Indoor industrial machine guidance using *Locata*: a pilot study at BlueScope Steel

Joel Barnes, Chris Rizos, Mustafa Kanli
School of Surveying & Spatial Information Systems, The University of New South Wales, Australia (UNSW)

David Small, Gavin Voigt, Nunzio Gambale, Jimmy Lamance
Locata Corporation Pty Ltd, Australia

Terry Nunan, Chris Reid
BlueScope Steel, Port Kembla Steelworks, Australia

BIOGRAPHY

Dr Joel Barnes is one of the senior researchers within the Satellite Navigation and Positioning (SNAP) group, at the School of Surveying & SIS, the University of New South Wales (UNSW), Sydney, Australia. He obtained a Doctor of Philosophy in satellite geodesy from the University of Newcastle upon Tyne, UK. Joel has assisted in the development of the *Locata* receiver and testing of the *Locata* technology. Other current research interests include pseudolites, GPS receiver firmware customisation and high precision kinematic GPS positioning.

Chris Rizos is a graduate of the School of Surveying, The University of New South Wales (UNSW), Sydney, Australia; obtaining a Bachelor of Surveying in 1975, and a Doctor of Philosophy in 1980 in satellite geodesy. Chris has been researching the technology and high precision applications of GPS since 1985, and is currently leader of the Satellite Navigation and Positioning group at UNSW. Chris is a Fellow of the Australian Institute of Navigation, a Fellow of the International Association of Geodesy (IAG), and is currently president of the IAG's Commission 4 "Positioning and Applications".

Mustafa Ozgur Kanli is a Ph.D student in the Satellite Navigation and Positioning (SNAP) group, at the School of Surveying & Spatial Information Systems, University of New South Wales (UNSW), Sydney, Australia. He is currently working with *Locata* Corporation developing low level software embedded in *Locata* technology. His research interests include pseudolites, attitude determination and embedded systems. He has a B.Eng. in Computer Engineering and M.Eng. in Biomedical Engineering from UNSW.

Locata Corporation is a start-up company, pioneering innovative solutions to positioning markets via their new *LocataNet* technology. Founded in 1995, *Locata* developed their systems in stealth mode for over 8 years. They currently have 13 granted patents (with many more pending) on devices and systems which advance radio-location technology to new levels. *Locata's* unique combination of reliability, adaptability and precision gives new options to markets where GPS-style positioning has been "challenging". They are expecting to deploy the first commercial *LocataNets* in Q1of 2006.

Terry Nunan and Chris Reid work in the Information Systems and Engineering Departments in the Industrial Markets Division of BlueScope Steel at their Port Kembla Works, Australia. They are responsible for developing a generic tracking system for guiding, tracking and managing the transport and storage of steel products by overhead crane, rubber tyred vehicle/forklift, or rail transport within the steelworks.

ABSTRACT

Locata Corporation has invented a new positioning technology called *Locata*, for precision positioning both indoors and outside. Using a network of time-synchronised transceivers, *point-positioning* with cm-level precision can be achieved. In this paper the feasibility of *Locata* for industrial machine guidance is demonstrated through a trial at the BlueScope steelworks. In the trial the *Locata* technology is used to track a crane within the slab handling yard. By comparing *Locata* position solutions with 'truth' positions derived using a total station (theodolite and electronic distance measurement) instrument, it is shown that cm-level positioning can be achieved in a severe multipath indoor environment.

1.0 INTRODUCTION

The BlueScope steelworks at Port Kembla in Australia turns iron ore into semi-finished steel products for customers such as the car industry. Large steel slabs are manufactured by the continuous casting process, and distributed to the slab handling area via an internal rail network. Slabs are unloaded either by overhead crane and stacked undercover, or with large forklift trucks and stacked in an outside holding yard, and stored until they are ready for shipping.

The steel slabs manufactured for a particular customer are unique and therefore their location must be tracked in the large holding area. Considering that there may be up to a few thousand slabs stored in multiple holding areas, tracking the steel slabs is an important but challenging task. Currently a crane tracking system (using resolvers and mileposts) is used to monitor the indoor slab stacks, but unfortunately the system is prone to break down, which is time consuming and expensive. This tracking system together with a Geographical Information System (GIS) has been developed to generate crane 'job instructions' and to automatically manage inventory information without driver data entry. No such tracking system is carried out for the forklift trucks that store and retrieve slabs in the outside holding yard. The maintenance of slab inventories in those areas is therefore by 'pen & paper' and is of lesser accuracy, and potentially hazardous for ground staff.

Real-time kinematic GPS has been trialed on both the forklifts and locomotives in the steelworks, but is not reliable in many areas of the works due to large buildings obstructing the satellite signals (Barnes *et al.*, 2002). For tracking the locomotives, the integration of GPS with an odometer and RFID tags has helped (but not solved) the problem of positioning availability across the steelworks. In order to track a variety of different vehicles in the steelworks, BlueScope Steel seek a generic indoor/outdoor positioning system.

2.0 THE *LOCATA* TECHNOLOGY

Locata is a new positioning technology, developed to address the limitations of existing technologies for precise, reliable, ubiquitous (outdoor and indoor) positioning. The *Locata* positioning concept uses a network of ground-based transmitters that cover a chosen area with strong signals, together with signals from GPS. As illustrated in Figure 1, a *Locata* receiver can track both GPS and *Locata* signals, thereby providing a seamless transition between environments where a user can utilise *Locata* signals, GPS signals, or both. A GPS receiver can only give precise reliable positioning with a relatively unobstructed sky view, which allows enough satellites (4 or more for 3D positioning) with good geometry to be tracked (scenario 1 in Figure 1). *Locata* is designed to improve GPS positioning, extending its capability into difficult indoor and urban environments (scenarios 2 & 3 in Figure 1). Additionally *Locata* can operate entirely independently of GPS (as demonstrated in this paper).

There are two core components of the *Locata* technology (see Barnes *et al*., 2003a for further details):

1. *LocataLite* – A transceiver which generates a GPS-like signal. The prototype device shown in Figure 2 transmits a GPS L1 signal and C/A code pseudorange, and incorporates the same receiver hardware as the *Locata*.

2. *Locata* – A stand-alone low cost GPS-like receiver that can track both GPS and *LocataLite* signals. The prototype hardware, shown in Figure 3, is based on an existing GPS chipset. When four or more *LocataLite* signals are tracked the *Locata* receiver is capable of 3-dimensional positioning with sub-centimetre precision.

When four or more *LocataLites* are deployed they cooperate to form a positioning network called a *LocataNet*. This positioning network is time-synchronous, which means a stand-alone *Locata* receiver can compute its position without any additional information or correctional data. The time synchronisation procedure is called *Time-Loc*, and is a key innovation of the *Locata* technology. This innovation and other special characteristics of the *LocataNet* are detailed

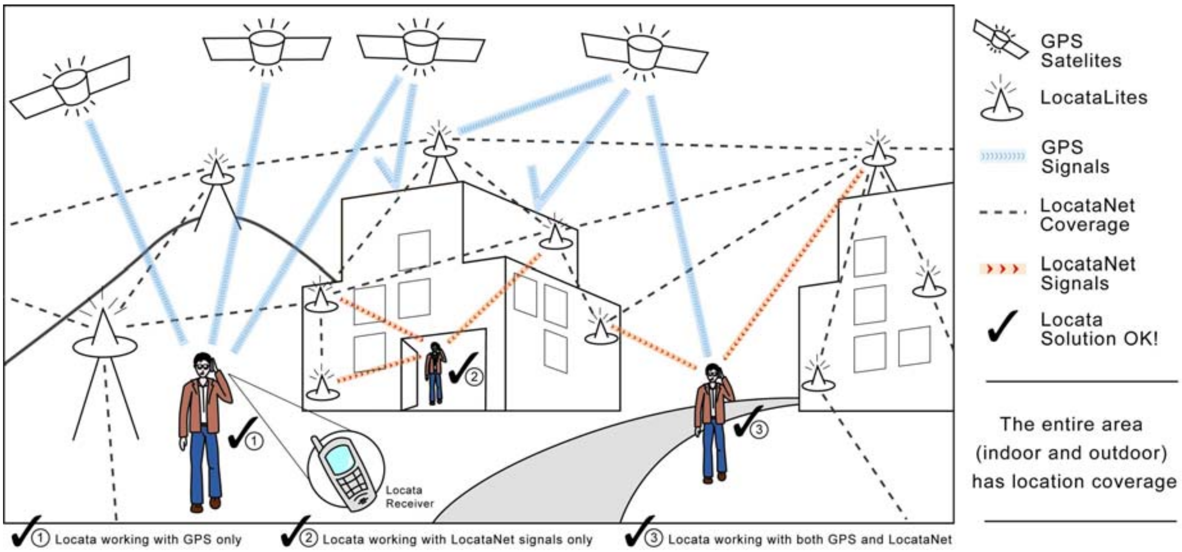


Figure 1. The *Locata* technology positioning concept

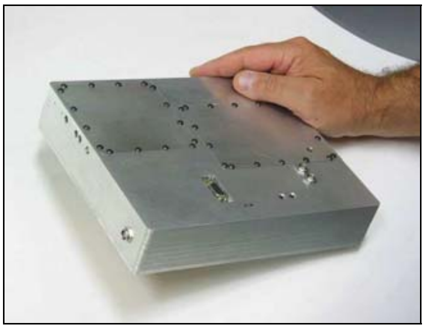


Figure 2. Prototype *LocataLite* (transceiver) hardware.

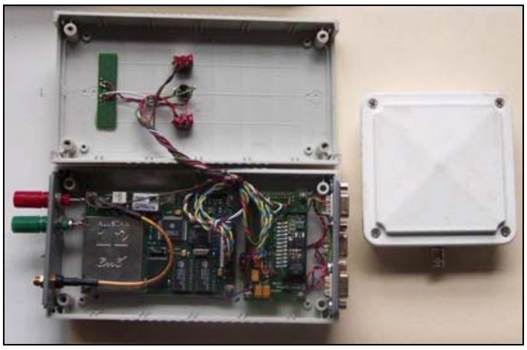


Figure 3. Prototype *Locata* (receiver) hardware.

in Barnes *et al.*, 2003a & 2003c.

Using the prototype hardware described above several studies have been conducted to demonstrate proof-of-concept for the *Locata* positioning technology, and verify key system methodologies and algorithms, including:

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

<u>Network propagation</u> - the *Time-Loc* methodology allows a *LocataNet* to autonomously propagate into difficult environments and over wide areas, covering many kilometres (Barnes *et al*., 2003c).

<u>Signal penetration</u> - 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).

<u>Indoor/outdoor positioning</u> - 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 static positioning inside with sub-cm precision for a *Locata* (Barnes *et al*., 2003c). Also, using the same test network, a *Locata* was tracked in real-time as it moved around the office building with sub-metre level precision. This level of precision is at least ten to one hundred times better than can currently be achieved using high sensitivity GPS receivers indoors. Moreover at an outdoor test network with line-of-sight signals the results are as good as if not better than RTK GPS, with cm-level precision (Barnes *et al*., 2003a).

This paper focuses on the feasibility of using *Locata* for indoor machine guidance, in an industrial and severe multipath environment, through a trial at BlueScope steel.

3.0 *LOCATA* PILOT STUDY AT BLUESCOPE STEEL

The BlueScope Steelworks at Port Kembla is located approximately 80km south of Sydney, Australia, and covers an area of approximately 3km^2. Operations at the works turn iron ore into semi-finished steel products. One of the products is large steel slabs, which vary in size from 6–12.5m in length, 0.75–1.8m in width, and 0.23–0.3m in thickness, and weighing 2.5-40 tons. As discussed in section 1 there is a great need for a positioning system to track a number of vehicles around the steelworks including forklifts, locomotives and cranes. This need arises from both safety and inventory management aspects.

The machinery used in this pilot study is a large crane that operates inside a long steel warehouse almost 1km long and approximately 60m wide (see Figure 4). The purpose of the crane is to unload/load large steel slabs from locomotive trucks that enter the warehouse and drop/lift

Figure 4. Structure of indoor crane at BlueScope steelworks for moving large steel slabs.

Figure 5. View from crane drivers cab with VDU for job instructions.

slabs in a particular area of the warehouse. The driver of the crane is given job instructions via a VDU and then must manoeuvre the tongs of the crane to the necessary location in the warehouse to drop/lift the required slab/s of steel (see Figure 5). The structure of the crane comprises of a large gantry which extends across the width of the warehouse, and runs on rails up and down the length of the warehouse (long-track). The crane tongs used to pick up the slabs is connected to a traveller by steel cables, that allow the tongs to be hoisted up or down. The traveller moves along the gantry on rails providing movement across the width of the warehouse (cross-track). Therefore, the tongs of the crane can be positioned in three dimensions, allowing slabs of steel to be manoeuvred within the warehouse.

The crane driver's cabin is mounted at one end of the crane body i.e. close to one side of the warehouse. Given the parallax error this introduces when trying to align the crane tongs above a stack on the opposite side of the yard, or when lifting or placing slabs from/into a near empty stack that is effectively hidden behind a full stack closer to the cabin, the driver is guided in long and cross travel positioning of the tongs by a tracking system based on resolvers and mileposts. The accuracy of the existing crane tracking system (ECTS) is estimated at the decimetre level, which is sufficient to ensure the driver has been guided to the correct stack (and is also commensurate with the limitations of the drive controls on the aged cranes). CCTV cameras mounted on the tongs allow the driver to make final adjustments to long travel, cross travel and hoist height to ensure each lift or drop is performed with safety. The current tracking system is based on 20 year old sensor technologies, with a particular weakness being the long travel milepost arrangement which uses a varying number of magnetic bars to effectively create a binary number (milepost identity) every 20m along the girders supporting the crane runway. A matching (full) set of magnets on each crane acts as the reader unit which can uniquely identify each milepost as it is passed, provided the separation between milepost and reader magnets does not exceed a few millimetres. Build-up of dust or magnetic material on the surface of these magnets brings the potential for incorrect/missed reads, while variation in the physical separation due to deterioration or replacement of crane wheels, crane rails or girders can cause physical contact between the crane and girder mounted magnets. The correction of such issues is seen as a source of maintenance costs and interruption to production that is unacceptable by today's standards.

3.1 CRANE TRACKING TRIAL USING *LOCATA*

On the 28th April 2004 a trial was conducted at BlueScope Steel to assess the performance of the prototype *Locata* technology for tracking a large crane, in a harsh multipath environment. For this industrial application, with the ECTS (see section 3), the horizontal positioning of the crane is the most problematic. Therefore, the following *Locata* crane tracking trial concentrates on horizontal 2D positioning. A *LocataNet* positioning network comprising of four *LocataLite* devices was established in an area of the shed approximately 50x50m. The four antennas of the *LocataLite* devices were mounted to walkways at the side of the warehouse at a heights of approximately 4-5m above ground level. Figure 6 shows the installation of two of the *LocataLites* antennas in the warehouse. The positions of the *LocataLite* antennas were manually surveyed using a total station (theodolite and electronic distance measurement) instrument. The coordinate system of the *LocataNet* was established such that it was approximately in line with that of the ECTS, with north/south along the length of the warehouse (long-track) and east/west across the width (cross-track). The *Locata* receiver antenna was mounted on a frame, extending from the front of the crane tongs to increase receiver visibility around the tongs. A prism was also mounted on the frame, directly beneath the Locata receiver antenna to

Figure 6. Example installations of *LocataLite* antennas and total station used for 'truth' positions.

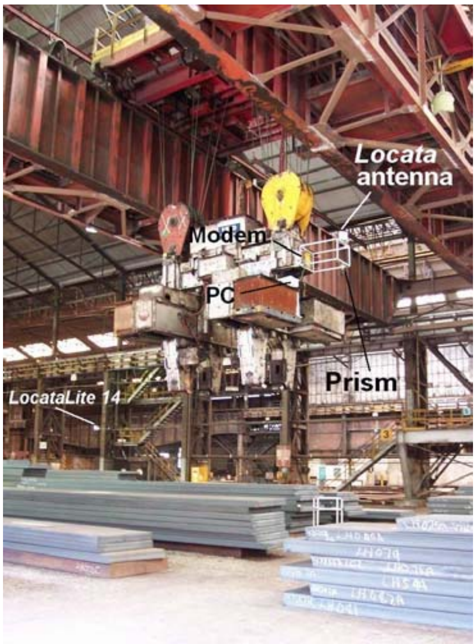


Figure 7. Crane tongs mounted with *Locata* receiver antenna, prism for total station, data modem and laptop.

allow independent ‘truth’ positions to be recorded using the total station (see Figure 7). Also mounted on the crane tongs was the *Locata* receiver, batteries, laptop computer for data logging, and a radio data modem. The purpose of the radio data modem was to allow the status of the receiver to be monitored from a safe distance. It should be stressed that the radio data modem data did not transmit or receive any kind of correctional data (as with RTK GPS).

After deploying the *LocataLite* network, time-synchronisation of the *LocataNet* was established within a few minutes. The *LocataNet* was established in an autonomous synchronisation mode (*TimeLoc*), entirely independent of GPS. Figure 8 shows the configuration of the time-synchronisation (*TimeLoc*) between the *LocataLites*. *LocataLite* devices 12 and 21 directly time-synchronised to 29, but 14 time-synchronised to 21 using the *Cascaded TimeLoc* methodology (see Barnes *et al*., 2003c for details). *LocataLite* 14 was time-synchronised in this way to minimise possible obstruction and multipath caused by the moving crane tongs.

In the current prototype, the *Locata* receiver first requires a static initialisation at a know point before carrier phase point-positioning can begin (see Barnes *et al*., 2003a for further details). A known ‘initialisation’ position was established approximately at the centre of the working area of the crane, using the total station. The test trial began by the driver manoeuvring the crane tongs over this point and an initialisation command being sent to the *Locata* receiver via the radio data modem. The *Locata* receiver then computed carrier phase point-positions once a second, which were logged to a laptop computer on the crane, together with raw carrier phase and pseudorange measurement data. Due to mechanical constraints of the crane the driver was unable to position the tongs over the initialisation point to better then approximately 15cm. However, positioning of the tongs to less than 1/2 cycle (~9.5cm) is required to determine the correct ambiguities. Because of this, the raw measurement data was used to post-process position solutions (used in the following results and analysis). The post-processed position solution was computed in exactly the same way as the real-time position, with no filtering or smoothing. However, it should also be noted that the *Locata* receiver computed a real-time position without any problems during the trial.

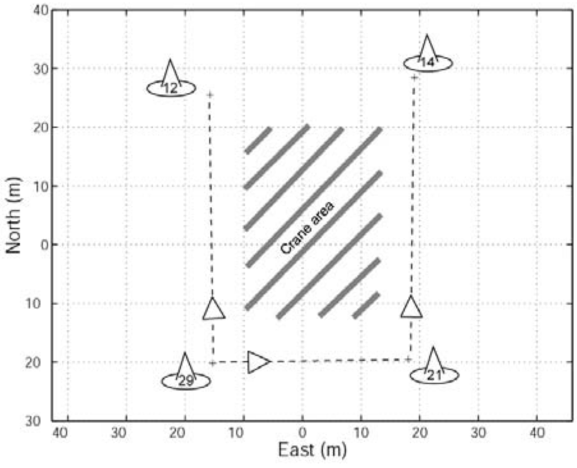


Figure 8. Time synchronisation of *LocataNet*.

After initialisation, the driver of the crane was given job instructions to move the crane tongs east, west, south and north by approximately 5m, and return to the centre after each move. There are two reasons why these particular manoeuvres were selected. First, with larger movements there were problems in measuring a position using the total station, because of the observing angle to the prism, and secondly these movements were easy for the crane driver to perform. Figure 9 shows the horizontal position track of the crane, which forms a cross type pattern. It should be noted that during the trial only three cycle-slips were detected (and subsequently repaired), in the difficult multipath environment. The crane tongs is attached by steel cables and therefore takes a period of time to stop “swinging” after a manoeuvre. Figure 10a shows east and north position time series during the 5m move east (from the east ‘true’ value, see below). The east position time series shows decreasing oscillations east-west as the swinging motion of the crane tongs stabilises. The north position time series shows virtually no oscillations, because the move was in an east direction only, and also less movement is possible in the north direction due to the configuration of the tongs cables. Figure 10a shows that after approximately 2 minutes the movement of the tongs is less than a couple of centimetres, and following this Figure 10b shows the position time series (from the east ‘true’ value) where the tongs are almost stationary for approximately 1 minute. At this time the ‘truth’ position was recorded using a total station and also from the ECTS. There were nine ‘truth’ positions recorded in total, and in measurement order they are east, centre, west, centre, south, centre, north, centre. In Figure 9 the positions recorded using the total station are indicated by a +, but for readability only one of the five centre positions is shown. It should be noted that the position time series for all of the moves were similar to the 5m move east described above.

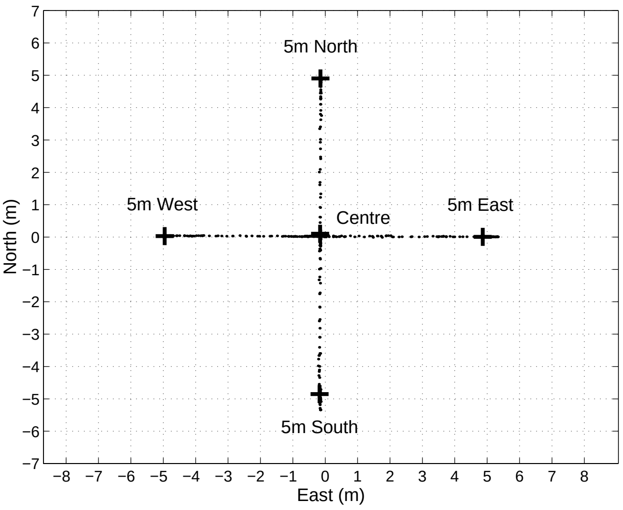
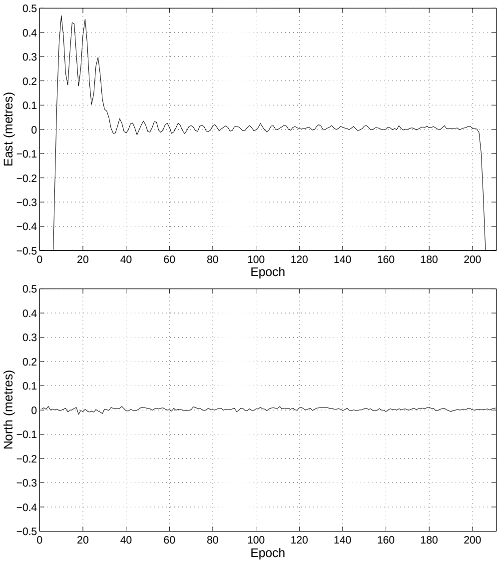
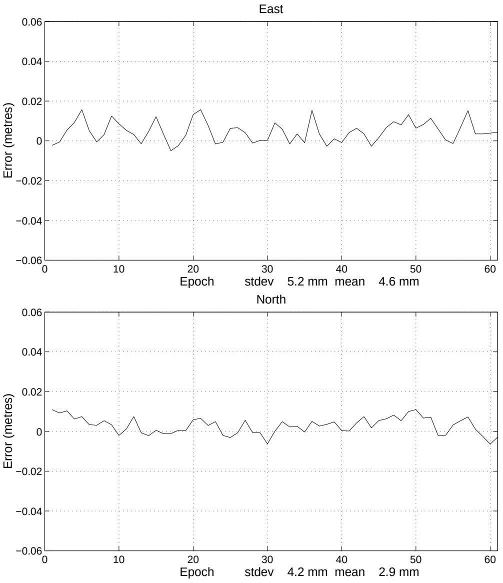


Figure 9. Track of crane movements.



a. Move and "swinging" crane tongs.



b. End part of data (~ 1 min) after crane tongs stabilise.
Figure 10. Horizontal position components from true value, after a move 5 metres east.

3.2 RESULTS AND ANALYSIS

To assess the accuracy and precision of the *Locata* positioning, the positions after each move were compared with the 'truth' position from the total station. Using approximately one minute of data, where the crane tongs were almost stationary, standard deviation and mean values from the true position were computed. Table 1 shows the standard deviation, mean values, and dilution of precision in east (E) and north (N), after each move. The precision of the horizontal position solutions are clearly sub-centimetre, with all less than 6mm in the east and north components, while the smallest position component standard deviation is approximately 3mm. The dilution of precision is slightly better in the east than the north component, and values do not vary greatly for the working area of the crane. Interestingly, there is not always a direct correlation between the DOP values and the standard deviations, and some of the variation could be due to the fact that the crane tongs were not entirely stationary during the analysis period. The mean values in Table 1 give an indication of the absolute positioning accuracy. The first centre position has no bias because it was used to initialise the *Locata* receiver position. Overall, all mean values are less than 2cm, but the majority of them (just over 80%) are better than 1cm. To illustrate the high-precision and accuracy achieved using *Locata*, Figure 11 shows the horizontal positioning result from the *Locata* receiver in relation to the 'truth' position (indicated by a +), for the nine locations after each move of the crane tongs. From the horizontal plots (where one grid square is 5x5cm) it can be seen that the position solutions are very consistent. Overall, the main factors affecting the system accuracy and precision can be attributed to mulipath error, errors in the surveyed location of the *LocataLite* antennas, small movements of the tongs after a move (assumed to be static in the analysis), and errors in the total station 'truth' positions.

Table 1. *Locata* mean position error (computed using 'true' total station coordinates) and standard deviations.

	Mean error (m)		Standard deviation (m)		DOP values	
Tongs position	East	North	East	North	E	N
Centre	0.0	0.0	0.0057	0.0046	0.85	0.63
East	0.0046	0.0029	0.0052	0.0042	0.85	0.62
Centre	0.0075	0.0022	0.0059	0.0040	0.85	0.63
West	0.0002	0.0188	0.0059	0.0034	0.89	0.62
Centre	0.0082	-0.0024	0.0042	0.0040	0.85	0.63
South	0.0100	-0.0055	0.0033	0.0053	0.81	0.65
Centre	-0.0019	0.0037	0.0040	0.0033	0.85	0.63
North	0.0107	-0.0023	0.0041	0.0032	0.85	0.62
Centre	-0.0015	-0.0007	0.0034	0.0035	0.85	0.63

To assess the accuracy of the existing crane tracking system (ECTS) the horizontal distance travelled (range) for each move was compared with a 'true' range from the total station coordinates. This approach was taken because there is an unknown horizontal rotation between the ECTS and the *LocataNet* coordinate systems. Table 2 shows the error in the ranges in each of the moves for both the ECTS and using the mean *Locata* coordinates

Table 2. Range errors for each crane move for existing crane tracking system (ECTS) and *Locata*.

	Range error (metres)	
Move	ECTS	*Locata*
Centre to East	-0.153	0.005
East to Centre	0.038	-0.003
Centre to West	-0.139	0.007
West to Centre	-0.126	0.008
Centre to South	0.104	0.003
South to Centre	-0.016	0.009
Centre to North	-0.338	-0.006
North to Centre	-0.497	-0.001

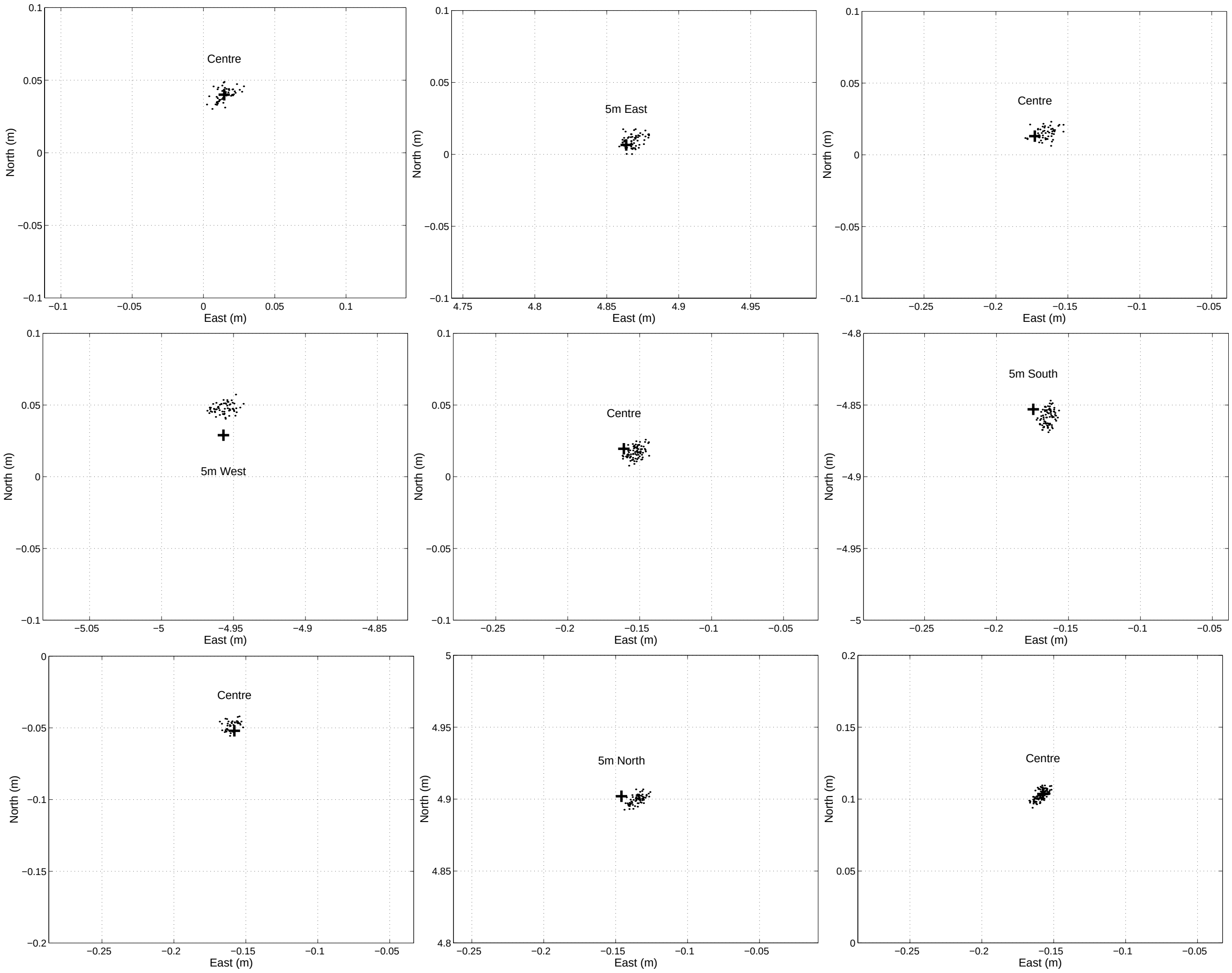


Figure 11. *Locata* receiver horizontal positioning solution after crane tongs move, and ‘true’ position (+) from total station.

compared to the total station. The ECTS range errors are inconsistent with a large variation in range errors, from approximately 1.5cm to 50cm. However, the majority of the range are between 10-50cm, providing decimetre-level of accuracy. In comparison the range error from the mean *Locata* positions are very consistent and all less than 1cm.

4.0 SUMMARY

In this paper the performance of the *Locata* positioning technology has been tested in a real-world industrial environment at BlueScope Steel. The trial application at Port Kembla steelworks involved tracking a crane inside a large metal warehouse. The purpose of the crane is to unload/load large steel slabs from locomotive trucks that enter the warehouse and drop/lift slabs in a particular area of the warehouse. With the large amount of steel within the warehouse, this is an extremely severe multipath environment. The *LocataNet* design was setup to reduce multipath effects through careful placement of both *LocataLite* and *Locata* receiver antennas. The *Locata* position solutions were compared with a ‘truth’ position from a total station. Despite the difficulty of the environment, the *Locata* technology allowed point-positioning of a *Locata* receiver with sub-cm precision, and cm-level absolute accuracy. This is at least ten times better than the existing crane tracking in use. Moreover these results are extremely encouraging for a prototype system, with significant enhancements yet to be put in practice.

BlueScope Steel seek a generic indoor/outdoor positioning system to track a variety of different vehicles in the steelworks. This need arises from both safety and inventory management aspects. This trial shows that the *Locata* technology has the potential to deliver a reliable ubiquitous positioning system for BlueScope Steel, and other environmentally harsh industrial type applications.

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