High accuracy positioning using Locata's next generation technology

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BIOGRAPHY

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Locata Corporation develops radio-location technology to provide precise positioning solutions to classically difficult environments. They currently have 16 granted patents on devices and systems which advance radio-location technology to new levels. *Locata's* combination of reliability, adaptability and precision gives new options to markets where GPS-style positioning has been "challenging". They are deploying the first commercial *LocataNets* in Q1of 2006.

ABSTRACT

Locata positioning technology was developed to address the shortcomings of current technologies for reliable positioning in challenging environments, such as when GPS satellite coverage is poor or not available. Previous research in this area has demonstrated proof-of-concept for the *Locata* technology using a first generation prototype system. In this paper details of *Locata's* next generation system are discussed, and positioning results are presented in an outdoor kinematic environment. It is shown that the accuracy of the kinematic positioning is comparable to GPS RTK. This paper will demonstrate the suitability of the *Locata* technology for machine tracking/guidance over wide outdoor areas where GPS satellite coverage is limited.

1.0 INTRODUCTION

RTK GPS has become the defacto positioning technology for precision ground vehicle tracking, guidance, and even automatic control in a number of application areas such as road construction and open-pit mining. The RTK GPS technology is mature and well understood, whereby a mobile dual frequency GPS receiver relies on differential corrections or measurements derived from a single reference station or Continuously Operating Reference Station (CORS) Network. It is well understood that acceptable GPS RTK performance is heavily dependent on the reliability of the wireless data link used, and on a relatively unobstructed sky-view, where there are at least five satellites with good geometry available. This is a significant limitation of the RTK GPS technology, and one which *Locata* Corporation aims to address through the development of its novel positioning technology. The

Locata positioning technology has been designed with four key objectives:

1. Available in all environments.
2. High reliability.
3. High accuracy.
4. Cost effective.

In *Locata* these objectives are achieved though a network of ground-based transmitters (a *LocataNet*) that cover a chosen area with strong signals, suitable for accurate positioning in classically difficult positioning environments (see Figure 1). Importantly, the *LocataNet* positioning signals are time-synchronized, which allows single-point positioning in the same manner as GPS. However, unlike GPS the sub-centimeter level of synchronization between *LocataLites* allows single-point positioning with GPS RTK level-accuracy without the use of a reference station. In order to demonstrate proof-of-concept for the *Locata* positioning technology, and verify key system methodologies and algorithms, a prototype first generation system was built. This first generation system used single frequency L1 transceivers (*LocataLites*) and a modified standard GPS receiver as the mobile unit (the *Locata* receiver). Through this system, fundamental concepts of the *Locata* technology have been demonstrated during the past two and a half years. Examples of these core concepts are summarised below:

Time-synchronized positioning network (*LocataNet*) – using *Locata's Time-Loc* methodology *LocataLites* (ranging signal transceivers) can be time-synchronized to better than approximately 30 pico-seconds to form a *LocataNet* (Barnes *et al*., 2003a). This is achieved without any hard-wires or external data links.

Network propagation – the *Time-Loc* methodology allows a *LocataNet* to autonomously propagate into difficult environments and over wide areas, such as an entire city (Barnes *et al*., 2003c).

Signal penetration – In comparison to GPS signals, *LocataLite* signals are orders of magnitude stronger. Because of this, signals from a *LocataNet* can penetrate buildings (Barnes *et al*., 2003b).

Indoor positioning – Using a test network at BlueScope Steelworks (Port Kembla, Australia), inside a warehouse, a large crane was tracked with cm-level RTK accuracy in a severe multipath environment (Barnes *et al.*, 2004a). Also, at a test network located outside a two-storey office building, *LocataLite* signals penetrated the building (brick walls and a metal roof) and allowed real-time positioning at the sub-metre level inside the building using non-line-of-sight signals. This level of precision is at least ten to one hundred times better than can currently be achieved using high-sensitivity GPS receivers indoors.

Outdoor positioning – Using a test network established at Parsley Bay suspension footbridge (Sydney, Australia), horizontal positioning of the footbridge was achieved with sub-cm precision (Barnes *et al*., 2004b).

Over the past two and a half years, the successful proof-of-concept of this prototype system has clearly been demonstrated, but it had significant limitations, including:

1. Interoperability with GPS – due to prototype *Locata* signal transmissions at the GPS L1 frequency.

2. On-The-Fly (OTF) carrier phase ambiguity resolution – the prototype system required a known point initialisation.

3. Multipath mitigation – only limited multipath mitigation was possible when using a standard GPS L1 C/A code signal structure in the prototype system.

4.Transmitter range and penetration – only limited transmission power was allowed in GPS L1 band, to mitigate interference with GPS signals.

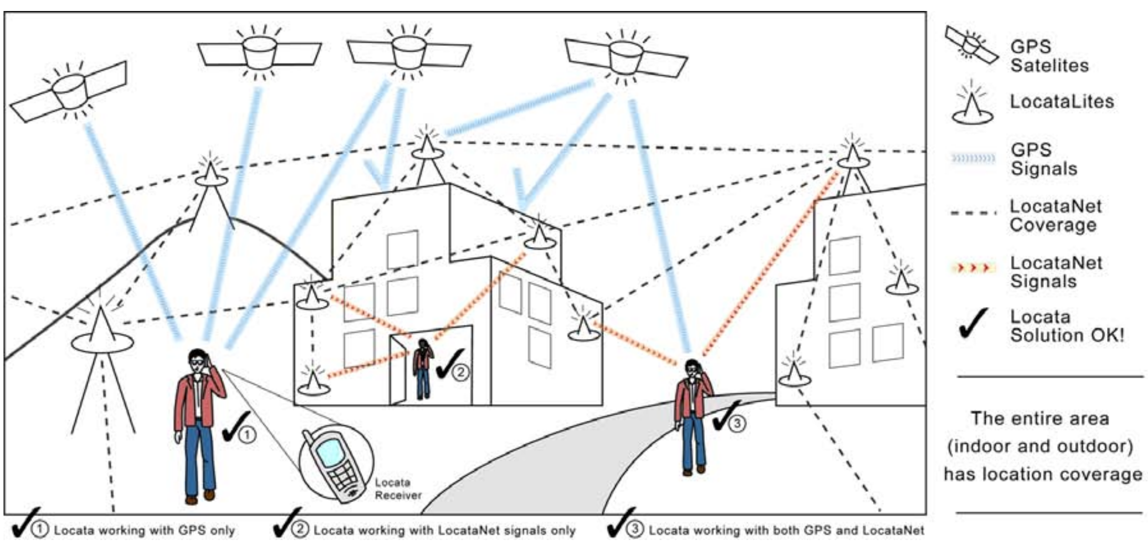

Figure 1. The *Locata* technology positioning concept.

To address the limitations of the prototype system, *Locata* has designed and built the current generation system.

2.0 *LOCATA'S* NEXT GENERATION SYSTEM

Locata's current generation system builds upon the fundamental technological concepts of the first generation system. This new design incorporates *Locata's* own proprietary signal transmission structure, and with complete control over both the signal transmitter and receiver comes enormous flexibility. This has allowed the limitations in the old system to be addressed with a completely new design for both the *LocataLite* (transceiver) and the *Locata* receiver (mobile user device). Core aspects of the new system design are discussed in the following sections and summarised in Table 1.

2.1 SIGNAL STRUCTURE

The first generation *Locata* system transmitted using the same L1 C/A code signal structure as GPS. 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 license for wide deployment of a ground based system on L1 would be extremely difficult (if not impossible) to obtain. If a license 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. Therefore *Locata's* new design incorporates a proprietary signal transmission structure that operates in the 2.4 GHz Industry Scientific and Medical (ISM) band. The 2.4 GHz ISM band has a bandwidth of approximately 80Mhz (2.4–2.4835 GHz), and, for direct sequence spread spectrum signals, FCC regulations (Parts 15 & 18) allow a transmit power of up to 1 watt. It is anticipated that this transmit power will allow line-of-sight *LocataLite* signals to be received from over 10 km away. Within the ISM band the *LocataLite* design allows for the transmission of two carrier signals. The exact frequencies at this stage are proprietary information, but the ISM band equates to a carrier wavelength of between 12.49 to 12.07 cm. These two carrier signals are modulated with a proprietary PRN code with a chipping rate of 10MHz (giving a chip length of approximately 30 metres). This new signal structure is beneficial in a number of areas in comparison to *Locata's* first generation prototype system including:

1. Interoperability with GPS and no licensing requirement.
2. Capability for On-The-Fly ambiguity resolution using dual-frequency measurement data.
3. Better multipath mitigation on code measurements due to the higher 10Mhz chipping rate, and theoretically less carrier phase multipath than GPS due to the higher frequency used.
4. Transmit power of up to 1 watt giving line-of-sight range of 10km.

Table 1. Specification summary of *Locata's* first (prototype) and current generation systems.

		First Generation System (prototype since 02)	Current Generation System (commercial deployment Q1/06)	Current Status (@ Sept. 05)
Signal structure	Frequencies	single frequency at GPS L1	dual-frequency 2.4 GHz (80Mhz bandwidth)	single frequency 2.4 GHz
	PRN code	C/A (1.023Mhz chipping rate)	proprietary (10Mhz chipping rate)	implemented
	License requirements	licensing issues & problem for wide area deployment	none required, FCC compliant	N/A
LocataLite (transceiver)	Hardware	FPGA & DDS technology	FPGA & DDS technology with a modular design	implemented
	Output power	several microwatts	maximum of 1 watt	100 mWatt
	Range	600 metres	10km line-of-sight	up to 3km
	Antenna	RHCP patch & ¼ wave (others also tested)	antenna design dependent on application	LP patch & ¼ wave
	Size	260x200x45mm (10.2x7.8x1.8 in)	240x135x30 mm (9.5x5.3x1.18 in)	N/A
	Weight	2.1 kg (4.6 lb)	1 kg (2.2 lb)	N/A
Locata (receiver)	Hardware	Zarlink/Mitel based GPS receiver chipset	FPGA technology, modular design	implemented
	Measurement rate	1Hz	25Hz	25Hz
	RT positioning	1Hz on-board	25Hz through LINE, 10Hz onboard	25Hz/1Hz
	AR	known point initialisation (KPI)	On-The-Fly	KPI
	Antenna	various types tested including RHCP patch and ¼ wave	Antenna design will depend on application.	¼ wave
	Size	200x100x40 (7.8x3.9x1.57 in)	130x135x30 mm (5.1x5.3x1.18 in)	N/A
	Weight	300 g (0.66 lb)	500 g (1.1 lb)	N/A

2.2 *LOCATALITE* (TRANCEIVER)

The *LocataLite* is an intelligent transceiver that transmits the dual-frequency signal structure described above. At least four *LocataLite* units are required to form a positioning network called a *LocataNet*, which is time-synchronized to 10s of picoseconds. This positioning network allows a single mobile *Locata* receiver to determine its position within the network. The *Locata* receiver can work in an environment with GPS or entirely independent of GPS. The *LocataLite* hardware design is modular with separate boards for the distinct sections of the design such as the transmitter, receiver and RF boards. Currently the *LocataLite* transmits on one frequency, but it is expected that within the next 6 months that the second (dual) frequency signal will be available. The receiver board is identical to the mobile user *Locata* receiver and is described below. Figure 2 shows the inside of the *LocataLite* unit with the transmitter and receiver board modules visible.

The *LocataLite* hardware design uses state of the art field programmable gate array (FPGA) devices from Xilinx. They provide configurable logic, on-chip memory and digital signal processing (DSP) capabilities. They therefore provide an extremely flexible design approach, and allow new design changes to be implemented without requiring a new chip fabrication and board re-design. In practice the *LocataLite* design comprising of FPGA logic and software is stored on a compact flash card and automatically uploaded when the *LocataLite* is powered up. The compact flash card can also be used to record raw data from the receiver. The transmitter and receiver in the *LocataLite* share the same clock, which is a low-cost temperature-compensated crystal oscillator (TCXO). Direct digital synthesis (DDS) technology is used in the time-synchronization procedure within the *LocataNet*, know as *Time-Loc* (Barnes *et al.*, 2003c). The DDS technology allows extremely fine adjustments to be made to the *LocataLite's* local oscillator, ensuring that all *LocataLites* within a *LocataNet* share a common time base.

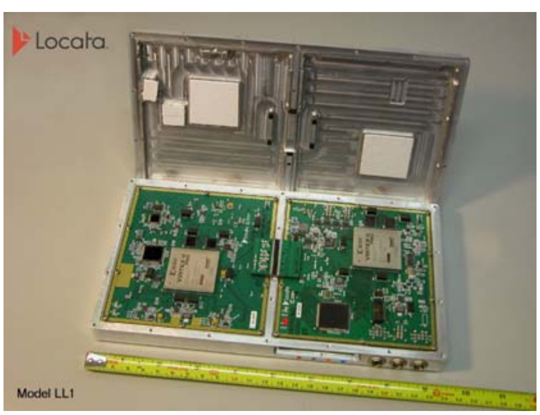

Figure 2. *LocataLite* (transceiver) hardware.

2.3 *LOCATA* RECEIVER

In the first generation prototype an existing GPS receiver chipset from Mitel (now Zarlink) was used, incorporating special firmware. This approach allowed faster development of the system, but was not flexible. In the current generation system the *Locata* receiver (like the *LocataLite*) uses Xilinx FPGA devices in the hardware design. With complete control over both the signal transmitter and receiver comes greater flexibility, and optimisation benefits. The *Locata* receiver (like the *LocataLite*) is a modular design with separate receiver and RF boards, and is approximately half the size of the *LocataLite*, as illustrated in Figure 3. The compact flash card in the receiver is used to automatically upload the receiver design (FPGA logic and firmware) and can also record raw data used for post-processing. Raw measurement data (pseudorange and carrier phase) from the receiver can also be streamed out serially via RS232 at rates up to 25Hz. Like the first generation design, real-time positioning on-board the receiver currently takes place at 1Hz. However real-time positioning rates of up to 25Hz are also possible by streaming the receiver data to the *Locata* Integrated Navigation Engine (LINE) application which runs on a laptop/PC running a Windows OS. The LINE application connects to *Locata* receiver data streams via TCP/IP sockets. These raw data streams can be logged to a file or processed in real-time to produce a position solution of up to 25Hz. The position output can be logged to a file or streamed to another TCP/IP socket where another application can use it for real-time display (vehicle tracking) or as input to a vehicle control system for machine guidance/control.

The *Locata* receiver and LINE use a direct carrier ranging (DCR) algorithm to determine its position from at least four (3D positioning) or three (2D positioning) *LocataLites*. This algorithm is similar to that of standard GPS single-point positioning but uses carrier phase measurements, and has previously been described in Barnes *et al.,* 2003a. In order to perform DCR the carrier phase ambiguities must first be resolved. In the current generation design the dual-frequency measurements play a key role in the ambiguity resolution process. However, dual-frequency measurements are not yet available (as discussed above), and therefore ambiguities currently are resolved via a known point initialisation as in the first generation prototype design.

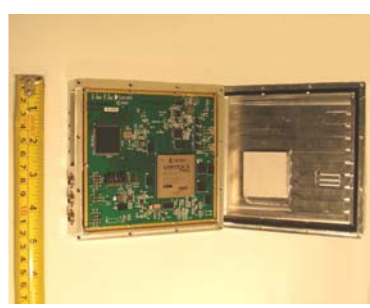
Figure 3. *Locata* Receiver hardware.

2.3 *LOCATA* ANTENNAS

In the first generation prototype system a number of different antennas have been used in tests, such as right-hand-circular polarized patch antennas (commonly used in GPS) and custom built ¼ wave antennas. From tests with the first generation design in a number of different environments (indoors high multipath, outdoors medium multipath, etc) it is clear that the application environment largely dictates the most suitable antenna design. For the current generation design two types of antenna have been used so far, which are suitable for low to medium levels of multipath outdoors. They are a linearly polarised (LP) patch antenna for the *LocataLite's* receive and transmit signals, and a custom built ¼ wave antenna for the *Locata* receiver (see Figure 4).

Figure 4. *LocataLite* LP patch antennas (left), and *Locata* receiver ¼ wave antenna (right).

3.0 KINEMATIC POSITIONING TEST

Locata Corporation has established a dedicated test facility near Numeralla (NSW, Australia) to allow extensive testing of the next generation technology. Covering an area of approximately three hundred acres the Numeralla Test Facility (NTF) is ideally suited to wide area testing of the system. On the 18th July 2005 a trial was conducted at the NTF to assess the performance of *Locata's* current system for tracking a moving vehicle. A *LocataNet* composed of five *LocataLites* was established at the NTF, with three (1, 3 & 4) mounted on permanently installed steel towers (3 metres in height) and two (2 & 5) mounted on tripods (see Figure 5). These locations were selected to provide good visibility of a road running through the property and to test the performance of the system over distances of up to 2.3 km. All five locations were surveyed using Leica System 500 & 1200 GPS receivers and processed using Leica Geo Office (LGO). Figures 6 and 7 illustrate the extents of the area used for the test and the *LocataNet* setup respectively. The time-synchronization of the *LocataNet* (*Time-Loc*) was established autonomously, entirely independent of GPS within a few minutes of turning on the *LocataLites*. In this *LocataNet* setup *LocataLites* numbered 2 to 5 all time-synchronized to *LocataLite* 1 at the southern end of the NTF. This would allow the *Time-Loc* methodology to be tested over distances ranging from approximately 1.2 km (*LocataLite* 1-2 & 1-5) to 2.3 km (*LocataLite* 1-4). For the kinematic test a road at the northern end of the NTF was used, which runs East-West and is a distance of approximately 0.66 km within the boundary. Table 2 shows the distances and elevation angles to the *LocataLites* from a middle location along the road. All *LocataLite* elevation angles are less than 5 degree and therefore the dilution of precision in the vertical direction is very poor. As a result the following tests will focus on a 2D horizontal positioning solution.

Figure 5. Example *LocataLite* installations 1, 2 & 4 (clockwise from top left).

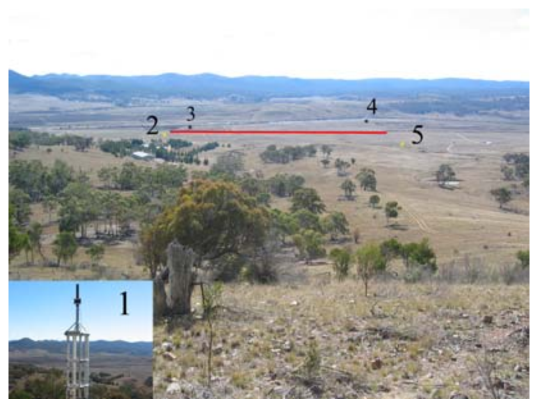

Figure 6. View of NTF and test area from *LocataLite* 1. The road is marked in red.

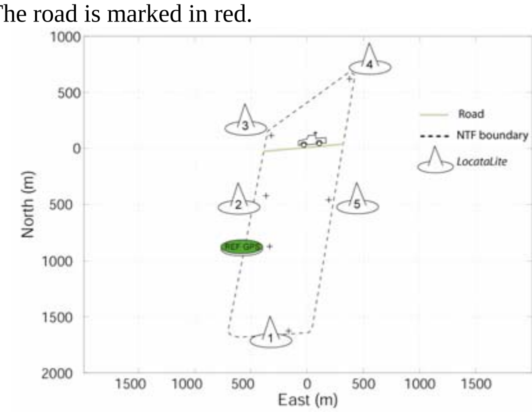

Figure 7. *LocataNet* setup for kinematic test.

Table 2. Elevation angle and distance to *LocataLites* from mid-road location.

	Elevation angle (deg)	Distance (metres)
1	4.74	1641.10
2	1.35	560.26
3	0.22	339.75
4	0.31	726.53
5	2.14	498.43

For the setup of the *Locata* receiver the antenna was mounted to the roof of a vehicle along with two GPS receiver antennas, to allow truth trajectories to be computed from two independent GPS systems (Leica System 1200 & Ashtech Z-Xtreme). As illustrated in Figures 8 & 9, the *Locata* receiver's ¼ wave antenna was mounted between the two GPS antennas separated by approximately 9 cm. Inside the vehicle was the *Locata* receiver connected to power and connected to a laptop PC, via a Lantronics serial-to-TCP/IP converter. As discussed previously, currently the *Locata* receiver first requires a static 'initialisation' at a know point before the DCR positioning can begin. A known 'initialisation' point was established on the road using a Leica GPS System 1200. The test trial began by the driver maneuvering the vehicle to this point and starting the LINE application to receive the streaming raw data from the *Locata* receiver. LINE then computed DCR positions at 25 Hz, as well as logging position solutions and raw data, and streaming the real-time position using an NMEA GGA message to a TCP/IP socket for real-time display through VisualGPSXP. Once the solution was initialised the vehicle drove two circuits of the road, turning around at the boundary of the NTF. One of the circuits involved driving straight up and down the road, whilst the other involved a series of tight turns ('wiggles') up and down the road. The maximum speed reached during the tests was approximately 40 kmh. While the test was conducted GPS data was logged from the Leica System 1200 (at 20Hz) & Ashtech Z-Xtreme (at 10Hz). The position of the Leica System 1200 GPS reference station is illustrated in Figure 7; it was located approximately 0.93 km from the road.

Figure 8. *Locata* and GPS setup: antennas mounted on truck roof (left), and *Locata* receiver connected to Lantronics serial-to-TCP/IP converter.

Figure 9. Vehicle on test road with antennas setup on roof.

3.1 RESULTS AND ANALYSIS

The kinematic GPS trajectories from both GPS data sets were processed using Leica Geo Office. There were 9 GPS satellites available and the HDOP and VDOP varied from 1 to 1.5 and 1.6 to 2.5 respectively. In addition a post-processed *Locata* solution was computed using LINE and an initial position derived from both the post-processed GPS solutions. This was necessary because maneuvering the vehicle alignment of the *Locata* receiver antenna to within cm level of the pre-surveyed point was not possible. It should be noted that a *Locata* real-time solution was seamlessly computed during the trial, and that the post-processed *Locata* solution was computed in exactly the same way as the real-time position, with no filtering or smoothing. For the *Locata* positioning solution the HDOP varied from 1 to 1.5.

To assess the positioning accuracy of the *Locata* system in comparison to kinematic GPS all three horizontal positioning trajectories are plotted together. Figure 10 shows the whole trajectory, and 'zoomed in' sections of the trajectory for Leica System 1200 (red), *Locata* (black) and Ashtech Z-Xtreme (blue). The two GPS antennas are approximately 9 cm either side of the *Locata* antenna, and from the plots in Figure 10 visually it can be seen that there is good agreement between the three position solutions. At the end of the circuit a 'truth' position was computed from the two GPS solutions, taking care of lever arm corrections. The difference between the end *Locata* position and 'truth' position in East and North was -0.024 m and -0.000 m respectively. For the second 'wiggles' circuit, Figure 11 shows a series of plots for all three horizontal positioning trajectories. The trajectory plots clearly show the vehicle turns, and like the first circuit visually there is very good consistency between all three positioning results. The difference between the end *Locata* position and 'truth' position in East and North was 0.004 m and 0.006 m respectively

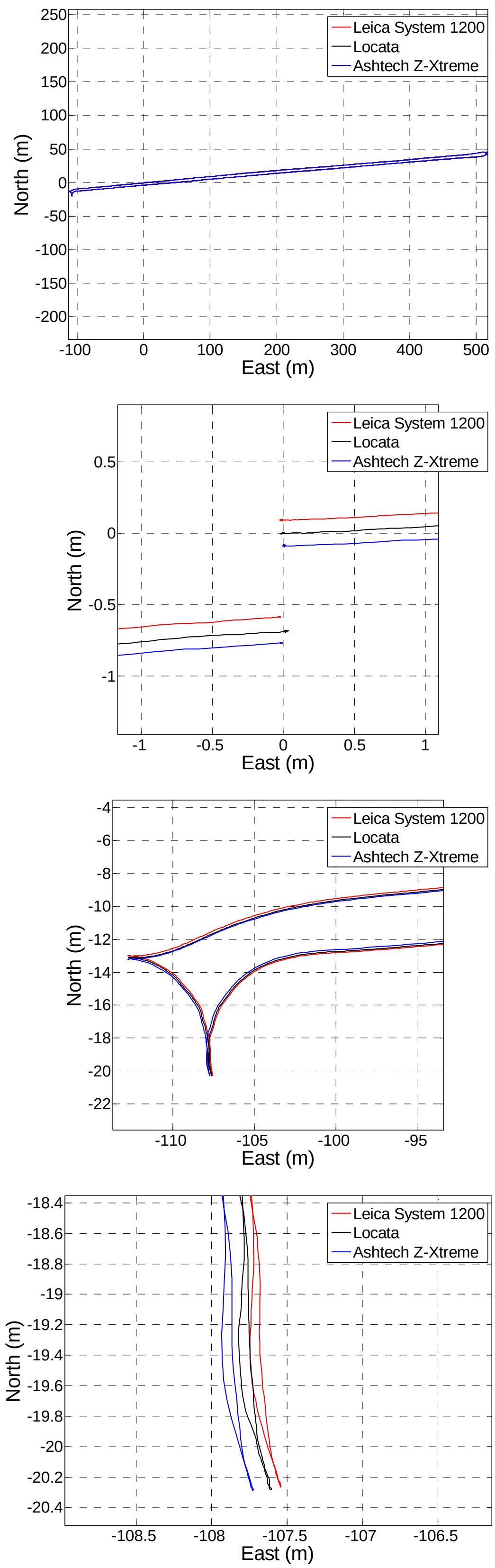

Figure 10. Circuit 1 GPS and *Locata* position trajectories from top to bottom: full circuit, start/end location, turn at East end, and 'zoomed' East end turn.

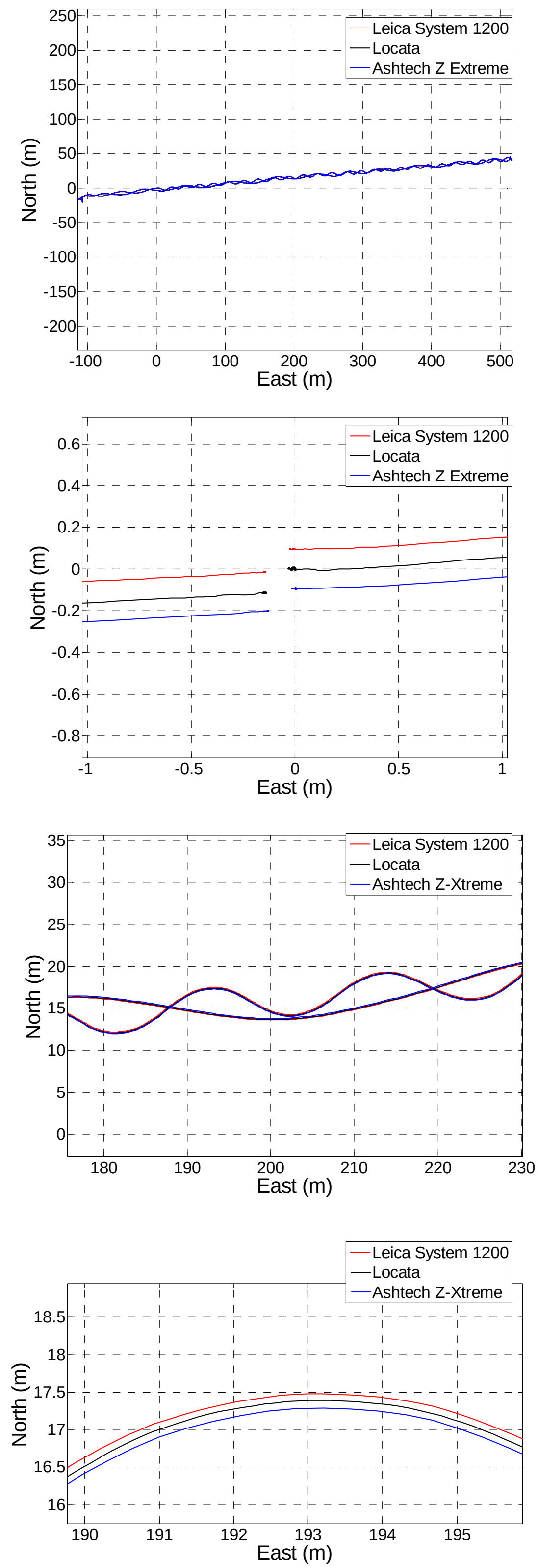

Figure 11. Circuit 2 GPS and *Locata* position trajectories from top to bottom: full circuit, start/end location, tight turns 'wiggles', and zoomed 'wiggles'.

Due to the unknown time varying offset between the *LocataNet* and GPS, and the different positioning rates of the *Locata* receiver (25 Hz) and two GPS receivers (20Hz and 10Hz) direct point to point comparison of the trajectories is not straightforward. However in order to better assess the accuracy of the *Locata* position solutions and assign statistics to the positioning results the following approach was used. Using the two GPS trajectories a 'truth' trajectory was computed taking into account the offset between the GPS antennas and the *Locata* antennas, via a lever arm correction. This trajectory was computed at a common rate of 10Hz for the GPS data. Then using vector geometry the cross track difference between the *Locata* position solution and the combined GPS trajectory was computed. Figure 12 shows the cross track difference for the first circuit and Table 3 details the statistics. The results confirm agreement between the *Locata* and GPS trajectories at the cm level, with a standard deviation of 0.006 m, and a maximum difference of 0.032 m. Overall the results indicate that the accuracy of RTK GPS and *Locata* are similar.

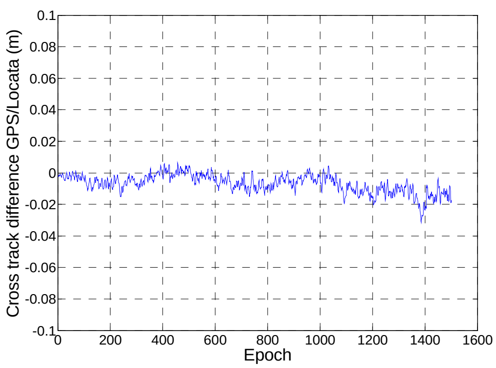

Figure 12. Circuit 1 cross-track difference GPS & *Locata*.

Table 3. Circuit 1 cross-track difference statistics GPS & *Locata*.

	Circuit 1 cross-track difference statistics (m)
Maximum	0.006
Minimum	-0.032
Standard deviation	0.006
Mean	-0.007

4.0 SUMMARY

In this paper details of *Locata's* current generation positioning technology have been discussed. This new design incorporates *Locata's* own proprietary dual-frequency signal transmission structure that operates in the 2.4GHz ISM band (global, license free). With complete control over both the signal transmitter and receiver comes enormous flexibility. This has allowed the limitations in the old prototype system to be overcome with a completely new design for both the *LocataLite* (transceiver) and *Locata* (mobile receiver). At a dedicated test facility in Australia a wide-area *LocataNet* was established where time-synchronization of the *LocataLites* was achieved over distances of up to 2.3 km. A *Locata* receiver mounted on a vehicle travelling up to 40 km/h computed real-time position solutions at 25Hz, using *LocataLite* ranging signals transmitted from up to 1.7 km away. By comparing post-processed kinematic GPS and *Locata* position solutions it has been demonstrated that accuracy of *Locata* is comparable to kinematic GPS (cm-level). This test demonstrates the suitability of *Locata* for machine guidance, control and tracking applications where there is reduced or unavailable satellite coverage. Overall this paper has shown that the current generation system is a significant leap forward to realising high accuracy (cm-level) ubiquitous positioning for a broad range of applications. It is anticipated that the *Locata* technology will ready for real-world deployment in commercial applications in Q1 2006.

ACKNOWLEDGMENTS

The authors would like to thank C.R Kennedy Australia and Leica Geosystems for the use of the GPS System 1200 and ancillary survey equipment, and the Airforce Institute of Technology (AFIT) for the use of the Ashtech Z-Xtreme.

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