Precise Engineering Applications of Pseudolites Augmented GNSS

Emily COSSER, Xiaolin MENG, Gethin W ROBERTS, Alan H DODSON, United Kingdom, Joel BARNES and Chris RIZOS, Australia

Key words: GPS, pseudolites, bridge deformation monitoring

SUMMARY

In satellite based positioning and navigation, the number and spatial distribution of the observed GNSS satellites are a function of the observation site. Insufficient number of satellites, poor geometry and weak signal in space (SIS) due to the obstructions of the surroundings are serious constraints to the various precise engineering applications. Resulting positioning solutions with this solo system cannot meet the precision requirements of these applications. This paper discusses how ground-based pseudolite transmitters are used to strengthen GNSS geometry and signal availability for reliable bridge deformation and deflection monitoring. The main content of the paper includes an introduction to the system configuration, algorithms for integrating GNSS and pseudolite data, field trials, and deformation information extraction. As two of the major factors affecting positioning precision, time invariant multipath mitigation techniques and optimal locations of pseudolites according to particular observation site are discussed as specific topics. The results from an actual bridge trial are compared with those from a GNSS/pseudolite simulator to validate the feasibility of this augmented system for highly precise deformation monitoring. The data processing proves that it is possible to achieve millimetre positioning precision in three dimensions.

Precise Engineering Applications of Pseudolites Augmented GNSS

Emily COSSER, Xiaolin MENG, Gethin W ROBERTS, Alan H DODSON, United Kingdom, Joel BARNES and Chris RIZOS, Australia

1. INTRODUCTION

The geometry of the GPS constellation, quantified by dilution of precision (DOP) values, changes over time and GPS receiver location (Elrod and Van Dierendonck 1995). It is known that for a reliable solution the GDOP (geometric DOP) should not exceed 6 (Hofmann-Wellenhof, et al. 2001). A low DOP is achieved with a scattered distribution of satellites at both high and low elevations and ideally with one satellite in each of the four quadrants (Hofmann-Wellenhof, et al. 2001). However, a compromise must always be made between low DOP values and the selection of an appropriate cut-off angle, as the effects of a number of GPS error sources are larger at low elevation angles (eg multipath and propagation medium errors). For bridge monitoring trials as with other high precision engineering applications a cut-off angle between 10º and 15º is usually chosen.

Santerre (1991) demonstrated that due to the inclination of the GPS satellite constellation at 55º, the distribution of the satellites will not be uniform in the sky. It will in fact be a function of the station latitude with the distribution at low latitudes being almost uniform; at mid-latitudes (such as the UK) almost no observations will be possible in the north direction (between 315º and 45º); and at high latitudes observations can only be made between elevations of 0º and 45º. In mid latitude areas such at Nottingham in the UK, an immeasurable hole is formed in the north direction. Figure 1 shows the satellite sky distribution for 24 hours at the Wilford Suspension Bridge in Nottingham, UK (52º 56′ North) on 19th June, 2002 with a 15º cut-off angle. The Figure clearly shows the immeasurable hole in the north direction where no satellites can be observed throughout the whole 24 hour period.

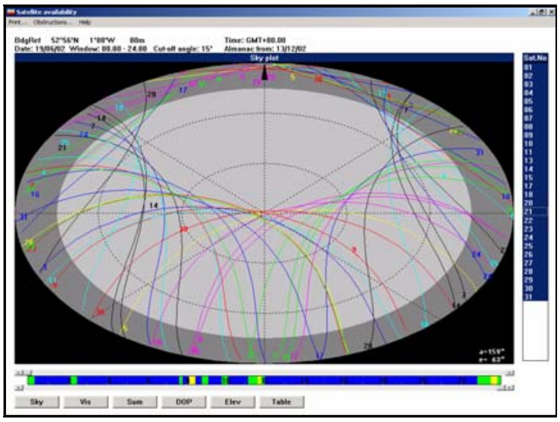

Figure 1: The satellite sky plot at the Wilford Bridge, UK (52º 51′ N, 1º 8′ W) for 24 hours on the 19th June, 2002

The uneven effect of the satellite geometry on the east, north and vertical components could lead to erroneous conclusions about the actual bridge dynamics. Meng, et al. (2002) highlights the case of a bridge in London where the satellite geometry causes it to appear as though the longitudinal movement is larger that the lateral movement, even though the wind loading was high. This disagreed with the expected bridge dynamics and also with parallel observations recorded by an accelerometer.

It is known that the GPS constellation usually causes the vertical positioning accuracy to be two to three times worse than the horizontal accuracy. This is due to all satellites being located above the horizon. For bridge monitoring applications the vertical component is the most important component and so improving the accuracy in this component is a research aim.

In certain areas such as urban or natural canyons and deep open pits, due to obstructions from the surrounding environment, the number of satellites can be insufficient for a reliable solution. Furthermore the current satellite constellation provides instances where there are insufficient satellites to allow positioning to be carried out even in ideal circumstances. During a bridge trial in June 2002 on the Wilford Bridge in Nottingham there was a period of approximately ten minutes each day when only four satellites were available above a cut-off of 15º (Figure 2). This caused the GDOP to rise to a maximum of 37 and meant that the coordinates calculated by the GPS-only system were unreliable. Such GPS outages can cause degradation in the accuracy of the results and can affect the reliability of the whole deformation monitoring system.

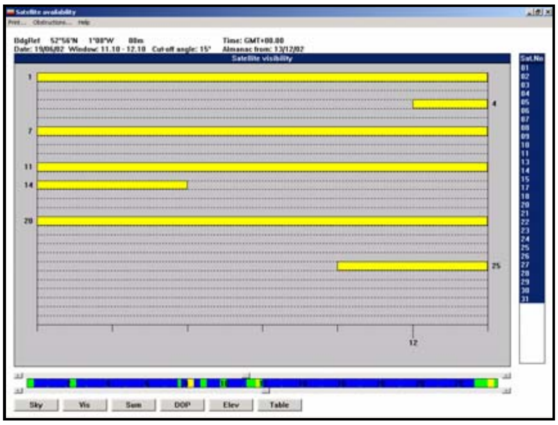

Figure 2: A situation on 19th June, during a bridge trial, where the number of measurable satellites fell to 4

Pseudo-satellites or pseudolites are ground based transmitters of GPS code and carrier phase signals transmitting on either L1 or L2 (usually L1). They are not a new concept in GPS positioning. In fact, before the first GPS satellite was launched pseudolites were used to validate the concept and to test initial GPS user equipment (Wang 2002).

For the purpose of creating a more accurate bridge deformation monitoring system and overcoming some of the deficiencies of the current GPS satellite constellation, the use of pseudolites has been investigated. Pseudolites transmitting GPS code and carrier phase signals, from known ground locations, can be used as another ranging source which can improve the DOP values and the overall quality of the solution. Through simulation (see section 4.1) it can be seen that with augmentation from just one pseudolites the GDOP value in the above situation (Figure 2) can be reduced from 37 to less than 3 for the whole observation session (Daub 2002).

When pseudolites are used to augment the GPS constellation there are additional error sources and issues that need to be taken into account due to the relatively close proximity of the GPS receivers to the stationary pseudolites. The issues include the near-far problem, pseudolite location bias, pseudolite multipath, atmospheric delay, pseudolite clock synchronisation and ambiguity resolution and are discussed in Dai, et al.(2001).

This paper introduces a pseudolite bridge trial conducted on the Wilford Suspension Footbridge in Nottingham, UK. The optimal location of pseudolites for improving particular components of the positioning solution is discussed. The theoretical improvements in precision calculated by a DOP simulator when one or three pseudolites are added to the positioning solution are introduced and compared to the actual positioning results for the Wilford Bridge. The removal of the pseudolite multipath bias is discussed and results before and after its removal are shown.

2. SIMULATIONS OF OPTIMAL PSEUDOLITE LOCATIONS

A DOP simulator has been developed at The University of Nottingham, the fundamentals of which are described in Meng, et al. (2004). In the simulator the user can simulate the locations of one or more pseudolites to form a modified ephemeris using the original GPS ephemeris. Using the receiver site as the origin the azimuth and elevations of each of the satellites and pseudolites are calculated on an epoch by epoch basis. From these values the DOP values in a local coordinate system are calculated for the various pseudolite configurations.

Using a real ephemeris from The University of Nottingham campus on 3 June 2000, various pseudolite locations were simulated to investigate the relationship between pseudolite location and DOP improvement. The following seven configurations were investigated.

- GPS only solution with original GPS ephemeris.
- A single pseudolite located 100m north of the receiver site at an elevation of -33º.
- A single pseudolite located 100m north of the receiver site at an elevation of 33º.
- Three pseudolites located at azimuth/elevation angles: -30.46º/15º, 0º/33º, 30.46º/15º.
- Three pseudolites located at azimuth/elevation angles: -30.46º/-15º, 0º/-33º, 30.46º/-15º.
- Two pseudolites located at azimuth/elevation angles: -30.46º/15º, 30.46º/15º.
- Two pseudolites located at azimuth/elevation angles: -30.46º/-15º, 30.46º/-15º.

Table 1 summaries the results from the above simulations for east DOP (EDOP), north DOP (NDOP), vertical DOP (VDOP), time DOP (TDOP), position DOP (PDOP) and GDOP. 1 refers to the best location of pseudolites for improvement of DOP values in that particular component direction, while 7 refers to the worst DOP values. Detailed analysis of these results can be found in Meng (2002). It can be seen from the table that the worst DOP values are always found when a GPS-only solution is used. So it can be concluded that inclusion of pseudolites into a solution will always improve the DOP values (even if this is only by a small amount- the minimum improvement found was 4%). Three pseudolites set up below the horizon provide the best solution for the EDOP, VDOP, TDOP, PDOP and GDOP improvement, while three pseudolites above the horizon provide the best improvement in the NDOP. The Table can be used to define the criteria for the selection of the best pseudolite locations in order to achieve specific outcomes or improvements in required direction(s) in mid latitude areas. However, this is only a theoretical investigation into pseudolite locations, it may be physically impossible to locate the pseudolites in the optimal simulated positions.

DOP	Order 1(best)	2	3	4	5	6	7 (worst)
EDOP %	GPS + 3 PLs below 19	GPS + 2 PLs below 18	GPS +3 PLs above 18	GPS +2PLs above 17	GPS + 1 PL below 8	GPS + 1 PL above 4	GPS
NDOP %	GPS +3 PLs above 34	GPS + 1 PL above 27	GPS +2PLs above 24	GPS + 3PL below 13	GPS + 2 PLs below 15	GPS + 1 PL below 10	GPS
VDOP %	GPS + 3PL below 53	GPS + 1 PL below 51	GPS + 2 PLs below 46	GPS +3 PLs above 22	GPS +2PLs above 18	GPS + 1 PL above 4	GPS
TDOP %	GPS + 3PL below 59	GPS + 1 PL below 55	GPS + 2 PLs below 52	GPS +3 PLs above 28	GPS +2PLs above 25	GPS + 1 PL above 7	GPS
PDOP %	GPS + 3PL below 40	GPS + 1 PL below 36	GPS + 2 PLs below 35	GPS +3 PLs above 24	GPS +2PLs above 19	GPS + 1 PL above 9	GPS
GDOP %	GPS + 3PL below 44	GPS + 1 PL below 40	GPS + 2 PLs below 39	GPS +3 PLs above 25	GPS +2PLs above 21	GPS + 1 PL above 8	GPS

Table 1: Summary of results from the DOP simulation of the seven pseudolite scenarios investigated, along with the percentage improvement compared to a GPS-only solution

3. PSEUDOLITE BRIDGE TRIAL - WILFORD BRIDGE, NOTTINGHAM, UK

A GPS and pseudolite bridge trial was conducted on the Wilford Suspension Footbridge in Nottingham on 16th October, 2002. The layout of the pseudolites and receivers can be seen in Figure 3. Three IN200 pseudolites were located at sites PL12, PL16 and PL32 transmitting the respective PRN codes with their antennas mounted vertically so they are pointing towards the receiver locations (Figure 4). Table 2 shows the elevations and azimuths of the pseudolites from the roving receiver Bdg2. It can be seen from the Table that all the pseudolites were located below the horizon. The environment surrounding the bridge meant that the only viable location had negative elevations. From Table 1 it is kown that this pseudolite constellation will provide good improvements in the EDOP and VDOP, but pseudolites above the horizon are needed for a good NDOP improvement. Simulations of the DOP values resulting from this pseudolite configuration are discussed in section 4.2. The coordinates chosen for the pseudolites' locations were already known to a high degree of accuracy from previous trials that had been conducted at the bridge, which was one of the reasons for the choice of their locations.

The reference receiver was also located on the bank of the river at point Ref1 and the rover was located at the mid-span of the bridge, point Bdg2. At both receiver locations there was a Leica dual frequency GPS receiver and an Allstar GPS/pseudolite receiver connected via a splitter to an AT502 antenna (Figure 5). The configuration was designed so that the data from the dual frequency Leica receiver could be compared directly to the results from the Allstar receivers. Data from the Leica receivers is not included in this paper. The attenuation of the pseudolites was adjusted so that there was a good signal to noise ratio at both receivers. The location of PL12 meant that the signal had to pass through a bridge arch to be detected at Ref1 (Figure 5). Problems were encountered during the trial when it was discovered that the receiver at Bdg2 had not been logging data. This meant that only about 40 minutes of data were collected at this site.

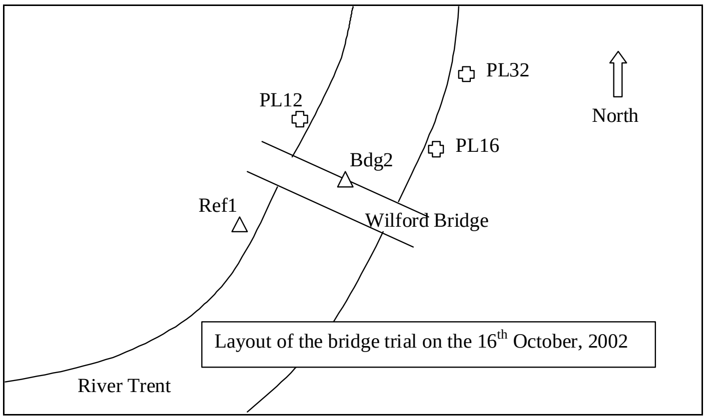

Figure 3: The layout of the pseudolites and receivers on and around the Wilford Bridge in Nottingham on 16th October, 2002

	Elevation	Azimuth
PL12	-7.42	311.66
PL16	-4.12	70.60
PL32	-3.11	51.79

Table 2: The elevations and azimuths of the pseudolites from roving receiver site Bdg2

Figure 4: The location of the three pseudolites, with their antennas mounted vertically facing the receiver locations, on the footpaths alongside the River Trent

Figure 5: The receiver locations. At both Ref1 and Bdg2 there was a Leica dual frequency receiver and an Allstar GPS/pseudolite receiver connected via a splitter to an AT502 antenna

4. SIMULATIONS OF WILFORD BRIDGE TRIAL DATA

The DOP values for two separate Wilford Bridge trials are investigated. Figure 2 shows a situation on from a bridge trial conducted in June 2002 where the number of observed satellites fell to only four. The effect of adding pseudolites to this situation is examined. Also a simulation of DOP values from the actual pseudolite bridge is conducted and compared to the real results.

4.1 June 2002 Bridge Trial

During the bridge trial that took place in June 2002 on the Wilford Bridge the number of observed satellites fell to only four. Due to the bad geometry of these four satellites the GDOP rose to a maximum of 37. It is known that a GDOP value above 6 should not be trusted (Hofmann-Wellenhof, et al. 2001).
Figure and

Table show the GDOP values for a GPS only solution and for GPS augmented by either one or three pseudolites. The location of each of the pseudolites corresponds to its position in the real pseudolite trial. It can be seen that with the inclusion of any one of the pseudolites the GDOP values falls to less than 5 for the whole observation session. When three pseudolites are included, the GDOP value is always less than 3. The need for augmentation is demonstrated for this bridge trial, to guarantee reliable solutions for the whole of the observation period.

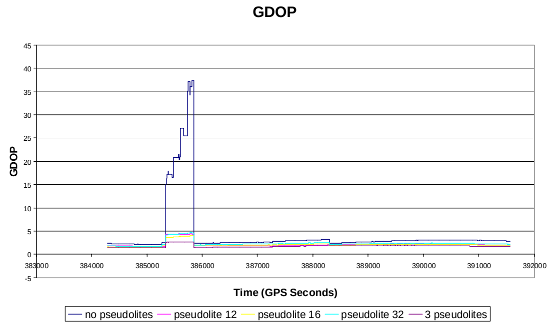

Figure 6: Simulated GDOP values with GPS only and GPS augmented by one or three pseudolites for the June 2002 Wilford Bridge trial

GDOP	Max	Min	Average
No pseudolites	37.43	2.07	4.28
Pseudolite 12	4.42	1.70	2.16
Pseudolite 16	3.51	1.67	2.27
Pseudolite 32	4.68	1.68	2.38
3 pseudolites	2.73	1.38	1.78

Table 3: Summary of GDOP values for GPS only and GPS augmented by one or three pseudolites for the June 2002 bridge trial

3.2 Pseudolite Bridge Trial, October 2002

Figure 7 shows the GDOP for a GPS only solution and for GPS augmented by three pseudolites for the pseudolite bridge trial conducted in October 2002. It can be seen from the graph that there is a period of approximately 19 minutes where the GDOP for the GPS only solution is above 7, making the coordinates produced unreliable. When three pseudolites are added it brings the GDOP down to just over 3 for the 19 minutes of concern. This is well below the accepted value and is sure to provide a more accurate and consistent solution.

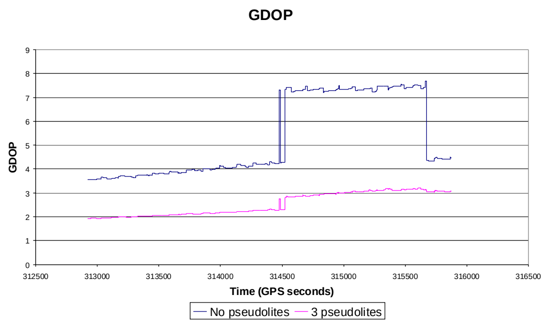

Figure 7: Simulated GDOP with GPS only and GPS augmented by three pseudolites, for October 2002 pseudolite trial on the Wilford Bridge

A summary of these DOP values in the east, north and vertical directions as well as the GDOP can be seen in Table 4. Improvements in the DOP in all coordinate directions can be observed when three pseudolites are added. There are large improvements of 47% and 59% in the east and vertical directions, whereas the improvement is much less in the north direction as expected (20%). The average DOP in the vertical direction is 1.5 when three pseudolites are added which is slightly better than the DOP in the north direction which is 1.6. This shows that the introduction of three pseudolites in the locations chosen has far more affect on the vertical component than on the north component of the positioning solution.

		GPS- only	GPS and 3 pseudolites	% difference
	Maximum	1.53	0.66	
EDOP	Minimum	0.89	0.56	
	Average	1.12	0.59	47
	Maximum	3.31	2.20	
NDOP	Minimum	1.43	1.18	
	Average	2.08	1.66	20
	Maximum	5.27	1.87	
VDOP	Minimum	2.50	1.20	
	Average	3.69	1.52	59
	Maximum	7.70	3.21	
GDOP	Minimum	3.54	1.93	
	Average	5.30	2.53	52

Table 4: Summary of DOP values for GPS only and GPS augmented by three pseudolites

5. RESULTS

The real results from the pseudolite bridge trial were processed using the baseline software developed at UNSW. The initial results can be seen in Figure 8 to Figure 10, which show the east, north and vertical displacements for the GPS only solution and GPS augmented by three pseudolites. All the graphs show an offset between the coordinates when pseudolites are included in the solution and when they are not. Due to the nature of the processing software the instantaneous coordinates of the rover needs to be known and input into the software for ambiguity resolution to be possible. This coordinate was calculated from the Leica receiver that was connected via a splitter to the Allstar. When the pseudolites are used in the processing, the positions in each component become further away from the 'truth'. The largest coordinate shift is evident in the vertical direction which can be seen in Figure 10. As well as this displacement of coordinates, the addition of pseudolites also makes the standard deviation of the north component worse, an increase from 8.9mm to 9.8mm.

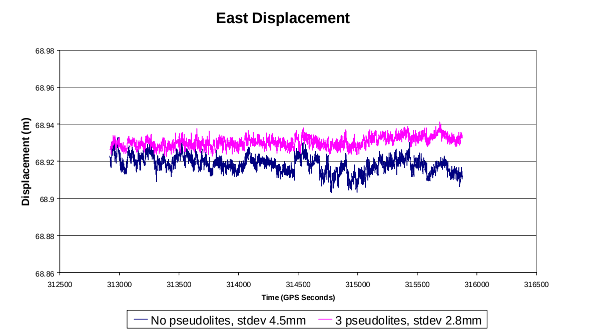

Figure 8: The east displacement with GPS only and GPS augmented by three pseudolites

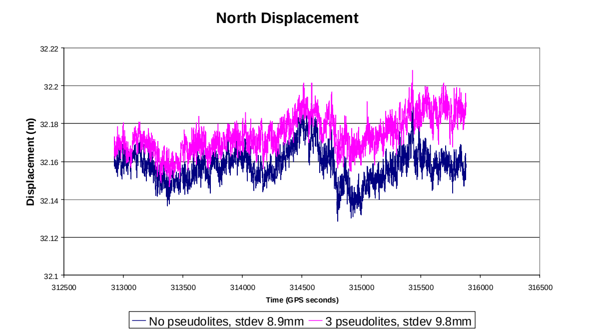

Figure 1: The north displacement with GPS only and GPS augmented by three pseudolites

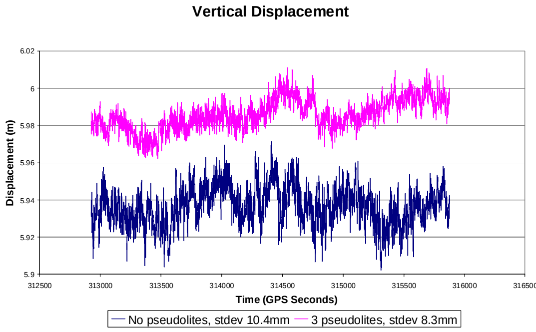

Figure 10: The vertical displacement with GPS only and GPS augmented by three pseudolites

The shift in coordinates and degradation in precision in the north component is caused by pseudolite and receiver multipath. Pseudolite multipath has different characteristics compared to GPS multipath. The amount of 'transmitted' multipath from a GPS satellite is small, but the transmitted multipath from a pseudolite is significant (Ford, et al. 1997). As in this case, the elevation angle of a pseudolites is often lower than for a satellite and so multipath is more serious. However, if the receiver is stationary (or semi-static in the case of the Wilford Bridge where the amplitude of movement is very small), the multipath bias from a pseudolite is constant and so can mitigated and reduced over time or calibrated in advance (Barnes, et al. 2002).

The pseudolite multipath bias displays itself as a constant bias in the positioning solution. Figure 11 to Figure 13 show the double difference residuals between satellite 5 (the base satellite) and each of the three pseudolites. It can be seen from the graphs that PL12 and PL16 have significant biases which offset them from zero. A typical satellite residual can be seen in Figure 14 for satellite 9, which exhibits a mean of approximately zero and the residuals are scattered about this. The average offset of the residuals is 51.4mm for PL12 and 38.8mm for PL16, while PL32 does not appear to have a significant bias. The large offset for PL12 could be due to the signal having to travel through the bridge arch to the reference receiver, as mentioned previously.

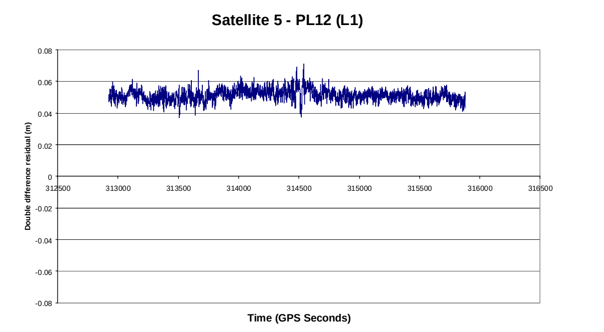

Figure 11: The double difference residual between base satellite 5 and pseudolite 12

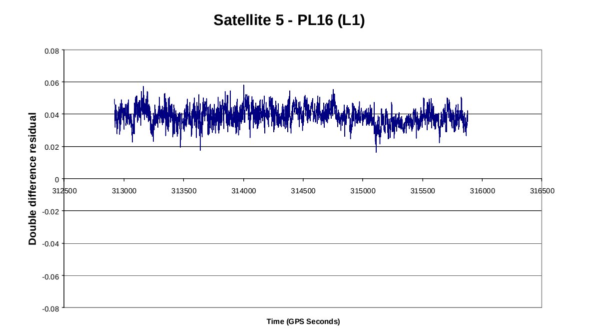

Figure 12: The double difference residual between base satellite 5 and pseudolite 16

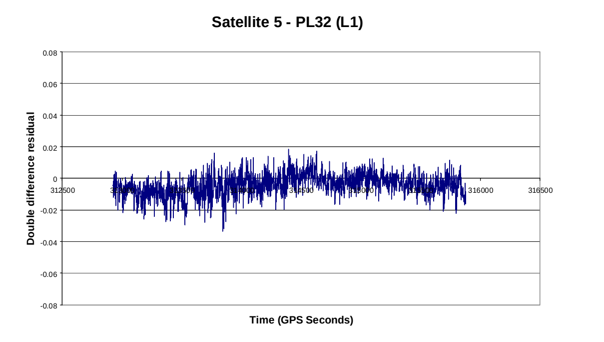

Figure 13: The double difference residual between base satellite 5 and pseudolite 32

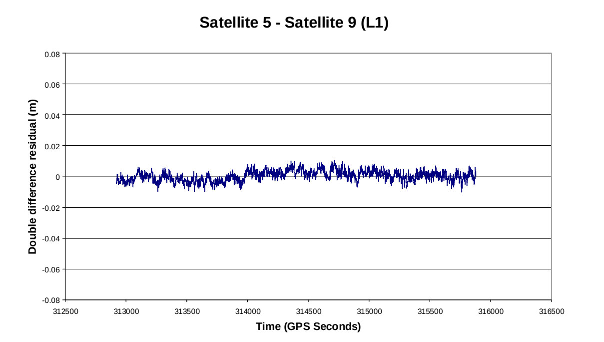

Figure 14: The double difference residual between base satellite 5 and satellite 9

Barnes, et al. (2002) calculate the magnitude of the pseudolite multipath bias from the double difference residuals and then remove this value from the raw pseudolite carrier phase and pseudorange data. Then the data is reprocessed with the multipath bias and coordinate offset removed. Another method of multipath removal that has been investigated involves calculating the pseudolite multipath in the same way from the double difference residuals, and then removing this value from the height component of the pseudolite, changing it location coordinates. The multipath is removed using both methods, which when compared produce identical results. It is likely that a component of the bias was caused by pseudolite location error and so modifying the pseudolite coordinate will help mitigate the location error also.

The degree of accuracy needed from the initial pseudolite coordinates is not achievable to completely remove pseudolite location bias. For the same location error as a normal satellite, if the satellite orbit is known to within 5cm, the pseudolite location needs to be known to within 10^{-4}mm (for a pseudolite 40 m away). It is obviously not possible for the coordinates of the pseudolite to be known to that degree of accuracy and so at least some location error will be present in the positioning solution. Since the receivers in a bridge environment are almost stationary the location bias will be present in the solution as a constant bias. So, it is not possible to distinguish the location bias from the pseudolite multipath bias. Both are removed by the methods mentioned above.

Once the biases were removed, the data was reprocessed and the results can be seen in Figure 15 to Figure 17. It can be seen from these Figures that most of the bias in the coordinates that was evident in Figure 8 to Figure 10 has been removed. There are also further improvements in the standard deviations in all three components when the pseudolites are added. In the east direction the introduction of pseudolites improves the positioning solution by 45%, while in the vertical there is an improvement of 36% reducing the standard deviation to 6.7mm. Figure 17 shows that the vertical coordinate fluctuations have been greatly reduced by the introduction of pseudolites and that the shape of the fluctuations are now actually very similar to those in the north component. The removal of the multipath bias has led to an improvement in the north component when pseudolites are introduced; however this improvement is still quite small at only 14%. This means that the standard deviation in the vertical component (6.7mm) is now actually lower than in the north component (7.6mm).

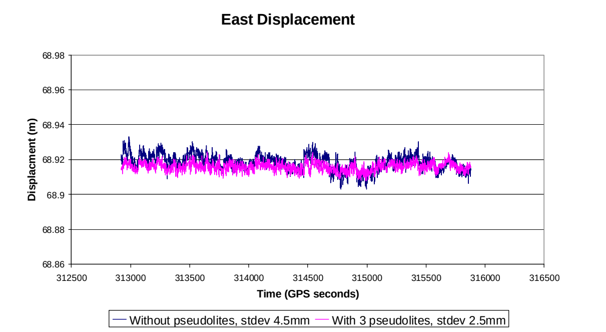

Figure 15: The east displacement with GPS only and GPS augmented by three pseudolites after the constant pseudolite multipath bias was removed

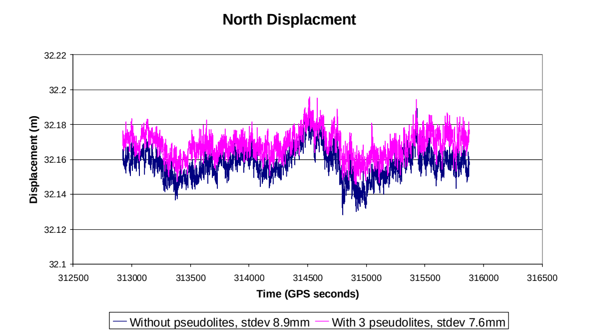

Figure 16: The north displacement with GPS only and GPS augmented by three pseudolites after the constant pseudolite multipath bias was removed

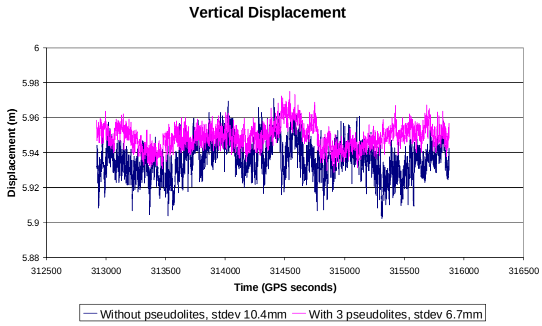

Figure 17: The vertical displacement with GPS only and GPS augmented by three pseudolites after the constant pseudolite multipath bias was removed

Looking back at the simulations in section 4.2 and also in section 2, the results are as expected. Section 0 shows that for an improvement in the north direction three pseudolites located above the horizon is the best constellation; however this is not good for improving the vertical direction and was also not physically possible at the Wilford Bridge. Section 4.2 showed DOP improvements of 47% and 59% in the east and vertical directions but only a 20% improvement in the north direction when the three pseudolites were added. Pseudolite locations for future trials could be on the towers of the bridge or further away on one of the surrounding buildings to investigate the effect of different constellations on the north component accuracy.

6. CONCLUSIONS

Simulations were conducted of seven different scenarios of pseudolite location. It was discovered that to improve the east and vertical component accuracies, three pseudolites located below the horizon was the best constellation. For improving the north accuracy, the best constellation was three pseudolites located above the horizon.

Simulations were also conducted to assess the improvement in coordinate accuracy when one or three pseudolites were introduced to bridge trials conducted at the Wilford Bridge. During a period when only four satellites were available and the GDOP for a GPS only solution rose to 37, the introduction of just one pseudolite reduced the GDOP to below 5, which meant that the positioning solution could be trusted for the whole of the observation window.

The simulations were compared to the results from the actual bridge trial. It was further seen from simulations that the pseudolite constellation was not ideal for improving the north component since all pseudolites had to be located below the horizon. The actual results showed that the vertical component was improved to better than the north component when the pseudolites were introduced.

Problems with pseudolite multipath and pseudolite location error were encountered in a bridge environment. The double difference pseudolite residuals show a bias, and since this particular bridge can be treated as static due to its small amplitude, these biases can be calculated and removed.

It has been demonstrated through simulations and the results from an actual bridge trial that the introduction of pseudolites improves the positioning solution in the all three components, particularly the vertical. Pseudolites enhance the solution improving the accuracy, reliability and precision of the resulting coordinates.

ACKNOWLEDGEMENTS

This project is funded by the UK's EPRSC in conjunction with Cranfield University. Dr Joel Barnes trip to the UK was funded by the Australian Research Council (ARC) International Linkage grant.

REFERENCES

Barnes, J., Wang, J., Rizos, C. and Tsujii, T. 2002. "The Performance of a Pseudolite-Based Positioning System for Deformation Monitoring." *2nd Symposium on Geodesy for Geotechnical and Structural Engineering*, 21-24 May, Berlin, Germany. 326-337.

Dai, L., Wang, J., Rizos, C. and Han, S. 2001. "Applications of Pseudolites in Deformation Monitoring Systems." *10th FIG Symposium on Deformation Measurements*, 19-22 September, Orange, California, USA. 11-22.

Daub, C. 2002. "Pseudolite for Deformation Monitoring," MSc thesis, The University of Nottingham, Nottingham, UK

Elrod, B. D. and Van Dierendonck, A. J. 1995. "Pseudolites." Global Positioning System: Theory and Applications Volume II, Parkinson, B. W., Spilker Jr, J. J., Axelrad, P. and Enge, P., eds., American Institute of Aeronautics and Astronautics Inc, USA, pp. 51-79

Ford, T., Neumann, J., Toso, N., Petersen, W., Anderson, C., Fenton, P., Holden, T. and Barltrop, K. 1997. "HAPPI- a High Accuracy Pseudolite/GPS Positioning Integration." *ION GPS 1997*, September, Kansas City, Montana, USA. 1719-1728.

Hofmann-Wellenhof, B., Lichenegger, H. and Collins, J. 2001. *GPS, Theory and Practice*, Springer-Verlag, Austria.

Meng, X. 2002. "Real-time Deformation Monitoring of Bridges Using GPS/Accelerometers," PhD thesis, The University of Nottingham, Nottingham, UK

Meng, X., Roberts, G. W., Dodson, A. H., Cosser, E., Barnes, J. and Rizos, C. 2004. "Impact of GPS satellite and pseudolite geometry on structural deformation monitoring: analytical and empirical studies." *Journal of Geodesy*, 77(12): 809 - 822

Meng, X., Roberts, G. W., Dodson, A. H., Cosser, E. and Noakes, C. 2002. "Simulation of the Effects of Introducing Pseudolite Data into Bridge Deflection Monitoring Data." *2nd Symposium on Geodesy for Geotechnical and Structural Engineering*, 21-24 May, Berlin, Germany.

Santerre, R. 1991. "Impact of GPS Satellite Sky Distribution." *Manuscripa Geodaetica*, 16: 28-53

Wang, J. 2002. "Pseudolite Applications in Positioning and Navigation: Progress and Problems." *Journal of Global Positioning Systems*, 1(1): 48-56

BIOGRAPHICAL NOTES

Ms Emily Cosser is a research student at the Institute of Engineering Surveying and Space Geodesy, University of Nottingham. She graduated in 2001 with a BSc in Mathematics from the University of Nottingham. Since 2001 she has been working towards her PhD on bridge monitoring with GPS and other sensors.

Dr Xiaolin Meng is a senior research fellow at the Institute of Engineering Surveying and Space Geodesy, the University of Nottingham. He holds a PhD in Highway, Urban Road and Airport Engineering from Tongji University in Shanghai, China and a PhD in Satellite Geodesy from the University of Nottingham. His research interests are in engineering surveying, satellite geodesy, spatial database development and quality control, GIS for Transportation (GIS-T), Intelligent Transportation System (ITS), GIS and GPS integration, and GPS, pseudolites and INS for structural integrity monitoring.

Dr Gethin Roberts is a senior lecturer at the University of Nottingham. He is also the chairman of the FIG's Working Group 6.4 "Engineering Surveys for construction works and structural engineering", as well as chair of Task force 6.1.1 "Measurements and Analysis of Cyclic Deformations and Structural Vibrations". He is also the UK's commission 6 delegate.
Professor Alan Dodson is Professor of Geodesy at the University of Nottingham, and Head of the School of Civil Engineering. He has a BSc in Civil Engineering, a PhD in Engineering Surveying and a DSc in Engineering Geodesy. He is a member, and recent Director, of the IESSG at Nottingham. He is a Fellow of the Institution of Civil Engineers, and the Royal Institute of Navigation, a member of the Royal Institution of Chartered Surveyors, and an editor of the Journal of Geodesy. Professor Dodson was, until recently, President of Section 1 (positioning) of the International Association of Geodesy (IAG) and is a past Dean of the Faculty of Engineering at the University of Nottingham.

Dr Joel Barnes is one of the senior researchers with the Satellite Positioning and Navigation (SNAP) group, at the School of Surveying and SIS, UNSW, Sydney, Australia. He obtained a Doctor of Philosophy in satellite geodesy from the University of Newcastle upon Tyne, UK. His research interests include pseudolites, LocataLites, GPS receiver firmware customisation and high precision kinematic GPS positioning.

Professor Chris Rizos is a graduate of the School of Surveying, UNSW, obtaining a Batchelor of Surveying in 1975, and a Doctor of Philosophy in 1980 in satellite geodesy. Chris has been researching the technology and high precision applications of GPS since 1985, and is currently the leader of the Satellite Navigation and Positioning Group at UNSW. He is a Fellow of the Australian Institute of Navigation, a Fellow of the International Association of Geodesy (IAG), and is currently president of the IAG’s Commission 4 “Positioning and Applications”.

CONTACTS

Emily Cosser
IESSG
University of Nottingham
University Park
Nottingham, NG7 2RD
UNITED KINGDOM
Tel. + 44 115 951 3933
Fax + 44 115 961 3881
Email: isxec@nottingham.ac.uk
Website: http://www.nottingham.ac.uk/~isxec

Joel Barnes
SNAP
4th floor Electrical Engineering building
Kensington Campus
University of New South Wales
Sydney 2052
AUSTRALIA
Tel. + 61 2 9385 4526
Fax + 61 2 9313 7493
Email: joel.barnes@unsw.edu.au
Website: http://www.gmat.unsw.edu.au/snap/staff/joel_barnes.htm