Locata: A new high accuracy indoor positioning system

Chris Rizos, Gethin Roberts, Joel Barnes, and Nunzio Gambale

Abstract—**Accurate indoor positioning is required for a variety of commercial applications, including warehouse automation, asset tracking, emergency first-responders, and others. In fact, the general expectation of users today is for "GPS-like" positioning performance anywhere they go. The inherent limitations of GPS signal availability indoors and in satellite-occluded environments, however, has forced researchers to investigate alternative technologies which may be able to replicate GPS/GNSS performance indoors. A new terrestrial RF-based distance measurement technology, trademarked "Locata", has overcome the technical challenges required to create "a localised autonomous terrestrial replica of GNSS". Signals from the Locata network are seen by receiver devices as equivalent to (but totally independent from) the GNSS satellite constellation(s). This technical paper describes indoor positioning results with the latest generation of Locata positioning devices. The results demonstrate that Locata's technology enables cm-level positioning in severe multipath environments where conventional high-accuracy radiopositioning has previously been impossible.**

Index Terms—**Indoor positioning system, Locata**

I. INTRODUCTION

The Global Positioning System (GPS) is a reliable, versatile, generally available and comparatively accurate positioning technology, able to operate anywhere across the globe. GPS is, in fact, the most effective general-purpose navigation tool ever developed because of its ability to address a wide variety of applications: air, sea, land, and space navigation; precise timing; geodesy; surveying and mapping; machine guidance/control; military and emergency services operations; hiking and other leisure activities; personal location; and location-based services. These varied applications use different and appropriate receiver instrumentation, operational procedures, and data processing techniques. But all require signal availability from a minimum of four GPS satellites for three-dimensional fixes.

In the coming decade a number of other Global Navigation Satellite Systems (GNSS), and regional systems and augmentations, will be launched. The number of satellites and transmitted signals suitable for centimetre-level accuracy positioning will at least triple. However, the most severe limitation of GPS performance will still remain; the accuracy of positioning deteriorates very rapidly when the user receiver loses direct view of the satellites, which typically occurs indoors or in severely obstructed urban environments. In such environments, the majority of receivers do not function at all, and even the high-sensitivity receivers have difficulty in providing coordinates with sub-dekametre level accuracies.

Accurate indoor positioning is required for a variety of commercial applications, including warehouse automation, asset tracking, emergency first-responders, and others. In fact, the general expectation of users today is for "GPS-like" positioning performance anywhere they go. The inherent limitations of GPS signal availability indoors and in satellite-occluded environments, however, has forced researchers to investigate alternative technologies which may be able to replicate GPS/GNSS performance indoors. Inertial navigation systems (INS) are useful but no panacea because positioning accuracy degrades rapidly with time due to the drift errors of the gyroscopes and accelerometers. Laser or optical-based systems suffer from line-of-sight restrictions, whereas traditional radionavigation-based systems are affected by multipath and time synchronisation challenges.

The University of New South Wales (UNSW), Sydney (Australia), with a number of academic partners including the University of Nottingham (U.K.), has conducted pseudolite research for many years in an effort to overcome problems found in GPS-occluded or denied environments. Experiments have included pseudolites in non-synchronous and synchronised modes for a variety of applications, using both the GPS L1 frequency as well as the 2.4GHz ISM band. (A "pseudolite" is a GPS-like signal transmitted by a ground-based transmitter, or "pseudo-satellite"). The extensive research directed at addressing these GPS challenges has concluded that pseudolites have fundamental technical problems that, even in a controlled or lab environment, are extremely difficult to overcome. The challenges of optimally siting pseudolites, controlling transmission power levels, trying to ensure extremely high levels of synchronisation, configuring special antennas, and designing the "field of operations" such that GNSS and pseudolites can work together (or at least not interfere with each other) have been largely insurmountable in the real world.

A new terrestrial RF-based distance measurement technology – trademarked "Locata" – has overcome the enormous technical challenges required to create "a localised autonomous terrestrial replica of GNSS". Signals from the *Locata* network are seen by receiver devices as equivalent to (but totally independent from) the GNSS satellite constellation(s). Locata requires ground-based transceivers - called *LocataLites* – that cover an area with strong time-synchronised ranging signals to form a *LocataNet*. It should be noted that a *LocataLite* is not a pseudolite in the traditional sense – it is true that both transmit signals on the ground but

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beyond this similarity the underlying synchronisation technology (which is vital for positioning) is fundamentally different. When a receiver uses four or more *Locata* ranging signals it computes high accuracy carrier phase-based positions entirely independent of GNSS or INS. In relatively open outdoor environments such as open-cut mining, construction sites, ports, etc, *LocataNets* are providing real-time stand-alone kinematic positioning (*without* differential base stations) at centimetre-level accuracy (equivalent to RTK-GPS).

Locata has developed a number of advanced features over a period of almost 15 years, through several technology generations. They include the *LocataNet* time-synchronised positioning network, network propagation to many *LocataLites*, improved signal penetration, changes of transmitting frequency and (or) signal structure, and spatial and frequency diversity. However, the most difficult technical challenge for high accuracy positioning indoors is multipath. This problem has been the nemesis and the bane of accurate and reliable results in indoor environments. Locata has worked for over 8 years on the development of a completely new type of antenna which would allow industrial-grade, cm-level positioning indoors. The result of this extensive development is now approaching commercial release.

The rest of the paper is organised as follows. In Section II, we first introduce the Locata technology, and describe the various past tests and potential applications of the Locata technology. In order to test Locata's technology for indoor positioning a *LocataNet* was set up in an all-steel warehouse environment – as described in Section III. The first results of the trials comparing Locata's positioning solutions with a robotic total station are presented. Section IV concludes the paper.

II. LOCATA TECHNOLOGY

A. Background

Pseudolites are ground-based transmitters of GPS-like signals which, in principle, can significantly enhance the satellite geometry, and even replace the GPS/GNSS satellite constellation in some situations. Most pseudolites that have been developed to date transmit signals at the GPS frequency bands (L1: 1575.42MHz or/and L2: 1227.6MHz). Both pseudorange and carrier phase measurements can be made on the pseudolite signals. The use of pseudolites can be traced back to the early stages of GPS development in the late 1970s, at the Army Yuma Proving Ground in Arizona ([1]), where the pseudolites in fact were used to validate the GPS concept before launch of the first GPS satellites. In the case of GALILEO, the GATE testbed ([2]) serves the same purpose.

Pseudolite research at UNSW commenced in 2000. UNSW researchers have experimented with them in the unsynchronised mode, using the GPS L1 frequency, on their own or integrated with GPS and Inertial Navigation Systems, for a variety of applications. (The reader is referred to the website [3] for a full list of pseudolite-related papers by UNSW researchers). Is Locata another pseudolite-based positioning system? The authors contend that there are sufficient unique characteristics of Locata that it should be considered as belonging to a new and separate class of terrestrial RF-based positioning systems.

B. Locata Technology

In 2003 Locata Corporation took the first steps in overcoming the technical challenges required to create "a localised autonomous terrestrial replica of GNSS" ([4]). The resulting *Locata* positioning technology was designed to overcome the limitations of GNSS and other pseudolite-based positioning systems by developing a time-synchronised transceiver called a *LocataLite* (Fig. 1a – the current system is based on FPGA technology). A network of *LocataLites* forms a *LocataNet*, which transmits signals that have the potential to allow carrier phase point positioning with cm-level accuracy for a mobile unit (a *Locata* – Fig. 1b). It can be used where GNSS can not (Fig. 2). In effect, the *LocataNet* is a new constellation of signals, analoguous to GNSS but with some unique features; such as, having no base station data requirement, having no wireless data link from base to mobile receiver, and also having no requirement for measurement double-differencing. [4], [5], [6], [7].

Fig. 1a. *LocataLite* inside box with cabling to antennas.

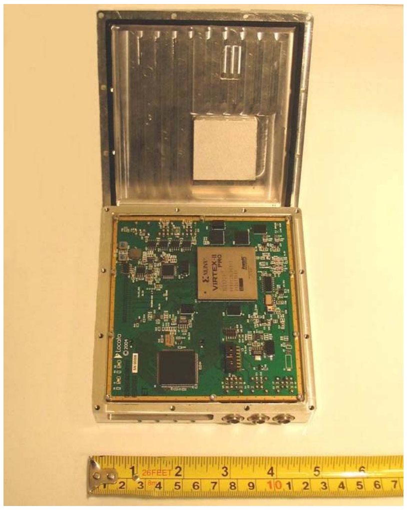

Fig. 1b. *Locata* receiver executed as an FPGA design.

In 2005 a fundamental change was made to the first generation Locata design that affirms its claim to *not* being a pseudolite ([7]). Locata's new design incorporates a

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proprietary signal transmission structure that operates in the Industry Scientific and Medical (ISM) band (2.4–2.4835GHz). Within the ISM band the *LocataLite* design allows for the transmission of two frequencies, each modulated with two spatially-diverse PRN codes. This new signal structure was beneficial in a number of respects in comparison to Locata's first generation system – or pseudolite-based systems in general – transmitting on the GPS frequency bands L1 and/or L2, including:

1. Interoperability with GPS and other GNSS.
2. No licensing requirement.
3. Capability for on-the-fly ambiguity resolution using dual-frequency measurements.
4. Better multipath mitigation on pseudorange measurements due to the higher 10MHz chipping rate, and theoretically less carrier phase multipath than GPS/GNSS due to the higher frequency used.
5. Transmit power of up to 1 watt giving line-of-sight range of the order of 10km or so.
6. Time synchronisation of all *LocataLites* at a level to support single Locata point positioning at cm-level accuracy.

More details can be found in a number of publications by UNSW researchers [3].

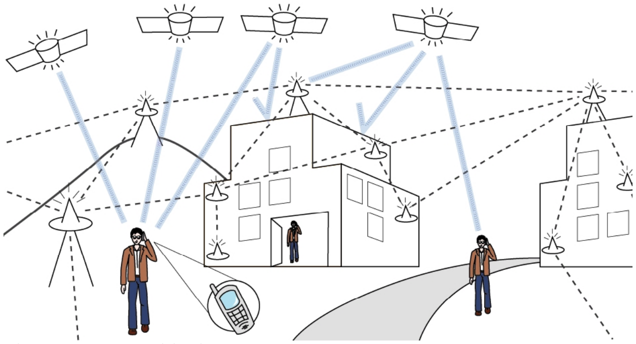

Fig. 2. Locata positioning concept.

C. Locata Applications

Since 2005 the Locata technology has been refined through tests carried out at Locata Corporation's Numeralla Test Facility (NTF) outside of Canberra (Australia), at the UNSW campus, the University of Nottingham campus, at the USAF's Holloman AFB, and at several real-world test sites including several bridges, in road tests, at two open-cut mines, and on a dam site.

From the beginning the driver for the Locata technology was to develop a centimetre accuracy positioning system that could complement, or replace, conventional RTK-GPS in classically difficult GPS signal environments such as open-cut mines, deep valleys, heavily forested areas, urban and even indoor locations. Tests confirmed that Locata on its own could deliver cm-level accuracy horizontal positioning. Although commercial applications suggested that RTK-GPS+Locata was an attractive solution for many outdoor kinematic positioning applications, Locata-only positioning was also a requirement in certain circumstances. The most recent indoor Locata-only tests are described in Section III.

Another important application of Locata (on its own or in combination with GPS) was deformation monitoring of structures such as buildings, bridges or dams. Early Locata testing was conducted in Sydney and in Nottingham, as reported in [8], [9], [10], [11], which demonstrated the benefit of *augmenting* GPS with Locata signals in order to improve availability, and consequently improve the horizontal accuracy. Recently first Locata tests were conducted on a dam structure – the Tumut Pond Dam, and reported in [12]. Comparison with 3D coordinates derived from a robotic total station confirmed sub-cm level repeatability.

The determination of the position and orientation (or "pointing direction") of a device (or platform to which it is attached), to high accuracy, in all outdoor environments, using reliable and cost-effective technologies is something of a "holy grail" quest for navigation researchers and engineers. Two classes of applications that place stringent demands on the positioning/orientation device are: (a) portable mapping and imaging systems that operate in a range of difficult urban and rural environments, often used for the detection of underground utility assets (such as pipelines, cables, conduits), unexploded ordnances and buried objects, and (b) the guidance/control of construction or mining equipment in environments where good sky view is not guaranteed. The solution to this positioning/orientation problem is increasingly seen as being based on an integration of several technologies. Researchers from UNSW and The Ohio State University (OSU), Columbus (Ohio, USA), assembled a working prototype of a *hybrid* system based on GPS, inertial navigation, and Locata receiver technology. The data processing methodology, based on a distributed Kalman filter, and the results obtained of tests conducted at the NTF, the UNSW campus (Fig. 3) and the OSU campus, have been described in a number of recent papers [13], [14].

Fig. 3. Integrated GPS+INS+Locata test car on UNSW campus.

In April 2004 the first indoor tests were conducted at BlueScope Steel, one of BHP Billiton's steel producing companies located in Wollongong, south of Sydney (Australia), to assess the performance of the prototype Locata technology for tracking a large crane in a harsh multipath

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environment (Fig. 4). A total station was used there to provide independent "ground truth". The results demonstrated cm-level accuracy ([5]). However no further public demonstration of indoor positioning was conducted until 2010, at which time a radically new Locata indoor antenna design (trademarked as a Small *TimeTenna*) was tested for the first time.

Fig. 4. 2004 Locata testing on a crane assembly in the BlueScope Steel factory.

UNSW and Nottingham University, as long time academic collaborators, were invited by Locata to collect data in order to independently report on the *TimeTenna* performance. This paper is the first to describe the tests that were carried out.

III. INDOOR LOCATA TESTING

A. Introduction

GNSS systems have difficulties operating indoors – the signals being severely attenuated when propagating through walls and become too weak for standard GNSS receivers to acquire and track these signals. Attenuation is not an issue with the Locata system as the signal power received is several orders of magnitude stronger than GNSS and is adjustable by the operator. The *LocataNet* antennas themselves can also be placed indoors to eliminate the propagation attenuation altogether. The strong Locata indoor signals, however, can create another set of problems due to multipath. Signals bouncing off walls and other objects may cause the receiver to track a reflected signal, or a composite direct/indirect signal, rather than the line-of-sight one. This will result in inaccurate range measurements and therefore incorrect position solutions.

To overcome the multipath problem and to enable accurate positioning and navigation indoors, Locata have developed a new multipath-mitigating antenna technology known as *TimeTenna*. Utilising an array of antenna elements and taking advantage of Locata's proprietary signal structure and time synchronisation features, the *TimeTenna* only tracks the direct line-of-sight ranging signals. This feature, together with the ability to transmit sufficiently strong signals indoors, makes possible accurate indoor positioning – opening up opportunities to many new location-based applications that were not possible previously. (Several patents have been submitted for the *TimeTenna* technology.)

In order to obtain an accurate position, the carrier phase measurements are used in the Locata solutions. As with GNSS receivers, this requires resolving the carrier ambiguities. Traditionally, the carrier ambiguities were determined by initialising the Locata receiver on a known point. This proved to be a cumbersome operation and an alternative method of resolving carrier ambiguities "on-the-fly" utilising an Extended Kalman Filter (EKF) was developed. This requires the Locata receiver to initially move in a random pattern for a number of seconds until the EKF converges.

In order to evaluate the performance of the new technology researchers from UNSW in collaboration with Locata Corporation conducted number of experiments. In particular, the accuracy of the generated position solutions in static and kinematic modes, using both the legacy navigation solution procedure (known-point initialisation) and the new EKF-based implementation, was investigated.

B. Experimental Setup

The indoor experiments were conducted at Locata's Numeralla Test Facility (NTF), located in rural NSW, Australia. The NTF spreads over an area of three hundred acres and is used by Locata Corporation to conduct many outdoor experiments. The NTF also consists of number of building structures, which include a large metal shed, approximately 30 metres long and 15 metres wide, where the indoor experiments took place. The shed was mostly empty with the exception of some furniture and hardware tools placed near the walls (Fig. 5). This ensures a severe multipath environment for any signals transmitted within it – an ideal scenario for these experiments.

A *LocataNet* consisting of five *LocataLites* was installed inside the shed. The coordinates of the network antennas were determined using a surveying Total Station. In addition, a point located in the middle of the network was also surveyed. This point was used for the known-point initialisation.

The Locata receiver was placed on a small trolley. The *TimeTenna* was mounted on a pole attached to the trolley and was connected to the receiver. In addition the trolley contained network equipment used to stream out the raw receiver outputs from the receiver and a powerboard to supply power to the different devices on the trolley. In order to compare reported receiver positions with the true position, a Robotic Total Station (RTS) was setup near the test area. A surveying prism was placed vertically above the phase centre of the *TimeTenna* which allows easy determination of the offset between the two. The RTS was programmed to track the location of the prism as it was moving and log the data internally for subsequent processing. The Locata receiver and RTS setup is shown in Fig. 5.

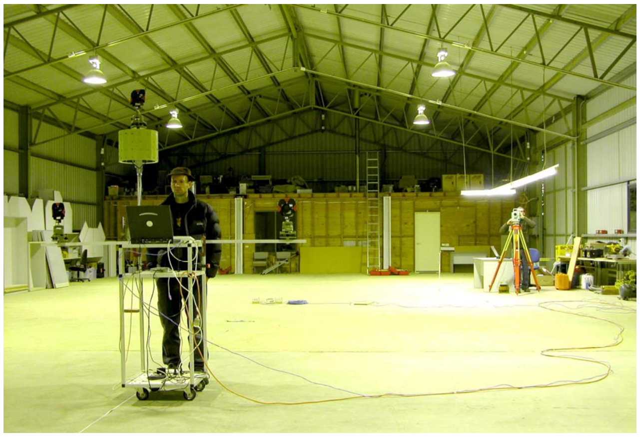

Fig. 5. Indoor test site, Locata receiver on trolley and RTS setup.

C. *Experiments*

All tests followed a similar methodology: the trolley was first positioned over the known-point so that the *TimeTenna* was vertically above the point with a known height offset. The carrier ambiguities were initialised once the receiver unit was powered on. This standard Locata version is referred to here as the "traditional navigation" implementation. For the EKF implementation this was not necessary, and instead the trolley by being moved between points (typically about 5m) ensured that initialisation was completed. The RTS was set to continuously track and log the position of the prism.

The data streams from the Locata receiver and from the RTS were logged for later analysis. The position solution rate for the traditional navigation implementation was 1Hz, the rate for the EKF-based one was 10Hz and the RTS logged positions at the rate of 5Hz. Both Locata solutions had a common time reference (the *LocataNet* time) while the RTS had its own time reference. The positions reported from all three were expressed in a local ENU coordinate system where the Origin (0, 0, 0) was the test area's known-point.

In the static test, nine points were measured and marked on the shed floor which are located on the edges and middle-points of the square spanning (East, North) = (-5, +5) to (+5, -5). The receiver was moved between adjacent points where it was left static for a period of at least one minute on each point before being moved to the next one. The points were traced in the following order (in metres): (0, 0), (-5, 0), (-5, -5), (0, -5), (+5, -5), (+5, 0), (0, 0), (-5, 0), (-5, +5), (0, +5), (+5, +5), (+5, 0), (0, 0). Fig. 6 shows the grid points and the order they were measured.

In the kinematic test, the receiver started on the initial known-point (0, 0) but was then moved continuously in a random pattern within the test area (Fig. 7).

D. *Results*

In order to allow comparison between the three sets of recorded position solutions they were interpolated to a common rate of 10Hz. The solution epochs from both Locata solution types were aligned using their common time reference. It was observed that the RTS clock suffered from a drift relative to the Locata network time.

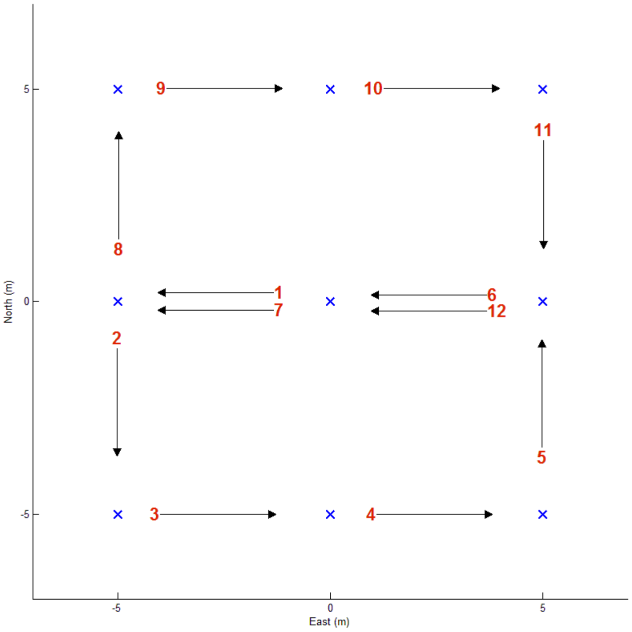

Fig. 6. Points used for static test and order of movement.

Static Test

As alignment of data was difficult, for each of the traced points in the static test all reported positions were grouped together and the mean and standard deviation were computed. The results are presented in Table 1.

Kinematic Test

Fig. 7 shows the trace of the three position solutions reported for the kinematic test. As an accurate alignment of the solutions was not possible, a visual inspection of the plot confirms that the solutions are very close together and essentially depict the same trajectory.

E. *Analysis*

Static Test Analysis

In order to analyse the accuracy of the results of the static test, we used the positions reported from the RTS as the "ground truth" and examined the mean distance of the navigation engine solutions from the true receiver position. It is important to mention that slight tilting of the RTS prism may have introduced small errors into the RTS solutions and it is quite probable that the Locata receiver results are actually even better than those reported here.

The mean 2D positions for each of the static points are listed in Table 1. It can be seen that for most points measured by the traditional navigation implementation the mean error in position (the difference between the mean coordinate computed by each technique and the correct coordinate at each point) is less than 2cm, and for more than half the cases it is in fact sub-cm. However, this approach requires initialising the receiver on a known-point at the start of the positioning, which may not always be feasible.

An examination of the mean positions from the EKF-based implementation indicates that the first two static points have a large position error. This behaviour is not unexpected as the EKF requires some geometry change before the algorithm converges to the true position. It is evident that once the EKF has converged (starting from the third point), the results were accurate to a few centimetres. This is a remarkable result given the extreme multipath conditions in the shed and taking into consideration that no prior knowledge of position of any point was assumed.

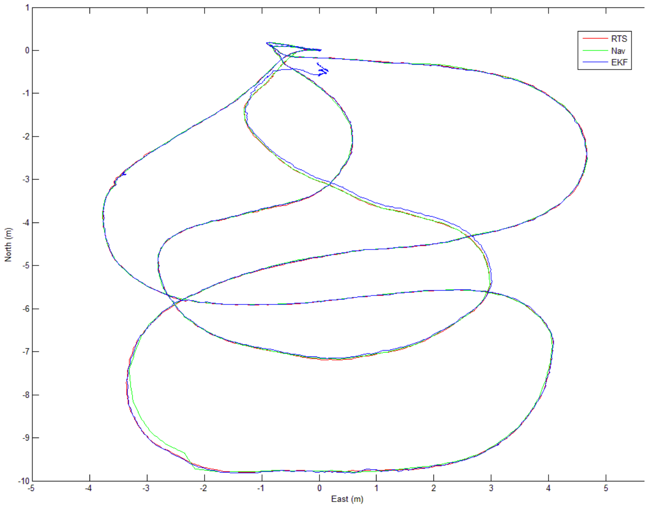

Fig. 7. Trace of kinematic test (scale: 11m x 11m).

Kinematic Test Analysis

The results from both Locata solutions are compared to the ones produced by the RTS (Fig. 7). It was found that there was an upper bound error of approximately 20cm in the navigation solutions, cooresponding to the start of the trajectory when the EKF was not yet converged, with the majority of the trajectory error being no more than 3cm.

IV. CONCLUDING REMARKS

This paper describes indoor positioning results with the latest generation of Locata positioning devices incorporating the new *TimeTenna* technology conducted recently in an all-steel warehouse environment. Using a Robotic Total Station as a truth system, the results demonstrate that Locata's *TimeTenna* enables cm-level positioning in severe multipath environments where conventional high accuracy radiopositioning has previously been impossible. Locata has not at this stage made any attempt to miniaturise or simplify the physical antenna. The *TimeTenna* used in this test is just the first of many different future variants of the core technology. Each will be optimised for different applications, environments and price points, but all will incorporate the fundamental multipath mitigation technology demonstrated by the version in this paper.

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Table 1: The Mean East and North Positions and Standard Deviation for Static Points (Traditional Navigation Implementation and EKF Implementation)

Point Index	Coords	RTS Mean E (m)	RTS Mean N (m)	RTS STD E (mm)	RTS STD N (mm)	Nav Mean E (m)	Nav Mean N (m)	Nav STD E (mm)	Nav STD N (mm)	EKF Mean E (m)	EKF Mean N (m)	EKF STD E (mm)	EKF STD N (mm)
1	(0, 0)	-0.002	0.014	0.5	0.6	-0.005	0.008	2.6	1.6	-0.544	-0.314	9.1	5.8
2	(-5, 0)	-5.015	-0.018	0.1	0.6	-5.034	-0.022	7.1	2.7	-5.301	0.012	19.6	3.0
3	(-5, -5)	-5.008	-4.995	2.0	0.8	-5.013	-5.006	3.7	3.6	-5.011	-4.989	6.5	4.2
4	(0, -5)	-0.015	-5.006	0.3	0.7	-0.020	-5.001	3.0	2.3	-0.020	-4.995	3.8	2.8
5	(+5, -5)	5.005	-5.000	0.3	0.7	5.005	-4.997	4.0	4.1	5.003	-5.006	4.7	4.8
6	(+5, 0)	4.992	0.007	0.5	0.8	4.989	0.002	5.4	3.6	4.970	-0.002	6.5	3.7
7	(0, 0)	0.001	0.011	0.5	0.6	-0.005	0.004	2.6	1.7	-0.021	0.002	3.2	2.2
8	(-5, 0)	-5.012	-0.019	0.2	0.5	-5.012	-0.019	3.1	3.4	-5.029	-0.017	4.1	4.2
9	(-5, +5)	-5.025	5.011	0.2	0.6	-5.067	5.008	4.1	2.0	-5.025	5.010	4.1	3.5
10	(0, +5)	-0.008	5.005	0.3	0.5	-0.013	4.988	4.0	2.2	-0.008	5.000	5.0	2.8
11	(+5, +5)	4.977	5.000	0.5	0.5	4.967	4.993	3.9	3.5	4.956	5.001	4.8	4.3
12	(+5, 0)	4.992	0.009	1.5	0.6	4.987	0.002	5.7	3.2	4.969	0.004	5.9	3.8
13	(0, 0)	0.002	0.003	0.5	0.6	-0.003	-0.004	2.5	1.9	-0.013	-0.002	3.0	2.2