PSEUDOLITES – A NEW TOOL FOR SURVEYORS?

Ip Ki Choi, Jinling Wang, Shaowei Han and Chris Rizos

School of Geomatic Engineering
The University of New South Wales
Sydney NSW 2052 Australia
Web: http://www.gmat.unsw.edu.au/snap

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Ip Ki Choi, B.Sc.(North East London Polytechnic, U.K.), Pg.Dip. (University of South West, U.K.), M.Eng.Sc.(The University of New South Wales, Australia). Mr. Choi has been a Professional Land and Hydrographic Surveyor (AHKIS, ARICS, MISAust.) since 1987. He served in the Hong Kong Government in various land and hydrographic surveying aspects for more than 15 years and is currently a Ph.D. student in the School of Geomatic Engineeing, UNSW, studying precise positioning applications in the mining industry. One of his major research areas is the pseudolite technology.

Jinling Wang is an Australian Research Council (ARC) postdoctoral research fellow, having starting in January 2000 in the School of Geomatic Engineering, UNSW. His current research interests are in the areas of GPS, GLONASS, Pseudolite and Inertial Navigation Systems (INS). He has research and teaching experience in China, Hong Kong and Australia. Jinling holds a Ph.D. from the Curtin University of Technology, Perth. He has authored over 60 publications, including more than 30 refereed journal papers and two widely-used commercial software packages, has attracted several competitive research grants, and has received over 10 academic awards.

Shaowei Han, B.Sc. (WTUSM), M.Sc. (WTUSM), Ph.D. (UNSW), joined the School of Geomatic Engineering, UNSW, as a Lecturer in April 1997 and is currently a Senior Lecturer. He has since been involved in projects concerned with GPS static and kinematic positioning, network and deformation analysis, and the application of digital signal processing techniques. He has won several best paper prizes in China, Australia and the U.S.A., and has authored over 60 refereed journal and conference publications during the last five years.

Chris Rizos is an Associate Professor at the School of Geomatic Engineering, UNSW, and leader of the Satellite Navigation and Positioning (SNAP) group, which specialises in addressing precise static and kinematic applications of GPS. Chris holds a B.Surv.(Hons.) and Ph.D., both from The University of New South Wales and has published over 100 papers, as well as having authored and co-authored several books relating to GPS and positioning technologies.

ABSTRACT

The study of pseudolites can be traced back to the early development period of GPS. The increasing application of GPS technology across a wide range of industries brings with it new challenges, one of the most demanding of which is the increasing demand for a 'reliable' GPS-based positioning service. The issue of signal *availability* is therefore a fundamental one. The 'pseudolite' (or 'pseudo-satellite') is a potential 'augmentation' for GPS in that it can provide extra signals for tracking. In May 1999, the Satellite Navigation and Positioning (SNAP) Group, The University of New South Wales (UNSW), purchased a pseudolite and commenced a study on the characteristics of this technology. In January 2000, an experiment involving a combination of several GPS receivers and three pseudolite transmitters was conducted at UNSW. The results of processing the pseudo-range and the carrier phase measurements made to the GPS satellites and to the pseudolites are presented. It appears that the pseudolite is indeed a feasible augmentation tool for GPS-based positioning, and could be used in certain GPS surveying applications.

INTRODUCTION

A pseudolite (from 'pseudo-satellite', often abbreviated to 'PL') in its simplest form is a GPS signal generator and transmitter. Current pseudolites are equip with several additional features to enhance their performance, such as different signal transmitting functions, user defined message formats, etc. The first proposal to use pseudolites can be traced back at least to the late 1970s. Ground-based GPS signal transmitters were used to test the GPS user equipment at the U.S. Army Yuma Proving Ground, Arizona (Denaro et al., 1978). In the mid 1980s, 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 pseudolites (Kalafus et al., 1986). In addition, the PRN code numbers 33 to 36 were recommended to be reserved for pseudolites. Pseudolite were suggested as additional GPS signal transmitters as well as a DGPS range correction datalink. This development was popular at that time when the 18-satellite GPS constellation was proposed. In the last few years, pseudolite development has been largely associated with flight navigation applications such as aircraft precision approach and landing to meet the stringent requirements of the aviation industry.

In May 1999, the SNAP group in the School of Geomatic Engineering, the University of New South Wales (UNSW), purchased the first pseudolite in Australia – the IntegriNautics IN200CXL instrument. Research work has been conducted since then in order to explore the application of a synchronised pseudolite system to augment the GPS signals for applications where satellite signals are often blocked by obstructions. The goal is to develop a suitable GPS augmentation system to raise the precise positioning 'productivity' in those industries which require uninterrupted GPS-based positioning.

In January 2000, two additional sets of IntegriNautics IN200C pseudolite equipment were loaned to the SNAP group by the Dept. of Geomatics Engineering, the University of Calgary, Canada. An experiment was carried out at UNSW using a combined GPS and multiple-pseudolite system (Figure 1). After overcoming several technical problems involving the operation and data collection procedures of the pseudolites, the results from processing the pseudo-range and carrier phase measurements are very encouraging.

PSEUDOLITE AND RECEIVER HARDWARE

Basically a pseudolite is a ground-based GPS signal transmitter, and most commonly transmits a signal at the GPS L1 frequency of 1575.42 MHz. In principle, there is no reason why a pseudolite could not be built to transmit at the GPS L2, or any other suitable frequency. As the pseudolite signal is modulated in that same way that GPS signals are both pseudo-range and carrier phase measurements can be made.

The current generation of pseudolites have several advanced features for overcoming past shortcomings of pseudolites and enhancing their performance, including the provision of different signal transmitting/pulsing modes, user defined data messages and format, out-power adjustment, external clock input and synchronisation functions. The technical specifications, and the main menu of the control software, for the IntegriNautics IN200CXL pseudolite are presented in the appendix for reference.

The NovAtel MiLLennium GPS receivers were used to track the pseudolite signals, and to make and log the corresponding measurements.

Figure 1 – The Pseudolite Hardware for the Experiment

MULTIPLE PSEUDOLITE EXPERIMENT

The objective of the experiment was to collect simultaneous measurements made on the GPS satellite and pseudolite signals in order to study the impact of the extra measurements positioning solutions. This experiment permits the study of the characteristics of the pseudolite instrument, an investigation of the possible effect of the stronger transmitted pseudolite signal on the GPS signal, and justifies the modification of existing GPS data processing software to accommodate the pseudolite measurements.

An experiment with three IntegriNautics IN200C pseudolites was conducted on the UNSW campus in late January 2000. The three pseudolites were set up on the roofs of three high buildings, namely Warrane College (WAR), the Applied Science Building (AP), and the Geography and Surveying Building (GAS), which are all in the vicinity of the UNSW cricket ground (Figures 2 & 3). Two sets of NovAtel MiLLennium GPS receivers were operated on, and around, the cricket ground, logging the GPS and pseudolite data in differential mode.

During this experiment the same six GPS satellites were tracked. The GPS and pseudolite measurements were collected using static receivers and the observation session length was about 20 minutes, with a data collection interval of 1 second. The combined GPS and pseudolite measurements were processed in the static mode using modified GPS data processing software developed by the SNAP group.

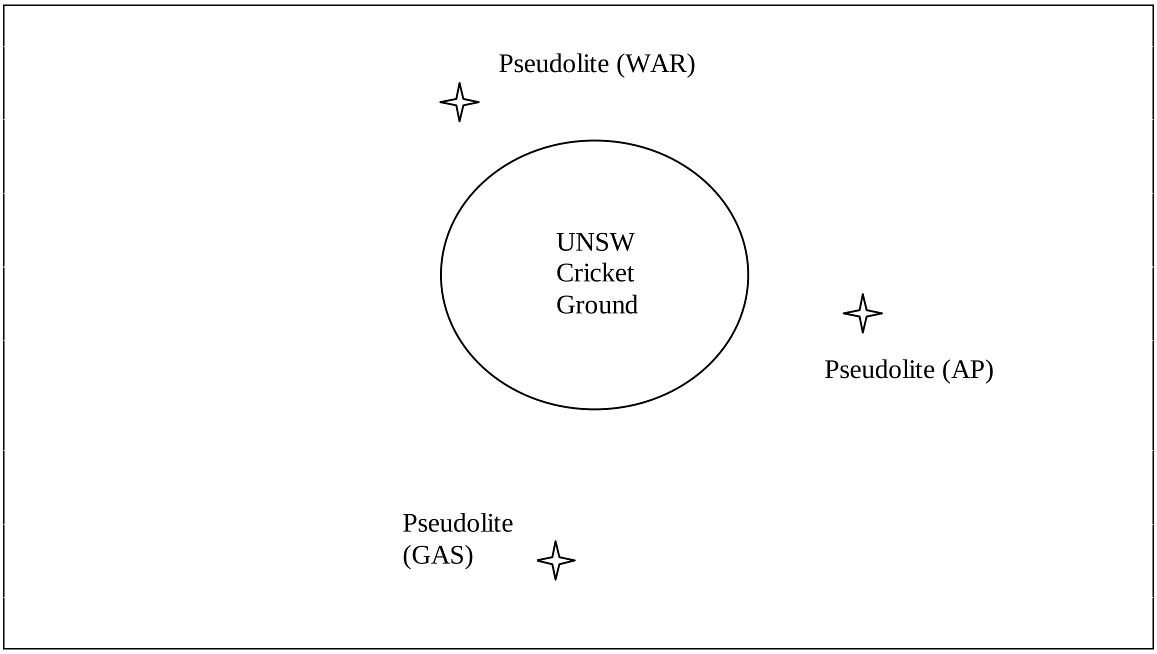

Figure 2 – Location Diagram of Pseudolites for January 2000 Experiment (not to scale). Distance between pseudolites & receivers varied from 120m to 270m. The GPS baseline length was approximately 39m.

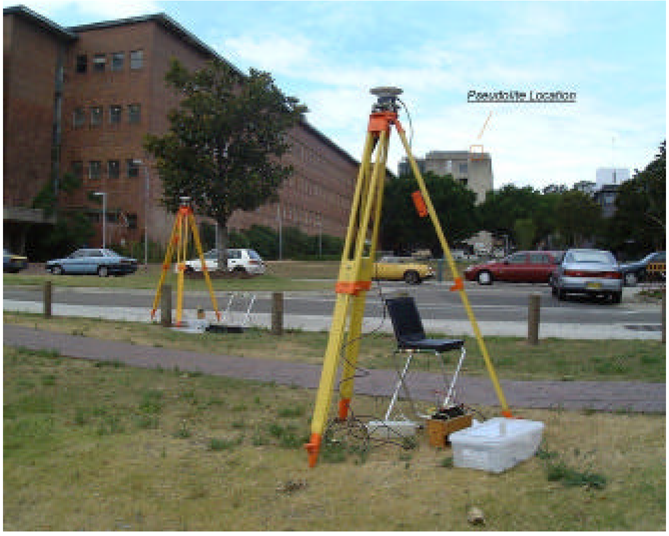

Figure 3a – Pseudolite (PL20) on the Roof of the Geography & Surveying Building.

Figure 3b – Pseudolite (PL28) on the Roof of the Applied Science Building.

Figure 3c – Pseudolite (PL32) on the roof of the Warrane College.

Processing Pseudo-Range Measurements

The double-differenced pseudo-range residuals (three of them between one GPS satellite and each of the pseudolite transmitters) are shown in Figure 4.

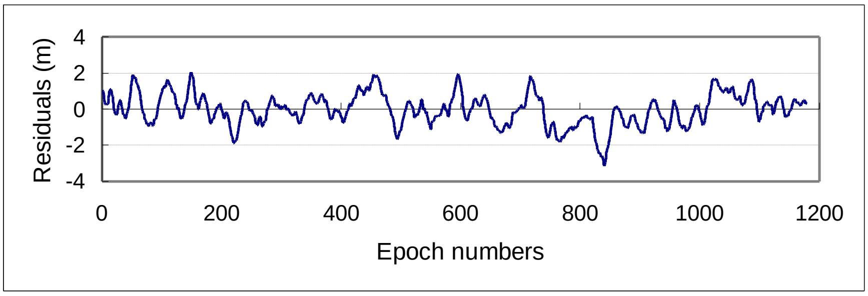

Figure 4a – Pseudo-range residuals for pair PRN 15 - PRN 25.

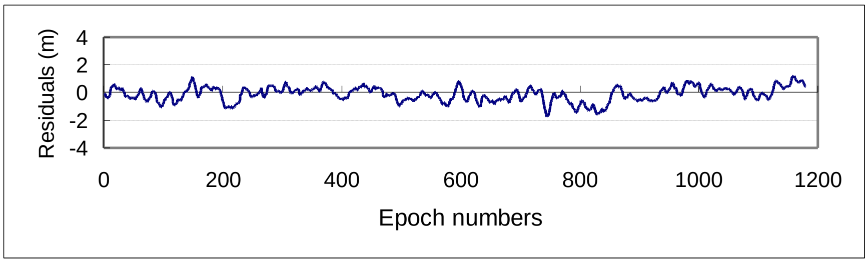

Figure 4b – Pseudo-range residuals for pair PRN 15 - PL 20.

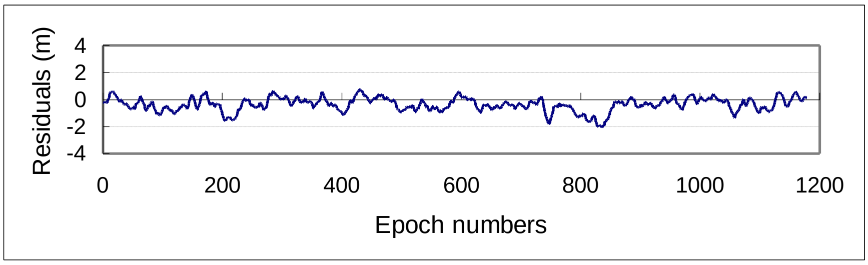

Figure 4c – Pseudo-range residuals for pair PRN 15 - PL 28.

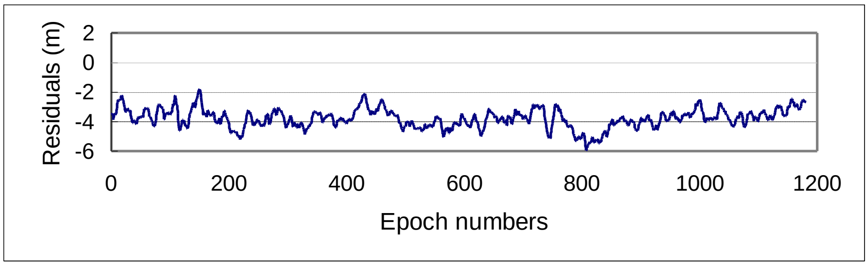

Figure 4d – Pseudo-range residuals for pair PRN 15 - PL 32.

From the above figures, it can be seen that:

- The noise level for the pseudolite pseudo-ranges are similar to those of the GPS pseudo-ranges;
- The pseudolite pseudo-ranges may be contaminated by what appears to be a constant multipath error.

The multiple pseudolite experiment confirmed the existence of an error in the form of a constant distance offset associated with the use of pseudo-range measurements made on pseudolite signals. This phenomena has been reported by Ford et al. (1996) who suggested that pseudolite transmitters create multipath signals. O'Keefe et al. (1999) also reported large biases with pseudo-range measurements which could have been caused by time invariant multipath. This issue has to be further investigated in order to find a solution to this, so as to facilitate the optimal use of pseudolite measurements.

Processing Carrier Phase Measurements

The carrier phase data was also processed, and the double-differenced residuals from a combined GPS and pseudolite positioning solution are shown in Figure 5.

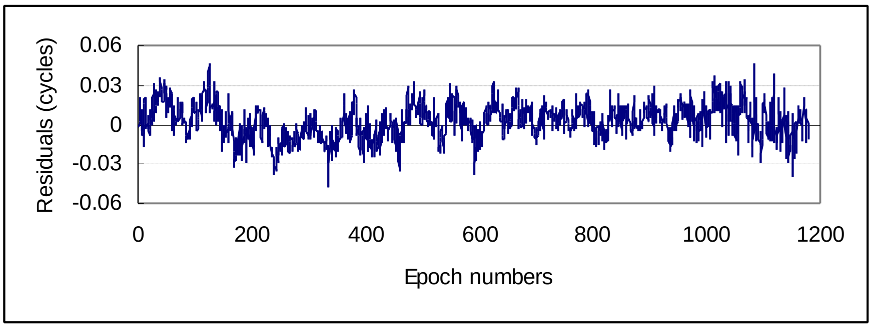

Figure 5a – Carrier phase residuals for pair PRN 15 - PRN 25.

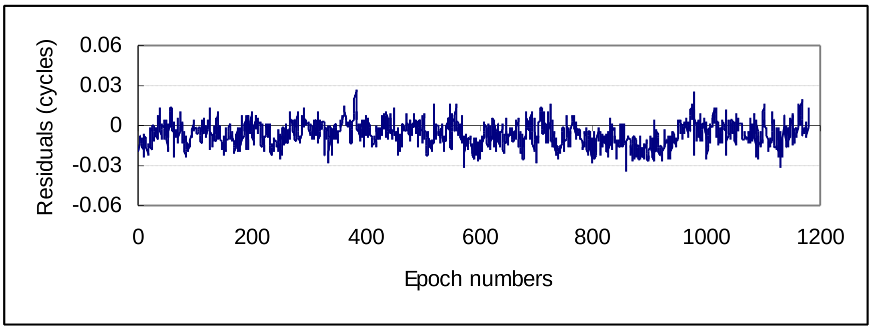

Figure 5b – Carrier phase residuals for pair PRN 15 - PL 20.

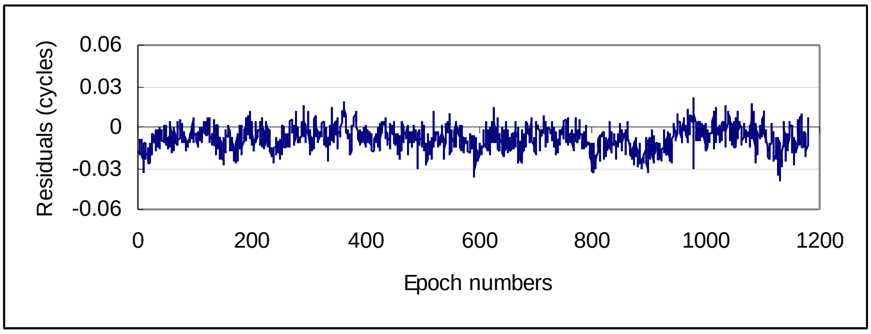

Figure 5c – Carrier phase residuals for pair PRN 15 - PL 28.

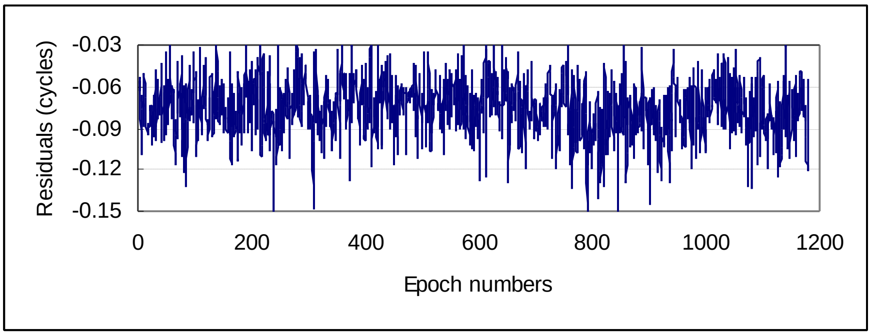

Figure 5d – Carrier phase residuals for pair PRN 15 - PL 32.

Similar to the pseudo-range results, the pseudolite carrier phase residuals also indicate the presence of constant offsets, or biases. However, these biases in the carrier phase residuals are not significant. The integrated GPS and pseudolite carrier phase solution (ambiguities fixed) is very close to the GPS-only solution (ambiguity-fixed). The differences in the baseline components (x, y, z) between these two solutions are 0.002m, 0.005m and -0.004m, respectively. The results appear to confirm that the carrier phase measurements made on the pseudolite signals are capable of providing positional accuracy comparable to those of GPS carrier phase. The baseline length in this experiment is rather short, being less than 50 metres. More experiments must be performed, with much longer baseline lengths, before more conclusive comments can be made.

CONCLUDING REMARKS

The multiple pseudolite experiment did demonstrate that the pseudo-range measurements made on the pseudolite signals suffered from an error in the form of time invariant bias, which manifested itself as constant offsets in the resulting position solutions. Without somehow accounting for this bias, the accuracy of the resulting solution will be degraded. More research work therefore needs to be carried out in order to determine a data processing methodology or algorithm that accounts for this bias error. On the other hand, there appears to be no significant bias error in the carrier phase residuals, suggesting that the carrier phase measurements on the pseudolite signals are capable of providing positioning performance comparable to those of GPS only.

This pseudolite experiment can be considered to be a success as it was the first time that multiple pseudolites have been used in Australia. The collected data was used to test and verify the SNAP-developed GPS data processing software, after modification to accommodate the pseudolite measurements. Some weaknesses, including the identification of 'blind spots' in the pseudolite operation, have been identified, and will have to be addressed in future experiments.

The age of GPS is undoubtedly here with a growing number of mission critical applications such as aviation and vehicle-control (for mining and agriculture). Therefore the demand for a more *reliable* GPS positioning service is increasing. The pseudolite technology is certainly a promising *augmentation* tool for such GPS-based positioning.

REFERENCES

Denaro R., Harvester V.G. and Harrington R.L. (1978), *GPS Phase I User Equipment Field Test*, 'Global Positioning System' – in *Navigation* Volume I, The U.S. Institute of Navigation, 125-131.

Ford T., Neumann J., Toso N., Anderson C., Fenton P., Holden T. and Bartrop K. (1996), *HAPPI – a High Accuracy Pseudolite/GPS Positioning Integration*, Proceedings of the 9th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS-96), 17-20 September, Kansas City, Missouri, 1719-1728.

Kalafus R.M., Dierendonck A.J. van and Pealer N. (1986), *Special Committee 104 Recommendations for Differential GPS Service,* 'Global Positioning System' – in *Navigation* Volume I, The U.S. Institute of Navigation, 101-126.

O'Keefe K., Sharma J., Cannon E. and Lachapelle G. (1999), *Pseudolite-based Inverted GPS Concept for Local Area Positioning*, Proceedings of the 12th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS-99), 14-17 September, Nashville, Tennessee,1523-1529.