An integrated Locata & Leica Geosystems positioning system for open-cut mining applications

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BIOGRAPHY

Dr Joel Barnes is Senior Navigation Engineer for Locata Corporation, and is also a Senior Visiting Research Fellow at the University of New South Wales, Australia. Joel has assisted in the development of the Locata receiver and testing of the Locata technology since 2000, whilst working at UNSW as a Research Fellow. He formally joined Locata Corporation in 2007, and currently his research is focused on navigation algorithm development and error modelling.

ABSTRACT

Open-cut mining techniques have come to rely heavily on GNSS technology as a critical input into machine control systems. However, as open-cut mines get deeper the visibility to GNSS satellites is greatly reduced, and therefore reducing the effectiveness of GNSS positioning systems placed on mining equipment. Locata and Leica have been working together to develop a solution to this problem using Locata's ground-based positioning technology.

During late 2006 through to early 2007 the first integrated Leica and Locata equipment was installed and tested at a major open-cut mine in South Africa. A backpack, dozer and drill system were equipped with integrated Leica/Locata positioning technology.

This paper will discuss the design and installation of the first "real-world" open-cut mine trial of Locata enabled technology, and present results and analysis demonstrating the performance of the proof-of-concept Leica/Locata mining systems.

1.0 INTRODUCTION

Acceptable RTK GNSS performance is heavily dependent on a relativity unobstructed sky-view, where there are at least five satellites with good geometry available, and on the reliability of the wireless data link used for differential corrections. In challenging GNSS applications where satellite occlusion is common, such as open-cut mining, the RTK based technology often fails to deliver the required positioning availability and accuracy.

Locata's solution to challenging GNSS applications is to deploy a network of terrestrially-based transceivers (LocataLites) that transmit positioning signals to augment or replace GNSS entirely. These transceivers form a positioning network called a LocataNet that can operate in combination with GNSS or entirely independent of GNSS (for indoor applications). One special property of the LocataNet is that it is time-synchronous, potentially allowing single point positioning (no differential corrections and data links required) with cm-level accuracy.

In the current system design the LocataLites transmit their own proprietary signal structure in the 2.4GHz ISM band (license free). This ensures complete interoperability with GNSS and allows enormous flexibility due to complete control over both the signal transmitter and the receiver. Details of the current system design have been detailed in Barnes *et al.* 2005, together with kinematic positioning results demonstrating RTK-level performance independent of GNSS.

In July 2006 Leica Geosystems announced publicly the signing of a co-operation agreement between Leica Geosystems and Locata Corporation for the distribution and support of Locata technology in two key market areas, namely:

- open-cut mining – for machine automation and mine monitoring operations, and
- structural deformation monitoring – for structures such as bridges, dams and buildings.

For open-cut mining the first outcomes from this collaboration were discussed in Barnes *et al*. 2006. In this paper details of a proof-of-concept integrated Leica/Locata system for drilling operations in open-cut mining was discussed. In this loosely coupled system, the Leica RTK GNSS receiver was used to initialise the Locata receiver's position. Following this initialisation, Locata operated entirely independently and demonstrated accuracies comparable to Leica RTK GNSS (cm-level).

The remainder of this paper will discuss and present results of the first "real-world" installation of Locata enabled technology in an open-cut environment.

2.0 VENETIA MINE TRIAL

During late 2006 through to early 2007 the first integrated loosely coupled Leica and Locata equipment was installed and tested at De Beers "flagship" Venetia diamond mine in South Africa. The Venetia mine pit covers an area of approximately 1.2 x 0.8 km and 0.25 km deep. Photographs of the Venetia mine are shown in Figure 1.

Figure 1. DeBeers Venetia Mine from East rim (top) and West rim (bottom).

The dimensions of the pit at present are such that GNSS positioning availability is approximately 90% for the majority of pit. This makes the mine an ideal test area to compare GNSS solutions with independently computed Locata solutions. As the pit depth gets deeper the GNSS availability is expected to drop significantly such that mining productivity will be severely affected.

The LocataNet was established around the rim of the pit and a backpack, dozer and drill system were equipped with integrated Leica/Locata positioning technology.

The desired positioning accuracy requirements at the outset of the trial was for a Locata-only solution (after GNSS RTK initialisation) to provide at the 95% level 10 cm in the horizontal and 20 cm vertical.

2.1 LOCATANET INSTALLATION

The LocataNet at Venetia mine was established with ten dual transmit LocataLites distributed around the rim of the pit. Figure 2 shows the location of each LocataLite (indicated by a red dot) around the rim of the pit, its number (1-10) and the PRNs broadcast by each LocataLite (1-20). The LocataLite site locations were selected to provide good coverage into the main pit work area, but were additionally constrained by logistical issues. An analysis of the geometry provided by the LocataNet was conducted. Figure 3 shows the HDOP in the pit assuming clear line of sight to the LocataLites. This analysis shows very good horizontal geometry with HDOP of 1 to 2 throughout most of the pit (provided there is clear visibility to the LocataLites). Similar analysis was conducted in the vertical geometrical component and found to be relatively weak. As a result a modified navigation algorithm was implemented essentially deweighting the vertical component. With a vertical weighting of 5 the vertical geometry in Figure 3 shows VDOP values of below 3 for most of the pit area.

Figure 2. Map showing LocataLite site locations, PRN numbers and the four test sites used in the backpack performance trial.

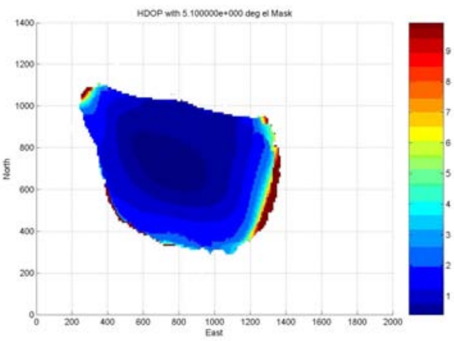


Figure 3. Expected horizontal dilution of precision from LocataNet.

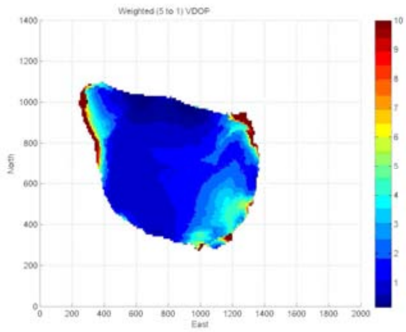


Figure 3. Expected weighted vertical dilution of precision from LocataNet.

For each site installation the LocataLite was housed in an environmental enclosure mounted within the base of a solar panel array. The solar panel array and battery allowed continuous operation of the LocataLite without requiring external power or maintenance. The two transmit and one receive LocataLite antennae were mounted on a six meter mast. The base of the antenna mast was bolted to a concrete base. The mast base included a hinge mechanism to allow the mast to be raised and lowered without unbolting the mast. During the installation, this flexibility allowed antennae to be easily adjusted to an optimal orientation. Figure 4 shows the LocataLite site setup with enclosure, mast and solar panel.

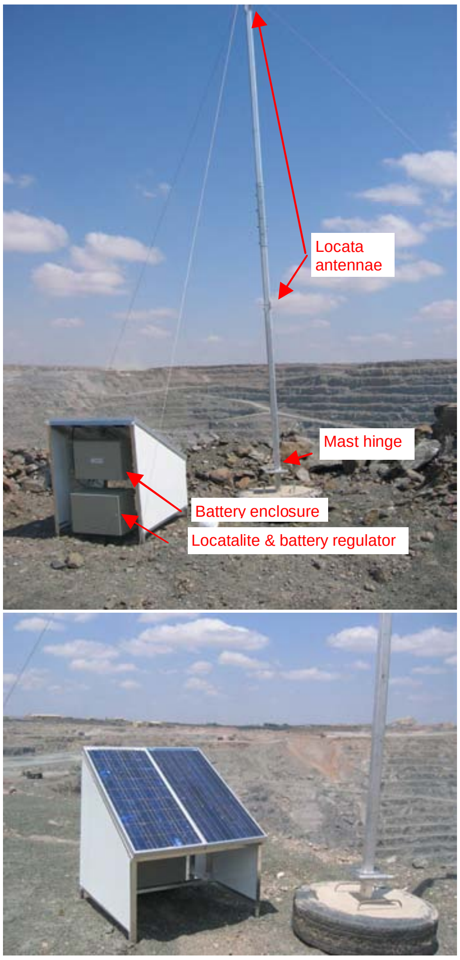


Figure 4. LocataLite site setup with mast and solar panel.

The coordinates of the LocataLite antennae were surveyed using Leica GNSS RTK and TPS (total station) equipment to provide WGS-84 Earth Centered Earth Fixed (ECEF) coordinates. Therefore coordinates from the Locata receivers are in the same system as GNSS equipment.

A backpack, dozer and drill system were equipped with integrated Leica/Locata positioning technology. All these systems comprised of a loose integration of Leica GNSS and Locata technology.

2.2 DRILL APPLICATION AND INSTALLATION

Leica Geosystems DrillNav Plus is a blast hole navigation system for drill rigs. The system graphically provides navigation guidance information to an operator, in order to follow a predefined drill pattern. The operator can visually see where each hole should be drilled and the location of previously drilled holes. In addition vertical information is provided that displays the depth of the drill bit. Position information is provided via two Leica 1200 series GNSS RTK systems. In this system, spread spectrum radio modems operating in the 2.4Ghz frequency band are typically used for the wireless RTK data link provided by the reference GNSS receiver, and for remote monitoring the location of the drill rig.

Figure 5 illustrates the components of a DrillNav Plus system, with the dashed box indicating the components installed on the drill rig. At the core of the system is the Leica control system (LCS). The LCS receives RTK data from the GNSS reference station via a wireless data link and passes this to two Leica 1200 series receivers. The antennas of the two 1200 series receivers are typically mounted on a 2 metre baseline at the top of the drill rig. The two GNSS units provide position velocity and timing (PVT) information back to the LCS in Leica's Open World Interface (OWI) format using a TPV message data structure. Using the PVT information from both GNSS units allows the orientation/heading of the drill rig to be computed. This heading information together with the known offsets between the drill bit and GNSS antennae is used to compute the position of the drill bit. By comparing position and heading of the drill bit with the predefined drill pattern in the LCS, navigation information is provided graphically to guide the operator via a day light readable display. Additionally the display is touch sensitive, providing the drill operator with a user interface control to the system.

In the integrated Leica/Locata DrillNav Plus system trialed at Venetia mine the two existing Leica 1200 series GNSS units were augmented with two Locata receivers. The Locata receiver antennae are mounted close to the Leica GNSS receiver antennae and in operation the LCS receives PVT information (in OWI TPV) from both the Leica and Locata receivers. After initialisation of the Locata rover solution using position information from the Leica receivers, positioning entirely independent of GNSS is possible. Thus if at any time after the Locata system is

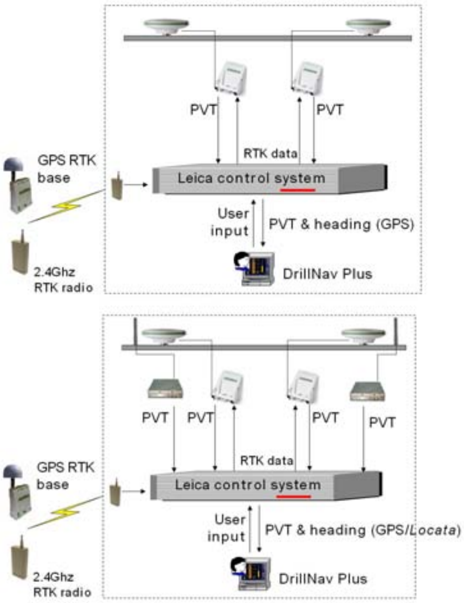


Figure 5. Components of existing Leica DrillNav Plus system (top) and Locata enabled system (bottom).

initialized the GNSS solution fails to meet specification (because of poor satellite geometry, satellite availability, loosing carrier ambiguities or wireless data link failure) the Locata receivers continue to deliver cm-level accurate PVT information to the LCS and drill operations are unaffected.

Figure 6 shows the installation of the Leica/Locata DrillNav Plus system installed on a drill at Venetia mine.

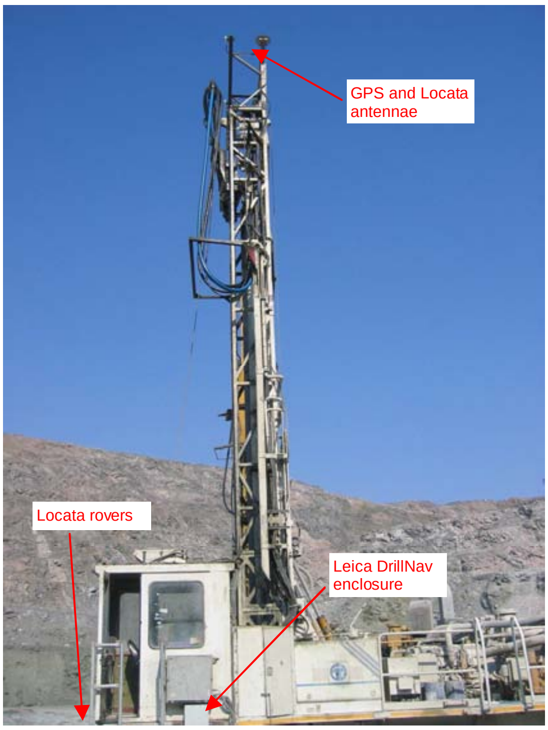


Figure 6. Drill installation.

2.3 DOZER INSTALLATION

Leica Geosystems Dozer 2000 is a machine guidance system utilizing an RTK GNSS receiver, Digital Terrain Models (DTMs) and a touch screen computer display. It reduces the requirement for survey staking and support, for moving dirt and clearing land.

The Locata receiver was integrated into Leica's Dozer system in a similar way to DrillNav plus, whereby the GNSS RTK position solution was used to initialize the Locata receiver's ambiguities. Following initialisation the Locata receiver provided PVT information into the Dozer 2000 system independently of the RTK GNSS solution. Figure 7 shows the setup of the Leica/Locata Dozer 2000 system installed on the D10 dozer. As illustrated in Figure 7 there is a fixed known offset between the GNSS RTK and Locata antennae. However in operation the orientation is unknown making the comparison between GNSS RTK and Locata more difficult.

As with the DrillNav systems, freewave 2.4GHz radios were used in the Dozer 2000 system to provide RTK corrections for the GNSS receiver and telemetry for monitoring dozer operations.

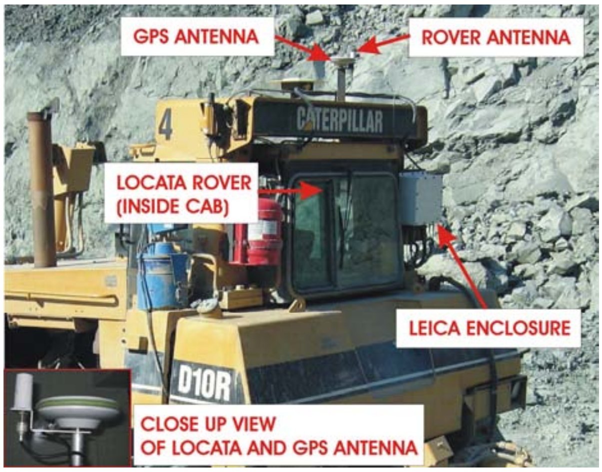


Figure 7. Dozer installation

2.4 BACKPACK SYSTEM

An integrated Leica/Locata backpack system was developed to allow rapid data collection in any area of interest in the mine without disturbing mining operations. Additionally the system demonstrates the capability of a Leica/Locata system for survey style applications. The backpack system is essentially a Dozer 2000 system contained in a backpack with a battery and a survey pole with the GNSS and Locata antennae, as shown in Figure 8.

The lever arm distance between the GNSS and Locata antennae is fixed and well known. When testing with the backpack, a constant GNSS-Locata antenna orientation was kept such that the difference between the two navigation solutions is simply a known bias; or if initializing the Locata solution from the GNSS, a zero bias.

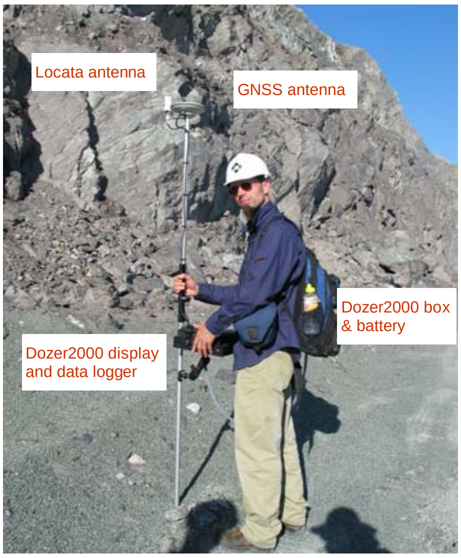


Figure 8. Backpack system.

3.0 PERFORMACE RESULTS AND ANALSYIS

During the trial data was collected to assess the performance of the three Leica/Locata integrated mining systems installed on the Drill, Dozer and Backpack. In all performance analysis a Locata-only solution was compared to a GNSS RTK 'truth' solution. Therefore performance evaluation of Locata can only be conducted where there was sufficient GNSS coverage for an RTK solution. In certain areas of the pit at certain times of the day getting a 'truth' solution from GNSS RTK was difficult due to the lack of satellite availability.

3.1 BACKPACK PERFORMANCE

Four test sites in the Venetia mine pit were established to evaluate the performance of the Locata positioning solution. The four test site are shown in Figures 2 & 9.

Figure 9. Photo showing four backpack test sites.

At each test site a diamond pattern of four points was occupied in succession using the backpack system. At each point on the diamond the receiver was stationary for about one minute, and then moved to the next point. These four points were occupied in a number of different trajectories and error statistics of Locata against GNSS were computed. Figure 10 shows typical GNSS RTK and Locata results for site 1 with the East, North and Height components time series for GPS (red) and Locata (black), with Figure 11 'zoomed' in at epochs 80 to 110. From the figures it is clear that the GNSS and Locata positioning time series compare to better than 5 cm in all three positioning components. The comparative results of GNSS and Locata for site 3 were similar to site 1.

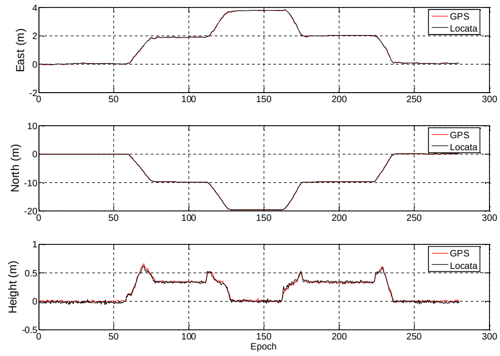


Figure 10. Backpack test site 1: typical GNSS versus Locata position solution.

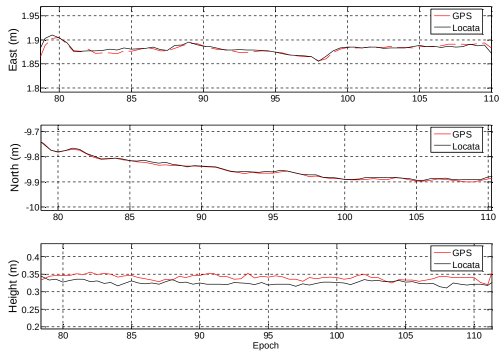


Figure 11. Backpack test site 1: typical GNSS versus Locata position solution zoomed at epochs 80-110.

Sites 2 and 4 were deliberately situated close to the pit high wall with one leg of the test trajectory as close as possible to the high wall. This was to simulate a "worst case" scenario of multipath and possible obstruction to LocataLite signals from the top of the pit rim. This situation is illustrated in Figure 12 where the LocataLite signal is obstructed by the high wall benches. In addition to signal obstruction, signal diffraction of the LocataLite signal can occur close to the high wall as illustrated in Figure 13. The diffracted signal is longer than the direct line-of-sight signal giving a significant range error. Locata has developed techniques to identify diffracted LocataLite signals so they rejected in the navigation solution.

Where there was direct line-of-sight visibility to the LocataLites for sites 2 and 4 the positioning results were similar to site 1. In the situation where LocataLite signals were obstructed or diffracted up against the high wall, in some cases there was insufficient vertical geometry for a 3D solution. Figure 14 shows one test trajectory for site 4 where there is a period around epochs 60-70 where a 2D solution is computed. Additionally the noise in the vertical component is greater at site 4 than site 1 due to poorer vertical geometry, but the solutions compare to better than 10 cm where there is a 3D solution.

It should also be noted that at times there was insufficient GNSS satellite coverage at sites 2 and 4 to obtain a 'truth solution' due to the high wall obstructing visibility to satellites.

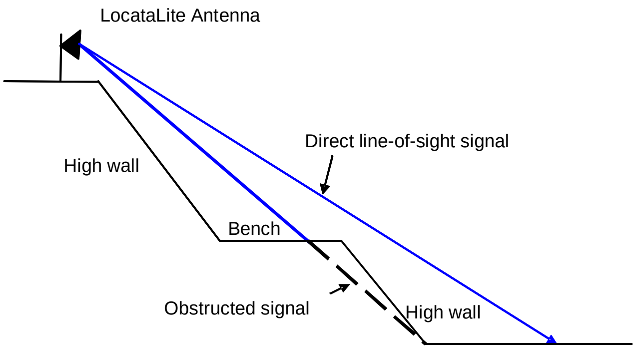


Figure 12. Obstructed LocataLite signal close to high wall.

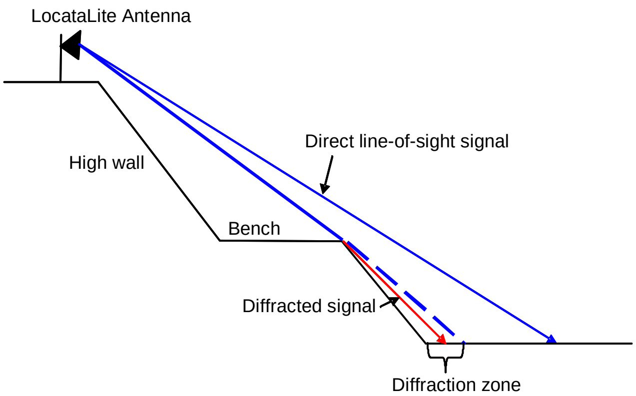


Figure 13. Diffracted LocataLite signal close to high wall.

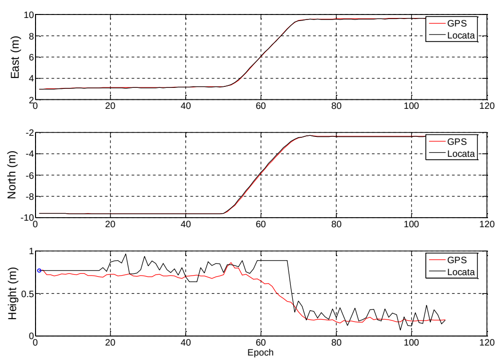


Figure 14. Backpack test site 4: GNSS versus Locata position solution.

In total 56 trajectory moves were collected at the four test sites and comparative GNSS and Locata statistics were computed. The statistics in Table 2 are the mean RMS and standard deviations from the full set of moves, Figure 15 graphically illustrates the RMS values in Table 2.

The reference positions for these statistics are the averaged GNSS position at each static location. The GNSS and Locata are statistically similar in the horizontal, with similar RMS and standard deviation values. However since GPS is used as the reference, it is expected that the GPS statistics should be better. In the trajectory moves the Locata solution was only initialized at the start and then computed solutions independent of the GNSS solution.

Static statistics at end of move summary						
	East (m)		North (m)		Height (m)	
	RMS	Std	RMS	Std	RMS	Std
Site 1						
GNSS	0.018	0.018	0.017	0.017	0.011	0.011
Locata	0.035	0.021	0.020	0.02	0.029	0.016
Site 2						
GNSS	0.026	0.026	0.029	0.029	0.014	0.014
Locata	0.045	0.031	0.044	0.031	0.201	0.088
Site 3						
GNSS	0.027	0.027	0.034	0.034	0.007	0.007
Locata	0.036	0.025	0.035	0.033	0.074	0.02
Site 4						
GNSS	0.036	0.036	0.027	0.027	0.011	0.011
Locata	0.046	0.038	0.047	0.027	0.203	0.080
Total						
GNSS	0.026	0.026	0.027	0.027	0.011	0.011
Locata	0.040	0.026	0.033	0.027	0.099	0.017

Table 1. GNSS RTK and Locata Backpack Site Summary Statistics.

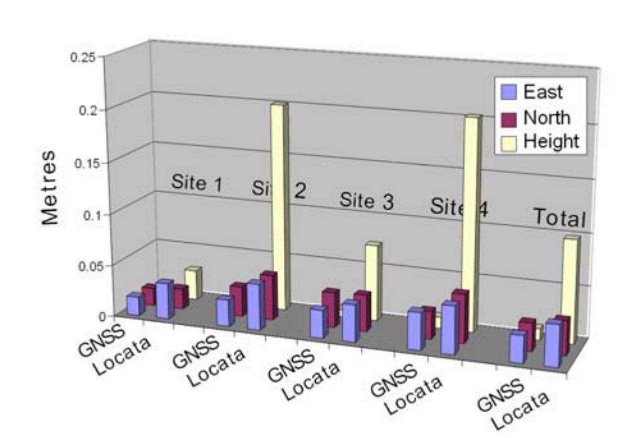


Figure 15. GNSS RTK and Locata Backpack RMS statistics.

The accuracy in the vertical component for Locata at sites 2 and 4 is much worse than the horizontal due to lack of sufficient geometry.

Points where the vertical geometry was insufficient for a 3-D solution, the Locata solution reverts to 2-D and these points are not included in the 3-D statistics. Interestingly, the GPS statistics in the height are better than the horizontal at sites 2 and 4. However the GPS geometry is also worse at these locations, and suggests that the GPS vertical solution is heavily filtered. The Locata solution is not filtered in either horizontal or vertical components. Data collected at site 1 shows both the horizontal and vertical components performing within 10 centimeters of the GNSS RTK solution and the horizontal within 4 centimeters of GNSS RTK.

3.2 DOZER & DRILL PERFORMANCE

Drill and dozer data were logged to the compact flash card within the Locata rover continuously during November and December 2006. Figure 16 shows the East, North and Height time series for one dozer work session for GNSS RTK and Locata. Due to the lever arm offset between the Locata and GNSS antennae the results comparison is more difficult since this could be up to 10 cm. However Figure 16 shows good agreement between the GNSS RTK and Locata position which is easily seen in the height time series where differences remain within 10 cm. The Locata solution was only initialised once at the start of the session and then "freewheeled". The difference between GNSS and Locata position solutions at the end of the session is less than 2cm in the horizontal and less than 10cm in the vertical as shown in Figure 17.

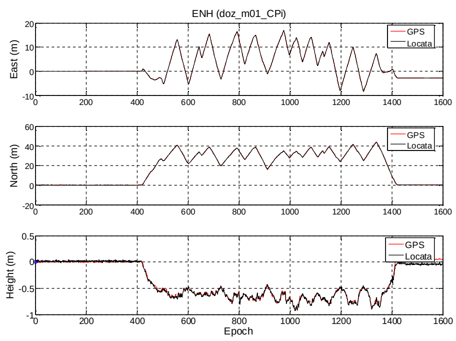


Figure 16. Dozer session: GNSS versus Locata position solution.

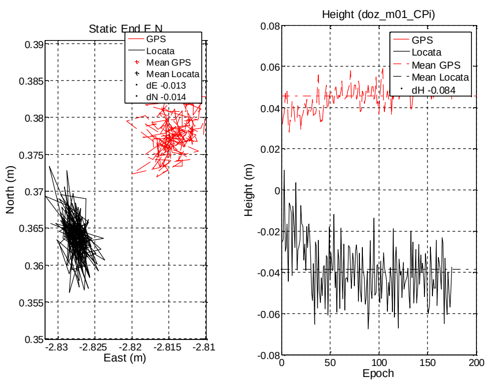
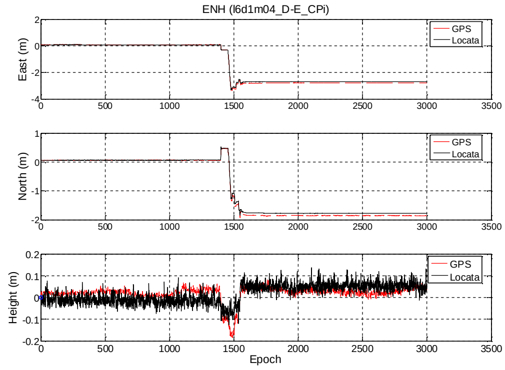
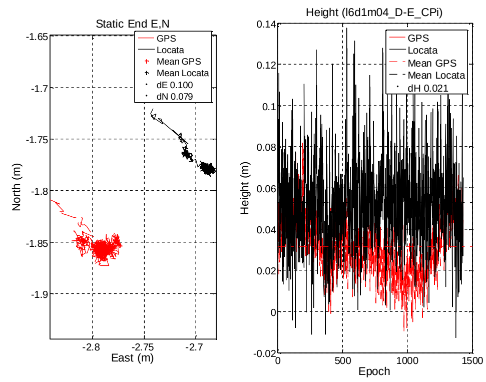


Figure 17. Dozer session: static data at end of session GNSS versus Locata position solution.

Figures 18 and 19 show the comparison between Locata and GNSS for one drill session. At the end of the move shown in Figure 19 the horizontal difference is approximately 0.1 m and the vertical is 0.02 m. These results are within accuracy requirements, but the slightly larger error than expected in the horizontal could be due to an undetected cycle-slip.





4.0 SUMMARY

In this paper details of the first "real world" mine trial for a proof-of-concept integrated Leica/Locata mining system has been discussed. In this trial a LocataNet was successfully deployed at DeBeers Venetia Mine in South Africa. Leica/Locata enabled positioning technology was installed on Drill, Dozer and Backpack systems. In all three systems the Leica GNSS RTK receiver was used to initialise the Locata receiver's position. Extensive data analysis of data collected over two months shows that overall performance is within the 10 centimeters horizontal and 20 centimeters vertical guidelines identified at the outset of the project, when there is sufficient LocataNet geometry to support a navigation solution. Overall the Locata rover tracked the Locata signals in the presence of wireless RTK data and telemetry links operating in the Locata 2.4Ghz frequency band.

Based on the success of the trial Leica and Locata are continuing to improve the proof-of-concept system with the goal to developing Locata enabled technology products for the open-cut mining market.

REFERENCES

BARNES, J., RIZOS, C., WANG, J., SMALL, D., VOIGHT, G., & GAMBALE, N., 2003a. *LocataNet*: The positioning technology of the future? *6th Int. Symp. on Satellite Navigation Technology Including Mobile Positioning & Location Services*, Melbourne, Australia, 22-25 July, CD-ROM proc., paper 49.

BARNES, J., RIZOS, C., WANG, J., SMALL, D., VOIGHT, G., & GAMBALE, N., 2003b. *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., RIZOS, C., WANG, J., SMALL, D., VOIGHT, G., & GAMBALE, N., 2003c. High precision indoor and outdoor positioning using *LocataNet*. *2003 Int. Symp. on GPS/GNSS*, Tokyo, Japan, 15-18 November, 9-18.

BARNES, J., RIZOS, C., KANLI, M., SMALL, D., VOIGT, G., GAMBALE, N., LAMANCE, J., NUNAN, T., & REID, C., 2004a. 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., RIZOS, C., KANLI, M., SMALL, D., VOIGT, G., GAMBALE, N., LAMANCE, J., 2004b. Structural Deformation Monitoring using *Locata*. *1st FIG International Symposium on Engineering Surveys for Construction Works and Structural Engineering*, Nottingham, UK, 28 June - 1 July 2004

BARNES, J., RIZOS, C., KANLI, M., PAHWA, A., SMALL, D., VOIGT, G., GAMBALE, N., & LAMANCE, J., 2005. 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., RIZOS, C., KANLI, M., & PAHWA, A., 2006. A positioning technology for classically difficult GNSS environments from *Locata*. IEEE/ION PLANS, San Diego, California, 25-27 April, 715-721.

BARNES, J., RIZOS, C., KANLI, M., & PAHWA, A., 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.