Locata: A New Constellation for High Accuracy Outdoor and Indoor Positioning

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Key words: Locata, indoor positioning, integrated positioning, GNSS

SUMMARY

The Global Positioning System (GPS) is the best known, and only currently fully operational, Global Navigation Satellite System (GNSS) providing positioning capability anywhere in the globe, on a continuous 24/7 basis, with accuracies ranging from the dekametre-level to the sub-centimetre-level. Despite this versatility, GPS/GNSS cannot satisfy the high accuracy positioning requirements for many applications in engineering and mining surveying, machine guidance/control, structural monitoring, urban and indoor positioning. Russia has deployed its own GNSS called GLONASS which will be fully operational by the end of 2010. Fueling growth in precise positioning applications will be *next generation* GNSSs that are currently being developed and deployed, including the U.S.'s modernised GPS-IIF and GPS-III, the revitalised GLONASS, Europe's GALILEO system, and China's COMPASS system. Furthermore, a number of Space Based Augmentation Systems (SBASs) and Regional Navigation Satellite Systems (RNSSs) will add extra satellites and signals to the multi-constellation GNSS/RNSS 'mix'. The main advantage that the multi-GNSS era will bring is *more satellites*. It is estimated that by 2015, if the planned deployments go ahead, there will be of the order of 150 – with perhaps six times the number of broadcast signals on which measurements can be made, compared to today's GNSS availability. However, despite these planned extra satellite constellations the fundamental challenge of space-based positioning remains – to deliver high accuracy in areas where direct line-of-sight to four or more satellites is not available, as is the case in deep open-cut mines, heavily wooded, rugged terrain, urban and indoor environments. *Locata*'s positioning technology solution for either augmenting GNSS with extra terrestrial signals (as in the case where there is insufficient sky view for accurate and reliable GNSS positioning), or to replace GNSS (for indoor applications). *Locata* can therefore be considered a new type of localised "constellation", able to provide high accuracy positioning coverage where GNSS fails. This paper introduces the technical aspects of this technology, summarises the R&D highlights, describes several tests that demonstrate a variety of applications for *Locata*, and presents some recent results of high accuracy outdoor and indoor positioning.

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1. 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.

Although GPS is currently the only fully operational Global Navigation Satellite System (GNSS), the Russian Federation's GLONASS is being replenished (fully operational by the end of 2010), the European Union's GALILEO may be operational by 2016-2018, and China's COMPASS is likely to also join the "GNSS Club" by 2020 (after first deploying a regional navigation satellite system by 2012). Together with dozens more satellites from other countries and agencies in the form of augmentation satellite or regional systems, it is likely that the number of GNSS satellites useful for high accuracy positioning will increase to almost 150 – with perhaps six times the number of broadcast signals on which carrier phase and pseudorange measurements can be made. However, the most severe limitation of GPS/GNSS 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, steep terrain and in deep open-cut mines.

Locata's positioning technology solution is a possible option to either augment GNSS with extra terrestrial signals (as in the case where there is insufficient sky view for accurate and reliable GNSS positioning), or to replace GNSS (e.g. for indoor applications) (http://www.locatacorp.com). Locata relies on a network of synchronised ground-based transceivers (*LocataLites*) that transmit positioning signals that can be tracked by suitably equipped user receivers. These transceivers form a network (*LocataNet*) that can operate in combination with GNSS, or entirely independent of GNSS – to support positioning, navigation and timing (PNT). This permits considerable flexibility in system design due to there being complete control over both the signal transmitters and the user receivers. One special property of the *LocataNet* that should be emphasised is that it is time-synchronous, allowing point positioning with cm-level accuracy using carrier phase measurements. This paper introduces the technical aspects of this technology, summarises the R&D highlights, describes several recent tests that demonstrate a variety of high accuracy outdoor and indoor positioning applications for *Locata*.

2. FROM PSEUDOLITES TO LOCATALITES

2.1 Background

Pseudolites are ground-based transmitters of GPS-like signals (i.e. "pseudo-satellite") which, in principle, can significantly enhance the satellite geometry, and even replace the GPS 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 (Harrington & Dolloff, 1976), 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 (http://www.gate-testbed.com/) serves the same purpose.

With the development of the pseudolite techniques and GPS user equipment during the last two decades, the claim has been made that pseudolites can be used to enhance the availability, reliability, integrity and accuracy in many applications, such as aircraft approach and landing (Lee et al, 2002; Soon et al, 2003), deformation monitoring applications (Barnes et al, 2005a), Mars exploration (Lemaster & Rock, 1999), and others (Barnes et al, 2002b; Tsujii et al, 2002; Wang et al, 2007). However, extensive research and testing 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, overcoming "near-far" problems, trying to ensure extremely high levels of time 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. Yet over the years a number prototype systems have been developed and many papers have been written dealing with this technology. As far as the authors are aware the only working pseudolite-based commercial product is the *Terralite XPS* multi-frequency integrated GPS+pseudolite system offered to the open-cut mining industry (http://www.novariant.com), now owned by the Trimble Company.

Pseudolite research at the University of New South Wales (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 http://www.gmat.unsw.edu.au/snap/about/publications_year.htm 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.

2.2 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" (Barnes et al, 2003). The resulting *Locata* positioning technology was designed to overcome the limitations of GNSS and other pseudolite-based positioning systems by using 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). 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, requiring no wireless data link from base to mobile receiver, and no requirement for measurement double-differencing (Barnes et al, 2003, 2004, 2005b).

Figure. 1a: *LocataLite* inside box with cabling to antennas.

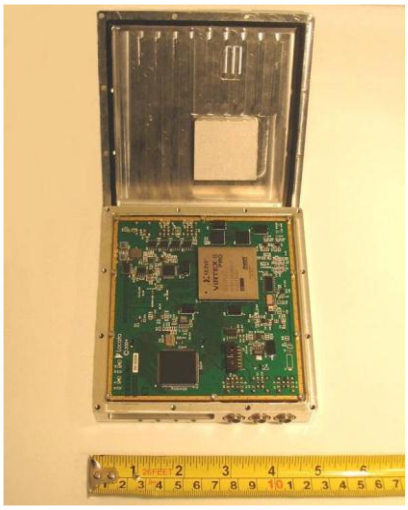


Figure 1b: *Locata* receiver in FPGA design.

The first generation *Locata* system transmitted using the same L1 C/A code signal structure as GPS. However, using the GPS frequency for signal transmissions has significant limitations for several reasons. The rules for transmitting on L1 vary throughout the world, but there is no doubt that a licence for wide deployment of a ground-based system on L1 would be extremely difficult (if not impossible) to obtain. If a licence was granted, ensuring there was no GPS signal degradation or interoperability issues would be of paramount importance. As a result this would limit the *LocataLite's* capability in terms of transmitter power – and therefore operating range – and penetration into buildings. It would also place a practical limit on the number of *LocataLites* in a *LocataNet* to ensure that no interference or degradation of the GPS signal quality occurred.

In 2005 a fundamental change was made to the first generation *Locata* design that affirms its claim to *not* being a pseudolite. Core aspects of the new system design are summarised in Table 1. *Locata's* new design incorporates a 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 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 point positioning with cm-level accuracy.

Table 1: Specification summary of *Locata's* first and current generation systems (Barnes et al, 2005b).

		First Generation System	Current Generation System
Signal structure	Frequencies	Single-frequency at GPS L1	Dual-frequency 2.4GHz (80MHz bandwidth)
	PRN code	C/A (1.023MHz chipping rate)	Proprietary (10MHz chipping rate)
	Licence requirements	Licensing issues & problem for wide area deployment	None required, FCC compliant
LocataLite (transceiver)	Hardware	FPGA & DDS technology	FPGA & DDS technology with a modular design
	Output power	Several microwatts	Maximum of 1 watt
	Range	~600 metres	~10km line-of-sight
	Antenna	RHCP patch & ¼ wave	Antenna design dependent on application
	Size	260x200x45mm	240x135x30 mm
	Weight	2.1 kg	1 kg
Locata receiver	Hardware	Zarlink/Mitel based GPS receiver chipset	FPGA technology, modular design
	Measurement rate	1Hz	25Hz
	RT positioning	1Hz on-board	25Hz through LINE software, 10Hz onboard
	AR	Known point initialisation	On-the-fly
	Antenna	Various types tested including RHCP patch and ¼ wave	Antenna design will depend on application
	Size	200x100x40	130x135x30 mm
	Weight	300 g	500 g

3. 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 (Australia), at the University of Nottingham campus (U.K.), at the Ohio State University campus (USA), 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-level accuracy positioning system that could complement, or replace, conventional RTK-GPS in classically difficult GNSS environments such as open-cut mines, deep valleys, heavily forested areas, urban and even indoor locations. 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 order to address indoor applications. Some of these test results are described below.

3.1 Kinematic Positioning

Tests conducted at the NTF were reported in Barnes et al (2005b, 2006). Figure 2 shows a *Locata* receiver together with two GPS receivers/antennas (to provide "ground truth") fitted to a truck. A sample of trajectory results from NTF kinematic on-road positioning tests are shown in Figure 3.

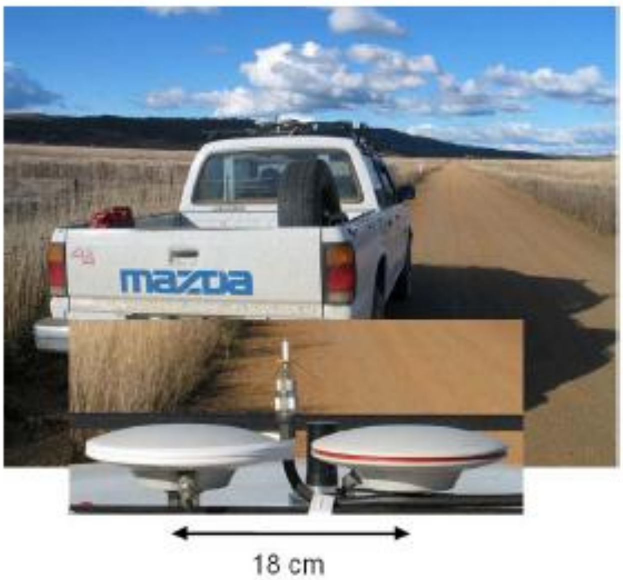


Figure 2: Kinematic test, *Locata* antenna between two antennas of the Leica RTK-GPS ground truth system.

The *Locata* technology's potential was confirmed in a recent (September 2010) announcement was made that Locata Corporation had been awarded a contract by the USAF 746th Test Squadron to deliver a system able to provide an independent high accuracy positioning (sub-decimetre-level) capability over almost 6500 square km of the White Sands Missile Range whenever GPS is undergoing jamming tests.

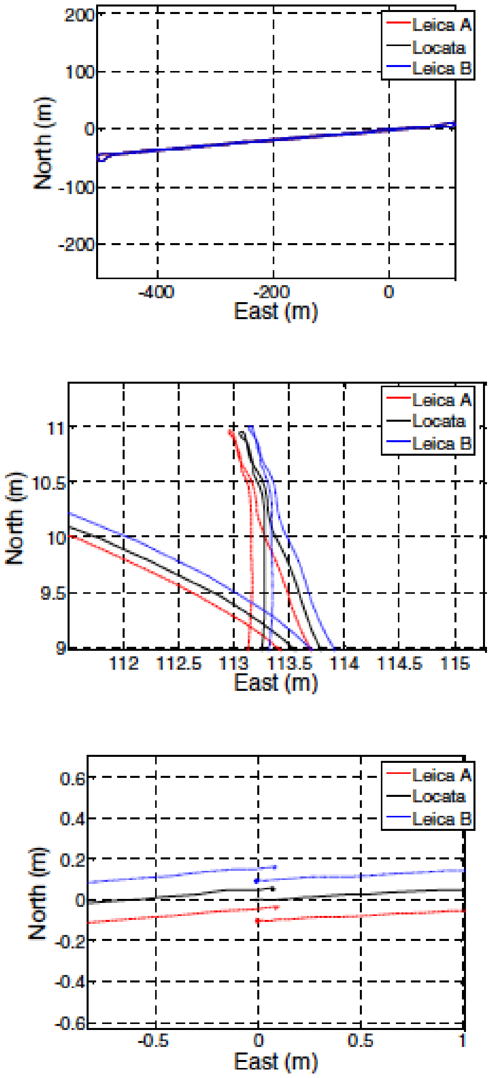


Figure 3: Some trajectory test results - *Locata* results versus Leica RTK-GPS ground truth system.

3.2 Deformation Monitoring

Another important application of *Locata* (on its own or in combination with GPS) is deformation monitoring of structures such as buildings, bridges or dams. Early *Locata* testing was conducted in Sydney (Figure 4a) and in Nottingham (Figure 4b), as reported in Barnes et al (2002a, 2005a) and Meng et al (2004), which demonstrated the benefit of *augmenting* GPS with *Locata* signals in order to improve availability, and consequently improve the horizontal accuracy. Recently first *Locata*-only tests were conducted on a dam structure – the Tumut Pond Dam (Figure 5a,b), and reported in Choudhury et al (2010). Comparison with 3D coordinates derived from a Robotic Total Station confirmed sub-cm level repeatability, as well as sub-centimetre accuracy (under the assumption there was no dam wall movement – Figure 6).

Figure 4a: Suspension bridge tests, Sydney.

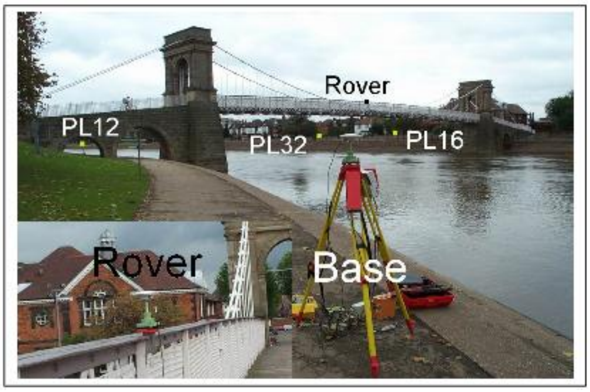


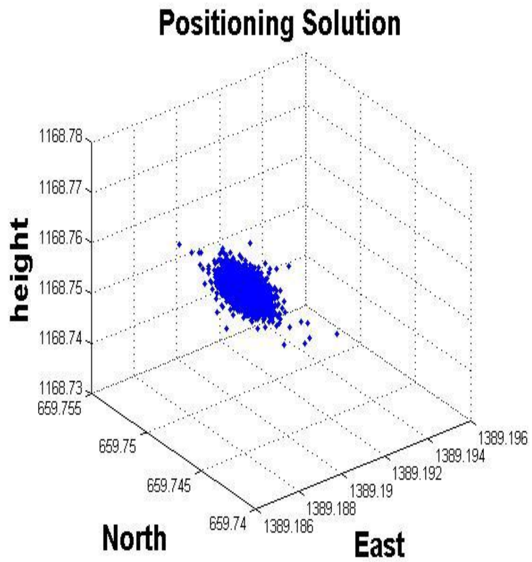
Figure 4b: Suspension bridge tests, Nottingham.


Figure 5a: Tumut Pond Dam (Total View).

Figure 5b: LocataLite and receiver installation.

3.3 Locata/GPS/INS Integration

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 (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 (Figure 7) and the OSU campus, have been described in a number of recent papers (Rizos et al, 2008, 2010a).



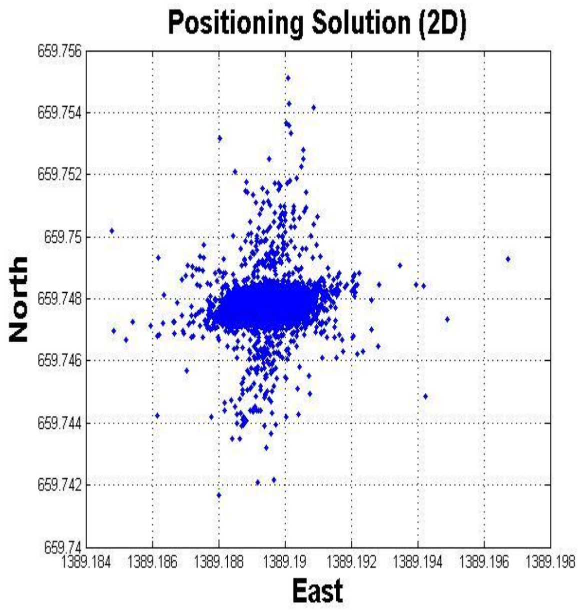


Figure 6a: Position solution (3D).

Figure 6b: Position solution (2D).

Figure 7: Integrated GPS+INS+Locata test car on UNSW campus.

3.4 Indoor Positioning

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 environment (Figure 8). A Total Station was used to provide independent "ground truth". The results demonstrated cm-level accuracy (Barnes et al, 2004). 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 at the NTF.

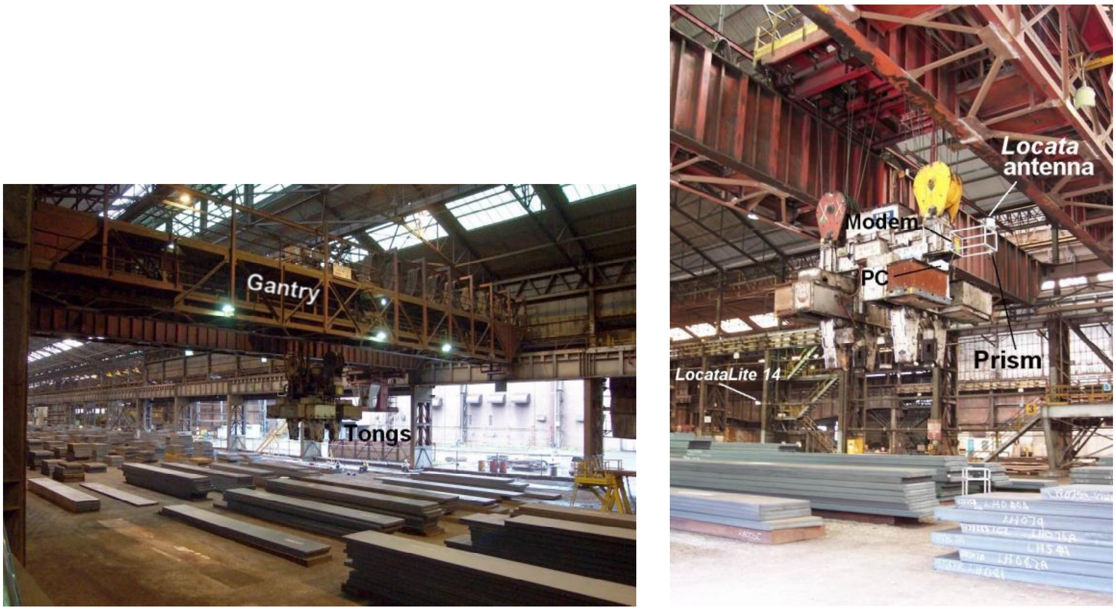


Figure 8: 2004 Locata testing on a crane assembly in the BlueScope Steel factory.

The 2010 indoor experiments were conducted inside a large metal shed, approximately 30 metres long and 15 metres wide (Figure 9). Such an environment guarantees severe multipath disturbance. A *LocataNet* consisting of five *LocataLites* was installed inside the shed. 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 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*. The RTS was programmed to track the location of the prism as it was moving and log the data internally for subsequent processing. The experimental setup is shown in Figure 9.

Static (*Locata* receiver placed over nine known points marked on the ground) and kinematic tests were conducted. Apart from some initial convergence challenges, all static coordinates were determined to cm-level accuracy. The kinematic tests indicated that the trajectory was in almost all cases less than 3cm from that derived using the RTS (Rizos et al, 2010b). (Note that the pole was not perfectly vertical, and that there was movement of the prism relative to the *TimeTenna*.) Nevertheless, impressive first results were obtained from this new multipath-mitigating antenna technology. *TimeTenna* consists of an array of antenna elements that take advantage of *Locata's* proprietary signal structure and time synchronisation features to track only the direct line-of-sight signals (Locata, 2011) – opening up opportunities to many new location-based applications that were not possible previously. More tests will be conducted in the coming months.

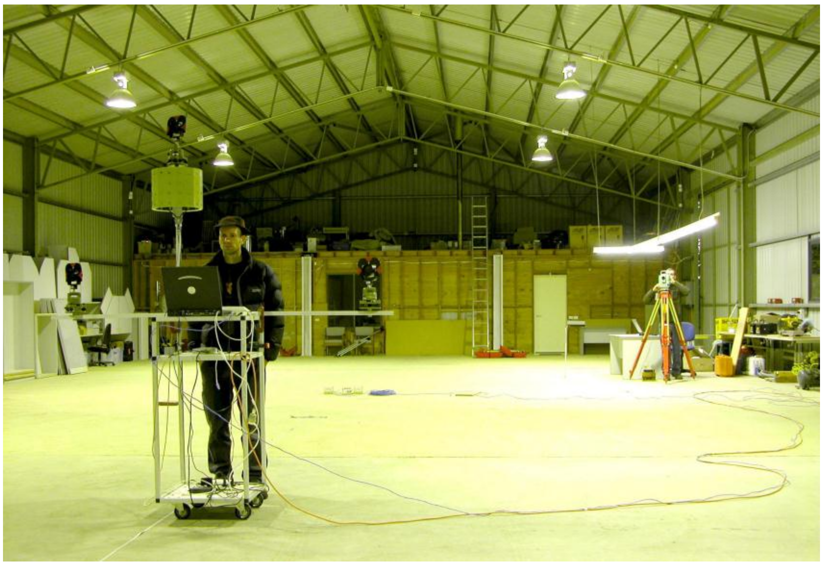


Figure 9: Indoor test site, Locata receiver on trolley and RTS setup.

4. CONCLUDING REMARKS

Locata can be considered a new type of localised "constellation", able to provide high accuracy positioning coverage where GNSS fails. This paper introduced some of the technical aspects of this technology, summarised the R&D highlights over the last decade or so, and described a variety of applications for *Locata* technology, including some recent results of high accuracy outdoor and indoor positioning. Over the coming years several commercial positioning systems will be developed that incorporate the ability to track *Locata* signals in addition to GNSS. *Locata* is a technological solution to high accuracy indoor and outdoor positioning where GNSS cannot on its own provide the requisite positioning capability. It is a terrestrial augmentation to GNSS where sky visibility is restricted due to high walls in open-cut mines, as indicated by a recent news announcement by Leica Geosystems (12 January 2011). Leica's new Jigsaw360 mine management system will have combined GNSS-*Locata* positioning capability, and is the first commercial product that integrates GNSS and *Locata* capabilities into a single navigation device.

There are no "GNSS equivalent" systems for indoor positioning, hence one cannot speak of *Locata* as an "augmentation" in such senarios. *Locata* is the only high accuracy RF-based system that does not have serious range restrictions, and can be used over distances of 100s of metres. However, it must be emphasised that *Locata* has its limitations. For example, for *Locata*-only positioning, the vertical position component is very weakly determined unless there is considerable variation in the height of the *LocataLite* transceivers to ensure low VDOP. Furthermore a *LocataNet* must be established to cover the area of interest. This area may be several kilometres in extent using the systems tested to date. However, a modified version of *Locata* is being currently installed at the USAF's Holloman AFB, and it will support Locata-only positioning over ranges of many tens of kilometres using high powered *LocataLite* transceivers.

In this paper the authors are unable to provide many technical details due to commercial-in-confidence considerations. However the Interface Control Document will be released in late September 2011.

REFERENCES

Barnes, J., J. Wang, C. Rizos & T. Tsujii (2002a). The performance of a pseudolite-based positioning system for deformation monitoring*, 2nd Symp. On Geodesy For Geotechnical & Structural Applications*, Berlin, Germany, 21-24 May, 326-337.

Barnes, J., J. Wang, C. Rizos, T. Nunan & C. Reid (2002b). The development of a GPS/pseudolite positioning system for vehicle tracking at BHP Billiton Steelworks, *15th Int. Tech. Meeting Of The Satellite Division Of The U.S. Inst. Of Navigation*, Portland, Oregan, 24-27 September, 1779-1789.

Barnes, J., C. Rizos, J. Wang, D. Small, G. Voigt & N. Gambale (2003). Locatanet: A new positioning technology for high precision indoor and outdoor positioning, *16th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation*, Portland, Oregan, 9-12 September, 1119-1128.

Barnes, J., C. Rizos, M. Kanli, D. Small, G. Voigt, N. Gambale, J. Lamance, T. Nunan & C. Reid (2004). Indoor industrial machine guidance using Locata: A pilot study at BlueScope Steel, *60th Annual Meeting of the U.S. Inst. Of Navigation*, Dayton, Ohio, 7-9 June, 533-540.

Barnes, J., C. Rizos, H.K. Lee, G.W. Roberts, X. Meng, E. Cosser & A.H. Dodson (2005a). The integration of GPS and pseudolites for bridge monitoring, In "A Window on the Future of Geodesy", F. Sanso (ed.), IAG Symp. Vol.128, Spinger-Verlag, 83-88.

Barnes, J., C. Rizos, M. Kanli, A. Pahwa, D. Small, G. Voigt, N. Gambale & J. Lamance (2005b). High accuracy positioning using Locata's next generation technology, *18th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation*, Long Beach, California, 13-16 September, 2049-2056.

Barnes, J., C. Rizos, M. Kanli & A. Pahwa (2006). A solution to tough GNSS land applications using terrestrial-based transceivers (LocataLites), *19th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation*, Fort Worth, Texas, 26-29 September, 1487-1493.

Choudhury, M., B.R. Harvey & C. Rizos (2010). Mathematical models and a case study of the Locata Deformation Monitoring System (LDMS), *XXIV FIG Int. Congress "Facing the Challenges - Building the Capacity*", Sydney, Australia, 11-16 April, procs on website http://www.fig.net/pub/fig2010/index.htm.

Harrington, R.L. & J.T. Dolloff (1976). The inverted range: GPS user test facility, *IEEE PLANS'76*, San Diego, California, 1-3 November, 204-211.

Lee, H.K., J. Wang, C. Rizos, J. Barnes, T. Tsujii & B.K.H. Soon (2002). Analysis of pseudolite augmentation for GPS airborne applications, *15th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation*, Portland, Oregan, 24-27 September, 2610-2618.

Lemaster, E. & S. Rock (1999). Mars exploration using self-calibrating pseudolite arrays, *12th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation GPS ION-99*, Nashville, Tennessee, 14-17 September, 1549-1558.

Locata (2011). Method and apparatus for forming a beam, International Patent WO 2011/000049 A1, publication date 6 January 2011.

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

Rizos, C., D. Grejner-Brzezinska, C.K. Toth, A.G. Dempster, Y. Li, A. Politi & J. Barnes (2008). A hybrid system for navigation in GPS-challenged environments: Case study, *21st Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation*, Savannah, Georgia, USA, 16-19 September, 1418-1428.

Rizos, C., D. Grejner-Brzezinska, C.K. Toth, A.G. Dempster, Y. Li, A. Politi, J. Barnes, H. Sun & L. Li (2010a). Hybrid positioning: A prototype system for navigation in GPS-challenged environments, *GPS World*, 21(3), 42-47.

Rizos, C., G.W. Roberts, J. Barnes & N. Gambale (2010b). Locata: A new high accuracy indoor positioning system, Proc. *Int. Conf. on Indoor Positioning & Indoor Navigation*, Zurich, Switzerland, 15-17 September.

Soon, B.H.K., E.K. Poh, J. Barnes, J. Zhang, H.K. Lee, H.K. Lee & C. Rizos (2003). Flight test results of precision approach and landing augmented by airport pseudolites, *16th Int. Tech. Meeting of the Satellite Division of the U.S. Institute of Navigation*, Portland, Oregan, 9-12 September, 2318-2325.

Tsujii, T., M. Harigae, J. Barnes, J. Wang & C. Rizos (2002). Experiments of inverted pseudolite positioning for airship-based GPS augmentation system, *15th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation*, Portland, Oregan, 24-27 September, 1689-1695.

Wang, J.J., J. Wang, D. Sinclair & L. Watts (2007). Flight test of a GPS/INS/Pseudolite integrated system for airborne mapping, *Spatial Sciences Conference*, Hobart, Australia, 14-18 May, 108-118.

BIOGRAPHICAL NOTES

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 400 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.

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