# Locata's VRay™ Antenna Technology – Multipath Mitigation for Indoor Positioning

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## BIOGRAPHY

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Allison Kealy is an associate professor in the Department of Infrastructure Engineering at the University of Melbourne. Allison is vice president of the IAG Commission 4 and chair of the International Federation of Surveyors Working Group 5.5 on Ubiquitous positioning. Her research interests include sensor fusion and filtering, high precision positioning and GNSS quality control.

Dr. Binghao Li is a Research Fellow with the School of Civil Engineering, The University of New South Wales, Sydney, Australia. Binghao obtained B.Sc. in Electrical & Mechanical Eng. from Northern Jiaotong University, P.R. China in 1994 and M.Sc. in Civil Eng., Tsinghua University, P.R. China in 2001. He received his Ph.D. from the University of New South Wales, Sydney, Australia in 2006. His research area is indoor positioning, pedestrian navigation, new positioning technologies and network-RTK.

Dr Mazher Choudhury is currently working at School of Civil and Environmental Engineering as a Research Associate. He obtained his PhD from UNSW where he investigated and analysed the potentiality of Locata Positioning Systems into deformation monitoring system. Currently he is involved in investigating real-time precise point positioning using multi GNSS observations. Previously, Dr. Mazher was involved in testing the space-qualified FPGA-based multi GNSS Integrated receiver for the GARADA Formation Flying. His research interests include land as well as space based GNSS positioning and navigation, multi-GNSS integration algorithms for navigation, GNSS data analysis procedure and improvement of testing procedure for receivers, Locata integration with GNSS.

Dr Suelynn Choy completed her PhD in 2009. Her current research interests are in multi-Global Navigation Satellite System (GNSS) Precise Point Positioning and using GNSS for atmospheric remote sensing. Suelynn is the co-chair of the International Association of Geodesy Working-Group 4.5.2: PPP and Network RTK under Sub-Commission 4.5: High Precision GNSS Algorithms and Applications.

Yanming Feng is a professor in Queensland University of Technology. His research interests include satellite orbit determination, GNSS triple frequency algorithms and data processing methods, and dedicated short-range communication.

## ABSTRACT

VRay™ antenna technology developed by the Locata Corporation, is demonstrating unprecedented high-accuracy positioning under extreme multipath conditions - especially in indoor environments. This new technology is an extremely flexible and adaptable foundation platform upon which many variations can be built for different uses. It therefore offers a new suite of technology solutions which will allow the entire positioning industry to address the many safety and liability critical applications where a robust positioning capability is emerging as an essential requirement - especially indoors and in urban areas. This paper details the latest tests performed with Locata's first commercial VRay technology antenna and electronics system which is today being integrated by commercial partners into industrial indoor positioning applications. The VRay multipath mitigation performance is quantified and the high-accuracy positioning capabilities in Global Navigation Satellite System (GNSS) difficult environments is demonstrated. These results establish this new capability as a major technological advance which can help revolutionize positioning indoors, in urban canyons, and other difficult environments where GNSS does not work because of multipath and signal obstruction constraints.

## INTRODUCTION

Despite the overwhelming success of Global Navigation Satellite Systems (GNSS) to deliver position, navigation and time (PNT) information to a plethora of users, it is evident that an increasing range of current and future applications require high-accuracy positioning information in environments where GNSS simply does not work, including urban areas, underground and indoors. In these GNSS-difficult environments, partial or complete unavailability of satellite signals as well as severe multipathing effects have emerged as key technical limitations for GNSS based positioning. The quest to deliver GNSS-like performance in these environments has motivated the development of a range of alternative or hybrid positioning solutions.

The Locata Corporation in Australia has developed one such alternative capability. Locata has pioneered the innovations behind a terrestrial based solution, which operates as a “constellation of ground-based satellites”. These additional points of reference can be used in conjunction with, or completely independent of, a GNSS satellite network. With the availability of the new VRay antenna Locata are now promoting a robust solution for multipath mitigation in some of the harshest of positioning environments. It is this capability that has captured the interest of the Australian Cooperative Research Centre for Spatial Information (CRC-SI). The CRC-SI maintains a strong interest in the delivery of high performance positioning and in 2014 initiated this project. With the overall aim of benchmarking the positioning performance capabilities of the very latest Locata technology, this paper presents preliminary results obtained from a range of test scenarios. The data was collected in collaboration with the Locata Corporation with independent validation completed using software developed at the University of New South Wales.

Table 1. Comparison of Locata with GPS/RTK and WiFi positioning technology

| Positioning Technology | Deployment of infrastructure | Coverage | Outdoor accuracy | Indoor accuracy |
|---|---|---|---|---|
| GPS/RTK | Yes, high cost | 50km | cm | N/A |
| Locata | Yes, medium-high cost | ~ 50km | cm | cm |
| WiFi | deployed for other purpose), very low cost | 50-100 m | 20-50m | 3-5m |

## LOCATA TECHNOLOGY

Locata’s positioning technology solution can be used as an alternative to GNSS in classically difficult GNSS signal environments. Locata Corporation’s technology, Locata, enables its positioning solution through a number of time-synchronised transceivers known as “LocataLites”. These LocataLites form a Locata network (or “LocataNet”) that transmits Locata signals in the licence-free 2.4GHz Industry Scientific and Medical (WiFi) band. In any LocataNet there is one master LocataLite and other LocataLites are time synchronised with that master. Upon synchronisation the LocataNet starts transmitting signals. When a Locata receiver tracks four or more signals from four different LocataLites, it can perform centimetre-level accurate single point positioning using phase measurements, without employing a differential technique requiring the transmission of data corrections. Figure 1 describes how Locata provides a positioning solution even in GNSS-challenged areas. Once a physical installation of the LocataNet has been done, a precise survey is required to determine the coordinates of the two transmit and one receive antenna connected to each LocataLite.

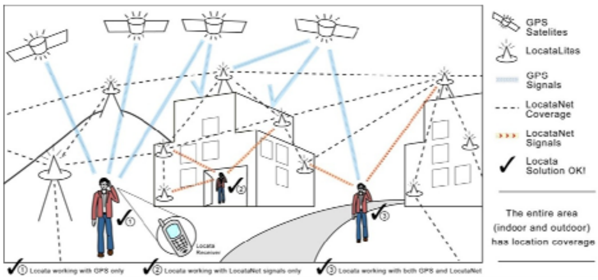


Figure 1. The Locata technology positioning concept (Barnes et al., 2003)

A Locata receiver is an electronic device that can record code and carrier phase measurements of the available LocataLites, along with measurements quality of the signals, as well as other proprietary parameters. The Locata receiver can provide real-time positioning at different data rates. Raw measurement data (i.e. pseudorange and carrier phase) from the receiver can be either recorded on a compact flash card or streamed out serially via RS232 at rates up to 25 Hertz. Figure 2 shows the Locata receiver and an antenna used in some of the reported tests. The Locata receiver (or rover) confined in a Locata network is able to output its position and time information in real-time using an in-built navigation processor. Additionally, it is also able to output the raw range measurements and other numerical data for offline solution computation and post-analysis.

Figure 2. Locata Receiver and antenna

The LocataLite, a transceiver, transmits a dual frequency proprietary Locata signal in the licence-free 2.4GHz Industry Scientific and Medical band. It can also receive signals from other LocataLites within the network at the same time. Upon receiving the Locata signals, a sophisticated time synchronisation process starts and the LocataLites become time synchronized to a designated Master LocataLite (one specified LocataLite among the available LocataLites). Barnes et al. (in 2003) reported that LocataLite clocks are synchronized to a handful of nanoseconds in a small network. Gauthier et al. (in 2013) shows in a large network (up to 73km), a few nanoseconds time difference can be achieved. This time synchronisation technology, called TimeLoc, helps to eliminate the use of a reference receiver for precise positioning. Details of the time synchronization process is described in Barnes et al. (2007) and Crawford (2006). Figure 3 shows the LocataLite and the antennas used for LocataLites.

Figure 3. A LocataLite and a LocataLite antenna setup

## VRAY ANTENNA

Locata's new beam-forming method is known as Correlator Beam-Forming (CBF). This method creates beams by sequentially switching through each element of an antenna array and forming the beam with phase and gain corrections in the receiver's individual channel correlators, using only one RF front-end. CBF gives each receiver channel the capability to independently "point" beams. The VRay antenna is capable of pointing multiple beams simultaneously in different directions. The elements are sequentially switched and all the elements are sequenced completely during a signal integration interval. During each switch interval, the gain and phase of the incoming signal is adjusted within the correlator by modifying the phase and amplitude of the carrier DCO to form the desired beam. The process is illustrated in Figure 4 (LaMance and Small, 2011).

To mitigate multipath, the beams formed at the receiver must be pointed in the directions of the LocataLite transmitters. The position of each LocataLite is known, thus each beam's direction is dependent on the location of the rover and the orientation of the antenna. The estimated location of the rover with a few metres accuracy is adequate for most applications. Both rough position and orientation are estimated from angle-of-arrival measurements by analysing the signals obtained from different beam settings. The receiver initially sweeps the beams searching for beam settings that maximise the signal power from each LocataLite. Once the optimal beam settings are determined, the corresponding angle-of-arrival measurements are used to estimate both the approximate location of the rover, and its orientation.

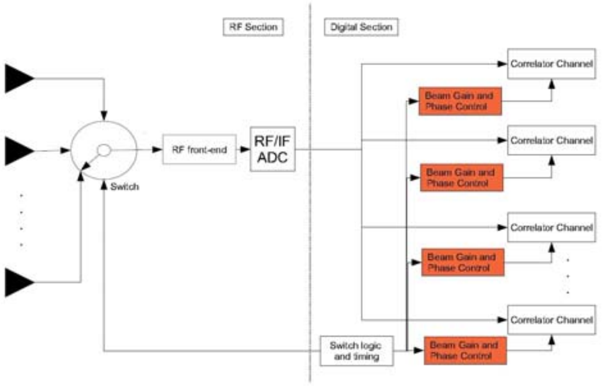


Figure 4. Locata beam-forming principle

The first VRay prototype was developed in 2007. It is a one dimensional 12 cm diameter board with 8 elements. The second prototype was a two dimensional 30 cm diameter device with 64 elements. The last prototype was developed in 2011 which was 3 dimensional with 80 elements. The productized commercial version was built in 2014 (see Figure 5).

The current VRay antenna is a basketball-sized spherical array consisting of 20 panels with 80 elements (refer to Figure 5). Each panel comprises four elements arranged with one central element and the three other elements forming a triangle. The element spacing between each panel is half the signal wavelength (LaMance and Small, 2011).

Figure 5. The proto types and current production of Locata beam-forming VRay antenna: first prototype, second prototype, third prototype and production version (from left to right, top to bottom)

VRay needs only one RF front-end for all elements, which is a simple and non-expensive antenna design. Every beam is controlled individually, hence as the platform on which the antenna is mounted moves, each beam adjusts dynamically. The elements are switched through at a rate of 80 elements every 100 microseconds, hence more than 2.5 million individual steered beams per second can be produced. The switches are implemented by a simple Programmable Logic Device (PLD), and the timing for the PLD switch control is provided by the digital section of the receiver.

With its spherical shape the VRay antenna has the ability to point in any direction (3D). The new generation Locata receiver is designed to deal with hundreds of simultaneous, unique beams every 100 microseconds, and hence can make measurements from many directions at once. However, the Locata receiver used in this specific experimental setup had experimental firmware that only enabled it to process thousands of beams per second. Therefore only the azimuth measurements could be decoded to obtain one-axial orientation solutions.

## INDOOR TEST

The latest indoor experiment was conducted on 24 June 2014 in a metal building at Locata Corporation’s Numeralla Test Facility (NTF), located in rural NSW, Australia (refer to Figure 6) . The warehouse was mostly empty with the exception of some furniture and tools placed near the walls. In total five LocataLites were installed in the warehouse. A Locata rover receiver was placed on a trolley with a VRay antenna and conventional omni-directional antenna mounted on it. Figure 7 shows the details of the receiver setup; all the relative offsets have been carefully measured. The benchmark system was an auto-tracking laser Total Station (TS), which could provide position and attitude ground truth information. The orientation of the antenna from the TS was determined by measuring the two prisms on the bar.

Figure 6. Indoor testing environment at NTF, showing TS

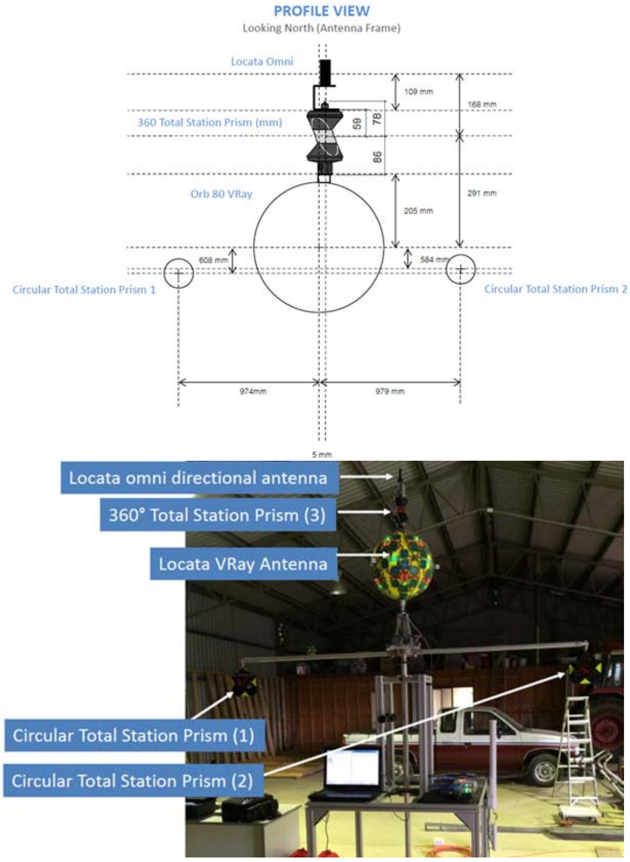


Figure 7. Setup of the receiver

Two types of tests, static test and kinematic test were carried out simultaneously. The rover receiver was moved randomly within the green circle showed in Figure 8. The start location was named point A. Before the rover receiver was moved to point B, a static test was carried out for about 1-2 minutes. At point B, a similar static test was carried out, then to point C, D … etc. In total, there were 10 static test points. At each static test point, the TS measured the position and attitude of the antenna.

The kinematic test consists of the movement of the rover receiver from start point to the end point. The TS also recorded the positions at a 5Hz frequency rate. However, the attitude of the antenna during the kinematic test could not be measured by the TS because it could not track both prisms (marked 1 & 2 on Figure 7) simultaneously. The raw data of LocataLites were recorded and then processed by the Locata Corporation and the University of New South Wales (UNSW) independently, using different algorithms.

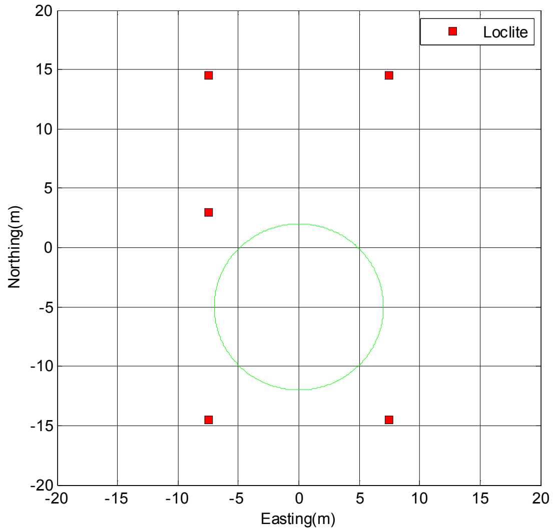


Figure 8. Locations of the LocataLites and the test area, the Locata rover receiver was moving randomly within the area indicated by the green circle

## TEST RESULTS AND ANANYSYS

The test results are reported in this section.

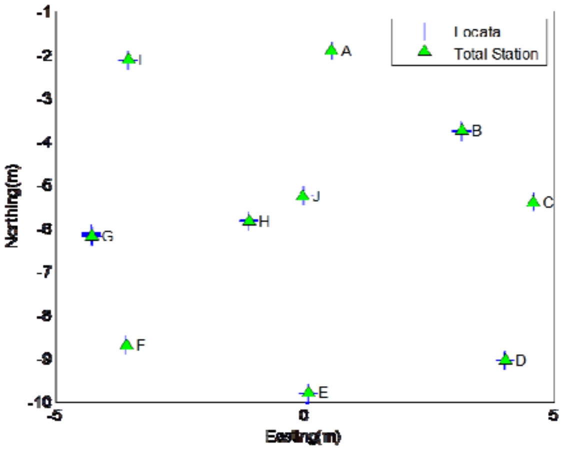


Figure 9. Static test results. The green triangles indicate the ground truth (TS results), the blue crosses show the results determined with Locata's algorithms.

The static test results of horizontal position are shown in Figure 9. It can be seen clearly that the position reported by Locata are almost identical with the ground truth. Figure 10 shows the orientation errors (Locata solution and UNSW solution). Generally speaking, the orientation error is far less than 1 degree at most test points and in the worst case the error is about 2 degree (UNSW solution). The standard deviations are less than 0.8 degree. UNSW solution reports similar results, some of the errors even smaller than that of the Locata solution and the standard deviation is generally smaller than the Locata solution. However, there are big errors at points D and J (refer to Table 2). The reasons behind the errors are not clear yet. Further investigation of the UNSW algorithm is being undertaken.

Figure 11 shows two scatter diagrams of the position differences (compared to the truth solutions from the TS) for the horizontal direction components. The red dot indicates the ground truth. The outer circle has a radius of 4cm and the inner circle a radius of 2cm. It can be seen that most points are located inside the 4cm radius circle for both Locata and UNSW solutions. Table 2 summarises the static tests results.

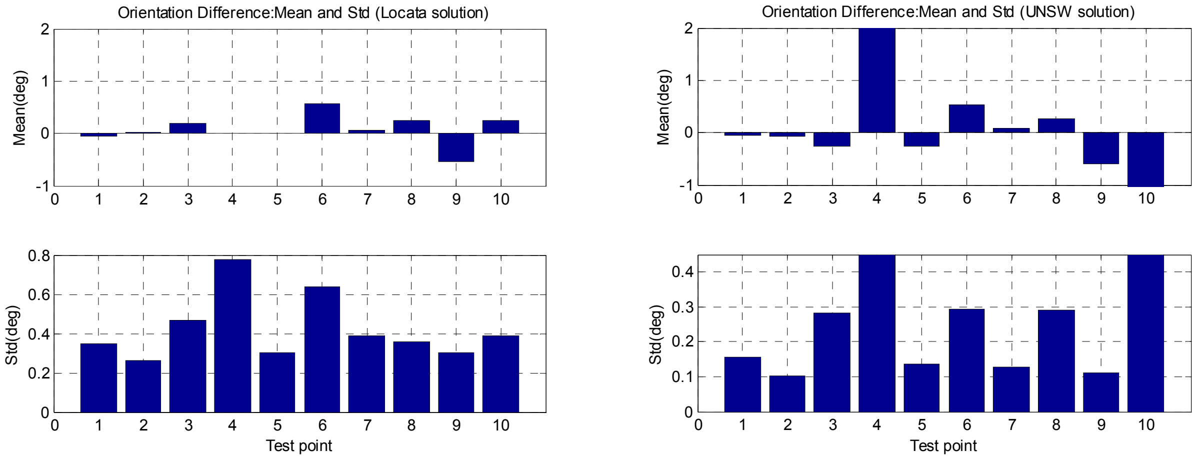


Figure 10. Orientation error

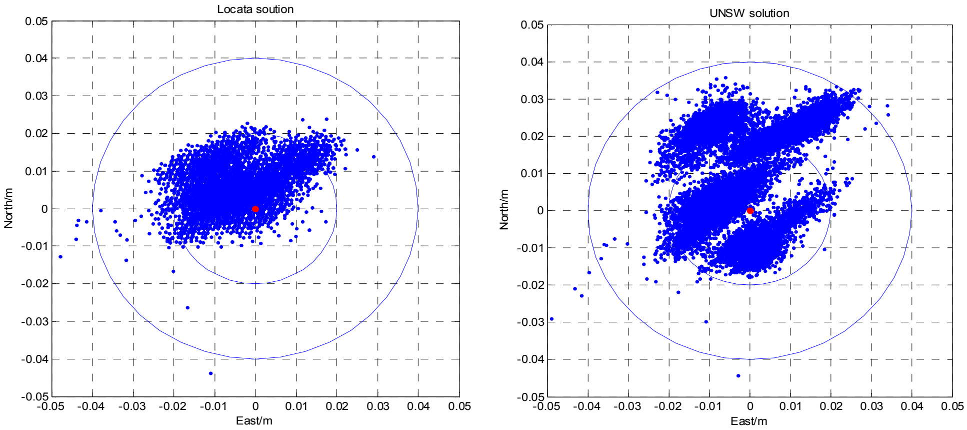
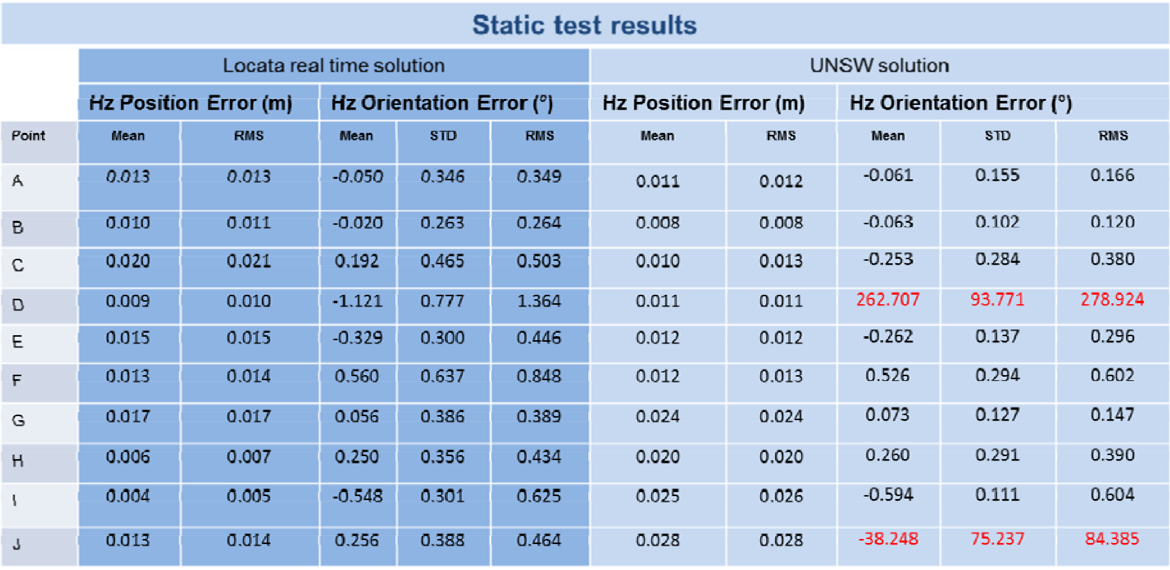


Figure 11. Performance at all 10 individual test points

Table 2. Details of the static test results



| Static test results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Locata real time solution | | | | | UNSW solution | | | | |
| | Hz Position Error (m) | | Hz Orientation Error (°) | | | Hz Position Error (m) | | Hz Orientation Error (°) | | |
| Point | Mean | RMS | Mean | STD | RMS | Mean | RMS | Mean | STD | RMS |
| A | 0.013 | 0.013 | -0.050 | 0.346 | 0.349 | 0.011 | 0.012 | -0.061 | 0.155 | 0.166 |
| B | 0.010 | 0.011 | -0.020 | 0.263 | 0.264 | 0.008 | 0.008 | -0.063 | 0.102 | 0.120 |
| C | 0.020 | 0.021 | 0.192 | 0.465 | 0.503 | 0.010 | 0.013 | -0.253 | 0.284 | 0.380 |
| D | 0.009 | 0.010 | -1.121 | 0.777 | 1.364 | 0.011 | 0.011 | 262.707 | 93.771 | 278.924 |
| E | 0.015 | 0.015 | -0.329 | 0.300 | 0.446 | 0.012 | 0.012 | -0.262 | 0.137 | 0.296 |
| F | 0.013 | 0.014 | 0.560 | 0.637 | 0.848 | 0.012 | 0.013 | 0.526 | 0.294 | 0.602 |
| G | 0.017 | 0.017 | 0.056 | 0.386 | 0.389 | 0.024 | 0.024 | 0.073 | 0.127 | 0.147 |
| H | 0.006 | 0.007 | 0.250 | 0.356 | 0.434 | 0.020 | 0.020 | 0.260 | 0.291 | 0.390 |
| I | 0.004 | 0.005 | -0.548 | 0.301 | 0.625 | 0.025 | 0.026 | -0.594 | 0.111 | 0.604 |
| J | 0.013 | 0.014 | 0.256 | 0.388 | 0.464 | 0.028 | 0.028 | -38.248 | 75.237 | 84.385 |

Kinematic test results are visualized in Figure 12. The two solutions are almost identical in easting and northing. The heights are slightly different (normally less than 0.1m). There are several spikes in UNSW solution which are caused by initialization at the beginning of some kinematic sessions. These spikes may be removed if some extra data are used to complete the initialization.

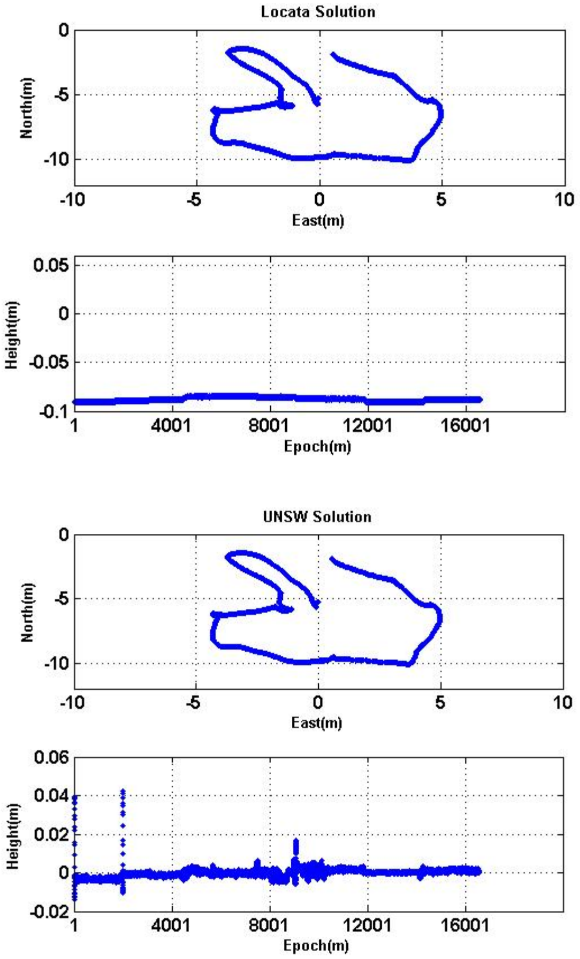


Figure 12. Kinematic test results

## CONCLUDING REMARKS

This paper undertook preliminary investigations into benchmarking the performance of the VRay antenna newly developed by the Locata Corporation, as an advancement to their terrestrial positioning solution. Promising enhanced multipath mitigation capabilities in GNSS difficult environments, this paper presented results obtained from static and kinematic experiments in an indoor environment. The results presented show the highly accurate positioning capabilities of the Locata positioning solution, with cm and sub-cm level positioning possible in indoor tests. In addition, the VRay provided robust estimates of orientation without using an inertial unit, and without displaying the drift which is common with IMU's. The Locata derived results correlated well with those of the independent solution generated from the UNSW research software. These results showcase the promising capabilities of the Locata positioning system and subsequent research will focus on experiments in unprepared environments as well as in the transitions zones between outdoor and indoor spaces.

## ACKNOWLEDGMENTS

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