the beginning of 1990, the research group of Stanford University developed a GPS pseudolite which can transmit L1 frequency and C/A code with low-price. However, IN200, IN300, IN500 series that produced by IntegriNautics were the first GPS pseudolite hardware equipments in business market in these recent years. These instruments could transmit GPS gold code number 1-37 in GPS L1 frequency. Despite it, the Model 7201 wide-frequency single producer from Stanford Telecome company and GSS pseudolite series from Spirent Communications all can be transmitted L1 signals of GPS C/A by after established. Thus, these GPS signal producer/pseudolite can be used as pseudolite system (Wang, 2002).

At the present, pseudolite mainly transmits GPS signal by L1 frequency (1575.42 MHz), and there are few L2 frequency (1227.60 MHz) can be transmitted. Originally, after updating instrument of acceptance, standard GPS instrument of acceptance can track signal of GPS pseudolite (Figure 1) in certain stable equipments conditions. Instruments of acceptance models are Millennium from NovAtel, Allstar GPS from Canadian Marconi [Rizos, 2002].

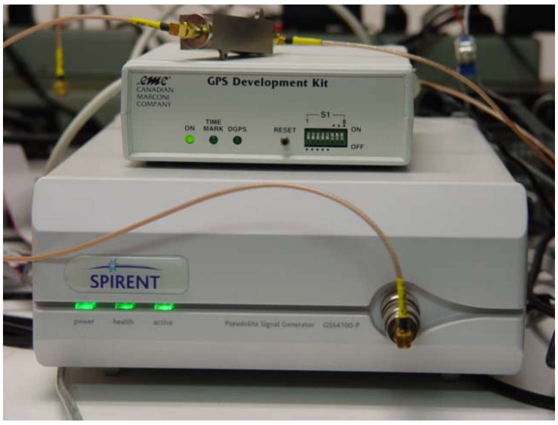

Figure 1: The Combination of GPS Signal Producer and GPS Receiver

The development of pseudolite related with navigation system, such as airplane landing and etc in pass years. They all need highly navigation accuracy. Now, each country has developed GPS navigation system or Wide Area/Local Augmentation System. GPS navigation system mainly uses real-time satellite-like transmittal technique to fix focusing error and improving system-operating competence. Wide Area/Local Augmentation System is mainly improving the navigation signal quality after airplanes' landing by set up pseudolite in near airport area.

In the use of surveying, GPS pseudolite that set up in the ground can increases numbers of GPS view of sky in order to accept GPS signals, but also raise accuracy of positioning. Further more, pseudolite can solve problems of GPS signal obstruction. In the example of figure 2, GPS signal obstruction because bad viewing environment, which decreases the viewing of satellite numbers. On the other hand, using GPS pseudolite to do positioning, it can provide extra measurements in order to increases positioning success percentage and become more accuracy.

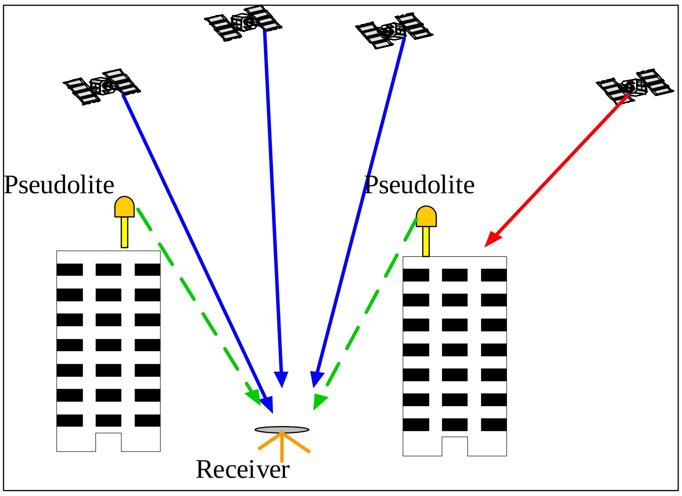

Figure 2: Operating a Satellite-Like Pseudolite System

Accordingly, pseudolite system has advantages in surveying and navigation operating.

- Protracting positioning Area and observed Time: Although GPS system covered all global, but it still limited by obstruction of ground surveying and positioning problems. Usually, the limited viewing satellite causes lacked positioning solution. Using pseudolite can increase extra viewing amount, so it is protracting positioning area and observed time.
- Increasing Competence of Positioning: competence means the ability of warning when GPS system cannot work properly. This is very important for navigation in real time or real time positioning. GPS instrument of acceptance would be able to eliminate unusual phenomenon to higher competence of positioning.
- Real Time Transforming Data: Via pseudolite transform data function, it can transform each GPS message, such as base-station data, pseudolite data, and real time static data to surveying stations. Pseudolite using L frequency operation, which is, does not affect by others.
- Rising Positioning Solution Speed and Accuracy: because grounded pseudolite and aerial GPS satellites have different geometry conditions, there are high geometry vertical conditions relative to pseudolite. It is also lower relation between surveying amounts that is raising positioning solution speed and accuracy.

From the point of view of engineering, GPS pseudolite technology can play an important role on the so-called Location-Based Service, or Location Commerce Service, for the following service fields:

- Airplane landing;
- Near-shore ship cruse;
- Cellular phone positioning;
- Underground transportation；
- Automatic machinery and equipment；
- Storehouse management;
- Indoor positioning;
- Topography and construction monitoring.

2. POSITIONING THEORY

After GPS developed, satellite positioning system technology is getting significant role. Compares with traditional surveying technique, the most advantage of satellite positioning system is that it is unobstructed. This provides positioning better elasticity and flexibility.

Generally, more numbers of satellites have been tracked, more higher the accuracy. On the other hand, in some bad conditions, such as in city, gorge, or mountain valley, it would be not enough for tracking satellites. Further more, the tracked satellites have be distributed over an area affects the solution of accuracy efficiently. From another point of view of GPS positioning, horizontal coordinates will be more accuracy than vertical direction. One of the reasons is low altitude satellites will not be tracked. Also, when they are tracked, other satellite signal would affect by atmosphere and have worse signal quality [Wang et al., 2001a].

The meaning of pseudolite exists is that it can ameliorate drawbacks of satellite GPS positioning. As pseudolite uses in aviation, navigation and land positioning fields, to discuss and research in pseudolite technology is getting enhancement. From positioning theory's point of view, the theory of pseudolite is similar to GPS's signal. Thus, the foundation of GPS positioning can be use in pseudolite positioning technology as well. In general condition, the formulas of GPS observables are pseudo-range and carrier phase which also can apply to pseudolite observables. The equations be shown as:

$$R_K^P = \rho_K^P + c \cdot (dt^P - dt_k) + T_K^P + dr_K^P + dm_K^P + \varepsilon_K^P \qquad (1)$$

$$\phi_K^P = \frac{1}{\lambda_P}\rho_K^P + \frac{c}{\lambda_P} \cdot (dt^P - dt_k) + N_K^P + \frac{1}{\lambda_P}T_K^P + \frac{1}{\lambda_P}dr_K^P + \delta m_K^P + e_K^P \qquad (2)$$

[Wang et al. 2001b]:
Where

R_K^P stands for the measured code pseudorange between observing site k and pseudolite p;
ϕ_K^P stands for the measured carrier phase in cycles from pseudolite p to receiver k;
λ_P stands for signal wavelength of pseudolite;
ρ_K^P stands for the geometric distance between observing site k and pseudolite p;
c stands for velocity of light;
dt^P stands for clock error of pseudolite;
dt_k stands for clock error of receiver;
N_K^P stands for integer ambiguity;
T_K^P stands for tropospheric delay;
dr_K^P stands for location error of pseudolite;
dm_K^P and δm_K^P stand for multipath effect of pseudo-range and carrier phase, respectively;
ε_K^P and e_K^P stand for measured error of pseudo-range and carrier phase, respectively.

In equations (1) and (2) the ionospheric delay correction of the signal was not shown, because both the pseudolite launching and the user's receiver were operating on the ground. Unlike airborne satellite signals, pseudolite signals are transferred by the lower troposphere. Because of this, pseudolite observables have to use tropospheric models, in order to correct the delays. In fact, pseudolite observable corrections in tropospheric delay are somehow similar to those of the Electronic Distance Measurement.

Because pseudolites do not have a high quality clock, there is a difference between pseudolite observables and GPS observables when they are operating. Therefore, it is necessary to eliminate the clock bias of pseudolite observables. For example, in the sketch illustrated in

Figure 3, which uses a single frequency pseudolite, there is no external time oscillator, so it cannot be calibrated before operating. It must use the double difference mode to obtain the baseline solutions with the phase observable (see figure 3).

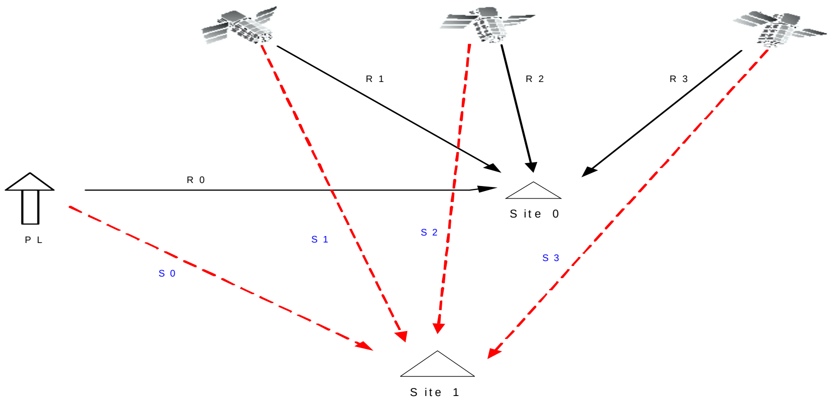

Figure 3: Double Difference Operation for GPS and PL Observation

3. TRIAL

3.1 Trial Area

The trial area is located at campus of the University of Nottingham as figure 4. There were four stations (PL1, PL2, PL3, PL4) to set up pseudolite, one unknown station (Centre) and one differential reference station (Ddref). All of the stations used dual frequencies receives to do four hours measurement and get the precise coordinates of each station.

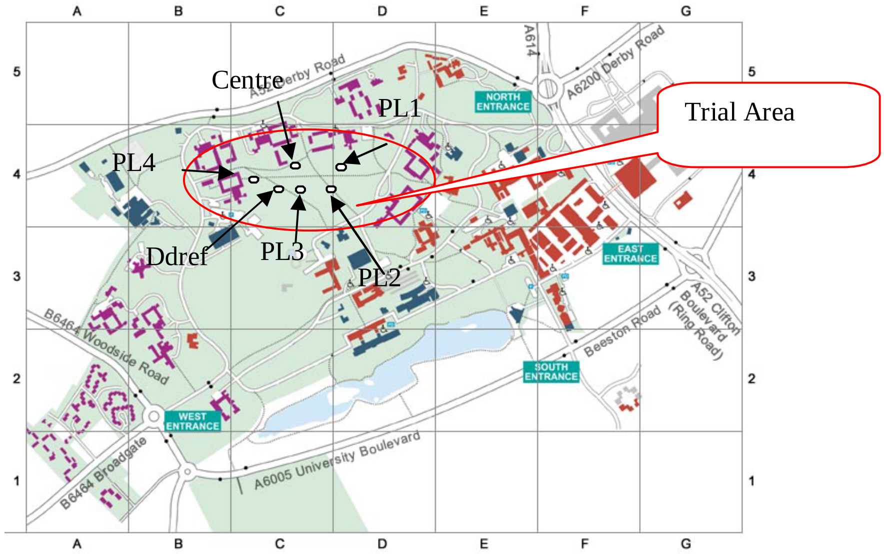

Figure 4: Trial Area of GPS and PL Observation

3.2 Zero-baseline Testing

Zero Baseline Test uses two GPS receivers via splitter to receive signal of same GPS antenna. These two GPS receiver are in the same condition, such as satellite condition, multipath, and delay in ionosphere and troposphere. All of these conditions and delay eliminated in the same time. (Rocken, et al., 1996). As a result, the baseline of this test will be zero (Jackson, et al., 2000).

Zero-baseline testing verified NovAtel receiver (see Figure 6), and calculate the observables by software of Trimble Geomatics Office (TGO) in this trial (see Table1). According to the result from table 1, two GPS receivers provide conformably GPS observables, so the baseline coordinates and other parameters reach the requirement of zero-baseline criteria.

Figure 5: GPS Signal Splitter

Figure 6: GPS Zero Baseline Trial

Table 1 Result of Zero Baseline Vector

Y component of baseline vector	0.00001 m	Azimuth	0°00'00"
X component of baseline vector	0.00000 m	Distance	0.00001 m
Z component of baseline vector	0.00001m	Ellipsoid Height	0.00001 m

3.3 Pseudolite Testing

This research uses IntegriNactics In200D pseudolite system to collect GPS pseudolite data. The outfit shows on Figure 7 that produces and transmit pseudolite signal. There is one extra illustration, this experiment posit center equipment in order to decrease GPS pseudolite signal transmit error. See Figure 8.

Figure 7: Pseudolite Signal Transmit System **Figure 8**: Transmitting Pseudolite Signal

To research the relationship between positioning and location of pseudolite, this research set up four base stations, PL1, PL2, PL3 and PL4, on August 4th, 5th, 7th and 12th, 2003 to transmit pseudolite signals during trial. In the same time, Centre and Ddref receive GPS pseudolite signal. See Figure 9. In order to get the same satellite geometry, so the observed time is the same.

All observed data transformed into RINEX format (see Table 2), and then using the software that provided by New North Wales University Australia to compute the position of rover station Centre. The data processing procedure sees the figure 10 for more detail.

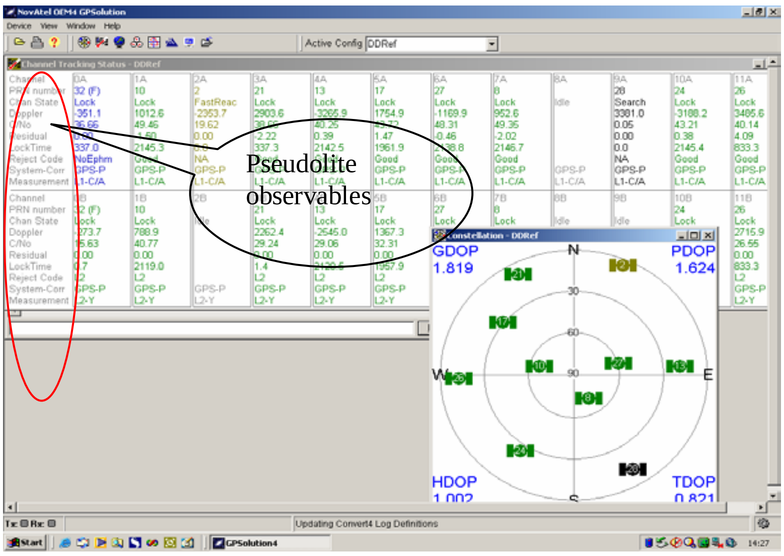

Figure 9: Operation Screen Showing Pseudolite Signal Received

Table 2: Example of RINEX Format Data Recorded

```
2.10 OBSERVATION DATA G (GPS) RINEX VERSION / TYPE
Convert CompanyName 04-Aug-2003 20:21 PGM / RUN BY / DATE
Signal Strength values S1,S2 are in dBHz COMMENT
Centre MARKER NAME
Centre MARKER NUMBER
Observer Agency OBSERVER / AGENCY
Rec Number NovAtel GPSCard Rec Version REC # / TYPE / VERS
Antenna Number Antenna Type ANT # / TYPE
0.0000 0.0000 0.0000 APPROX POSITION XYZ
 0.0000 0.0000 0.0000 ANTENNA: DELTA H/E/N
 1 1 WAVELENGTH FACT L1/2
 1 1 7 G08 G09 G10 G17 G18 G21 G26WAVELENGTH FACT L1/2
 1 1 3 G27 G28 G32 WAVELENGTH FACT L1/2
 COMMENT
 8 C1 L1 D1 S1 P2 L2 D2 S2 # / TYPES OF OBSERV
 1.000 INTERVAL
 2003 08 04 14 59 30.0000000 GPS TIME OF FIRST OBS
 2003 08 04 15 38 42.0000000 GPS TIME OF LAST OBS
 13 LEAP SECONDS
 END OF HEADER
 03 08 04 14 59 30.0000000 0 6G32G28G26G10G17G 9
 33554432.04746 177110385.48846 -1397.12546 43.000
```

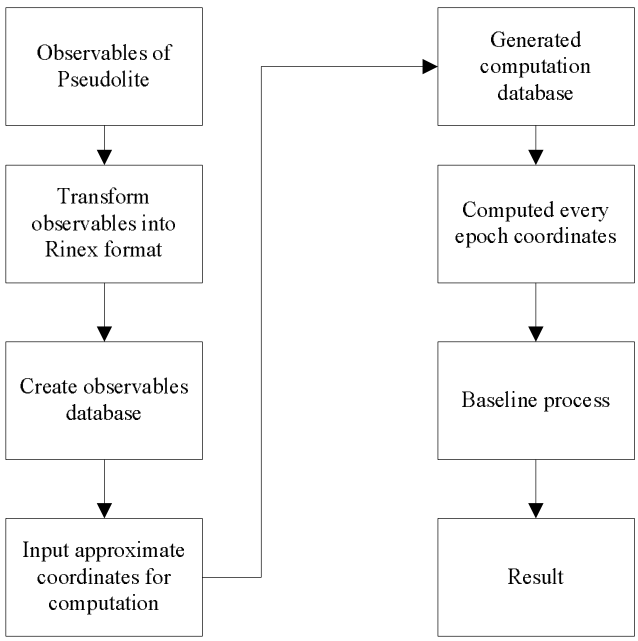

Figure 10: Flow Chart of Pseudolite Data Processing

4. ANALYZING RESULT

After the trials, there were four sets of observation data which had an epoch rate of one second, for two hours. All data was processed by UNSW software with added multipath corrections. All data, from the pseudolite setting locations labeled PL1, PL2, PL3 and PL4 were associated with the sessions of I, II, III and IV, respectively.

4.1 Comparing Precision for Each Session

The analysis of results will compare GPS only solutions with GPS+PL solutions. The results of position standard deviation in three components (N, E, h) are shown in Figure11, Figure12, Figure 13 and Table 3, 4.

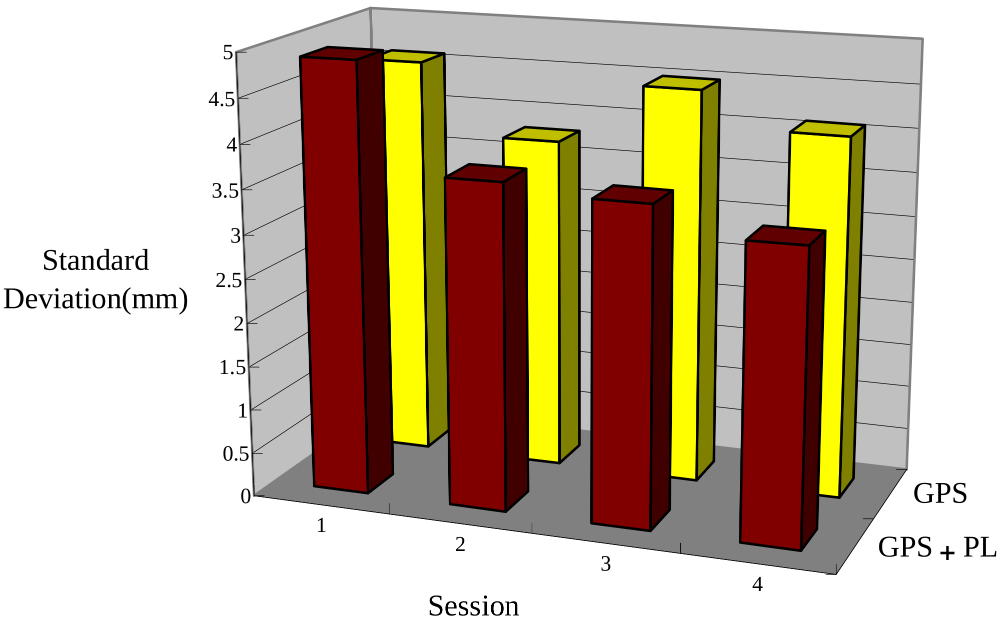

Figure 11: Precision Comparisons between GPS and GPS+PL for N Component

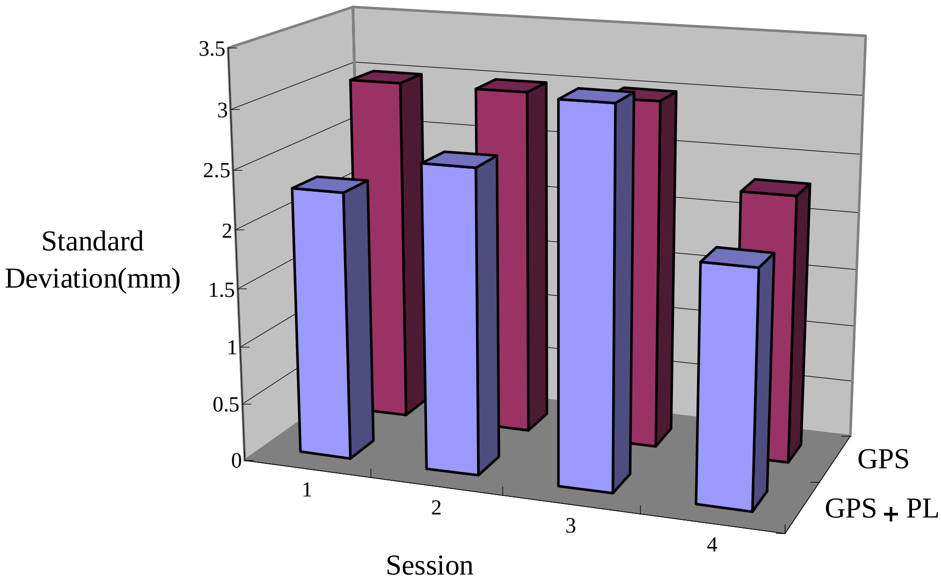

Figure 12: Precision Comparisons between GPS and GPS+PL for E Component

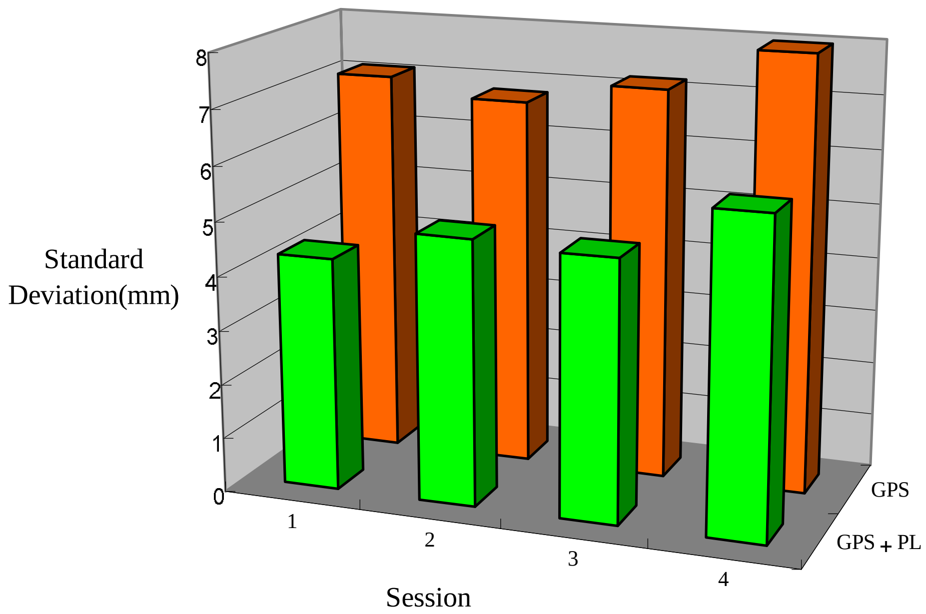

Figure 13: Precision Comparisons between GPS and GPS+PL for h Component

Table 3: Standard Deviations of GPS Solutions

Session	σ_N (cm)	σ_E (cm)	σ_h (cm)
I	0.3	0.5	0.7
II	0.3	0.4	0.7
III	0.3	0.5	0.7
IV	0.2	0.4	0.8
Repeatability	0.3	0.4	0.7

Table 4: Standard Deviations of GPS+PL Solutions

Session	σ_N (cm)	σ_E (cm)	σ_h (cm)
I	0.2	0.5	0.4
II	0.3	0.4	0.5
III	0.3	0.4	0.5
IV	0.2	0.3	0.6
Repeatability	0.3	0.4	0.5

From above results, it shows a consistency of GPS only and GPS+PL. The difference either both solutions have only 0.1 cm difference. The N and E components are not improved significant, but the h component improved more than N and E components. The reasons is PL located at lower elevation angle. For example, the accuracy of vertical component of GPS+PL improves from 0.7 cm GPS only to 0.5 cm in session II (See Figure 14 and Figure 15).

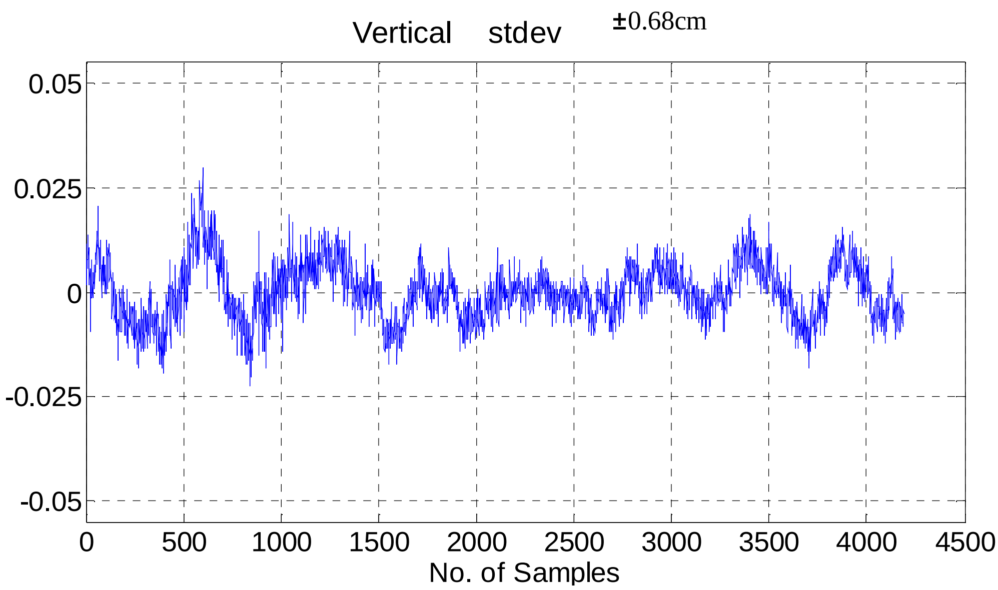

Figure 14: Variations of GPS Height Solutions for Session II

±0.49cm

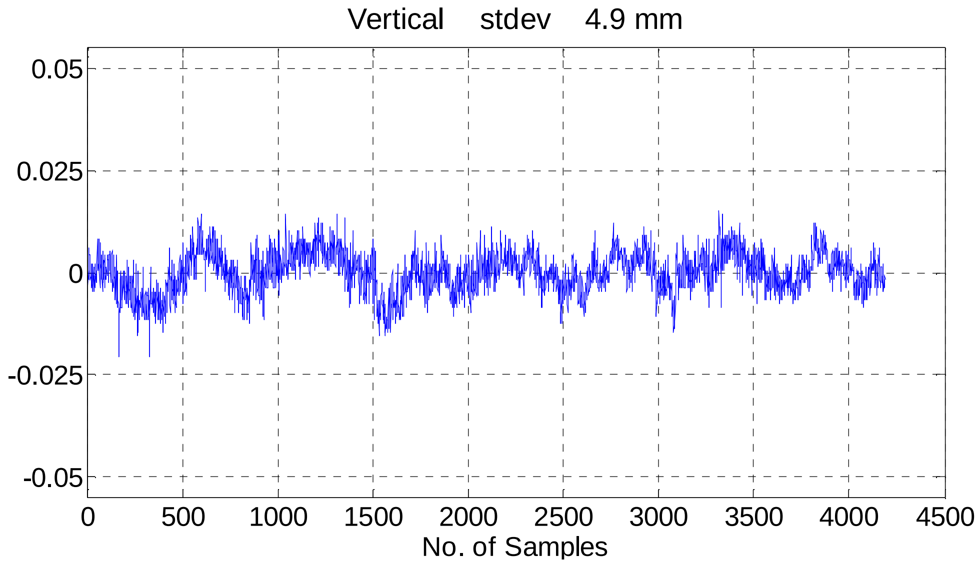

Figure 15: Variations of GPS+PL Height Solutions for Session II

4.2 Comparing the Coordinate Differences between Every Session

As can be seen from Tables 3 and 4, there is a consistency between GPS only and GPS+PL for each session. The average weighting value of the four sessions is a standard value that can be compared with the four session results to determine differences. These differences can be indices of baseline repeatability. In other words, the smaller the difference between the results and the average, the greater the fitness of the same test station in different sessions. For the difference between the results and the standard value for the four sessions and repeatability, see Table 5 (GPS only) and Table 6 (GPS+PL).

Table 5: Coordinate Differences for GPS Solutions

Session	□N(cm)	□E(cm)	□h(cm)
I	-0.5	-0.5	1.3
II	1.1	0.6	0.3
III	0.3	-0.3	0.7
IV	-0.5	0.1	3.0
Repeatability	0.7	0.5	1.9

Table 6: Coordinate Differences for GPS+PL Solutions

Session	□N(cm)	□E(cm)	□h(cm)
I	-0.6	-0.4	0.5
II	0.9	0.6	-0.2
III	0.0	-0.4	0.4
IV	-0.2	0.1	-1.4
Repeatability	0.6	0.5	0.9

From above tables, they show that result of GPS+PL and GPS in horizontal components are still consistency. The value is about 0.5-0.7 cm. The vertical component repeatability of GPS+PL (about 1 cm) is better than GPS only (about 2 cm). In other words, the baseline processing result in vertical component accuracy of GPS+PL is about 50% better than GPS only. It is the benefit of operation with pseudolite.

5. CONCLUSION

This research has proved that the GPS pseudolite combination can promote accurate positioning results, especially when there are no obstacles in the trial area; good repeatability was also obtained in the vertical component. This shows that GPS pseudolite can improve results in areas lacking a good view of the sky, such as in the downtown areas of cities or in valleys. In this study the vertical component precision increased by almost 50%; the improvement in the horizontal component was not significant.

REFERENCES

Cobb, S. and M. O'Connor (1998), Pseudolite: Enhancing GPS with Ground-based Transmitters, GPS World, Vol. 9, No. 3, pp. 55-60.

Denaro, R., V. G. Harvester and R. L. Harrington (1978), GPS Phase I User Equipment Field Test, Global Positioning System, Vol. I, Institute of Navigation, pp. 125-131.

Jackson, M. et al. (2000), GPS Receiver and Antenna Testing Report for SuomiNet, University NAVSTAR Consortium.

Kalafus, R.M., A. J. van Dierendonck and N. Pealer (1986), Special Committee 104 Recommendations for Differential GPS Service, Global Positioning System, Vol. I, Institute of Navigation, pp. 101-126.

Klein, D. and B. W. Parkinson (1986), The Use of Pseudo-satellite for Improving GPS Performance, Global Positioning System, Vol. III, Institute of Navigation, pp. 135-146.

Parkinson, B. W. and K. T. Fitzgibbon (1986), Optimal Locations of Pseudolite for Differential GPS, Navigation, Vol. 33, No. 4, pp. 259-283.

Radman, L. (2002), Position Based Services, Umea Universitet, Sweden, 17 pp.

Rizos, C. (2002), The Use of Integrated GPS and Pseudolite Systems for Deformation Monitoring, Presented at the National Chung Hsing University, Taichung, Taiwan.

Rocken, C. et al. (1996), UNAVCO Academic Research Infrastructure (ARI) Receiver and Antenna Test Report, University NAVSTAR Consortium.

Stansel T. A. Jr. (1986), RTCM SC-104 Recommended Pseudolite Signal Specification, Global Positioning System, Vol. III, Institute of Navigation, pp. 117-134.

Wang, J., L. Dai, T. Tsujii, C. Rizos, D. Grejner-Brzezinska and C. K. Toth (2001a), GPS/INS/Pseudolite Integration: Concepts, Simulation and Testing, Proceedings of the U.S. Institute of Navigation (GPS-2001), Utah, pp. 2708-2715.

Wang, J., T. Tsujii, C. Rizos, L. Dai and M. Moore (2001b), GPS and Pseudo-satellites Integration for Precise Positioning, Geomatics Research Australasia, No. 74, pp. 103-117.

Wang J. (2002), Pseudolite Applications in Positioning and Navigation: Progress and Problems, Journal of Global Positioning System, Vol. 1, No. 1, CPGPS, pp. 48-56.

CONTACTS

Mr. F.S. Ning
Department of Civil Engineering National Chung Hsing University
250, Kuo Kuang Road,
Taichung City, 402
TAIWAN
Tel. + 886 4 3611 0733
Fax + 886 4 3611 9577
Email: fsn@ms4.hinet.net