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Measuring rock dumps from space? How new technology could change the way we measure rock dumps and tailings dams

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The measurement of rock dumps' and tailings dams' volumes and tonnages has traditionally been conducted using conventional survey methodology such as manual tacheometry utilizing either theodolites and staffs or more recently total stations, laser reflectors and differential global navigation satellite system (GNSS). New technologies now exist which offer a potentially more cost-effective method to obtain this information. These techniques include land and airborne light detection and ranging (LIDAR), digital aerial photography and high resolution stereo satellite imagery. This study will compare the newer methods against the traditional methods on the basis of time taken, accuracy, cost and ease of use. The results of the assessment could be used to modify the current practices employed by Anglo Platinum's operations if they can be seen to be fit-for-purpose and more cost-effective. A test site at Rustenburg Platinum Mines' Khusuleka Mine was identified to conduct these comparisons

Introduction

Anglo Platinum Limited is currently the world's largest platinum group metal producer and at the time of writing has the largest number of platinum group metal (PGM) mining operations worldwide[1]. The Anglo Platinum mining operations are located in South Africa and as such have to comply with South African mining legislation and practices. One of the legislative requirements is the annual return to the Department of Mineral Resources (DMR) of waste rock dump, ore stockpile and residue stockpiles (tailings dams) volumes and tonnages[2]. The measurement of these features is carried out by the respective survey department of each operation and in most cases is the responsibility of the surface surveyor.

Traditional methods of measurement relied on the technique of tacheometry which enabled a surveyor to measure height and distance differences at selected points on the dump and to then calculate a volume based on these points. Estimates of density are then obtained from the dump and thus tonnages can be calculated. The process is time consuming, relatively unsafe and not particularly accurate.

Modern techniques have largely replaced the tacheometry survey method, typically using laser based total station theodolites, reflectors and differential GNSS. The modern techniques still require physically traversing the dumps; however, they are quicker and more accurate because of the speed of point data acquisition.

Recently land-based laser scanners have become popular with the mining operation's surveyors because they image three dimensional objects rapidly and provide very accurate three dimensional models of surface features. The main drawback with this technique is the cost of the instrumentation and the volume of data produced. The resultant data-set has to be interpreted using dedicated hardware and software and requires specialized knowledge which also introduces an additional cost component to what is a relatively simple exercise.

Solutions using remote sensing techniques such as traditional stereo aerial photography that yield accurate contours of the feature from large-scale photography, or alternatively airborne light detection and ranging (LIDAR) surveys which rapidly yield digital elevation models (DEMs) and digital terrain models (DTMs) of surface features are becoming more widely used but again are often considered an expensive option for a simple task. One of the most recent developments is the deployment of high resolution satellites that are capable of collecting stereo imagery of surface features at sub metre spatial resolution. Although not as accurate as LIDAR or aerial photography, this technique promises to provide an adequate measurement solution at a reasonable cost.

The more relevant of the techniques discussed above will be compared in terms of volume results, time taken, cost of acquisition, and satisfaction of legislative and governance requirements.

Test site locality

In order to conduct this comparison a site was chosen at one of Rustenburg Platinum Mines' ((RPM)—a wholly owned subsidiary of Anglo Platinum Limited)[3]—operations to assess the different techniques. Requirements were that the site had to be available over a long period of time, typically six months, and would need to be unchanged in size over this period. The Khusuleka rock dump adjacent to Khusuleka 2 shaft was chosen as it met these requirements. Figure 1 shows the location of the RPM mining operations in relation to the Bushveld Complex; Figure 2 shows the location of the rock dump in relation to the current mining operations. Figure 3 shows the rock dump as depicted by high resolution (12.5 cm/pixel) aerial photography and by way of comparison also by high resolution (50 cm/pixel) GeoEye1© satellite imagery of the same area. Both images were acquired over approximately the same period which was July to August 2009.

Legislation and governance requirements

There are two different requirements for the generation of dump and residue stockpile volumes and tonnages. The primary requirement is externally driven and is necessary to satisfy mining legislation, which dictates that dumps and residue stockpiles are measured on a yearly basis and submitted to the DMR in the form of schedules and plans.

The second requirement is internal, where tonnages and grade are required for annual mineral resource and ore reserve reporting, which is published in the Anglo Platinum

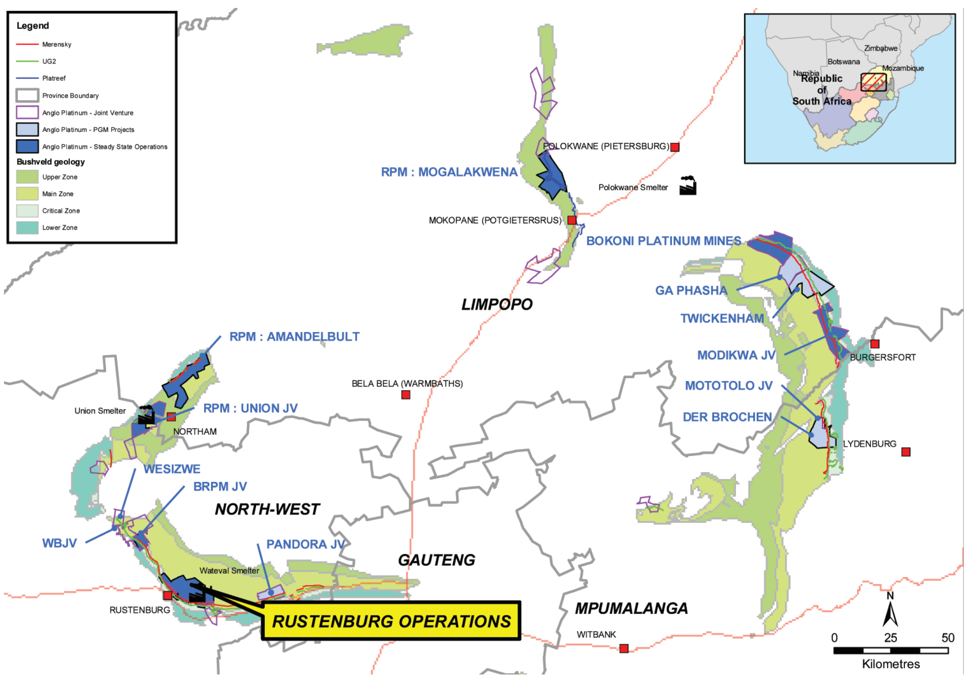

Figure 1. Location of Rustenburg operations in relation to the Bushveld Complex

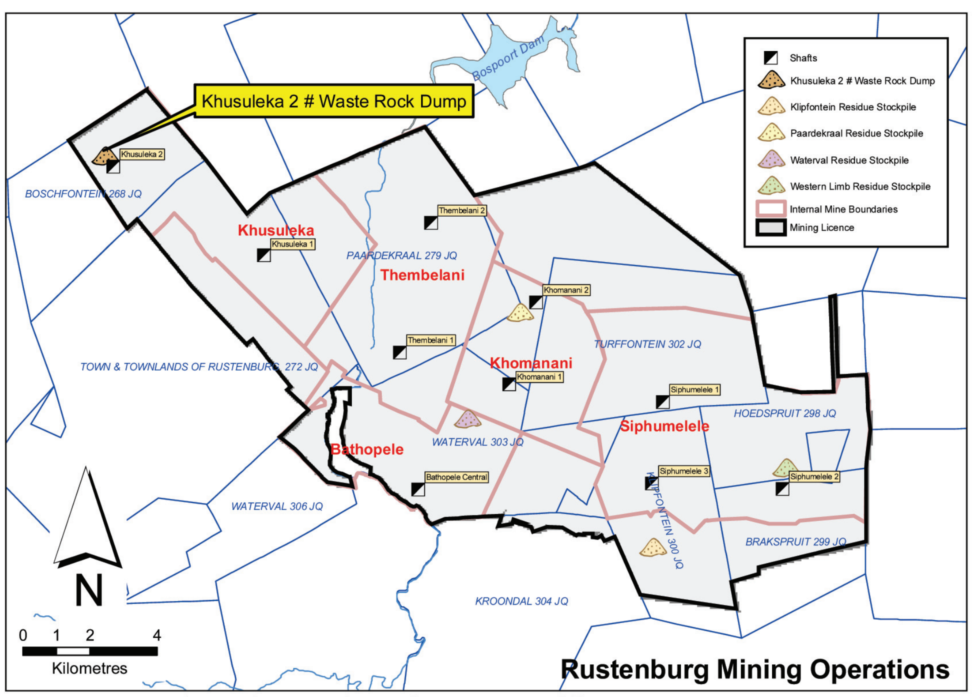

Figure 2. Location of Khusuleka 2# waste rock dump

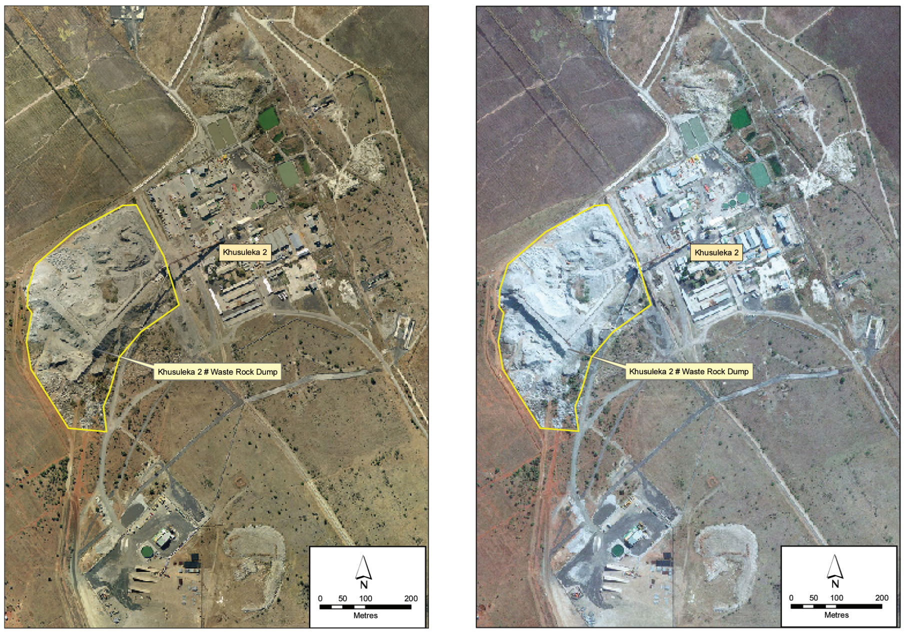

Figure 3. Aerial photograph (left) and Geoeye1 image (right) of the Khusuleka 2 # waste rock dump

Limited annual report.

Techniques assessed

In total seven different techniques are discussed below, although in practice only three are compared because the more traditional methods of tacheometry and total station have been replaced by GNSS. Thus the comparison revolves around two ground based solutions, namely differential GNSS and laser scanner vs. one remote sensing solutions namely stereo satellite imagery.

A second remote sensing dataset utilizing the airborne LIDAR technique was also available; however, it was acquired in mid 2009 and since that time the dump has changed shape and therefore does not offer a direct comparison with the dataisets collected in March to May 2010 and was not included in the comparison

Tacheometry

Tacheometry is a method of surveying, by which the positions, both horizontal and vertical, of points on the earth surface relatively to one another are determined without using a chain or tape or a separate levelling instrument[4].

The ordinary methods of surveying with a theodolite, chain, and levelling instrument are fairly satisfactory when the ground is clear of obstructions and not very precipitous, but it becomes extremely cumbersome when the ground is covered with bush, or broken up by ravines. Chain measurements then become slow and liable to considerable error. Levelling is also hampered by terrain and obstructions which results in a degradation in data collection speed and accuracy.

These difficulties led to the introduction of tacheometry, in which, instead of the pole formerly employed to mark a point, a staff similar to a level staff is used. This is marked with heights from the foot, and is graduated according to the form of tacheometer in use. The horizontal distance is inferred either from the vertical angle included between two well-defined points on the staff and the known distance between them, or by readings of the staff indicated by two fixed wires in the reticule of the theodolite. The difference of height is computed from the angle of depression or elevation of a fixed point on the staff and the horizontal distance already obtained. Thus all the measurements requisite to locate a point both vertically and horizontally with reference to the point where the tacheometer is centred are determined by an observer at the instrument without any assistance beyond that of a person to hold the staff. Using this methodology an accuracy of ~0.1 m can be achieved in terms of elevation.

Tacheometry is primarily of historical interest in surveying, as the use of total stations and differential GNSS has increased.

Total station

A total station is an electronic/optical instrument used in modern surveying. The total station is an electronic theodolite integrated with an electronic distance meter (EDM) to read distances from the instrument to a particular point.

Functions performed by a total station are inter alia:

Coordinate measurement

Coordinates of an unknown point relative to a known coordinate can be determined using the total station as long as a direct line of sight can be established between the two points. Angles and distances are measured from the total station to points under survey, and the coordinates (X, Y, and Z or northing, easting and elevation) of surveyed points relative to the total station position are calculated using trigonometry and triangulation.

To determine an absolute location a total station requires line of sight observations and must be set up over a known point or with line of sight to 2 or more points with known location.

For this reason, some total stations also have a GNSS interface which does not require a direct line of sight to determine coordinates. However, GNSS measurements may require longer occupation periods and offer relatively poor accuracy in the vertical axis.

Angle measurement

Most modern total station instruments measure angles by means of electro-optical scanning of extremely precise digital bar codes etched on rotating glass cylinders or discs within the instrument. The best quality total stations are capable of measuring angles to 0.5 arcsecond. Inexpensive ‘construction grade’ total stations can generally measure angles to 5 or 10 arcseconds.

Distance measurement

Measurement of distance is accomplished with a modulated microwave or infrared carrier signal, generated by a small solid-state emitter within the instrument's optical path, and reflected by a prism reflector or the object under survey. A typical total station can measure distances with an accuracy of about 1.5 mm over a distance of up to 1 500 metres. Reflectorless total stations can measure distances to any object that is reasonably light in colour, to a few hundred metres.

Data processing

Some models include internal electronic data storage to record distance, horizontal angle, and vertical angle measured, whereas other models are equipped to write these measurements to an external data collector, such as a hand-held computer. When data are downloaded from a total station onto a computer, application software can be used to compute results and generate a map of the surveyed area.

GNSS survey systems

GNSS survey systems have largely replaced total stations as land survey instruments and are used routinely to measure distances and elevations of surface features, and in this instance to provide xyz coordinates over the rock dump in question. Two instruments were used to improve the speed of the survey; these where the Trimble R8 (see Figure 4(a)) and the Trimble 5700 GNSS. These machines are differential GNSS machines and are an enhancement to the global positioning system (GPS) GNSS. Accuracies of sub decimeter can be achieved with the correct set-ups. The Trimble R8 uses the Trignet system and was connected to the nearest base beacon at Brits, RSA via cell phone GPRS. The Trimble 5700 is the older model and uses local known points and beacons and a radio link to the base station. The procedure employed was to obtain points at 2 m intervals around the bottom or toe of the dump and along the top edge. A nominal 2 m grid on the top of the dump was also established. The number of points surveyed with the Trimble R8 was 3740 and the number of points surveyed with the Trimble 5700 was 3746. Five different base stations were used. Problems experienced were poor cell phone reception on the western side of the dump using the R8 to connect to Brits and lack of access to certain sections of the dump.

The points captured by both instruments are shown as green dots in Figure 4(b) and the resultant 3D colour coded model in Figure 4 (c). Immediately obvious from this depiction of the location of the data points is the areas of non coverage which highlight one of the major short coming of this traverse based data acquisition system. The resultant 3D model yields a fair representation of the surface of the dump but fails to interpolate where data points are absent. Modelling was carried out using ESRI’s 3D Analyst© software which generated a triangular irregular network (TIN©) model of the surface of the dump.

Laser scanner

Ground based LIDAR or laser scanners can accurately model surface features in 3D and by extension produce extremely accurate volume calculations. In this case a Trimble GX 3D scanner (see Figure 5 (a)) was used to image the rock dump. The instrument comprises an advanced surveying and spatial imaging sensor that uses high speed laser and video to capture coordinates and image data. Millions of data points are collected and then processed using specialized software. The scanner has a range of up to 350 m to a reflective surface and can acquire data points at a speed of up to 5 000 points per second. The accuracy of the system is quoted as being approximately 6 mm over 200 m[5]. The survey of the rock dump required 44 set-ups and 88 GNSS orientation points. These were placed around the dump using the Trimble R8 GNSS to place the scanner. The survey took 9 full days spread over a month due to bad weather and other work commitments.

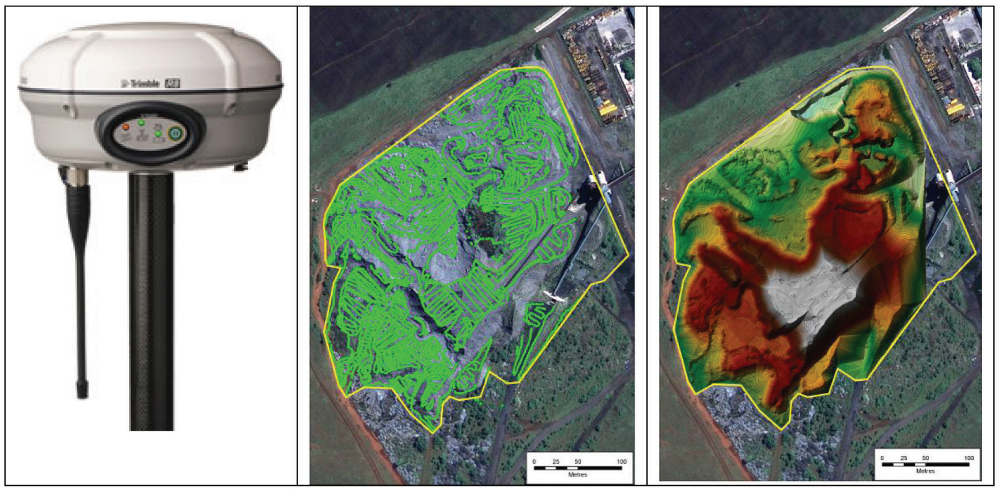

Figure 4. (a) Trimble R8; (b) location of GNSS collection points; (c) resultant colour-coded elevation model

The resultant point cloud is depicted in Figure 5(b) and indicates the density of points obtained by this technique compared with the GNNS technique. The resultant 3D model was generated using the same methodology as that GNNS data-set; however, the resultant colour-coded model (see Figure 5(c)) reveals from more detail and does not show any major areas of non data. The two methods did not produced similar tonnages and volumes (see Table II), as the GNNS values where probably underestimated due to the areas of no data. Processing problems of the point cloud revolved primarily around elimination of non-valid data points due to dust particles, vegetation and infrastructure. This led to the long processing time (see Table II) which was also enhanced by the lack of experience of the operator.

Airborne LiDAR

LiDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target[6]. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. Applications of LiDAR include airborne laser swath mapping (ALSM), laser altimetry or LiDAR Contour Mapping.

Airborne LiDAR sensors are used by companies to compliment remote sensing images. Point clouds of the earth surface are gathered and used for further processing to generate DTM and digital surface models (DSM).

In this study LiDAR data was available from a survey conducted in mid 2009; however, it could not be used in comparison with the other methods because the shape of the dump changed between collection time and collection of current survey methods (scanner, GNSS and satellite). For the sake of completeness Figure 6a shows a simplified schematic of how the technique is deployed from a fixed wing aircraft; Figure 6(b) shows the point cloud generated from the survey (decimated); and Figure 6(c) shows the resultant 3D model that was generated by the same methodology as the other methods under review. Visually this technique yields the highest resolution model and yields elevation points to within 25 cm resolution. No quantitative comparison could be conducted because of the different shapes of the dump at the time of the surveys.

Aerial photography DTM

Photogrammetry is the practice of determining the geometric properties of objects from photographic images. Photogrammetry can be dated back to the mid-nineteenth century. A sophisticated technique, called stereo

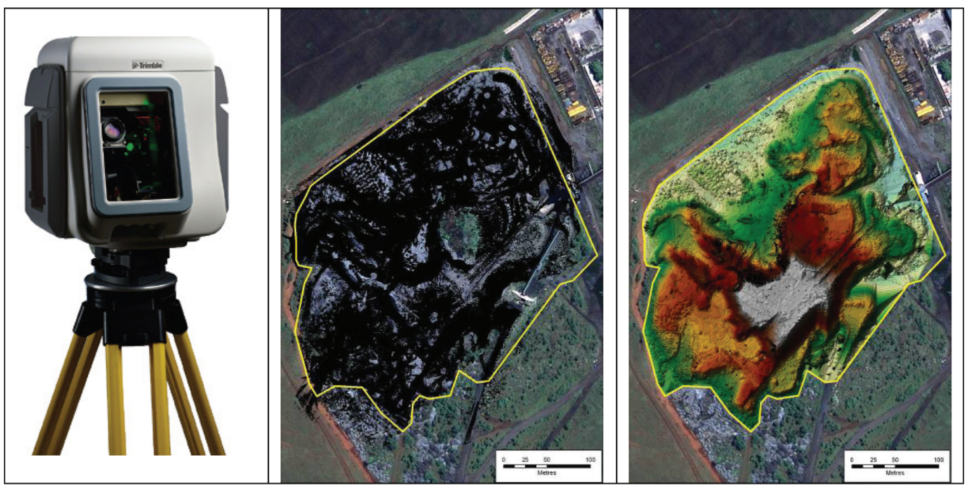

Figure 5. (a) Trimble GX; (b) land scanner point cloud; (c) land scanner colour-coded elevation model

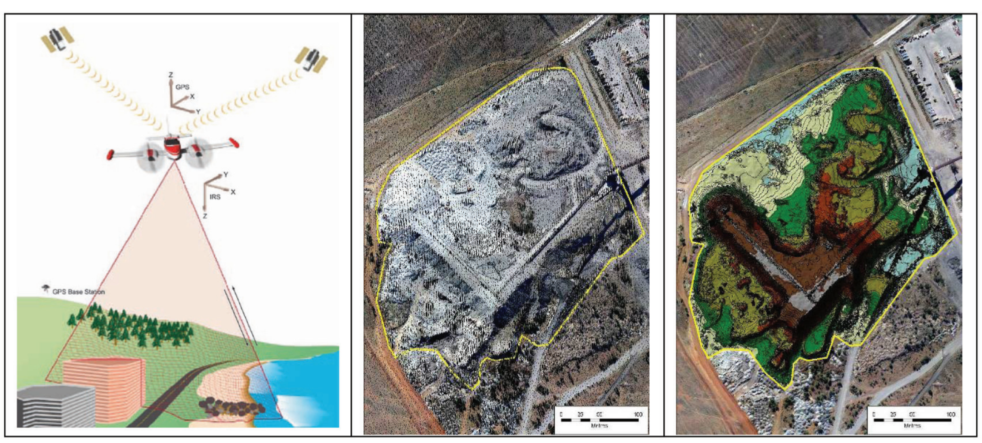

Figure 6. (a) LiDAR schematic diagram(b) LiDAR data points; (c) LiDAR scanner colour-coded elevation model

photogrammetry, involves estimating the three-dimensional coordinates of points on an object. These are determined by measurements made in two or more photographic images taken from different positions. Common points are identified on each image; a line of sight (or ray) can then be constructed from the camera location to the point on the object. It is the intersection of these rays (triangulation) that determines the three-dimensional location of the point.

Photogrammetric data with dense point data from remote sensing surveys complement each other. Photogrammetry is more accurate in the x and y direction, whereas range data is generally more accurate in the z direction. This range data can be supplied by techniques such as LiDAR, laser scanners (using time of flight, triangulation or interferometry), white-light digitizers and any other technique that scans an area and returns x, y, z coordinates for multiple discrete points (commonly called ‘point clouds’). Photos can clearly define the edges of buildings when the point cloud footprint can not. It is beneficial to incorporate the advantages of both systems and integrate it to create a better product.

As discussed above this technique could not be utilized in this comparison despite the survey data being available over the dump in question. The LiDAR survey and resultant aerial image survey was conducted in 2009, at which stage the dump was larger than it is now and therefore could not offer a true comparison to the current data-sets being discussed here.

Satellite imagery stereo pair DTM

The use of stereo satellite imagery to determine DTM surfaces has been in use from 2004 when high resolution imagery was made available to non-military, commercial users[7]. The technique employed in this test was to obtain two GeoEye1© pan-chromatic scenes and to apply a series of fundamental and well-established photogrammetric techniques to extract elevation information. The basic approach is a bundle adjustment using a unified, weighted least squares method[8]. The adjustment solves for the exterior orientation parameters and 3-D coordinates of all measured ground points by minimizing the sum of the squares of the image residuals.

The process creates normal equations for the least squares solution by explicitly forming the partial derivatives of the sensor's observation equations with respect to the unknown sensor parameters. Since the observation equations are non-linear, the least squares solution must iterate until it meets the adjustment's convergence criteria. All unknown parameters are weighted, thus providing a robust method of adjusting the parameters.

Upon convergence, the process generates a three-dimensional object grid for each photo. These grids are used to generate a set of rational function coefficients that can be used for either real-time compilation of planimetric and terrain features or orthorectification. Accuracy estimates for the exterior orientation parameters and points are computed using standard error propagation techniques.

After having performed the triangulation of the satellite scenes successfully, the Generate Rational Functions command was used to update the model files for use with Z/I Imaging data compilation applications.

This allowed for a 1m spaced DTM to be generated which was then contoured in 25 cm, 50 cm and 1 m intervals.

The satellite used for this test was GeoEye1© (see Figure 7(a)) operated by GeoEye Limited. The imagery was acquired 30 April 2010 and was classified as cloud free. Table I shows the current specifications of the GeoEye1 satellite.

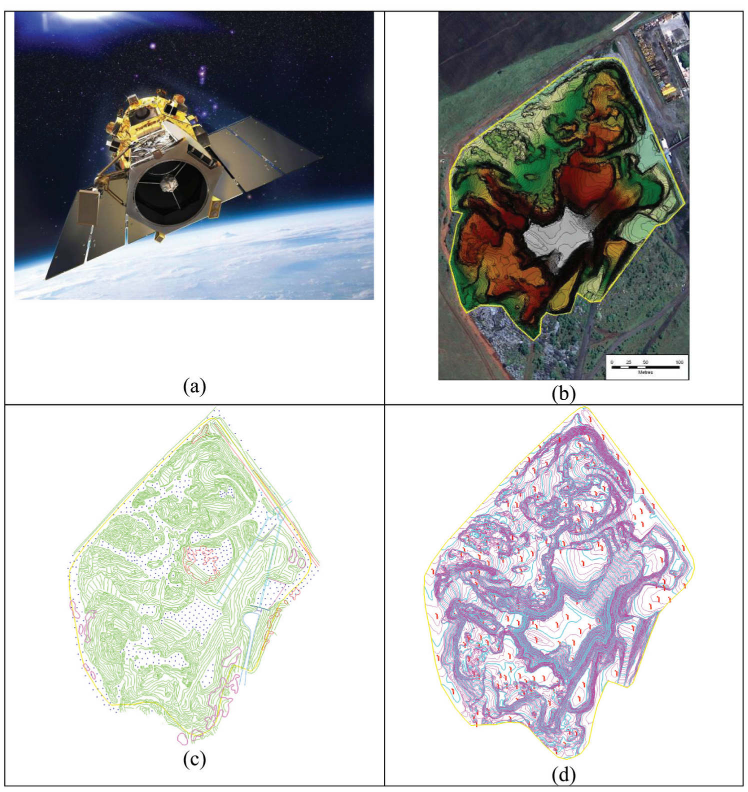

Figure 7. (a) GeoEye 1 satellite; (b) 3D colour-coded model; (c) planimetric interpretation showing surface features (d) 25 cm contour map of the Boschfontein rock dump

The processing of the resultant imagery was carried out by Pacific Geomatics Limited and the DSM generation was conducted by 4DGIS Limited. Both companies are based in Vancouver, Canada. Processing turnaround from acquisition to delivery of final 25 cm contours totalled 9 days.

As with the other techniques a 3-D model was generated for the resultant xyz data points and is shown in Figure 7(b). Figure 7(c) depicts the surface features that were extracted from the satellite imagery and Figure 7(d) depicts the resultant 25 cm contour map of the mine dump.

Results

Table II shows various metrics from the different techniques

Analysis

The land scanner results and the satellite stereo imagery results compare very favourably and are within 2% of each other, whereas the GNSS survey result was greater than 5% different from the other two values. This can be ascribed to different footprints being measured resulting in a discrepancy of ~100 000 tonnes between the results. The LiDAR ground scanner results can be treated as provisionally representative of the dump but would need verification by an updated GNSS survey over the same footprint.

To adequately compare the results of the satellite against the land based survey methods, there should be two or more comparable results against which to compare. As this was not the case then firm conclusions cannot yet be drawn other than to state the satellite results are provisionally comparable to the land scanner results.

The LiDAR tonnage results could not be used for comparison because they represented the state of the dump a year earlier than the state it was in when the GNSS, land scanner and satellite imagery results were collected.

Table I
Specifications of the satellite GeoEye1©

GEOEYE-1 specifications	
Spatial resolution	Panchromatic sensor— 0.41 metres × 0.41 metres Multispectral sensor—1.65 metres × 1.65 metres
Spectral range	450–800 nm 450–510 nm (blue) 510–580 nm (green) 655–690 nm (red) 780–920 nm (near IR)
Swath width	15.2 km
Off-nadir imaging	Up to 60 degrees
Dynamic range	11 bits per pixel
Mission life expected	> 10 years
Revisit time	Less than 3 days
Orbital altitude	681 km
Nodal crossing	10:30 a.m.

Cost-effectiveness

It is difficult to produce equivalent cost components for each technique because of a number of either hidden or indeterminable costs. However, a qualitative assessment can be carried out which takes into account some of the cost benefits of each method.

Ground based GNSS

The ground based GNSS survey is still a cost-effective method to use when trying to obtain tonnages of surface rock dumps. However, it is time consuming, limited by accessibility and potentially unsafe for the surveyor. The results obtained in this test would have been comparable with the other methods without the access problems encountered. The survey cost the same or more in some cases (see Table II).

Land scanner

The use of a Trimble GX Scanner is an effective method to obtain an accurate 3-D model of the rock dump being assessed. It is also, however, a time consuming process and requires specialist skills to produce efficient cost-effective results. The initial cost of the equipment is the biggest negative factor for this method; however, if a contractor is used with its own equipment then the unit cost would rise but would be offset by the lack of capital investment.

Airborne LiDAR

If the survey area is large and covers a large number of rock

Table II
Comparison of results from the land based and airborne survey techniques

Technique	Footprint (m^2)	Volume (m^3)	Tonnage (Mt)	Time taken to survey	Time taken to process	Cost estimate	Accuracy Rating***
Differential* GNSS	77 710	633 523	1.2	9 days	5 days	R50 000	90%
Land Scanner	98 286	710 111	1.3	9 Days	10 days	R75 000 (Excluding instrument costs)	100%
Airborne** LiDAR	91 415	800 644	1.5	1 days	5 days	Total cost R450 000	100%
Satellite stereo imagery	103 540	721 784	1.3	1 day	10 days	R40 000	100%

Notes:
* Tonnage lower than expected due to reduced accessibility
** Data collected over the dump in 2009 when it had significantly more volume. The difference is the amount the size has reduced.
*** Estimate of percentage of total volume captured
Green shading—provisionally comparable results
Pink shading—results excluded and need to be gathered again to be included in a future comparison

dumps that need assessing, as is the case with the Rustenburg operations, then LiDAR is potentially a cost-effective solution to providing the necessary information. The turnaround in general is quick (usually counted in weeks) and the results exceed the required accuracy. Negative factors are, however, adverse weather conditions and high relative costs compared to satellite imagery. Further work needs to be conducted to provide the requisite direct comparisons between, GNSS, LIDAR, ground scanner and high resolution satellite imagery

High resolution satellite imagery

The implementation of stereo satellite imagery techniques to provide accurate volume calculations of rock dumps is potentially the most cost-effective solution to providing the information required. Positive factors are quick turnaround, fixed cost per job, and delivery of the required accuracy. The only drawback with this methodology is the limitation imposed by weather conditions. If the information is required annually only and it is acceptable for it to be obtained in the winter months, then this methodology could be adopted.

Summary

Volume calculations and hence tonnage estimates over a waste rock dump at the Khusuleka 2 Shaft Complex on the RPM's mining operations at Rustenburg were obtained using four different techniques. The objective of the test was to compare cost-effectiveness, accuracy and ease of use of each technique with a view to derive best practice guidelines for futures tonnage measurements.

The results from two of the four techniques were provisionally directly comparable and indicate that satellite stereo imagery DTM generation is potentially a cost-effective solution; however, if results are required within a specific time frame that precludes the collection of the satellite image, then Airborne LiDAR is provisionally the next best option, although this still needs to verified. Traditional land based survey methods using GNSS and total station can in certain instances be replaced with the remote sensing techniques assessed in this test once further testing against all four techniques has been conducted and if manpower is limited and accessibility is a problem.

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Jim arrived in RSA in 1983 from the Middle East after working in seismic exploration business and started working in a gold mine as a geologist. I then joined the J.C.I. Geophysical Team in 1985 as a seismic interpreter and worked under Mr G. Campbell for ten years. I returned to geology in 1995, built up the GIS capacity in J.C.I. until 2000 when the company folded. I ran my own GIS consultancy for six years and then joined Anglo Platinum Limited full time in 2006. I have worked since then until September last year within the Geology Department, however due to restructuring, I now report into MRM survey and systems. I am responsible for GIS functionality in MRM Survey.