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The Potential of Locata Technology for Structural Monitoring Applications

J. Barnes

Locata Cooperation, Canberra, Auatralia

C. Rizos, A. Pahwa, N. Politi

School of Surveying and Spatial Information Systems, University of New South Wales, Sydney, NSW 2052, Australia

J. van Cranenbroeck

Leica Geosystems AG – Surveying and Engineering Division, Heerbrugg, Switzerland

Abstract. *Locata* technology is becoming part of Leica Geosystems solution for the structural monitoring applications such as bridges and dams. This paper assesses the performance of the *Locata* technology using a test *Locata* network (*LocataNet*) established at the University of New South Wales. Using this network a long term static tests and a simulated deformation movement test, with GPS as a comparison, were conducted. This paper described the *LocataNet* established at UNSW and presents the results and analysis of the tests conducted. Overall the paper demonstrates the suitability of *Locata* for structural deformation monitoring type applications (such as bridges and dams) where there is reduced or unavailable satellite coverage.

Keywords: *Locata*, *LocataLite*, *LocataNet*, structural monitoring.

1 Introduction

Ideally the movements of man-made engineering structures should be monitored on a continuous basis and with high accuracy in order that departures from the expected movements of a structure can be detected quickly and necessary action taken. In the past few years Global Navigation Satellite Systems (GNSS) such as GPS have been applied to monitoring the structural deformation of bridges, dams and buildings [Roberts *et al.*, 2004], by permanently installing GNSS receivers at key locations on the engineering structure so as to provide cm-level positioning information on a 24/7 basis. However, the major problem with such GNSS receiver installations is that, the accuracy, availability, reliability and integrity of position solutions is very dependent on the number and geometric distribution of the available satellites. This means that the precision of positioning solutions will vary by typically up to 3 times during the day in Sydney, Australia (from an analysis of PDOP values). The large variation in positioning precision obtained with GNSS is undesirable for a continuous deformation monitoring system. More-over, the accuracy of the height component is typically 2-3 times worse than for the horizontal (because of the geometrical distribution of the satellite constellation and the poorer quality of data at low elevation angles). This situation becomes worse when the line-of-sight to GNSS satellites becomes obstructed, as on a bridge, and there may be insufficient GNSS satellites for positioning.

Another limitation of the GNSS technology for precise (cm-level) real-time continuous positioning is the requirement for differential corrections or measurements from a single reference station or Continuously Operating Reference Station (CORS) Network. Acceptable performance from RTK GNSS in structural deformation monitoring type applications is therefore heavily dependent on the reliability of the wireless data link used, and on a relatively unobstructed sky-view, where there are at least five satellites with good geometry available. To address these significant limitations of the GNSS *Locata* has developed a novel positioning technology.

2 *Locata* Positioning Technology

Locata's solution to "difficult" Global Navigation Satellite Systems (GNSS) environments is to deploy a network of terrestrially-based transceivers (*LocataLites*) that transmit positioning signals. These transceivers form a positioning network called a *LocataNet* that can operate in combination with GNSS (such as in urban environments) or entirely independent of GNSS (for indoor applications). One special property of the *LocataNet* is that it is time-synchronous, potentially allowing single point positioning (no differential corrections and data links required) with cm-level accuracy.

In the current system design the *LocataLites* transmit their own proprietary signal structure in the 2.4GHz ISM band (license free). This ensures complete interoperability with GNSS and allows enormous flexibility due to complete control over both the signal transmitter and the receiver. Details of the current system design have been detailed previously in Barnes *et al.* 2005.

On the 19th July 2006 Leica Geosystems announced publicly on their website the signing of a co-operation agreement between Leica Geosystems and *Locata* Corporation for the distribution and support of *Locata* technology in two key market areas, namely:

- open cast mining – for machine automation and mine monitoring operations, and
- structural deformation monitoring – for structures such as bridges, dams and buildings.

In addition, Leica Geosystems will develop the first integrated GNSS/*Locata* receiver.

As a first step in assessing the suitability of the *Locata* technology for deformation monitoring applications the University of New South Wales has conducted tests to assess the *Locata* network stability and the level of movement that can be detected by the system. The remainder of this paper describes the *LocataNet* established at UNSW and some of the tests conducted.

3 *LocataNet* installation used for the trial

To test and evaluate the performance of *Locata* technology for the purpose of structural deformation monitoring, a small semi-permanent *Locata* network (*LocataNet*) was set up at the University of New South Wales (UNSW) from early January to mid February 2007. The term *LocataNet* describes a network of *LocataLites* (at least four *Locata* transceivers) that transmit the positioning signals (in the 2.4GHz ISM band). Typically a *LocataNet* is deployed around the area where the *Locata* positioning signals are required. Once a *LocataNet* is established a *Locata* receiver (or rover) can determine its position independently of other positioning technologies (GNSS etc).

The *LocataNet* established at UNSW is illustrated in Fig. 1. It consists of 10 *LocataLites* situated on top of three buildings. The *Locata* receiver antenna was situated on the roof of the Electrical Engineering building (Elec. Eng in Fig. 1), and the distance from the *Locata* receiver antenna to *LocataLites* ranged from approximately 5 to 80 metres. The *Locata* receiver's omni-directional antenna was mounted on a tripod, and the *Locata* receiver was located in an office below via a 30m low-loss coaxial antenna cable. Each *LocataLite* (LL) was assigned consecutive PRN codes (except LL8), starting from the "Master" in a clockwise direction. In operation, the "Slave" *LocataLites* 2-10 time-synchronise to the "Master" *LocataLite* 1. A *Locata* receiver using these positioning signals can compute a carrier-phase single point position with cm-level accuracy (without requiring a differential reference receiver and data links).

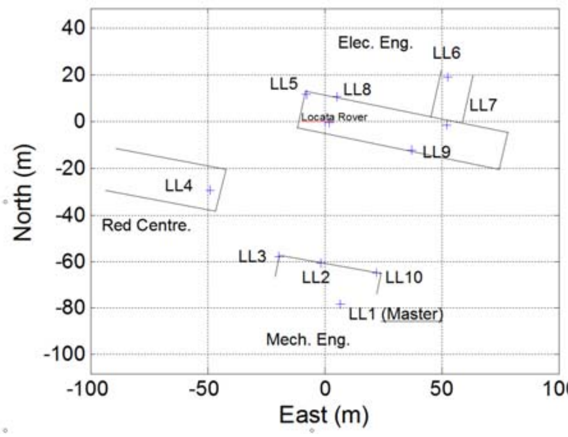

Fig. 1 *LocataNet* of 10 *LocataLite*s established on the roof-tops at UNSW.

Each of the *LocataLite* sites consists of three main components: a pole with three antennas attached, a *LocataLite*, and a power source. For a fully operational *LocataLite* utilising spatial diversity (see Barnes et al., 2006), two transmitting antennas and one receiving antenna are required. In the UNSW setup, directional patch antennas with beam width of 70 degrees were used for both transmission and reception. The transmitting antennas were positioned towards the rover antenna work area and attached to a vertical pole with a separation of approximately 75cm; the receiving antenna was directed towards the "Master" *LocataLite* and mounted just below the top of the transmitting antenna (see Fig. 2). The *LocataLites* were enclosed in customised weatherproof boxes, allowing for external connections to the antennas, data communication ports and power sources. The external interface is then wired to the *LocataLite* inside, as shown in Fig. 2.

Fig. 2 *LocataLite* (5) antenna setup (top left) and weatherproof enclosure (top right). *Locata* receiver antenna setup (bottom left) and *Locata* receiver (bottom right).

With the exception of the "Master" *LocataLite*, which operated on a mains power source, the *LocataLite* locations were powered by 12V/55AH batteries, which allowed a continuous run time of over 24 hours per battery. Y-splitters were connected to the power cables, which enabled the connection of a replacement battery in parallel to the exhausted one before disconnecting the latter, thus providing uninterrupted power to the *LocataLites.*

During early January to mid February the *LocataNet* was in continuous operation for several days at a time, without any network failure. A number of static tests of several hours in length were conducted during this time, and the next section gives a description and results from a typical static test.

3 Long term static test

In deformation monitoring applications (such as bridges), the monitored structures are generally relatively static and it is any deviation from this state that requires early detection. The long term stability of a positioning solution is therefore critical for deformation monitoring applications. For the purposes of this test, the network setup described in the previous section was used and Fig. 2 shows the setup of the *Locata* receiver antenna on the tripod.

The *Locata* receiver in the office was connected to a laptop computer via two serial ports. After powering up the receiver the *LocataLite* signals are acquired and tracked within 10s of seconds. For a single point carrier-phase solution the receiver currently requires initialising at a known point to resolve the carrier-phase ambiguities. When *LocataLites* transmit on a second frequency in the 2.4GHz ISM band (expected in the next 6-12 months) the *Locata* receiver will be able to resolve ambiguities On-The-Fly. The coordinates of the *Locata* receiver were surveyed using differential GPS, at the same time as the *LocataNet* survey was conducted. The receiver was initialised via a command through the laptop and then the receiver output single point carrier-phase solutions at a 1Hz rate in the NMEA format, which was logged and visually displayed. In addition to this the real-time position solution, raw data (containing pseudorange and carrier-phase) were logged. Data in this particular test were collected for approximately 13.5 hours. Due to the fact that the elevation angle to the *LocataLites* from the receiver location are all less than 8 degrees, the geometry in the vertical is very poor. The following results will therefore concentrate on the horizontal component.

3.1 Results and Analysis

Figs. 4 and 5 show the horizontal scatter plot of the position error (with respect to the true position surveyed using GPS) and the individual East and North positioning error components. The mean position error in both East and North are less than 1mm and the standard deviation in East and North was 2.1 and 1.5mm respectively. The slightly larger standard deviation in the East component is due to the fact that the dilution of precision in the East-West (0.543) component is slightly worse than the geometry in the North-South direction (0.530). Visually from Figs. 3 and 4 it is clear that the overall precision and stability of the position solution is very good over the 13.5 hour period with no evident long term drifts. However, there are approximately 7 position solutions (out of ~48600) that could be considered as outliers, and the largest with a maximum error of 2 cm in the North component. *LocataLites* internally monitor their time synchronisation integrity. If the time synchronisation is not within specification the *LocataLite* takes steps to ensure the *Locata* receiver "sees" the signal as "unhealthy". However, in this particular *LocataNet* the distances from the *LocataLites* to the rover are very short (5-80 metres). At this distance it may have been possible for a rover to occasionally track "unhealthy" signals. On a *LocataNet* with distances of several hundred metres to the rover this is not likely to be an issue. In addition, these are "single events", so they could be easily removed using a filter or using data snooping techniques.

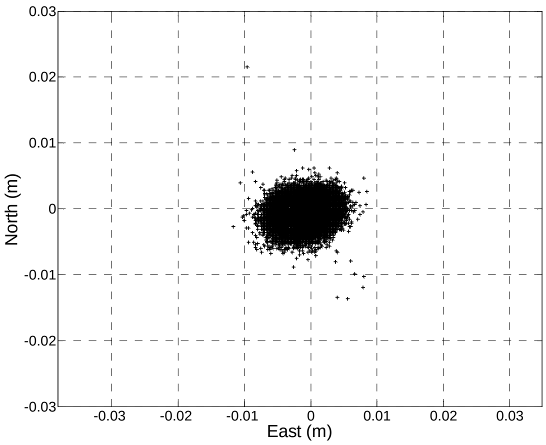

Fig. 3 Horizontal error scatter plot for long term (13.5 hour) static positioning test.

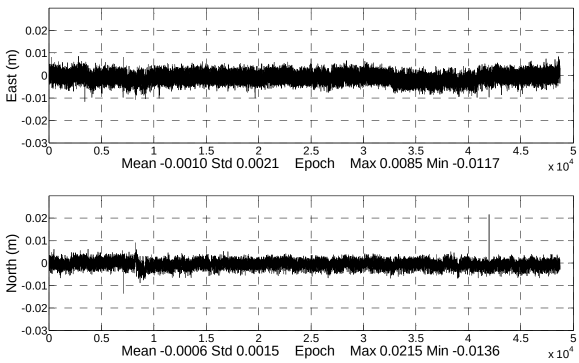

Fig. 4 East and North error for long term (13.5 hour) static positioning test.

4 Simulated deformation movement test

In some structural deformation monitoring applications (such as for bridges) the positioning technology used must be able to detect centimetre to millimetre level movements. The purpose of this test was to establish if the accuracy of the *Locata* technology allowed one centimetre level movements of the *Locata* receiver's antenna to be detected.

For the purpose of this test, the rover antenna was required to move accurately over a small distance in a pre-defined pattern. The process needed to be automated and repetitive in order to test the system over a long-term period. To satisfy these requirements a HP XY plotter table was used. Both a *Locata* receiver antenna and a Leica GPS system 500 AT502 antenna were mounted to the printing-head of the plotter (as shown in Fig. 5). The use of such a plotter enabled control of the device using a serial port connection to a laptop. The plotter supports the HPGL graphic language and thus, by creating appropriate computer scripts, it allowed the automation, repetition and accuracy of movement which was required.

The plotter, with the antennas attached, was placed on a levelled table on the roof of the Electrical Engineering building near the *Locata* rover antenna used in the static test. This location had a clear line-of-sight to all surrounding *LocataLites*. The coordinate of the *Locata* receiver antenna at the centre of the plotter table was surveyed using a reflector-less total station. In addition the plotter table was orientated so that the X and Y axes were as closely aligned with true North/South and East/West as possible.

It was decided to make this test more "challenging" by only using five of the *LocataLite* locations and thereby making the network geometry worse (and more "real world"). The five *LocataLites* used were LL1, LL4, LL5, LL7 and LL8. Conducting the test in a similar way to the static test, the *Locata* receiver was first initialised at the know point and the receiver then output positions at a 1Hz rate. After one minute, both antennas were moved 1 cm in the West direction. After one minute of static data collection, the antennas were moved a further 1 cm to the West. This procedure was repeated until the antenna was 12 cm to the West of the initial position. The antenna was then moved 1cm to the East repeatedly until the antenna was a full 12 cm East of the initial position. The antenna was then moved by 1cm steps in the West direction again until the antenna was back at the initial start location. The procedure described above was then repeated giving a total of 149 static points (each with 1 minute of data), with the entire test taking approximately 2.5 hours to run. The GPS receiver data was post-processed using Leica Geo Office relative to an MC500 Leica GPS reference station with a AT504 choke ring antenna, located approximately 55 metres from the test area.

Fig. 5 HP XY plotter table with *Locata* and Leica AT502 antennas.

4.1 Results and Analysis

Figs. 6 to 11 show epoch-by-epoch position solutions from *Locata* and GPS for the horizontal trajectory and in East/North components. Visually from the figures the *Locata* solution is more stable and repeatable than the GPS solution. The *Locata* position solution has consistent positioning geometry with a HDOP of 0.64 with 5 *LocataLites*. In comparison the GPS HDOP varies from 1.5 to 4.1 with 5 to 9 available satellites. The section of poorer GPS geometry can easily be seen in the middle section of the data for the North component. For the *Locata* North time series there is a repetitive pattern of movement in the North direction (as the antenna moves East-West), with a maximum deviation of about 2.5 mm. There are two possible explanations for the repetitive movement in the North-South direction. First, the error could be due to the actual movement of the plotter head. The second possible reason is multipath error. In an RF-based terrestrial positioning system the multipath error at a particular position in the network will have a similar multipath error if the same position is reoccupied. This is assuming the transmitter locations and local factors (buildings etc) do not change. The repetitive nature of the error signature in this particular test suggests that it may be possible to reduce the multipath error in a relatively static environment through calibration, although further investigations would be required to verify this.

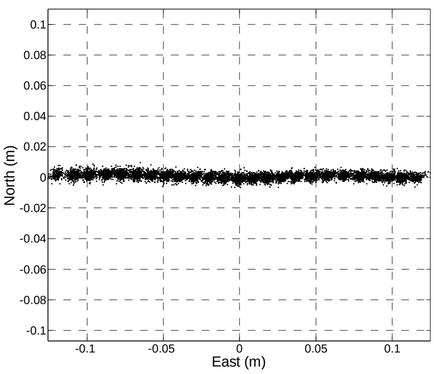

Fig. 6 Horizontal trajectory: *Locata.*

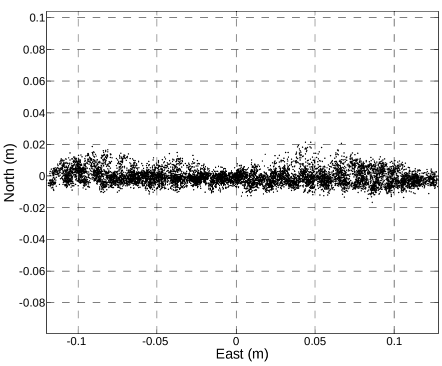

Fig. 7 Horizontal trajectory: GPS.

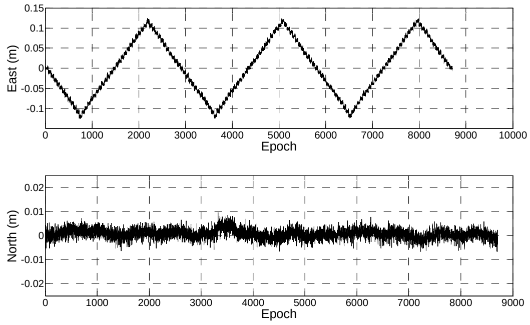

Fig. 8 East and North time series: Locata.

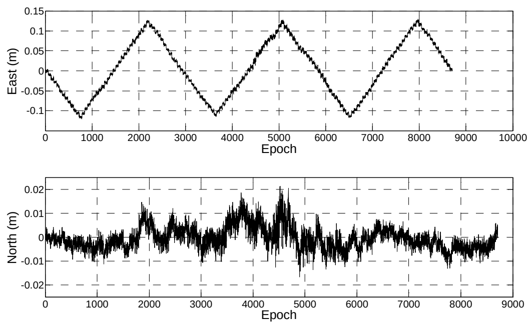

Fig. 9 East and North time series: GPS.

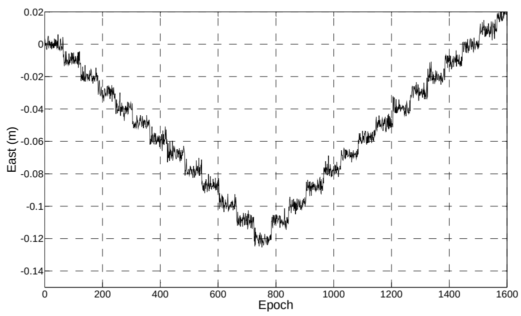

Fig. 10 East time series, 1st 1600 epochs: *Locata*.

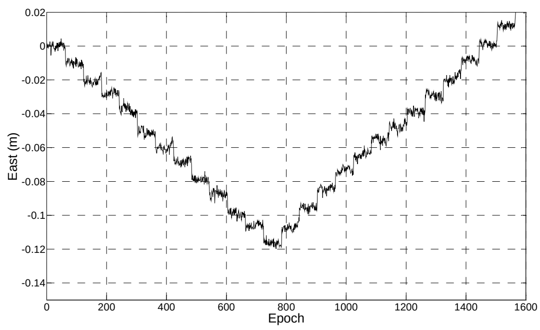

Fig. 11 East time series, 1st 1600 epochs: *GPS*.

The mean static position of each location was computed (from each 1 minute of static data) for the *Locata* and GPS solutions. These are plotted in Figs. 12 & 13 for the East and North components. Figs. 14 &15 shows the first 24 mean static points for the East component. In addition the East and North standard deviation of each static point for *Locata* and GPS are shown in Figs. 16&17. For *Locata* the largest standard deviation in the East and North coordinate components was 3.2 mm and 1.2 mm respectively, with the smaller North component being due to better geometry (lower DOP). For GPS the largest standard deviation in the East and North coordinate components was 4.0 mm and 5.3 mm respectively, which are correlated with the section of worse satellite geometry. The distance 'travelled' with each 1 cm step was computed based on the mean position values, and the error computed, assuming a 'true' step value of 1cm. Figs 18&19 show the error in the distance moved with a maximum error of 2.7 mm for *Locata* and 7.2 mm for GPS. This indicates that a 1 cm move can easily be detected using *Locata*, but for GPS cannot always easily be detected due to the varying satellite geometry. In addition the *Locata* solution can be improved by positioning the *LocataLites* in a more optimal network configuration to improve geometry.

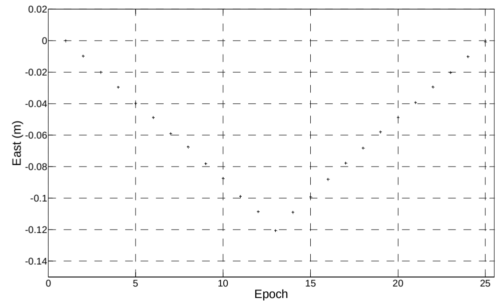

Fig. 14 Mean static East 1st 24 moves: *Locata*

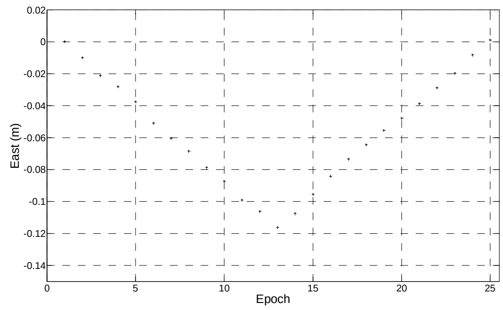

Fig. 15 Mean static East 1st 24 moves: GPS

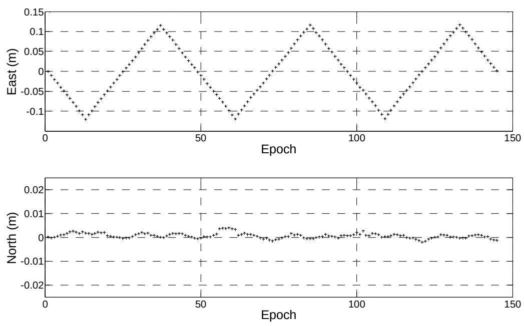

Fig. 12 Mean static East and North time series: *Locata*

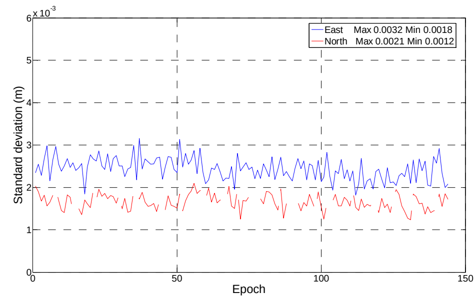

Fig. 16 Standard deviation of static East and North: *Locata*.

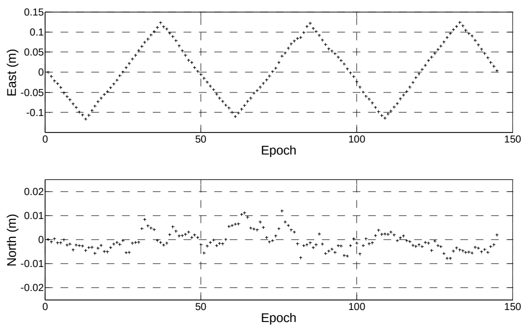

Fig. 13 Mean static East and North time series: GPS

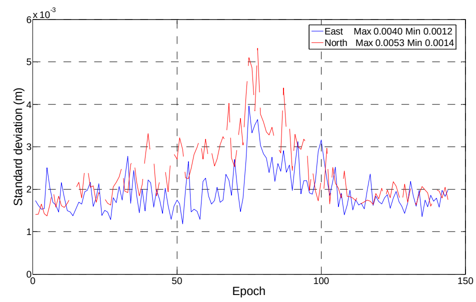

Fig. 17 Standard deviation of static East and North: *Locata*.

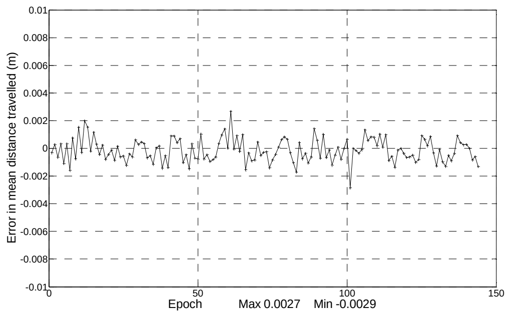

Fig. 18 Error in distance travelled for each 1cm move (computed from mean position values): *Locata*

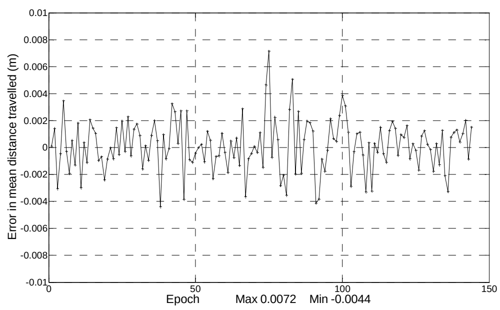

Fig. 19 Error in distance travelled for each 1cm move (computed from mean position values): GPS

5 Conclusions

In this paper a *LocataNet* was successfully established at the University of New South Wales for assessing the suitability of *Locata* technology for structural deformation monitoring applications. Using this network a long term static test and a simulated deformation movement test were conducted. The static test over approximately 13.5 hours verified the long term stability of the *LocataNet*. The resulting position standard deviation of the test was approximately 2 mm, and there were no evident long term drifts. The position solutions in this test were computed on an epoch-by-epoch basis with no filtering or smoothing, once a second. For structural deformation monitoring applications it is likely that a combined epoch solution or smoothed solution would be more appropriate. Therefore work is now focused on methods to combine several epochs of data to generate solutions with higher precision and better integrity.

In the simulated deformation movement test a *Locata* receiver antenna and GPS antenna were repeatedly moved by 1 cm steps and static data was collected for one minute after each move (149 static points in total). For the GPS solution the maximum error in distance moved computed from the mean static positions was 7.2 mm, and indicates that a 1cm movement of the antenna cannot always be detected due to the varying satellite geometry. However for *Locata* the maximum error in distance moved was 2.7 mm, and suggests that Locata technology can easily detect movements of 1cm. For *Locata* this result can be improved with a more optimal (better geometry) *LocataNet* design.

In the tests conducted for both *Locata* and GPS the atmospheric effects are insignificant due to the size of the *LocataNet* and the close proximity of the reference station in the case of GPS. Work is now under investigation to remove multipath error via calibration and improve the positioning results further. In addition tests will now focus on larger *LocataNet* installations (where tropospheric effects are greater), and at real structural deformation monitoring sites (such as bridges and dams).

Overall the tests conducted have demonstrated that *Locata* technology has the potential to meet the expected requirements for structural deformation monitoring type applications (such as bridges) where there is reduced or unavailable satellite coverage. The *Locata* technology is very soon ready for trial investigations to begin at real structural monitoring test sites (bridges, dams etc).

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