Near real-time stockpile volume calculations

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This article presents a proof-of-concept trial that was conducted at a mine in South Africa to investigate whether terrestrial laser scanning with real-time 3D computation could be adapted from space and military applications for the mining industry.

The premise being that a terrestrial system would have the benefits of fully-automated remote management, near real-time reporting, a high accuracy of data, and the output of a 3D model that could be accessed via a web interface from the mine office without additional software being installed. The area of interest was two mine stockpiles, which required volume calculations to reconcile volumes between quantity mined and quantity sent to the crusher. The trial was conducted in the first half of 2015 and involved installing a demonstration terrestrial system that was set up to run automatically over a period of six weeks. This was compared to two scheduled aerial lidar scans within the same period. The study proved that terrestrial laser scanning can be used successfully for mining topographic survey tasks and that it has numerous advantages over conventional survey methods, such as overcoming visual obstacles like dust; safety, keeping the surveyor away from the mining area; reducing manual input to a minimum; and, most significantly, making near real-time data available on the selected area as regularly as required.

Fig. 1: ROM stockpiles A1 east and A2 east.

Laser scanning technologies have been available for a few decades and are becoming an ever more accepted and affordable way of performing topographic surveys. The technology was initially restricted to military and space applications as the cost was prohibitive. Its first applications were in the field of meteorology in the United States where it was used to measure clouds; after which it was utilised during the Apollo 15 mission, in

1971, when astronauts used a laser altimeter to map the surface of the moon [1]. Today it is becoming more accessible in surveying and mapping applications.

Performing topographic surveys using laser scanning technologies is normally referred to as “lidar”, “3D laser mapping” or, simply, “laser scanning”. Lidar is an acronym for light detection and ranging and is analogous to radar, but uses a different part of the electromagnetic spectrum. Radar uses radio waves or microwaves, while lidar uses laser beams that scan a subject, creating a cloud of accurately measured points in a matter of seconds. This raw set of data, known as a point cloud, contains millions of measurements, which are accurate to millimetres or fractions of a millimetre. Each point is precisely referenced with x, y and z co-ordinates relative to all other point locations. The lidar surveys are usually either performed using a mobile platform, such as an aeroplane or helicopter, or a fixed platform on the ground. These techniques are known respectively as aerial or terrestrial lidar surveys.

Fig. 2: Scanners installed at crusher plant and 15 m scaffolding.

One of the challenges of using lidar data for topographic surveys is the size of these point clouds. Millions of points can be generated in a few seconds. Often a lidar survey of a few hours will result in data that will take days to reduce to a more manageable survey result. The different scans need to be combined into one scene, geo-referenced to a real world co-ordinate system, and often reduced to a more manageable size to be handled by traditional surveying and mapping software.

Many mines throughout the world already employ aerial lidar survey techniques for surveys and mapping. One of the applications of these surveys is a volume calculation of stockpiles. These stockpile surveys are usually performed on a monthly basis to reconcile volumes mined versus volumes in the stockpiles, or to reconcile volumes that have been mined by contractors.

When a mining group in South Africa realised the advantages that terrestrial lidar could offer them, they recognised that the data collection was relatively simple, but required the data to be reduced more rapidly to give them "close to real-time volumes". This would enable the mine to reconcile these volumes more regularly than once a month, possibly weekly, daily, or even per shift. This paper discusses how the solution to this problem could be addressed.

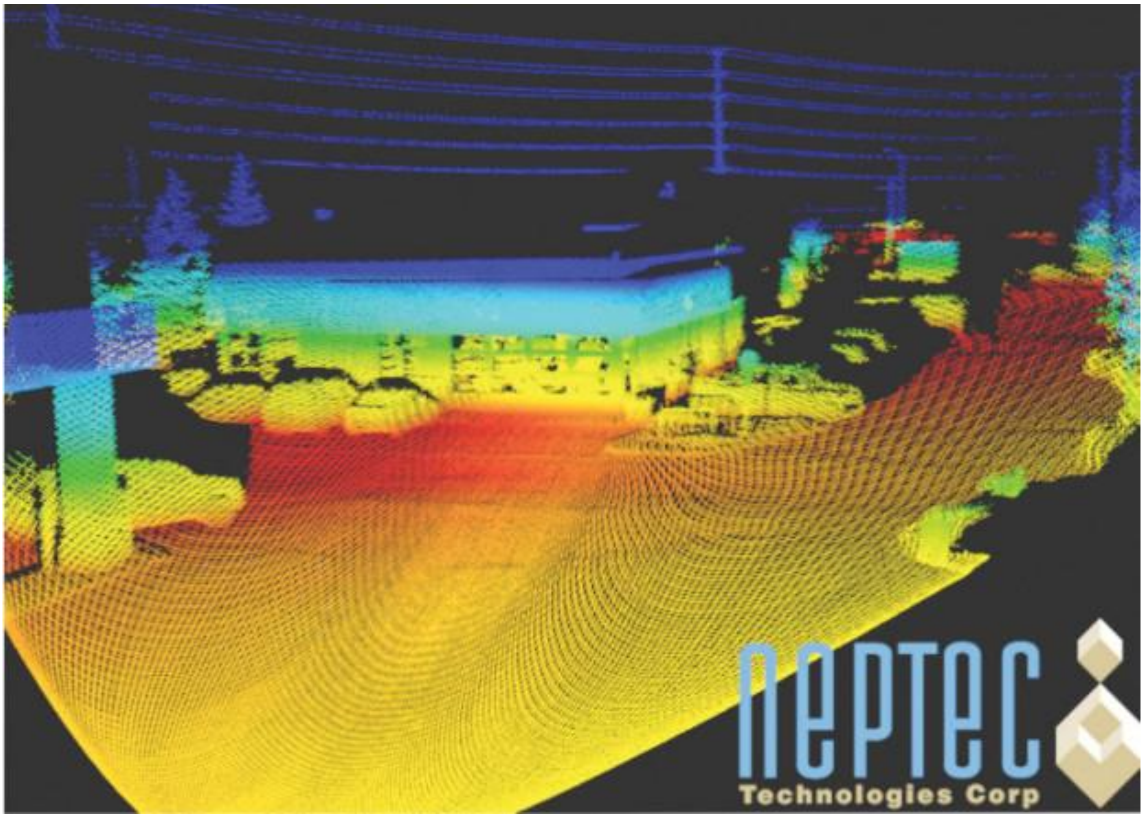

Fig. 3: Entire scan scene showing five seconds of data.

The mine in question required volume surveys of their run-of-mine (ROM) stockpiles to reconcile volumes mined with volumes that go to the crusher plant. Furthermore, they had the following additional requirements:

- The system should be remote, without the need for surveyors to physically access the stockpiles.
- Real-time, or as close to real-time as possible.
- Fully automated – or at least requiring limited manual work.
- Easy to troubleshoot.
- Remote support.
- Accurate.
- The data should include a 3D model (point cloud that is spatially referenced).

Terrestrial lidar appeared to be the best solution for this particular set of requirements. Acting as local consultants, Optron, based in South Africa, approached Trimble Mining to provide us with the hardware and software components that would enable us to build the solution. In September 2014, Trimble had signed an agreement with Neptec Technologies, a Canadian laser technology partner, for distribution and technology development specifically for the mining industry.

Fig. 4: Frame holding the scanners in position and a housing for batteries, battery charger and rugged computer running 3DRi software.

Neptec Technologies develops intelligent 3D sensor-driven automation applications for harsh environments to improve the safety, productivity and cost-effectiveness of their customers' operations. Founded in 2011, the company is a spin-out of Neptec Design Group, an award-winning innovator and NASA Prime Contractor. Neptec Technology's family of real-time 3D laser scanners called OPAL (Obscurant-penetrating Autosynchronous Lidar) and its 3DRi (3D Real-time intelligence) software technology for real-time processing of point clouds are based on technologies developed for the space market. Their 3D sensor solutions were used on 40 space shuttle missions.

Neptec technology is also used in military applications. Helicopter pilots can encounter situations of degraded visual environments (DVE) when they land or take-off in the presence of obscurants such as dust, snow, fog and smoke. Under these conditions, pilots cannot see nearby objects that provide the visual references necessary to control the aircraft near the ground. There are many reported rotary wing accidents and maintenance costs due to what is known as "brownout" [2]. Neptec developed a patented obscurant-pernetrating lidar technology specially designed to penetrate dust or degraded visual environments. This could also be very relevant in mining conditions.

As with many space and military technologies, technology development companies normally look to the mining industry to commercialise these products, which Neptec has done in this case. Not only does Neptec provide the hardware technology, but it also has very advanced 3D real-time intelligence software, called 3DRi, which is designed to solve real-world automation problems in industries like mining, oil and gas; defence and aerospace; or any field where intelligent 3D can help automate complex or dangerous tasks.

With the challenge of a South African mine requiring a near real-time stockpile volume calculation, it was an ideal opportunity to build a mine-orientated solution using terrestrial lidar and 3DRi technology and run it as a proof of concept.

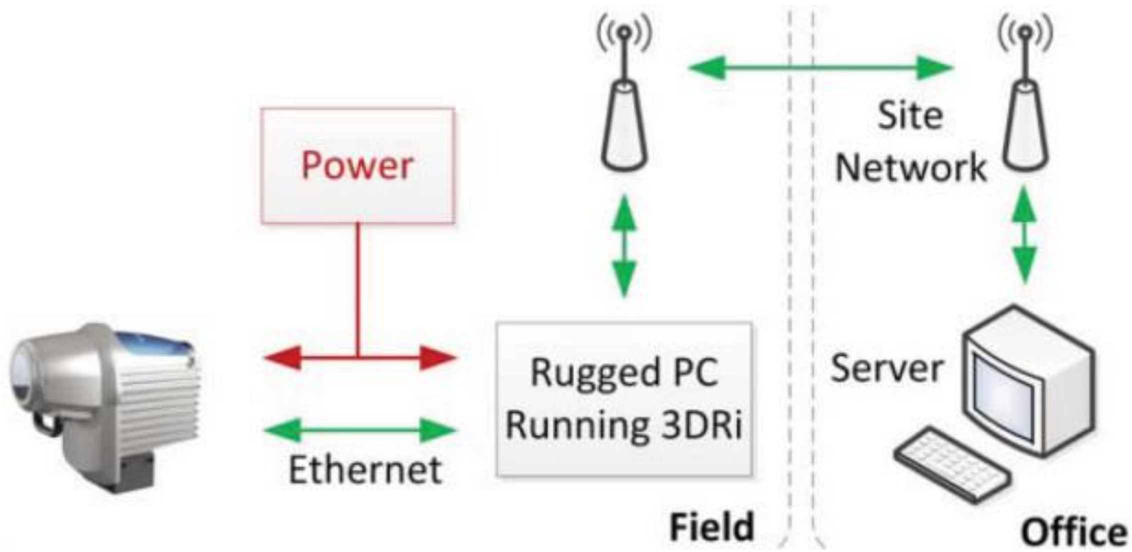

Fig. 5: Schematic showing system architecture.

Proof of concept methodology

With Trimble's distribution partner in South Africa, Optron, a demonstration was set up on the mine to test the proposed solution. Two Neptec scanners, branded by Trimble as the TMRX1 series, were used in conjunction with rugged computers with specialised software at each scanning position, as well as a WiFi radio network. The advantage of having the rugged computers and software at each scanning position is that the data from each scanner are combined, referenced and computations are done "at the point of collection", in real-time. These computed volumes are then made available to the user within a few minutes, without the user having to manually combine, reference and then compute the volumes. The volumes obtained in this manner were then compared to the aerial lidar surveys performed for the mine at a monthly interval.

This solution was demonstrated on two of the run-of-mine (ROM) stockpiles, A1 east and A2 east. The positions shown in Fig. 1 were chosen for ease of deployment within the given budget and time constraints.

The demonstration ran for six weeks to prove capability, reliability and accuracy. These stockpiles were covered using two scanners as shown in the aerial photograph in Fig. 1.

One scanner was set up at the crusher plant, denoted TMRX1-360 and the second scanner was installed on a 15 m high scaffolding at position TMRX1-120, as shown in Fig. 2. Ideally, full deployment would have these at 46 m heights to get better coverage of the stockpiles; however these positions were satisfactory for the proof-of-concept.

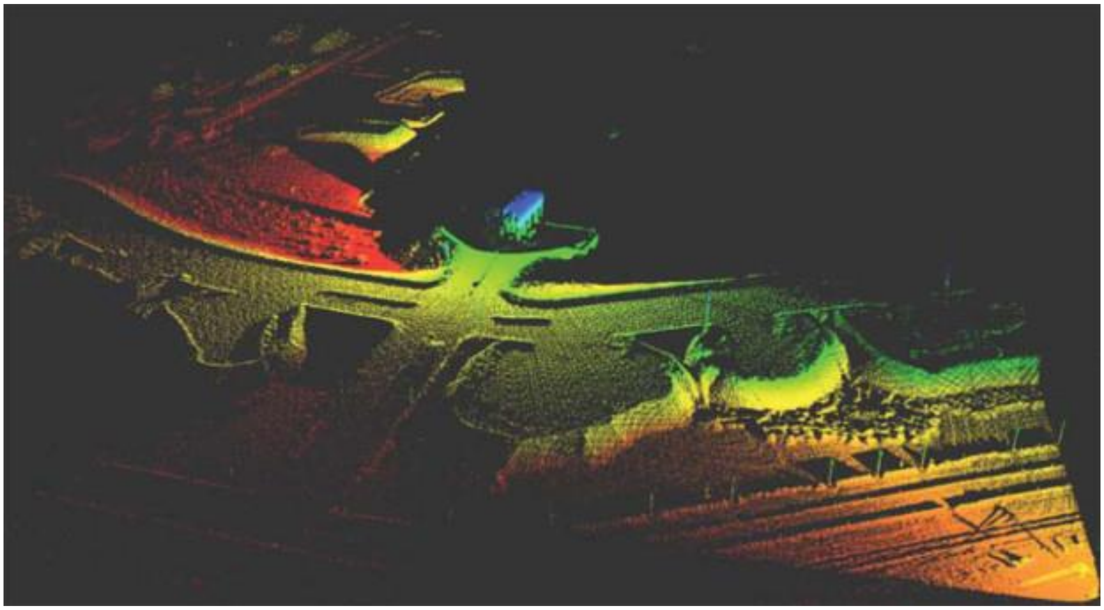

Fig. 6: Data combined from two scanners with five seconds of lidar data.

Software and hardware used

TMRX1 scanners

There were a number of models of scanner that could have worked for the trial. The decision to use a TMRX1-360HP and a TMRX1-120HP, was based on site-specific considerations such as the area to be covered and the distances to be scanned. Some of the advantages of using these scanners for this type of application are that they are:

- Extremely rugged, already proven in space and military markets. IP67 rated with a solid aluminium housing, suitable for tough mining conditions.
- No external housing with air-conditioning required.
- Vibration and shock tolerant.
- Effective scanning range of 360 m to 4000 m at the reflectivity of the stockpile material.
- 25 000 to 200 000 points per second acquisition rate, depending on application.
- Unique scan pattern to enable very quick acquisition over entire scanner area.
- Eye-safe laser.
- Penetrates obscurants like dust, fog or smoke.
- Data assimilation and all processing is done at the scanner.

Rugged computers and power supply

Each system was supplied with power via two 12 V batteries. These batteries are continuously charged by 220 V supplied by the mine. In the case of a power interruption, the batteries will continue to power the system for a number of days. The photographs in Fig. 4 reveals the system in place, which is made up of the TMRX1 scanner, the rugged computer running specialised software, and a WiFi radio. The schematic that follows in Fig. 5 outlines the entire system architecture.

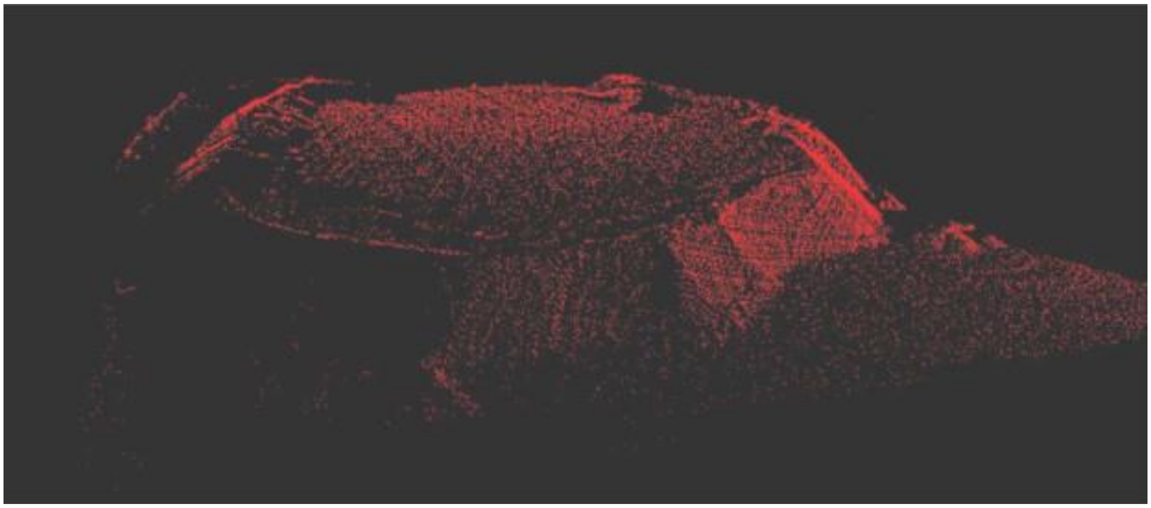

Fig. 7: Data combined from two scanners showing a shadow area that was not covered by either scanner.

3DRi stockpiles software

In combination with the scanner set-up outlined above, there is also 3DRi Stockpiles software application running on the rugged computer. 3DRi (3D real-time intelligence) is a collection of highly efficient algorithms and software able to extract actionable information from 3D sensor data in real-time. 3DRi stockpiles is a fully automated stockpile volume reporting solution that uses a small number of TMRX1 3D laser scanners deployed around a group of stockpiles to automatically monitor individual stockpile levels and accurately and consistently report their volumes. The dust-penetrating TMRX1 scanners are specifically designed for harsh environments and can be installed on conveyer structures, poles, or any existing infrastructure around the stockpiles without any special air-conditioned or heated enclosures. A network of only one to four scanners can be optimised to cover multiple large stockpiles.

3DRi software technology is used to perform all 3D data processing and volume calculations automatically right at the point-of-collection and in real-time. This eliminates both the need for costly month-end manual or aerial surveying of stockpiles, and greatly simplifies stockpile management workflows by eliminating the cost and complexity of collecting, managing and post-processing huge 3D point clouds to estimate stockpile volumes.

Acquisition and processing

The scanning schedule is configured via a web interface that runs on the installed rugged computer, and is accessed from the user's office. No software needs to be installed on any of the office computers. Scheduling, acquisition and processing is run on the rugged computer at the scanner, and accessed over WiFi using an office terminal. It can run on a schedule, or scan at the push of a button. For this proof-of-concept, it was set to calculate volumes every six hours, starting at midnight.

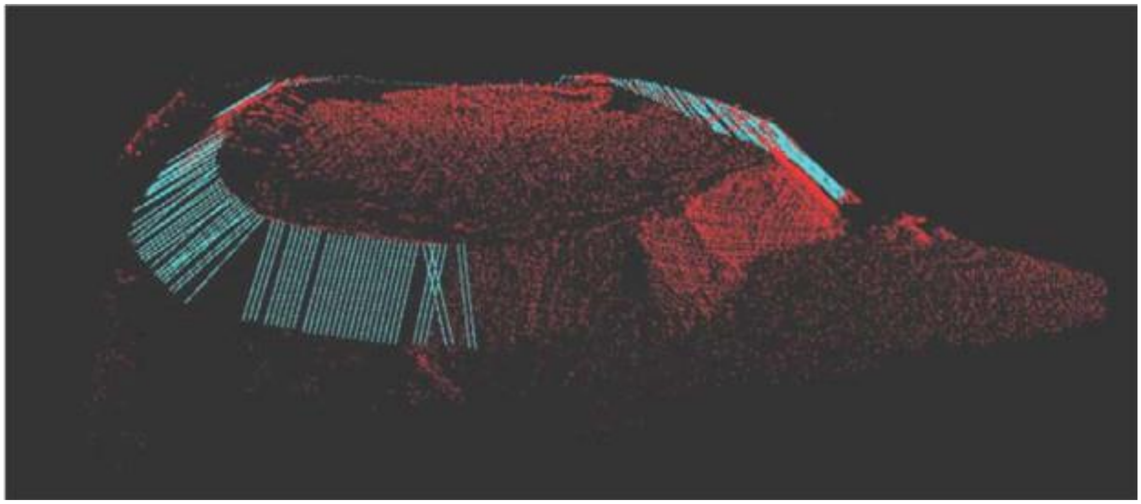

Fig. 8: Visual representation of how the additional points are added in the shadow area.

Once the scan is complete, the data is automatically combined and geo-referenced as shown in Fig. 6, which details lidar data captured for only five seconds.

For this proof-of-concept, the scanners were set to acquire data for five minutes. With this amount of data the 3DRi software is able to automatically remove any moving objects in the scan, such as haul trucks or bulldozers.

There are a number of advantages of using terrestrial lidar, but one of the possible limitations of using terrestrial lidar is that if the scanners are not installed high enough above the ground, there may be shadow areas that the scanner may not be able to survey. The ideal solution would be to install the scanners as high as possible to avoid shadowing, however this is not always practical. In this case, the 3DRi stockpile software has advanced algorithms to extrapolate points in these shadow areas.

The 3DRi stockpile algorithms identify the crest of the stockpile and compute vectors from this crest to intersect the base level or floor of the stockpiles area. This vector angle will either be computed using the slope angles of adjacent slopes, or using a known angle of repose of the stockpile, entered by the user. Fig. 8 gives a visual display of how these vectors are calculated.

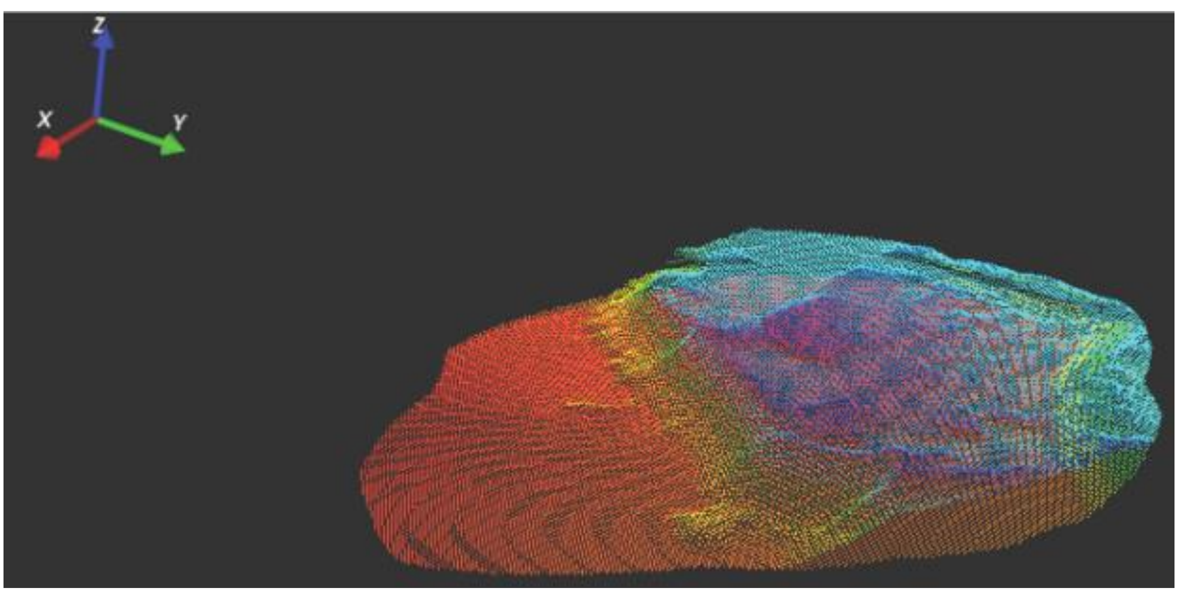

Fig. 9: The stockpile shown above the base or floor level, colour-coded according to elevation.

Once these vectors have been calculated the point cloud of the stockpile is reduced to a predefined grid, in this case 0,5 by 0,5 m. This grid interval is defined by the user and makes the point cloud far more manageable for the conventional software that is currently used by the mine. The resultant point cloud can then be imported and manipulated in that software, if required. The volumes of the stockpiles are also calculated on this reduced point cloud. This makes it unnecessary for any user intervention to arrive at the final volumes. There is no requirement to “register” or geo-reference the point clouds manually, and then to reduce the data by defining toes and crests before an accurate volume can be calculated.

Not only does the 3DRi software reduce the point cloud to a predefined grid, but it also automatically removes any “noise” in the scene, such as haul trucks and bulldozers. This is done by analysing the scan scene and removing any moving objects. Once again, no user intervention is required for this.

In this particular proof-of-concept, the floor (or base level) of the stockpiles was provided by the mine. The volumes were calculated above this base level, colour coded according to elevation as revealed in Fig. 9.

Once the volumes have been calculated automatically, they are displayed via a web interface. For this proof-of-concept this process was schedules to be automatically repeated every six hours, and each time the results were calculated in six minutes. Within the six minutes, the scanners were set to capture data for five minutes, to remove any moving machinery in the scene. The next minute was used to automatically combine the scans, calculate points in shadow areas and then to reduce the point cloud of the stockpiles. The user was then able to access the remote rugged computer to see these calculated volumes. The user was also able to download these point clouds in a .csv (comma separated value) file.

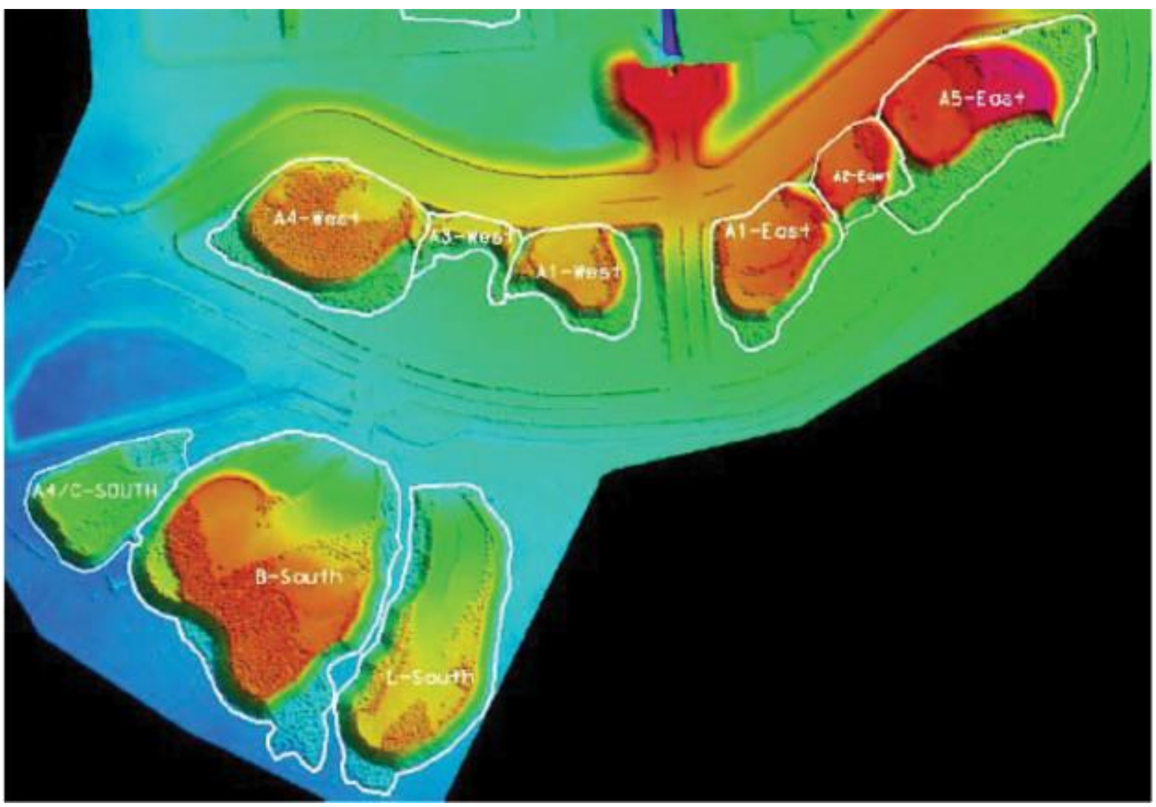

Fig. 10: Aerial lidar relief map from April 2015, note the boundary between A2-east and A5-east and how it differs in Fig. 11, as well as the many small piles.

Results

The volumes that were calculated with this Trimble terrestrial lidar system were compared with volumes that were obtained using an aerial lidar system. These aerial lidar flights were done on 24 April 2015 and 26 May 2015, and the Trimble terrestrial lidar volumes of those mornings were used as a comparison. Overall the results were very good on the larger stockpiles, less than 1% difference in volume. Keeping in mind that the entire process was automated with no user intervention required after the system was commissioned. Where there were discrepancies between the aerial lidar and terrestrial lidar volumes it was not caused by limitations in the technology, but rather other factors, including:

- Differing stockpile boundary points were used between consecutive aerial lidar flights. This is particularly evident if looking at the boundary between A2-east and A5-east in Fig. 10 compared to the boundary in Fig. 11. If the boundary had been agreed upon, this could have been uploaded as a .csv file to the 3DRi software, ensuring that the 3DRi software computed volumes using the similar data to the aerial lidar.
- As Trimble scanner is installed at a height of only 15 m above ground level for this proof-of-concept, there were many shadow areas that need to be interpolated. This is not a problem for consistent slopes, but becomes a problem when there are many small piles also shown in Figs. 10 and 11. This can be resolved by installing the scanners at a height of 46 m, and more stockpiling discipline. The design for the production system to cover all the stockpiles in the area uses four TMRX1 scanners and minimises the shadowing of individual stockpiles.
- There will be a small difference in how the Inertial Navigation System (INS) in the aerial lidar corrects the points it surveys on the ground. There is no correction needed by the Trimble scanners as they are on a stable platform and therefore more accurate and repeatable.

Detailed in Table 1 are the volumes obtained by the Trimble terrestrial system on the dates of the aerial lidar surveys.

With the scanners installed at the proposed 46 m height instead of the 15 m height of the scaffolding, there would be far less “shadowing” and therefore more consistent volumes when there are many small piles on and around the stockpile. The volumes would also be more consistent if boundary co-ordinate files were used to demarcate boundaries of the stockpiles.

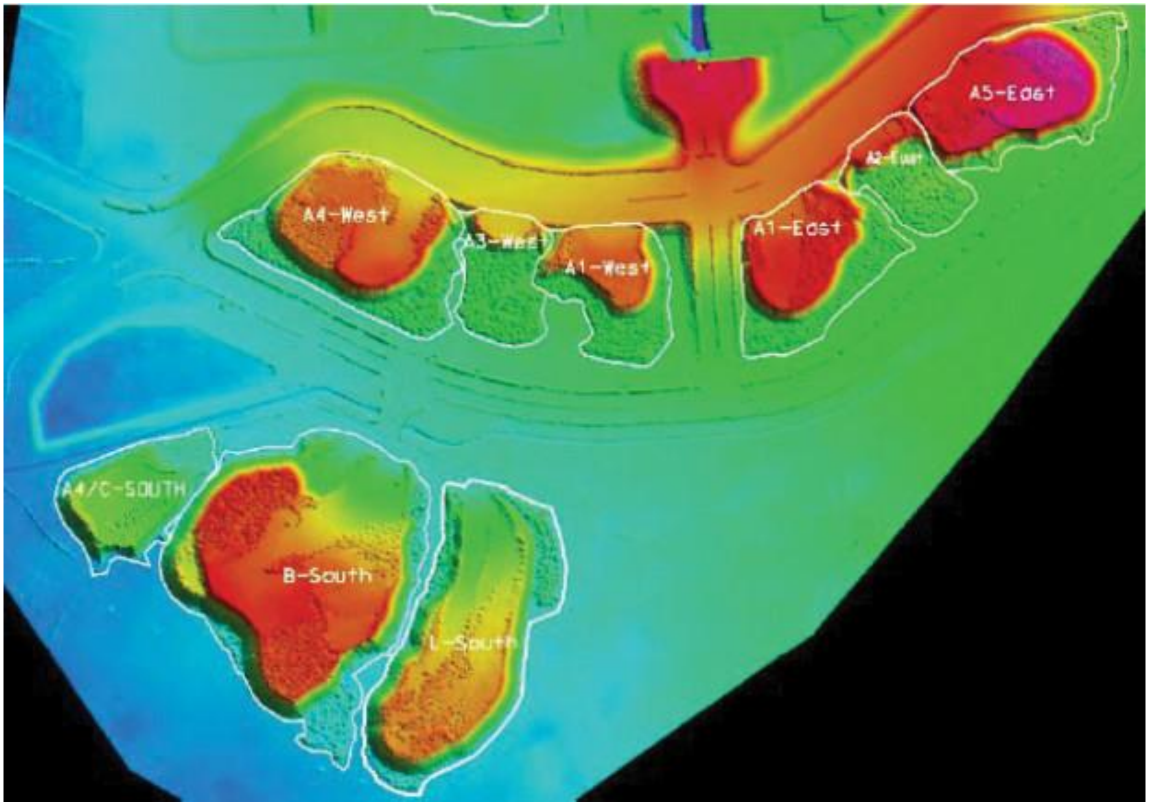

Fig. 11: Aerial lidar relief map from May 2015.

Conclusion

The proof-of-concept implementation of Trimble Terrestrial Lidar carried out by Optron on a mine in South Africa, using an integrated hardware and software solution developed by Neptec from proven space technologies showed that this terrestrial lidar solution can be used for mining volume surveys.

Over a six-week period, the system captured data every six hours. This data was computed and converted automatically and without user intervention into a volume that could be accessed remotely, within six minutes of the scan. Beyond the initial installation of the systems on site, little manual input was required as the system is fully automated and scans regularly, using a user-defined schedule and parameters. During the trial period, scans ran for five minutes to eliminate moving objects and took one minute to extrapolate findings, so generating a volume and a 3D data model in just six minutes.

The proof-of-concept fulfilled all requirements set out by the mine, namely:

- The system is remote from the active mining and stockpiling area and removes the need for surveyors to access the stockpiles physically.
- It is near real-time, and computes volumes within a few minutes. The time could be under a minute if possible obstacles in the scan area can be ignored.
- Fully automated, requiring very limited manual work after installation.
- It is easy to troubleshoot remotely.
- It was accurate – discrepancy in volumes was less than 1% when compared with traditional survey methods over the same areas and probably more accurate due to reasons outlined in the body of this article.
- The reduced data included a 3D model (point cloud which is spatially referenced).

Table 1: Differences between aerial and terrestrial lidar volumes. (*Different boundary points and poor coverage of small piles due to low scanner height.)

	Aerial lidar		**Trimble lidar**		**Differences**	
Date	**A1 east (m³)**	**A2 east (m³)**	**A1 east (m³)**	**A2 east (m³)**	**A1 east**	**A2 east**
24 April	16 7205	77 213	165 621	85 109	-1%	+9% *
26 May	19 9395	38 443	198 027	35 433	-0,7%	-8% *

This proof-of-concept proved that terrestrial lidar in mining is advantageous over conventional survey methods as it is more accurate, safer because it is done remotely, and it is available in near real-time, as often as required.

References

[1] GG Goyer and R Watson: "The laser and its application in meteorology", Bulletin of the American Meteorological Society 44(9): 564-575 [568], September 1963.
[2] E Trickey, P Church and C Xiaoying: "Characterization of the OPAL Obscurant Penetrating lidar in various degraded visual environments", Neptec OPAL White Paper, Neptec Design Group, Canada.

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