Test Results of Locata Technology for Deformation Monitoring

Mazher CHOUDHURYand Chris RIZOS, Australia

Key words: deformation monitoring, static positioning, Locata

SUMMARY

Deformation monitoring requires very high levels of precision as well as accuracy. Although GNSS is a popular choice for 24/7 deformation monitoring applications, it suffers from interference and multipath vulnerability. In addition, the number of visible satellites and their geometric distribution plays an important role in the resultant accuracy and precision. To address these shortcomings, Locata Corporation invented a positioning technology called “Locata”. Locata provides position solutions using a network (a “LocataNet”) of time-synchronised pseudolite-like transceivers (or “LocataLites”) which can be installed almost anywhere for better network geometry. As soon as a Locata receiver tracks four or more LocataLite signals it can compute millimetre-level precise and millimetre-to-centimetre-level accurate position entirely independent of GPS. As these ranging signals have frequencies in the licence-free 2.4GHz Industry Scientific and Medical (ISM) band, other devices that also use the ISM band may cause degradation of Locata’s position solution. This paper evaluates the performance of the Locata technology in the presence of interfering signals. Zero baseline (ZBL) tests are used to observe the performance of two Locata receivers in conditions ranging from benign to hostile (high signal interference). Results from ZBL tests help to identify several research directions which can be pursued in order to improve Locata’s position solution for static applications such as deformation monitoring.

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1. INTRODUCTION

Deformation monitoring requires millimetre-to-centimetre-level accuracy with high precision. For the last two decades GNSS (actually GPS, however for this paper GNSS will be the term used to cover all types of satellite-based positioning systems) has been the most popular tool for 24/7 deformation monitoring. However, GNSS-based positioning solutions suffer from interference and multipath disturbances. These solutions further degrade when GNSS has a low number of visible satellites or the geometric distribution of visible satellites becomes poor. To address such issues, Locata Corporation invented a positioning technology referred to as “Locata”. Locata provides position solutions using a network (known as the “LocataNet”) of time-synchronised pseudolite-like transceivers (referred to as “LocataLites”). These LocataLites can be installed almost anywhere for better network geometry. As soon as a Locata receiver tracks four or more LocataLite signals, it can compute millimetre-level precise and millimetre-to-centimetre-level accurate position solutions entirely independent of GNSS. These ranging signals are transmitted in the licence-free 2.4GHz Industry Scientific and Medical (ISM) band. However, Locata position solutions may be degraded as there are other transmitters which also operate in the ISM band (e.g. WiFi devices).

Evaluating the performance of a Locata system is an important consideration before deploying it in a deformation monitoring application. Zero baseline (ZBL) tests are used to study the performance of Locata receivers under conditions ranging from benign to hostile (i.e. high signal interference). As two receivers are connected to the same antenna with a low-noise splitter, all common errors will be eliminated and only receiver noise will be present. In this paper, two ZBL tests are conducted to identify possible signal quality issues in using Locata for deformation monitoring applications.

This paper is organised as follows. In section 2, the Locata system and Locata receiver performance issues are briefly introduced; section 3 describes the test scenario along with the hardware used; section 4, explains the experiment setup as well as presents the test results. Finally, section 5 concludes the paper.

2. BACKGROUND

2.1 Locata

Locata’s positioning technology solution can be used as an alternative to GNSS in classical difficult GNSS signal environments. A network of terrestrial transceivers (LocataLites) transmits strong signals in the licence-free 2.4GHz ISM band. These transceivers form a positioning network (LocataNet) that can operate in combination with GNSS, or entirely independent of GNSS. One special property of the LocataNet is the time synchronization of the individual LocataLites, which permits carrier phase-based Single Point Positioning (i.e. no differential methods or transmitted data corrections are required). When a Locata receiver tracks four or more signals from different LocataLites, it can compute 3D position entirely independent of GNSS. A description of the Locata technology can be found in, for example, Barnes et al. (2004), and publications over the last 6 years that can be found at http://www.gmat.unsw.edu.au/snap/about/publications_year.htm.

2.2 Locata receiver performance considerations

The Locata receiver's performance is based on the number of LocataLites in the LocataNet, LocataNet geometry, signal obstructions, atmospheric conditions, RF interference and multipath. In unfavourable environments the Locata receiver performance can be expected to degrade, in a similar manner that GNSS does in adverse signal and geometry conditions. However, the most important issue for static applications such as structural deformation monitoring is RF interference (RFI). Overall receiver noise level rises when nearby transmitting devices operate in the same band as Locata (i.e. the licence-free 2.4GHz ISM band). In real world scenarios, RFI, which is not consistent and not continuous, can either reduce the signal's strength and accuracy, or even block the reception of some of the Locata signal entirely. A detailed and elaborate explanation and the impacts of RFI is presented in Khan et al. (2010). This makes the Locata position accuracy vulnerable because if the initial state (i.e., SNR, signal quality parameter, interference signal output by the Locata receiver, etc.) of the ambiguity resolution epoch is changed over time, then the accuracy may change. However, as the dynamics of the environment are often continually changing, the ambiguity resolution method must be robust. In this paper, the Known Point Ambiguity Resolution (KPAR) method is used to validate the results from ground truth.

Atmospheric disturbance is another critical issue for deformation monitoring systems. For short time frames, such as 2-4 hours when atmospheric conditions (i.e. temperature, pressure and humidity) do not change dramatically, hence the KPAR absorbs atmospheric errors (Choudhury et al., 2009). However, for continuous positioning applications, a atmospheric model should be used. In this paper, no tropospheric model is used as the test was conducted for only two hours.

However, any of these factors will affect all the Locata receivers when they are operated in static mode and connected to one antenna (i.e. for zero baselines). Since the two receivers are connected to the same antenna with a low-noise splitter, all common errors (e.g. atmospheric, multipath, WiFi interference, signal quality variation, etc.) are eliminated (Meng, 2002).

3. TEST SCENARIO AND HARDWARE USED

To test the Locata receivers' performance, a zero baseline test was conducted at The University of New South Wales (UNSW) where a Locata network has already been established. The Locata receiver antenna was mounted on a tripod (Figure 1). The network's dilution of precision (DOP) values are listed in Table 1.

EDOP	0.40
NDOP	0.47
HDOP	0.62
VDOP	3.26
PDOP	3.32

Table 1: Locata position DOP

Locata receivers output raw measurements of Integrated Carrier Phase (ICP) measurements, pseudorange (PR) measurements, Locata Signal Strength Indicator (LSSI), low-correlator-output-events (LCOE), along with other proprietary engineering parameters. LSSI is an indicator for the usability of an observation in a position solution. LCOE (i.e. the number of times per observation interval the correlator output was unable to satisfy the preset threshold) indicates the presence of interference which was high enough to impact on the correlator performance (Khan et al., 2010). As ICP provides a high level of accuracy, it is the most appropriate measurement for deformation monitoring applications. All other measurements are used to validate the position solutions derived from ICP measurements.

4. EXPERIMENT SETUP & TEST RESULTS

4.1 Case 1: Benign conditions

4.1.1 ZBL setup

During September 2010, a series of ZBL tests were conducted at UNSW. Locata receivers and a Hyperlink Omni antenna (model: HG2403MGURB), with a signal splitter were employed (Figure 1). The data collected during all experiments were processed in the KPAR method using post-processing software (Choudhury et al., 2010). Characteristics of the resulting 3D coordinate residuals were analysed. The assumptions were that using KPAR, atmospheric errors and other unmodelled errors cancel out for zero baseline tests, that the receiver noises become the dominant component of the solution residuals, and both Locata receivers have identical noise levels.

4.1.2 ZBL results

Raw ICP measurements, and the position solutions derived from them, were analysed. Figures 2 and 3 are the 3D coordinate differences from the initial coordinates (i.e. the KPAR point). The raw data sets were recorded at 2Hz sampling rate. These raw measurements were used in the post-processing Locata software (ibid, 2010) to generate coordinate solutions, as well as the residuals which were derived from the known coordinates. After removing outliers, receiver 1 has accuracies of 0±6mm, -1±11mm, and -5±56mm for the east, north, and height coordinate components (at the 99.7% confidence level (CI), or three times Root Mean Square (RMS), a statistical measure of the magnitude of a varying quantity), respectively. Receiver 2 has accuracies are 0±6mm, -1±10mm, and -6±57mm for the east, north, and height coordinate components (at the 99.7% confidence level (CI)), respectively. The residuals (i. e. epoch by epoch coordinate solution formed by deducting R2 from R1) between receivers are 0±2mm, 0±2mm, and 2±9mm for the east, north, and height coordinate components at 99.7% CI, respectively. Table 2 shows a comparison between the two receivers' performance.

Figure 1 (a): ZBL Setup

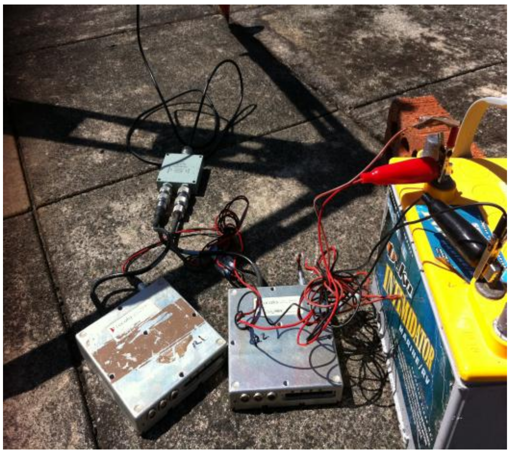

Figure 1 (b): ZBL Setup

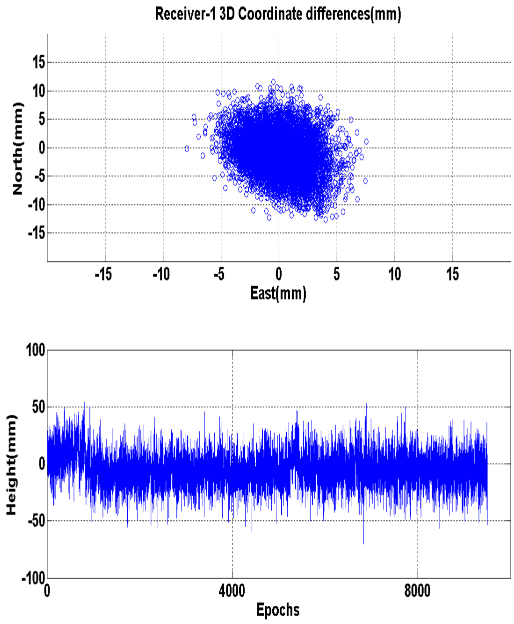

Figure 2: Receiver 1

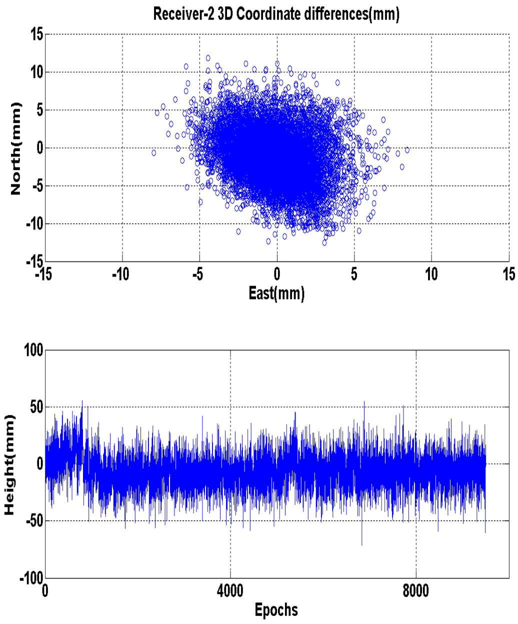

Figure 3: Receiver 2

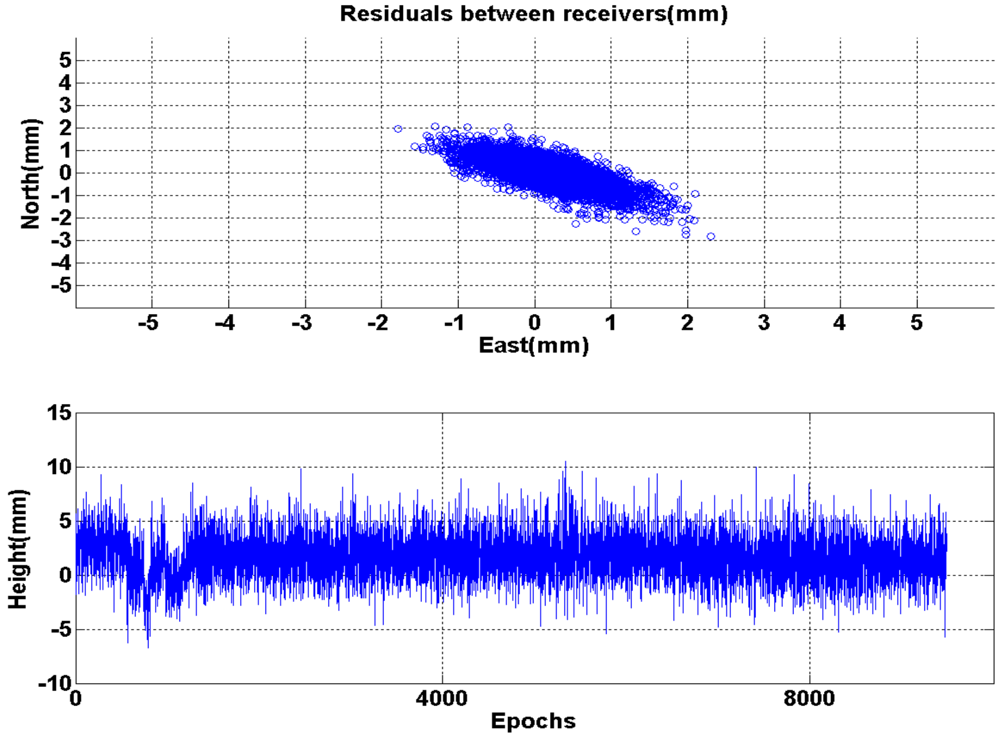

Figure 4: Residuals between receivers

Receiver	Mean (metres)			Max Residuals (mm)			Min Residuals (mm)			RMS (mm) (99.7% CI)		
	E	N	H	E	N	H	E	N	H	E ±	N ±	H ±
R1	-108.401 ±0.002 (1σ)	45.897 ±0.004 (1σ)	25.035 ±0.019 (1σ)	8	13	70	-8	-13	-70	6	11	56
R2	-108.400 ±0.002 (1σ)	45.897 ±0.003 (1σ)	25.029 ±0.019 (1σ)	8	13	71	-8	-13	-71	6	11	57
R1-R2	0 ±0.001 (1σ)	0 ±0.0004 (1σ)	0.006 ±0.003 (1σ)	2	3	11	-2	-3	-11	2	2	9

Table 2: Comparison of results between two Locata receivers

Histograms of residuals (i.e. difference between receivers) are shown in Figures 5, 6 & 7. It can be observed that residuals caused by the receiver noise appear to have a normal distribution for the east and north position component. However, in the case of the height component there is a slight shift to the right. These biases could be due to weak vertical geometry. From these histograms it can be concluded that the least squares adjustment of this measurement data is acceptable.

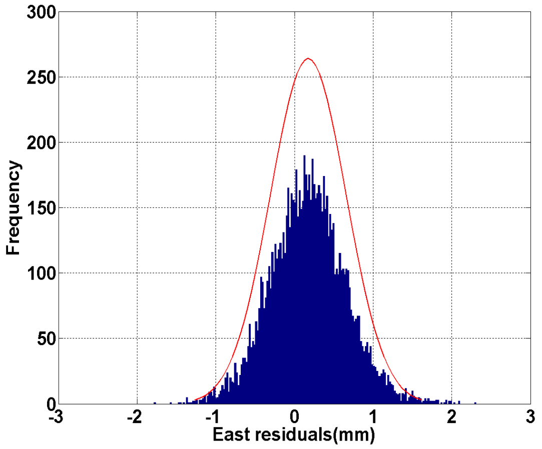

Figure 5: Histogram of East residuals

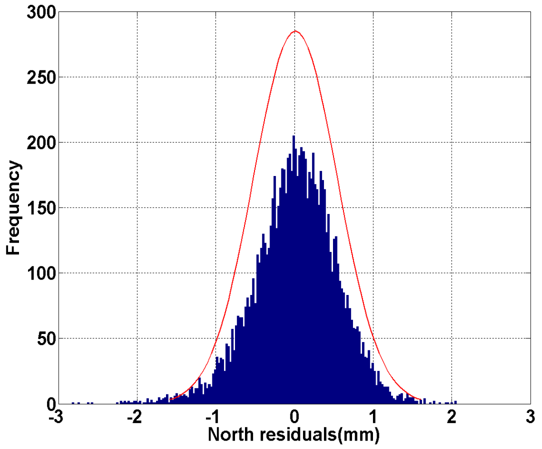

Figure 6: Histogram of North residuals

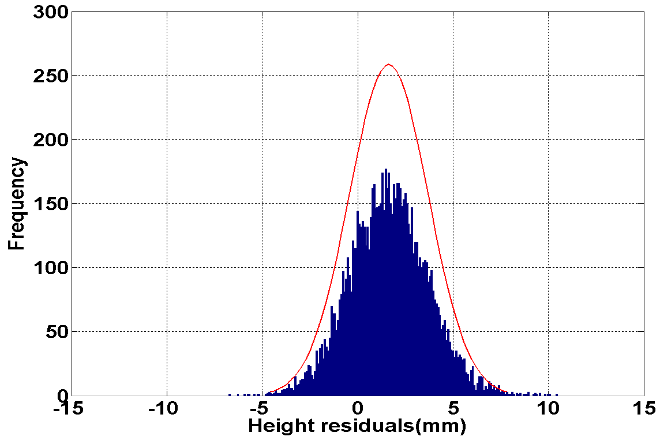

Figure 7: Histogram of Height residuals

LocataLite residuals are plotted in Figure 8. These are the differences between the two receivers' residuals (generated from the least squares adjustment procedure). Most of the time these difference lies within ±2 mm for all four LocataLites. However there are a few instances when this difference jumps to between ±6 mm. Figures 9 and 10 show the LSSI and LCOE for both receivers, which indicate that there is no significant interference. (If there were any interference, the LCOE value should rise and the LSSI value should decrease.)

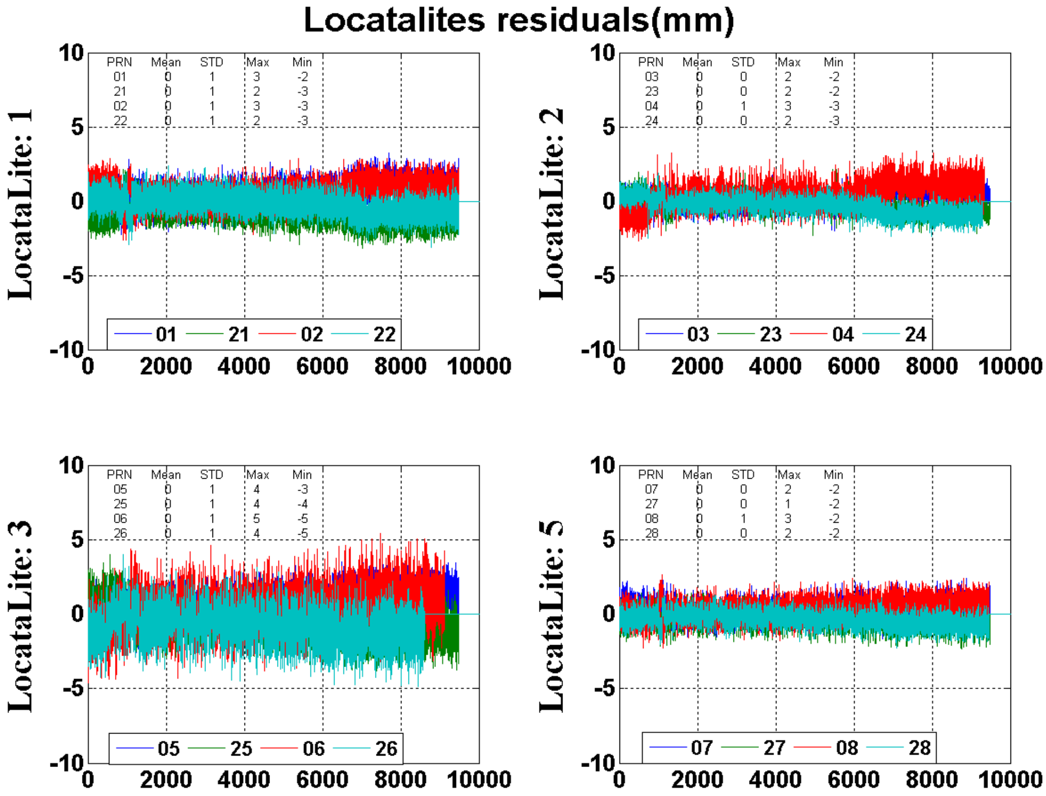

Figure 8: LocataLite residuals

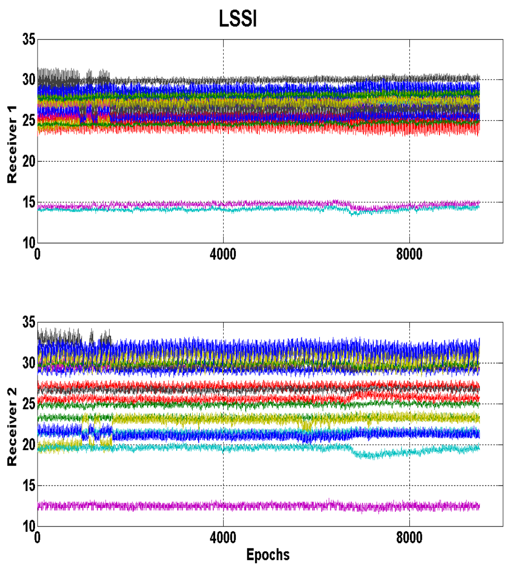

Figure 9: LSSI values

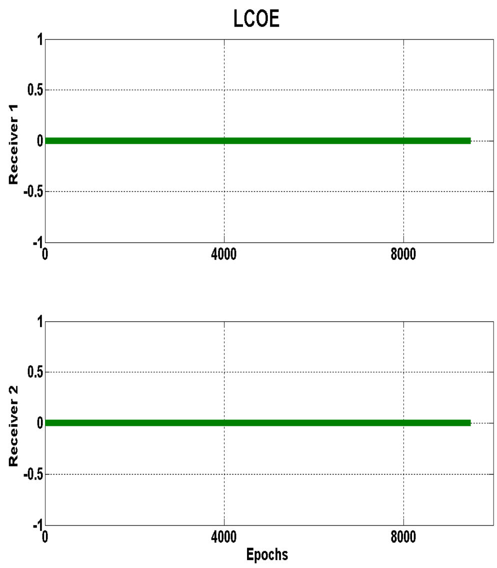

Figure 10: LCOE values

From this experiment it can be concluded that in an ideal situation with no RF interference present, both Locata receivers' performance are very similar.

4.2 Case 2: with interference

In the presence of WiFi interference, Locata faces challenges in maintaining sub-centimetre-level accuracy. However, as soon as the interference fades, position accuracy again improves. Figures 11 and 12 are showing the performance of the Locata receivers in the presence of interference. This is an issue for deformation monitoring applications as this type of interference could generate false deformation alarms.

4.2.1 Experiment setup

A Locata receiver and a Hyperlink Omni antenna (model: HG2403MGURB) antenna were setup at known points for two hours. During this period, data files were transferred from one laptop to another laptop. This setup was intended to simulate a real world scenario where WiFi interference can be a common phenomenon. The result of interference can be seen when the LCOE values rise, as the assumption is that only WiFi interference is present.

4.2.2 Results

Figures 11 and 12 show the 3D coordinate differences from the initial coordinates. Coordinate solutions are generated using the same post-processing Locata software as before. After removing outliers, receiver 1 has a RMS of 1±8mm, 3±16mm, and 15±80mm compared to 1±8mm, 3±16mm, and 17±82mm for receiver 2, for the east, north, and height coordinate components, respectively. The residuals between the receivers are 0±2mm, 0±2mm, and -3±13mm for the east, north, and height coordinate components (at 99.7% CI), respectively. Table 3 shows a comparison between the two receivers' performance under WiFi interference. Figure 13 shows the coordinate residuals from the two receivers. It can be observed that in the presence of WiFi interference the performance of both receivers degrades.

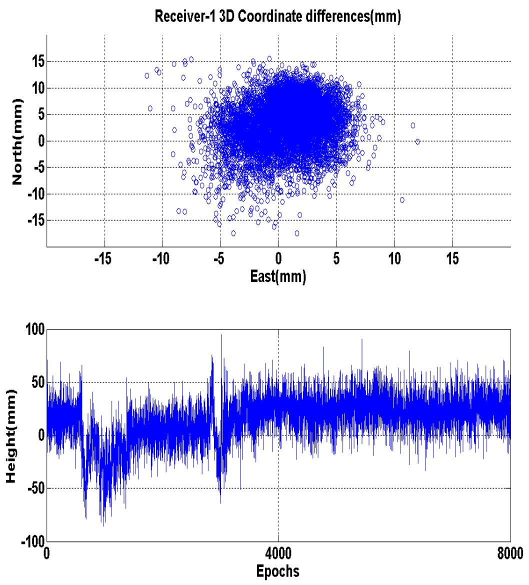

Figure 11: Receiver 1(with interference)

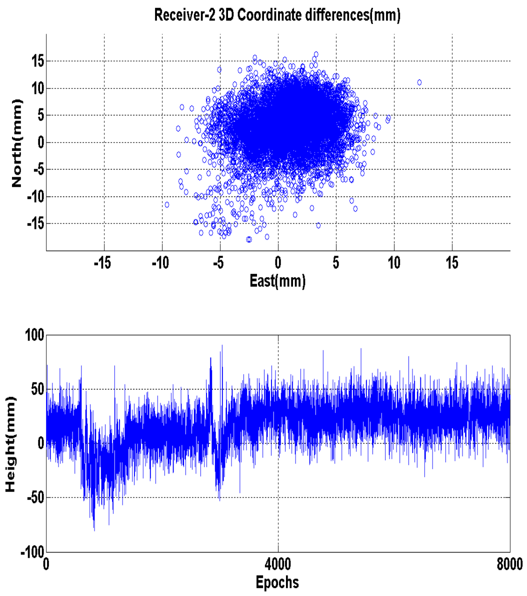

Figure 12: Receiver 2 (with interference)

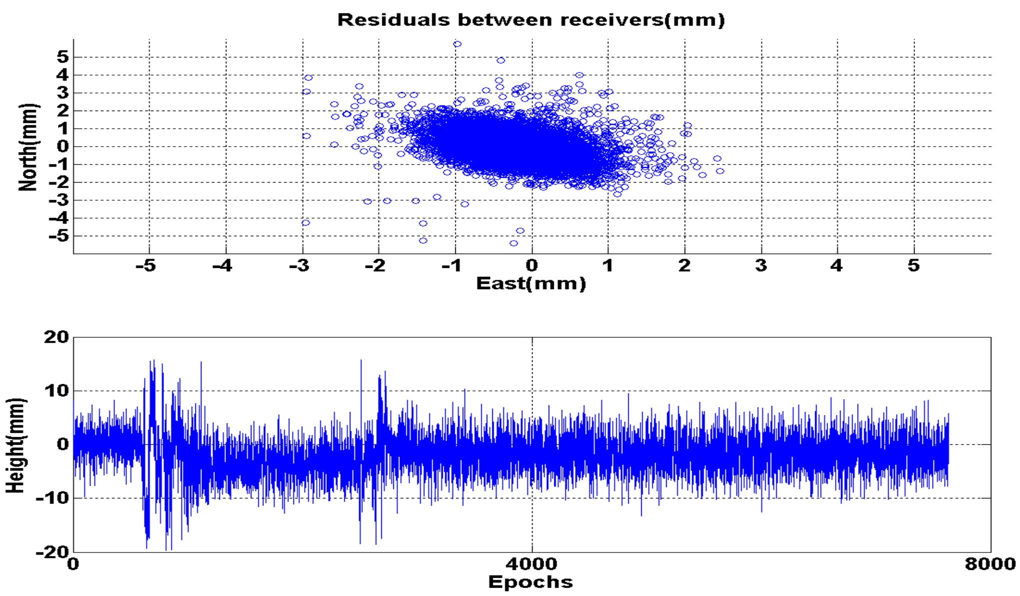

Figure 13: Residuals between receivers (with interference)

LocataLite residuals together with LSSI and LCOE values are plotted into Figures 14, 15 & 16. From the LSSI and LCOE values both receivers indicate that there is significant interference which causes degradation in the LocataLite residuals and impacts on the position accuracy (Figures 11 or 12).

Rec-eiver	Mean (metres)			Max Residuals (mm)			Min Residuals (mm)			RMS (mm) (99.7% CI)		
	E	N	H	E	N	H	E	N	H	E ±	N ±	H ±
R1	-108.400 ±0.004 (1σ)	45. 900 ±0.004 (1σ)	25.047 ±0.023 (1σ)	12	16	95	-12	-17	-85	8	16	80
R2	-108.400 ±0.003 (1σ)	45. 900 ±0.004 (1σ)	25.050 ±0.022 (1σ)	12	16	90	-10	-17	-80	8	16	80
R1-R2	0 ±0.001 (1σ)	0 ±0.001 (1σ)	-0.003 ±0.004 (1σ)	3	7	15	-2	-3	-19	2	2	9

Table 3: Comparison between two Locata receivers (under WiFi interference)

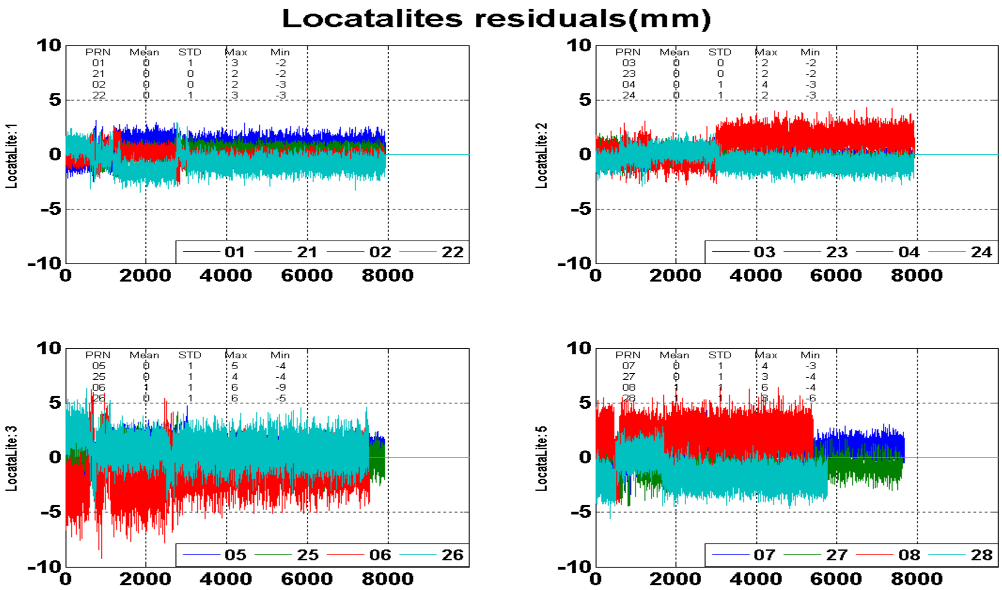

Figure 14: Locata residuals (with interference)

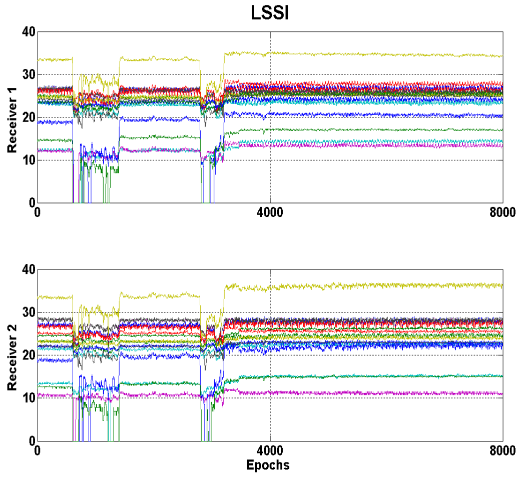

Figure 15: LSSI values (with interference)

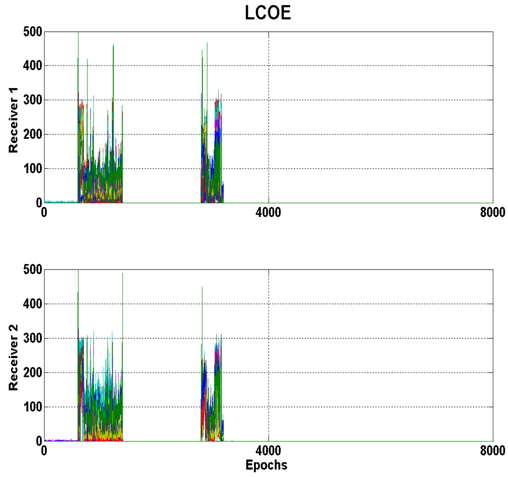

Figure 16: LCOE values (with interference)

4.3 Observations

From the above two experiments it can be observed that both receivers perform similarly, with or without interference. This implies that Locata receivers can be used in deformation monitoring applications. Table 4 provides performance comparison statistics of a Locata receiver, with and without interference. It can be observed that the mean for the east and north changes are at the millimetre level, and the height changes are at the centimetre level. At the same time, ranges between the maximum and minimum as well as RMS also degrade. Figure 15 shows that receiver 1 (same situation has been observed for receiver 2) accuracy for all three position components are unable to maintain the same level of accuracy as before (i.e. without interference). This type of interference could generate false alarms in deformation monitoring applications using the Locata technology. On the other hand, position solution algorithm for Locata can also be improved by rejecting the degraded epochs, or by a using a more sophisticated stochastic model, or by reinitialising the ambiguities "on the fly".

Receiver	Mean (metres)			Max Residuals (mm)			Min Residuals (mm)			RMS (mm) (99.7% CI)		
	E	N	H	E	N	H	E	N	H	E ±	N ±	H ±
R1 (without WiFi)	-108.401 ±0.002 (1σ)	45.897 ±0.004 (1σ)	25.035 ±0.019 (1σ)	8	13	70	-8	-13	-70	6	11	56
R1 (with WiFi)	-108.400 ±0.004 (1σ)	45. 900 ±0.004 (1σ)	25.047 ±0.023 (1σ)	12	16	95	-12	-17	-85	8	16	80

Table 4: Locata receiver performance for the two RFI scenarios

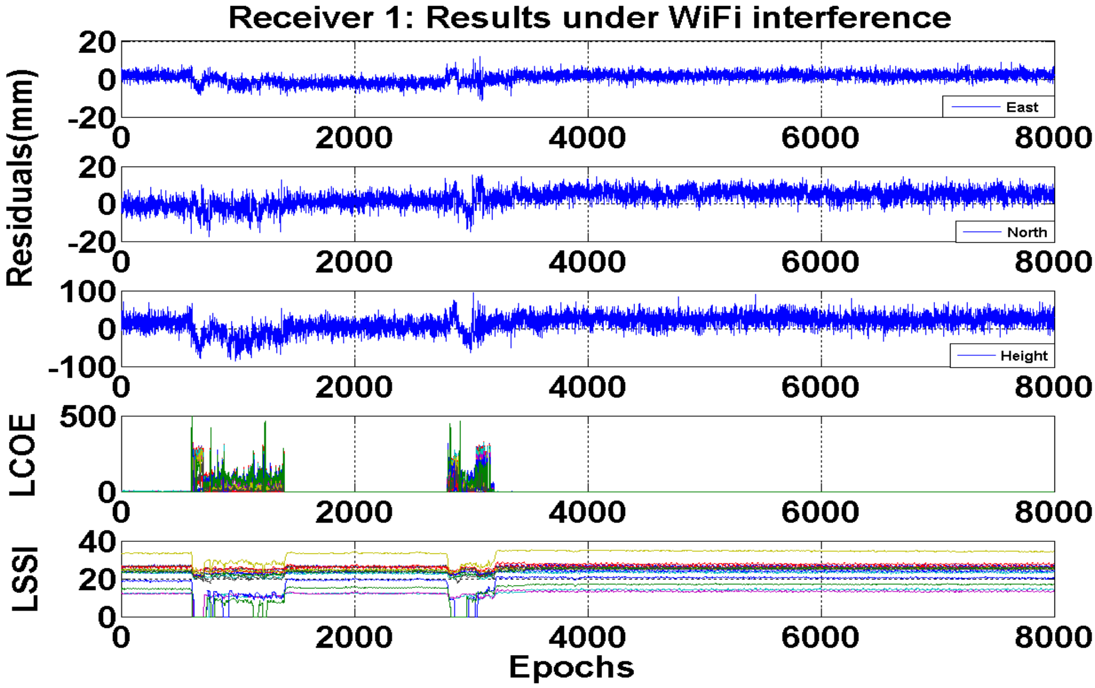

Figure 15: Results under WIFI interference

5. CONCLUDING REMARKS

In this paper, the Locata receiver performance was studies under conditions ranging from benign signal condition to WiFi-interfered conditions. The accuracy was impacted by interference. However, for both interfered and non-interfered situations Locata provides millimetre-level precision for horizontal position and centimetre-level vertical precision for all observed epochs. The accuracy of the coordinate solutions was at the millimetre level with very low horizontal standard deviations (few millimetres) and at the centimetre level for the vertical component. This indicates a high usability of Locata in deformation monitoring applications.

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BIOGRAPHICAL NOTES

Mohammad Mazher-ul Alam Choudhury is currently a Ph.D. student at the School of Surveying & Spatial Information Systems, University of New South Wales (UNSW), Sydney, Australia. His current research area is investigating the use of Locata technology for deformation monitoring applications. He holds a Masters in Computer Science from UNSW, and a B.E. (Computer Science) degree from the North South University, Bangladesh.

Chris Rizos is currently Professor and Head of the School of Surveying & Spatial Information Systems, UNSW. Chris has been researching the technology and high precision applications of GPS since 1985, and has published over 500 journal and conference papers. He is a Fellow of the Australian Institute of Navigation and a Fellow of the International Association of Geodesy (IAG). He is currently the Vice President of the IAG and a member of the Governing Board of the International GNSS Service.

CONTACTS

Mr. Mazher Choudhury
School of Surveying & Spatial Information Systems,
Faculty of Engineering,
The University of New South Wales
Sydney, NSW 2052,
Australia
Tel. +61423355034 Fax + 61293137493
Email: mohammad.choudhury@student.unsw.edu.au
Web site: www.gmat.unsw.edu.au