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Locata: A Positioning System for Indoor and Outdoor Applications Where GNSS Does Not Work

Chris Rizos
School of Surveying & Geospatial Engineering, University of New South Wales
c.rizos@unsw.edu.au

ABSTRACT

The Global Positioning System (GPS) is a reliable, versatile, generally available and comparatively accurate positioning technology, able to operate anywhere across the globe. In the coming decade, a number of other Global Navigation Satellite Systems (GNSS) and regional systems will be launched. Nevertheless, 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-decametre level accuracies. A new terrestrial radio frequency (RF)-based distance measurement technology, known as 'Locata', has now overcome the technical challenges required to create "a localised autonomous terrestrial replica of GPS". This paper describes some of the technical aspects of this Australian technology and discusses the possible role Locata can play as part of the National Positioning Infrastructure. Locata can complement, and even replace, GNSS for difficult signal environments. For example, a recent news release (September 2012) by Leica Geosystems has announced a combined GNSS+Locata positioning capability – the first commercial product that integrates GNSS and Locata capabilities into a single high-accuracy and high-availability positioning device for open-cut mine machine automation applications. Accurate indoor positioning is required for a variety of commercial applications, including warehouse automation, asset tracking, emergency first-responders, robotics, and others. GNSS is not suitable for high-accuracy indoor positioning. Locata has developed a new type of antenna which allows industrial-grade, centimetre-level positioning indoors by mitigating multipath by forming and pointing tight beams at the Locata transmitters, significantly reducing the effects of multipath corruption of the direct positioning signal. This paper briefly describes Locata tests conducted in a number of conditions, including indoors, at an open-cut mine, airborne flight testing, and on Sydney Harbour.

KEYWORDS: *Locata, GNSS, indoor positioning, location.*

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 can 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. However, all require signal availability from a minimum of four GPS satellites for 3-dimensional fixes.

GPS and the Russian Federations' GLONASS are currently the only fully operational Global Navigation Satellite Systems (GNSSs). However, the European Union's Galileo may be operational by 2016-18, and China's BeiDou will join the 'GNSS Club' by 2020 (by 2012 it had deployed a Regional Navigation Satellite System, or RNSS). 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 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) (Locata, 2013). 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 describes some technical aspects of this technology, and summaries several recent tests that demonstrate a variety of high accuracy 'GNSS-challenged' applications of Locata technology.

2 FROM PSEUDOLITES TO LOCATALITES

2.1 Background

Pseudolites are ground-based transmitters of GPS-like signals (i.e. 'pseudo-satellites') 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: 1575.42 MHz and/or L2: 1227.60 MHz). 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, where the pseudolites in fact were used to validate the GPS concept before launch of the first GPS satellites.

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, deformation monitoring applications, Mars exploration, and others. 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.

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 SAGE (2013) for a full list of pseudolite-related papers by UNSW researchers. However, Locata is not a pseudolite-based positioning system.

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". 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 (Figiure 1a). 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 – Figure 1b). In effect, the LocataNet is a new constellation of signals, analogous 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.

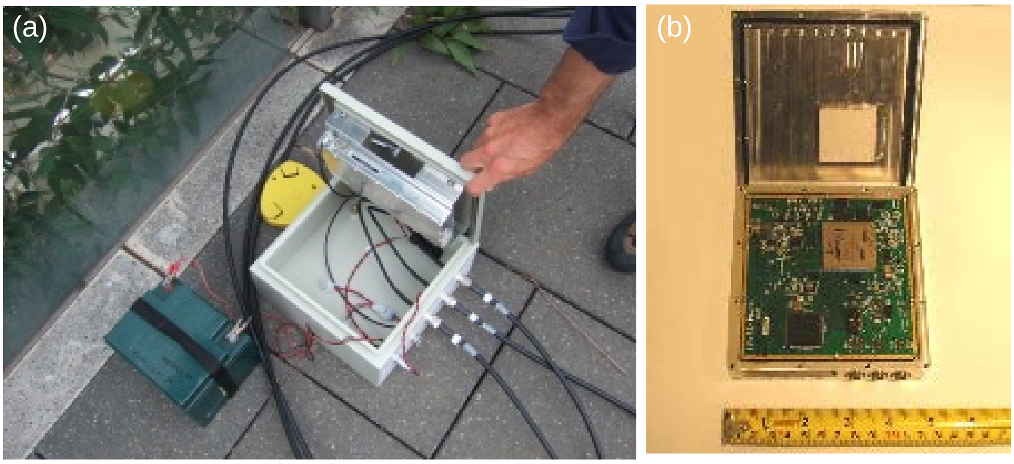


Figure 1: (a) LocataLite inside box with cabling to antennas, and (b) Locata receiver box.

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. Locata's new design incorporates a proprietary signal transmission structure that operates in the Industry Scientific and Medical (ISM) band (2.4-2.4835 GHz). Within the ISM band the LocataLite design allows for the transmission of two frequencies, each modulated with two spatially-diverse Pseudo Random Noise (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 10 MHz 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 10 km or so.
6. Time synchronisation of all LocataLites at a level to support single point positioning with cm-level accuracy.

3 LOCATA APPLICATIONS

Since 2005 the Locata technology has been refined through tests carried out at Locata Corporation's Numeralla Test Facility (NTF) outside Canberra (Australia), at the UNSW campus (Australia), at the University of Nottingham campus (U.K.), at the Ohio State University campus (USA), at the U.S. Air Force (USAF)'s Holloman Air Force Base (AFB), and at several real-world test sites including several bridges, in road tests, at two open-cut mines, a dam site, and on Sydney Harbour. From the beginning, the driver for the Locata technology was to develop a centimetre-level accuracy positioning system that could complement, or replace, conventional Real Time Kinematic (RTK)-GPS in classically difficult GNSS environments such as open-cut mines, deep valleys, heavily forested areas, urban and even indoor locations. Some of these test results are described below.

3.1 Kinematic Positioning

Figure 2 shows a Locata receiver together with two GPS receivers/antennas (to provide 'ground truth') fitted to a truck. Extensive tests over many years have confirmed few centimetre-level positioning accuracy for truck trajectories. During first flight trials conducted in May 2011, a UNSW test aircraft locked onto signals from a Locata network at distances from 3-49 km at around 7,000 feet, producing metre-level accuracy pseudo-range and decimetre-level accuracy carrier-phase solutions.

The Locata technology's potential was confirmed in a September 2010 announcement that Locata Corporation had been awarded a contract by the USAF 746th Test Squadron (746TS) to deliver a system able to provide an independent high-accuracy positioning (sub-decimetre-level) capability over almost 6,500 square kilometres of the White Sands Missile Range whenever GPS is undergoing jamming tests (see Figure 3 for one of the LocataLite installations). Locata was used on several types of aircraft. Craig and Locata Corp. (2012) reported on the extensive tests results. The USAF awarded Locata Corporation the contract for the delivery of technology for the High Accuracy Reference System through to the year 2025. The 746TS described Locata as “the new ‘gold standard truth system’ for the increasingly demanding test and evaluation of future navigation and navigation warfare systems for the U.S. Department of Defense”.

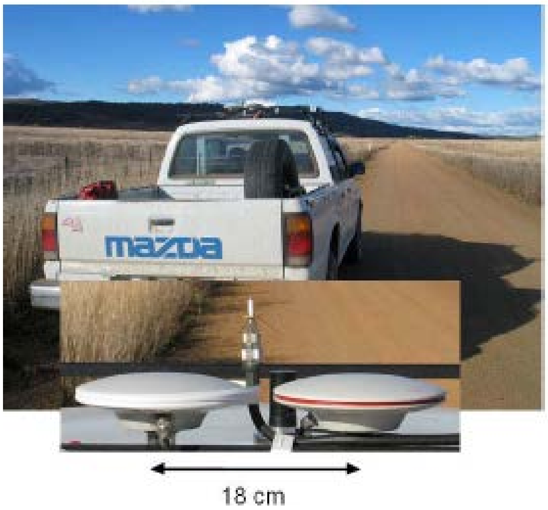


Figure 2: NTF kinematic test set-up, Locata antenna between two antennas of the Leica RTK-GPS ground truth system.

Figure 3: One LocataLite installed on a mountaintop at White Sands Missile Range.

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 and in Nottingham (U.K.) and demonstrated the benefit of augmenting GPS with Locata signals in order to improve availability, and consequently improve the horizontal accuracy. Recently Locata-only tests were conducted on a dam structure, the Tumut Pond Dam (Figure 4). Comparison with 3D coordinates derived from a robotic total station confirmed sub-cm level repeatability, as well as sub-cm accuracy (under the assumption there was no dam wall movement).

Figure 4: (a) Tumut Pond Dam (total view), and (b) LocataLite and receiver installation.

3.3 Locata/GPS/INS Integration

The determination of the position and orientation 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 (e.g. pipelines, cables and 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 (Figure 5), and have reported the results in a number of papers (see SAGE, 2013).

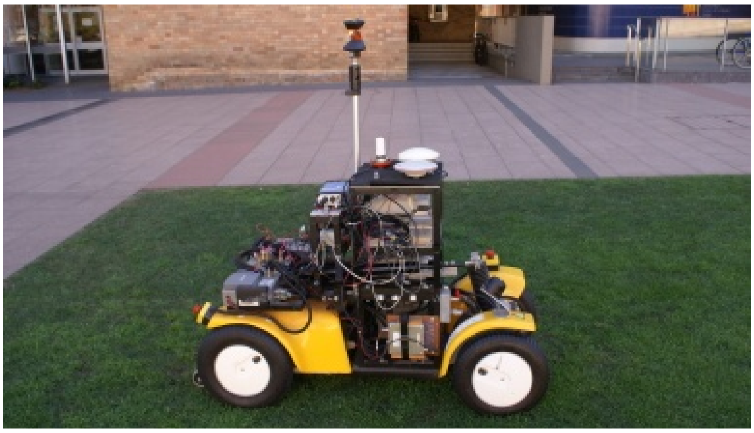


Figure 5: Integrated GPS+INS+Locata test car on UNSW campus.

3.4 Open-Cut Mining

Many of the ‘new paradigms in mining’ have at their core the requirement for reliable, continuous centimetre-level positioning accuracy to enable increased automation of mining operations. The deployment of precision systems for navigating, controlling and monitoring machinery such as drills, dozers, draglines and shovels with real time position information increase their operational efficiency, and reduce the need for humans to be exposed to hazardous conditions. GNSS cannot satisfy the high accuracy positioning requirements for many applications in mine surveying, and mine machine guidance and control. The reason is that increasingly open-cut mines are getting deeper, resulting in a reduction of the sky view necessary for GNSS systems to operate satisfactorily.

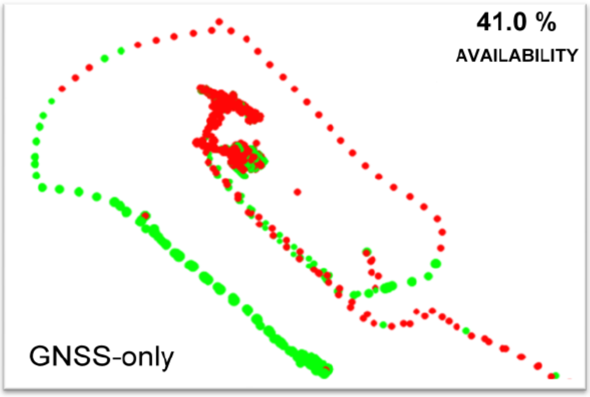
In the last week of September 2012, Leica Geosystems capped off five years of product development with the global launch at the huge MINExpo Convention in Las Vegas of the world's first "Powered by Locata" network for mining fleet management. Leica revealed they had already installed the first operational LocataNet at one of the world's biggest gold mines – Newmont Mining's Boddington Gold Mine in Western Australia. This open-pit mine (like most others) experiences severe machine control GPS outages as the mine gets deeper and visibility to sufficient satellites for a position solution is reduced. The efficiency of the mine suffers significantly during GPS outages, as machine control reverts to manually positioning machinery.

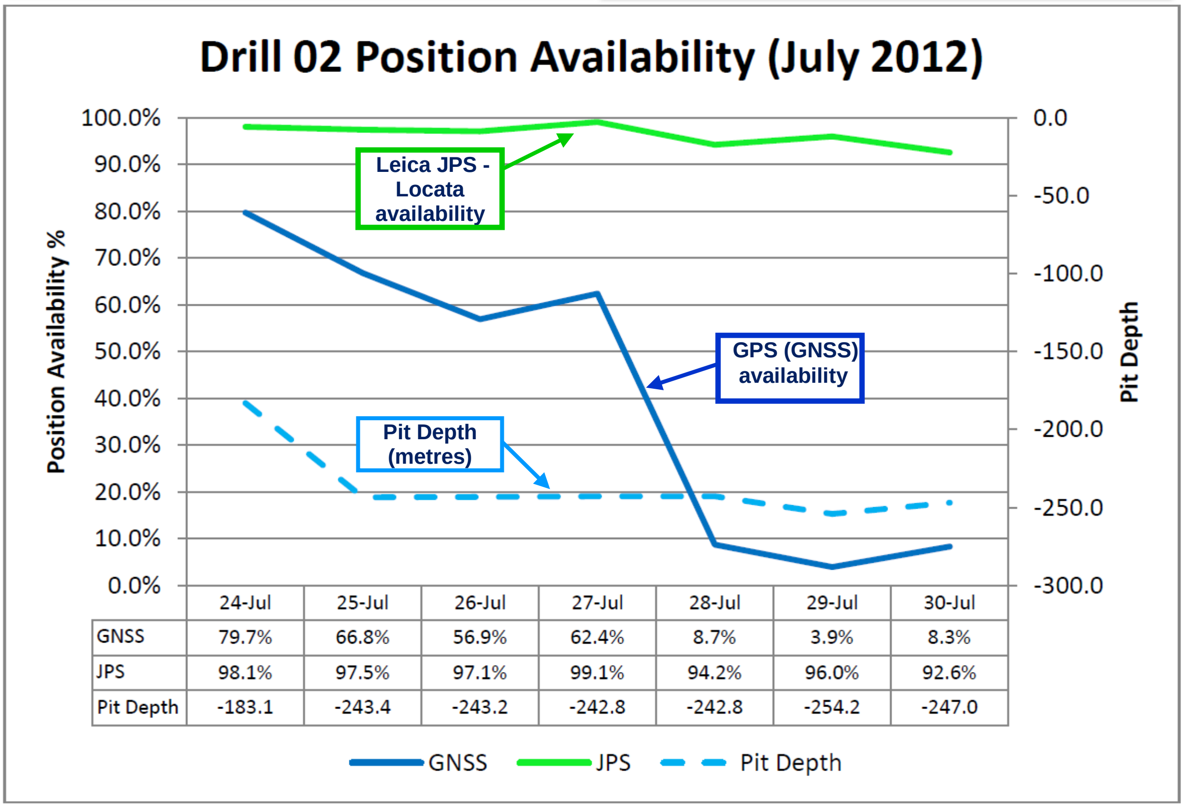
The results since the first Leica LocataNet became operational in May 2012 have been spectacular, both in terms of efficiency gains and financial return to the owners. Over a 2-month period, two Locata-enabled drill rigs in the pits worked an extra 4.7 days compared to the non-Locata drills – at a cost of over $1,000 per machine per hour, this represented over $112,700 of efficiency gains for those two drills alone. A comparison of availability of GPS-only versus Locata is shown in Figure 6. As of October 2012, the mine had installed the first of Leica's integrated GNSS+Locata receiver units on 10 drill rigs. Not only was the signal availability of the LocataNet an impressive achievement, but comparison measurements showed that these drills are being positioned to an accuracy of about 1.2 cm across the mine – an exceptional performance by any measure in such difficult physical environments.

3.5 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. A total station was used to provide independent 'ground truth'. The results demonstrated cm-level accuracy. 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.

The 2010 indoor experiments were conducted inside a large metal shed, approximately 30 m long and 15 m wide (Figure 7). 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 set-up is shown in Figure 7.





	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul	30-Jul
GNSS	79.7%	66.8%	56.9%	62.4%	8.7%	3.9%	8.3%
JPS	98.1%	97.5%	97.1%	99.1%	94.2%	96.0%	92.6%
Pit Depth	-183.1	-243.4	-243.2	-242.8	-242.8	-254.2	-247.0

Figure 7: Indoor test site, Locata receiver on trolley and RTS set-up.

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 3 cm from that derived using the RTS. (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 – opening up opportunities to many new location-based applications that were not possible previously. More tests have since been conducted.

3.6 Urban Positioning: Sydney Harbour Tests

In October 2012, a Locata test-bed for positioning in the Sydney Harbour area was set-up with the assistance of NSW Land and Property Information (LPI) and Sydney Ports. A LocataNet was deployed to service the area of Farm Cove (Figures 8 & 9), and the Locata receiver was deployed on a Sydney Ports vessel (Figure 10). Preliminary results were shown by Paul Harcombe (Chief Surveyor and Director of Location Policy, LPI) at the spatial@gov Conference in Canberra in November 2012, in a presentation titled "Sydney satellites – towards ubiquitous positioning infrastructure". A comparison with GPS-only positioning showed that the Locata-only solutions were different by about 4.4 cm. This was the first demonstration of Locata positioning using signals across water, and the first trial of Locata in an urban-like environment.

Figure 8: LocataNet established for 10 October 2012 Sydney Harbour tests.

Figure 9: (a) LocataLite atop Sydney Harbour Bridge, and (b) LocataLite near seawall of Botanical Gardens.

Figure 10: Locata receiver and GPS antennas on Sydney Ports vessel.

It is hoped that a permanent Locata test-bed will be established in the city of Sydney in 2013. This would be a first step to demonstrating that the network of signal transmitters to support Locata-based positioning could be included within a plan for deploying National Positioning Infrastructure (NPI). It would go part of the way to addressing the shortcomings of GNSS-based positioning for urban and other difficult GNSS signal environments.

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 recent news announcements by Leica Geosystems.

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, many more tests will be necessary to investigate the operational issues associated with deploying a LocataNet and developing user solutions based on the Locata technology.

Finally, the issue of Locata infrastructure, within the context of an NPI must be addressed. It is necessary to study how a LocataNet could be deployed and operated across an urban area, to support critical high-accuracy and high-availability positioning applications (which cannot be satisfied using GNSS-only solutions). Only very early trials have been conducted. Many more are needed, and could be undertaken using a permanent test-bed in a downtown urban area.

Locata is an Australian invention, it is here, and it is working now. Locata technology represents an unprecedented opportunity for Australia to become a world leader in positioning, one of the most important hi-tech markets of the future. It's not every day that a completely new, game-changing technology is invented in Australia. Opportunity knocks. Let's embrace it.

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