RECENT ADVANCES IN REMOTE GEOLOGICAL AND GEOTECHNICAL SURVEYING

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ABSTRACT

Following a recently well-publicised Corporate Manslaughter trial against a small geotechnical consultancy, QuarryDesign reviewed their Health and Safety Policy and their working practices to see if there were any remaining potentially dangerous practices still being employed.

In reviewing their processes, they found that employees obtaining geological and geotechnical rock-mass data could potentially inadvertently break the Company's safety rules for obtaining this data and place themselves in a position of unacceptable risk. In order to ensure that this was not possible, QuarryDesign decided to undertake a study of modern surveying techniques and associated software to determine if these risks could be practicably ameliorated.

This paper presents their findings into long-range high-definition LiDAR (laser scanning) and its application to safely obtaining geological and geotechnical data in the UK Quarrying Industry and takes its inspiration from practices currently employed in the large open-pit mines associated with precious metals and minerals.

Wilkinson, A. P., 2014. Recent advances in remote geological and geotechnical surveying.
Pp. 147-155 in Hunger, E., Brown, T. J. and Lucas, G. (Eds.)
Proceedings of the 17th Extractive Industry Geology Conference, EIG Conferences Ltd. 202pp.
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INTRODUCTION

This last paper of the EIG 2012 conference was presented as a highly pictorial presentation with numerous photographs, videos and live manipulation of data. What follows is an attempt to turn this graphical paper into a technical paper worthy of that Proceedings.

When this paper was accepted by the EIG Organising Committee, many of the techniques presented at the conference were in their infancy in the UK Extractive Industry. As computer based systems double their power every two years (a general approximation known as Moore's Law originating around 1970), then by the time these Proceedings are published it is more than likely that many more hardware systems and software solutions will be available than described herein.

Elements of this paper have already been covered in another paper from the EIG 2012 conference, namely Ian Brewer's paper on Dolyhir Quarry (Brewer et al, 2014) which shows the wide range of applications and industry take-up of these systems in the relatively short time that they have been commercially available.

It should be noted that the techniques presented in this paper reflect how the author uses these techniques in his role as a geologist/geotechnical engineer. He does not profess to be an expert in the mechanics of LiDAR (Light Detection and Ranging), photogrammetry or UAV (Unmanned Aerial Vehicle) systems.

Following the first successful prosecution of a Company and its Directors under the case of Corporate Manslaughter in the UK, QuarryDesign decided to review its practices and to see if there were any remaining potentially dangerous practices still being employed. The results of that review identified that it could be possible for a geologist to inadvertently stray into potentially dangerous locations while obtaining discontinuity data (vital data for determining accurate final quarry design criteria). Conversely, and potentially just as important; by only collecting data from safely accessible parts of the quarry (low quarry faces, low faces at the ends of haul ramps and within the reach of a geologist), then the subsequent analysis of that limited data could be incorrect and a potentially dangerous failure of the rock-mass could occur as a result of a flawed analysis and incorrect quarry design criteria being issued.

TRADITIONAL SURVEYING AND GEOLOGICAL MAPPING TECHNIQUES

'Traditional' survey systems comprise of either Total Station systems (Figure 1) or Global Navigation Satellite Systems (GNSS) (Figure 2).

Total Station systems can be manual (2 man) systems with one man tracking the prism held by the second man; or robotic (1 man) systems where the theodolite

Figure 1. *Total Station in use.*

Figure 2. *GNSS in use.*

tracks and follows the prism held by the surveyor. Modern total stations also incorporate reflector-less systems that enable the surveyor to record features without a prism making them particularly suitable for recording the crests of face locations.

GNSS (of which the well-known GPS is one system) can be either Real Time Kinematic (RTK) systems adopting an on-site base-station to provide corrected location information to a rover held by the surveyor; or a network RTK that uses a GPRS mobile phone network to provide corrected location information to a rover held by the surveyor.

Both total station and GNSS systems have their own strengths and weaknesses and most surveyors will have both systems at their disposal.

Geological mapping has traditionally encompassed recording data obtained by visual observation, hand-samples removed from the rock-mass or dip and strike data obtained directly from the rock-mass by a hand-held compass-clinometer (Figure 3). These data are usually recorded on a paper plan or in a notebook.

The advantages of collecting data manually in this way are that it is tangible data (data collected in this manner is accepted by the geological community as reliable data) and it can be collected accurately with simple training and inexpensive equipment (a compass-clinometer and notebook).

The disadvantages of using this method are that it requires direct contact with the rock-face and therefore can only be safely collected from low quarry faces. It is also limited to data within the reach of the geologist. Finally, a geologist working on a low quarry face at the end of a haul ramp may, by working along that face, inadvertently stray into an area of potentially dangerous higher sections of the face. By virtue of their location on a haul road, the geologist is also potentially working with the added risks associated with a proximity to mobile plant.

REMOTE SURVEYING TECHNIQUES

In researching possible remote survey methods, QuarryDesign looked at several photogrammetric software solutions and several LiDAR systems.

Photogrammetric solutions are relatively inexpensive, requiring a good quality camera from which to obtain sharp photographs (the sharper the images the more accurate the resultant 3D model) and a photogrammetric software package. The camera invariably needs to have a calibrated lens and in order to produce 3D models at different distances a series of calibrated lenses at different focal lengths will be needed (wide angle for short-range modelling to telephoto for long-range modelling). Depending on which photogrammetric package is used then either the relative position of the camera needs to

Figure 3. *Traditional geological/geotechnical mapping.*

be known or the relative positions of features in the photographs needs to be known. Obtaining these positions usually requires the use of additional surveying equipment.

The advantages of photogrammetric modelling over traditional manual systems are that on-site data collection is generally rapid, data is collected for the whole of the study area (not limited by the height of the geologist), accurate modelling enables discontinuity data to be obtained in the office not in the field, and accurate cross sections can be produced for rock-fall analyses. As surveying equipment is usually required to reference the stereo-photographs it is easy to geo-reference the resultant photogrammetric point-cloud. Finally, a permanent record is created that can be referred back to if need be.

The disadvantages are that it needs reasonable visibility; it cannot be used directly into the sun, in snow, thick fog or intense rain, it needs targets in the photograph or the camera location to be known which usually requires additional survey equipment, the camera and lenses require regular (annual) calibration, the camera is set-up on a heavy tripod to avoid movement and so, along with the necessary survey equipment, quite a lot of equipment needs to transported to site. Finally, although good quality 3D models are produced from which discontinuity data and rock-fall sections can be determined, its repeatability was not sufficiently proven by the author to be used for rock-fall monitoring.

LiDAR (Light Detection and Ranging) or laser scanning has been around and used in the extractive industry for a number of years and is the principal that most of the blast engineer's face-profiling equipment is based upon. LiDAR systems are highly diverse and vary from ultra-fast acquisition, ultra-high resolution, short-range scanners for indoor modelling (F1 teams use these scanners to model their vehicles to undertake virtual PC based wind-tunnel testing) to low-resolution, long-range LiDAR scanners more suited to producing exterior building or topographical surveys. Compared to photogrammetric systems they tend to be more expensive; a high quality LiDAR scanner will cost around £75,000-£125,000. It is important to use the correct LiDAR scanner for the specific task as a short-range scanner will not be able to scan across the width of a quarry. Further, a long-range scanner with poor range accuracy or wide beam divergence can be used for topographical work, but a long-range scanner with high range accuracy and narrow beam divergence will be required for remote discontinuity analysis, rock fall analysis and rock fall monitoring.

The advantages of using LiDAR scanners over traditional manual systems are that the collection of data can frequently be collected from outside the quarry or from designated safe areas within the quarry, as shown in Figure 4. This greatly reduces the residence time of the geologist in the quarry, though some data, notably joint roughness, joint infill etc. still needs to be obtained by eye but requires less time at the face than required for recording dip and strike data. Data from the full quarry is obtained and is not restricted by the height of the geologist. The resultant model is a permanent record and can be referred back to if need be. For discontinuity analyses a scanner levelled on a tribrach on a tripod can be simply orientated using a compass. Additional survey equipment is only needed if the resultant 3D model is to be geo-referenced.

The disadvantages of LiDAR scanners are that they are expensive and in general require reasonable visibility and clement weather. Whilst they can work at night, they cannot work in thick fog, rain, snow or particularly dusty conditions. They also need regular (annual) calibration. The equipment is quite bulky (scanner, batteries, tripod) and requires the use of a site vehicle (but as discussed above only to a safe peripheral area of the quarry).

At the end of their research, QuarryDesign decided to adopt a LiDAR based system provided by the Canadian company Optech. At the time of their research, this LiDAR unit (ILRIS-3D-ER) had the greatest range-accuracy and narrowest beam divergence of any LiDAR scanner with a maximum range approaching 2,000m.

At the time of writing this paper, QuarryDesign had also acquired a photogrammetric package for use with their GeoCopter Unmanned Aerial Vehicle (UAV) to provide aerial derived point-clouds of topographical features (notably tips, lagoons, stockpiles and recently a specific request to provide an accurate survey of rock-traps between the toe of a face and a well-used haul road).

Figure 4. *LiDAR scanner in use. The red rectangle indicates the scan shown in Figure 5.*

LIDAR SCANNING AND POINT CLOUDS

In essence LiDAR works by applying the speed of light (approximately 0.3 meters per nanosecond) for a given pulse of light generated on a given local bearing. Using that constant, the instrument can calculate how far a returning light photon has travelled to and from an object using the equation

Distance = (Speed of Light x Time of Flight) / 2.

This is done in the following way:

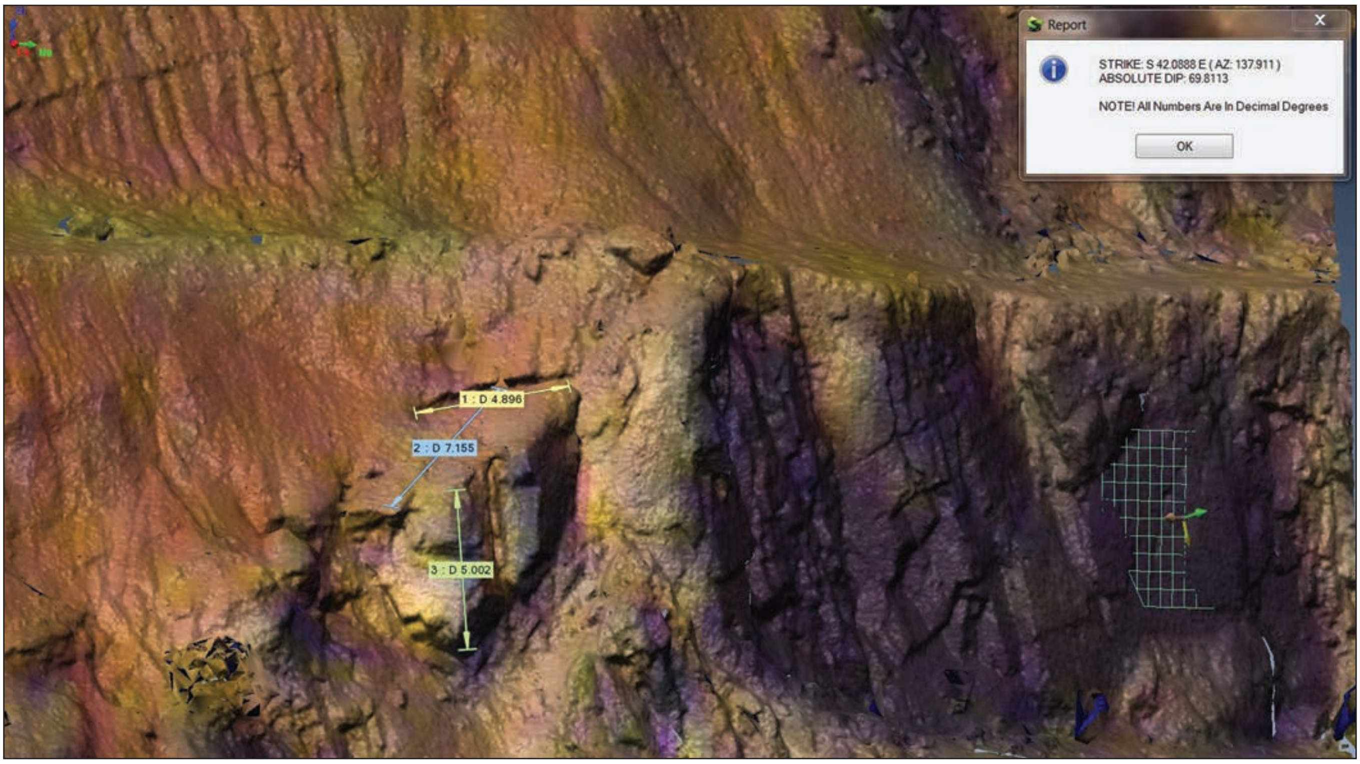
- First, the laser generates an optical pulse.
- The pulse is then reflected off an object and returns to the system receiver. A high-speed counter measures the time of flight from the start pulse to the return pulse.
- Finally, the time measurement is converted to a distance by using the formula above.

The acquired distance and bearing data is then downloaded and processed in to local XYZ co-ordinates, or if control points are scanned then they can be processed to a given co-ordinate system. Once the data has been converted into XYZ format, it can be further processed to produce composite survey models by stitching together multiple scans and triangulating that data; from which cross sections can be generated, break-lines created, or volume changes between successive scans compared.

It should be noted that laser measurements can be weakened through interaction with dust and vapour particles, which scatter the laser beam and reduce the signal returning from the target. By processing the last-pulse returning measurements, such effects can be removed from the subsequent model. However, by doing so the resultant scan will comprise wider spaced survey points than intended (less have returned) and in effect the range usually has to be reduced as the longer the photon has to travel the more likely it is to be affected in its journey and thus the more likely it is to be subsequently processed out of the model (personal communications with ILRIS sales representative).

Under ideal conditions the ILRIS-3D-ER has a maximum range of 2,000m. This range reduces to 1,700m upon a material with 80% reflectance and to 650m upon a material with 10% reflectance. It is capable of scanning at 20μrad (approximately 0.001146°) equivalent to a 2mm spacing at 100m (Optech Incorporated, 2009). The ILRIS has a range accuracy of +/-7mm at 100m compared with +/-50mm at 100m for alternative long-range scanners which ensures that accurate joint planes (for kinematical analyses) and cross sections (for rock-fall analyses) can be generated even at long distances. Scanners with poor range accuracy will produce ‘spikey’ data that cannot be used for such detailed analyses. The data can however be used for updating the face positions of the site’s topographical survey. Figure 5 shows an exceptionally sharp, high-resolution scan of a section of a quarry (shown in Figure 4) from a distance of 800m. In the resultant point-cloud, each point is allocated an RGB (Red Green Blue) value taken from the on-board calibrated digital camera. The point cloud can then be ‘meshed’; a process whereby triangulation between adjacent points in-fills the small gaps between the points and creates a solid surface. Each meshed triangle or mesh surface takes the colour from the points that were used to create the triangle.

The amount of light returning to the sensor is recorded as ‘reflectance intensity’ and is presented on a greyscale range of 0-255, with highly reflective surfaces generating white points in the resultant point cloud image and low reflective materials generating black points, as shown in Figure 6.



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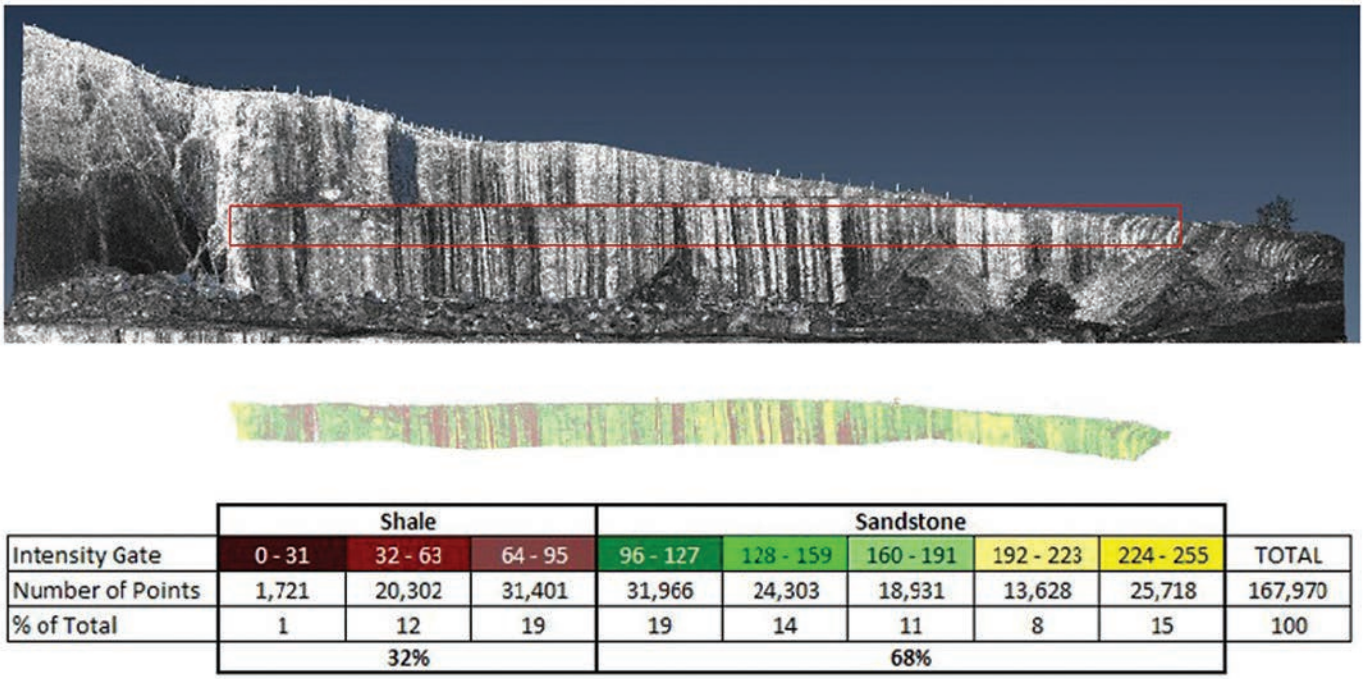
NOTE! All Numbers Are In Decimal Degrees

Figure 5. *Colour scan; meshed and measurements made (manually) of a section of the face shown in Figure 4 from a range of 800m.*



	Shale			Sandstone					
Intensity Gate	0 - 31	32 - 63	64 - 95	96 - 127	128 - 159	160 - 191	192 - 223	224 - 255	TOTAL
Number of Points	1,721	20,302	31,401	31,966	24,303	18,931	13,628	25,718	167,970
% of Total	1	12	19	19	14	11	8	15	100
	32%			68%					

Figure 6. *Reflectance intensity scan; highly reflective materials are shown as pale points and low reflective materials are shown as dark points. Subsequently assigned alternative colours for 8 bands of 32 intensity values shows the range of geological units scanned, enabling a form of 'point-sampling' analysis to be undertaken.*

REMOTE GEOLOGICAL MAPPING

In the Brewer et al. (2014) paper, geological boundaries between low reflectance shales and high reflectance greywackes were clearly defined in a reflectance intensity point-cloud. These boundaries were digitised and could be exported into a number of 3D geological modelling and 3D quarry design software packages. A particularly prominent shallow, normal fault was clearly defined, digitised and exported in this manner.

As well as being able to map geological boundaries remotely, reflectance intensity can also be used to provide qualitative data for a mine or quarry operator. In terms of geological mapping, it has been found that different strata return different reflectance intensities of the originally transmitted photon. For instance, clays, shales and vegetation exhibit low intensity values (with a greater amount of the light being absorbed than being reflected), whereas granites, sandstones and limestones exhibit high intensity values (with more light being reflected than absorbed).

In Figure 6, the reflectance values attributed to the points in the point-cloud have been grouped together to form eight bands of 32 intensity values. These banded points can then be assigned colours and allocated to a geological material. Comparing the number of points for each material with the total number of points enables the relative percentages of each geological material to quickly be determined. In the instance shown on Figure 6; 32% Shale and 68% Sandstone. In a similar manner, different grades of weathering of the same material can return different intensity values; with the more weathered material returning lower intensity values than the less weathered material.

REMOTE GEOTECHNICAL MAPPING

In addition to geological mapping of the strata, geotechnical data can be obtained from the LiDAR scans in the form of discontinuity data; dip, dip direction, spacing, persistence and roughness. Discontinuity data can be obtained by either, manually digitising each joint plane and recording its dip and dip direction (as shown in Figure 5), or, by utilising automated software specifically written to obtain geotechnical data from collected point clouds such as Split-FX, shown in Figure 7.

With a manual point-cloud analysis, the geologist/geotechnical engineer has the same control that they would have had in the field (had they been collecting the data with a compass-clinometer) but with the added benefit that the readings will not be restricted to low 'safe' faces and not restricted to the height of the geologist. However, this manual process can be slow to undertake and, as is human nature, can be influenced by what the geologist thinks are the joint sets, i.e. if he sees three sets he will preferentially record the dip and dip direction on the joints that match those sets.

One of the many advantages of an automated method is that it produces far more data and can reduce the potential 'human' influence of the geologist. When using automated software every visible joint plane within the scan is assessed. This means that blast induced joints are also recorded which widens the distribution of the documented joint orientations. The automated software Split-FX also expresses the area of each measured joint on a stereonet with small circles indicating small joint planes and larger circles indicating larger joint planes, something that is not normally recorded in a traditional manual analysis (see Figure 8).

These automated discontinuity data can be exported as a text file for subsequent importation into rock-mass analysis software such as DIPS, shown in Figure 9. In the dataset shown in Figure 9, five joint sets were identified from 2,621 discontinuity readings.

This is crucial information for the quarry design geologist/geotechnical engineer. With every discontinuity orientation being recorded a more accurate kinematical analysis can be undertaken, and the subsequent design coming out of the analysis should be more accurate than for a design generated from limited manual readings taken from limited, safe locations within the quarry.

Rock-fall analyses are wholly dependent on accurate face surveys. Figure 10 shows a recent LiDAR rock-face survey spliced with an earlier topographical survey of the same quarry faces. This image clearly shows how the LiDAR survey has picked up every joint and block irregularity, critical to rock-fall compared with the simple

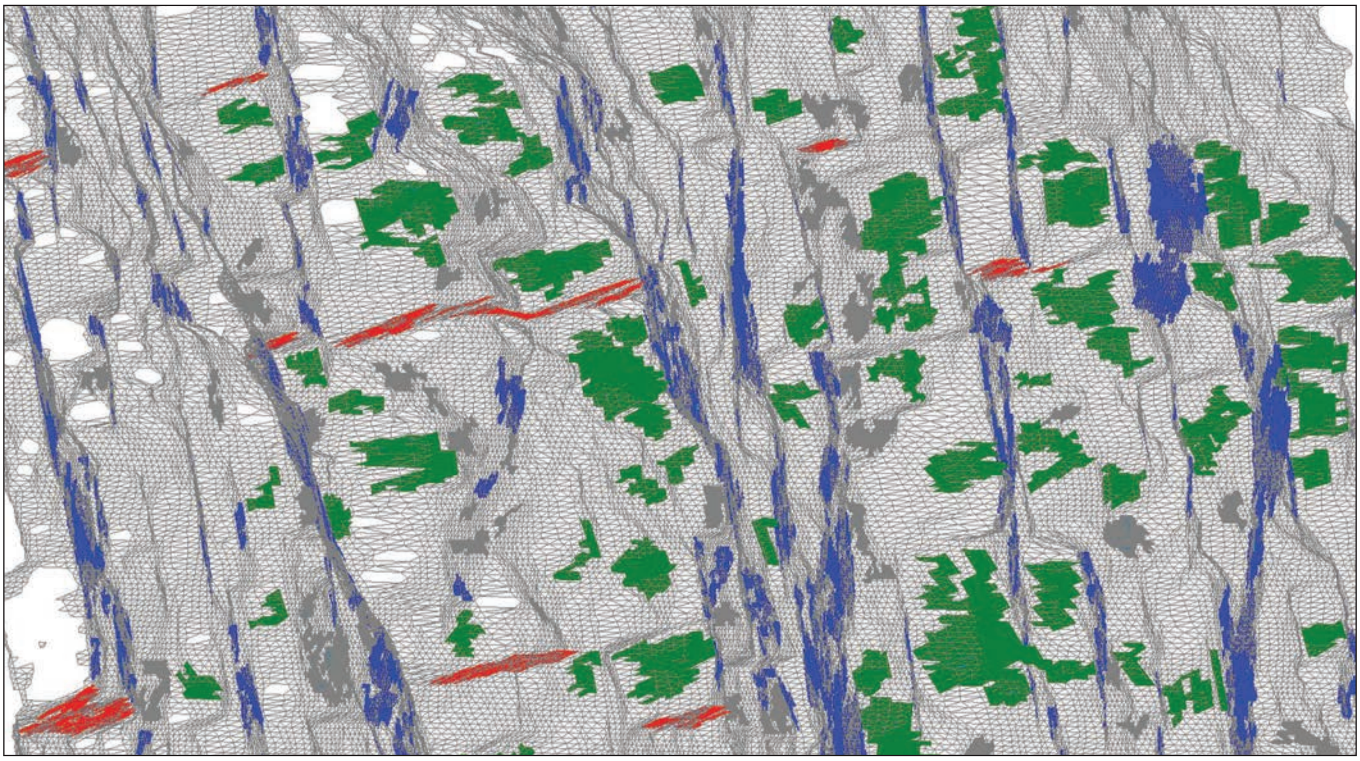


Figure 7. *Automated discontinuity analysis in Split-FX, with colour coded discontinuity sets. Sub-horizontal bedding is coloured red and two sub-vertical joint sets (perpendicular to each other) are coloured green and blue.*

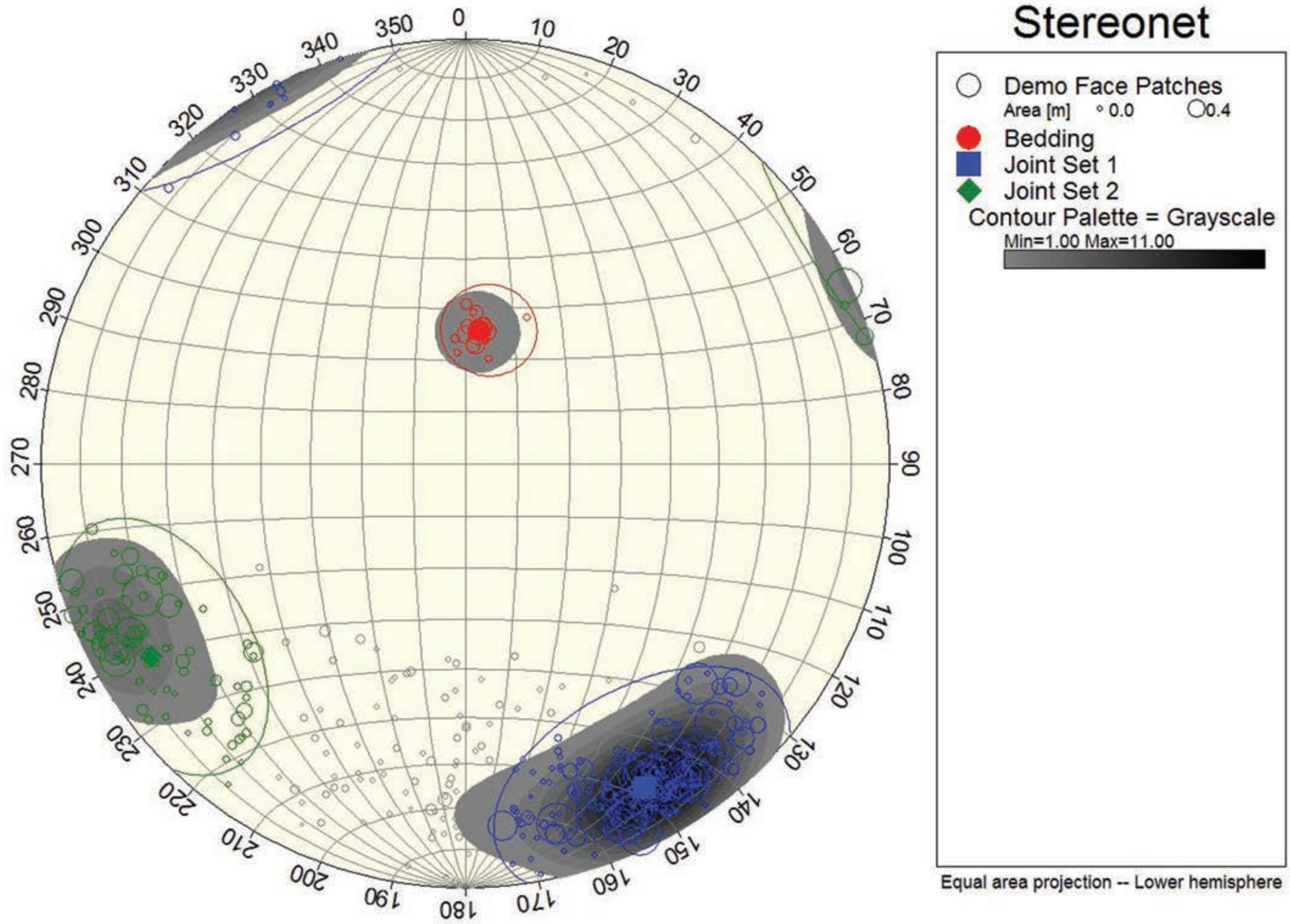


Figure 8. *Split-FX stereonet showing the bedding and joint set data shown on Figure 7. The size of each joint circle relates to the exposed size of the joint in the quarry face.*

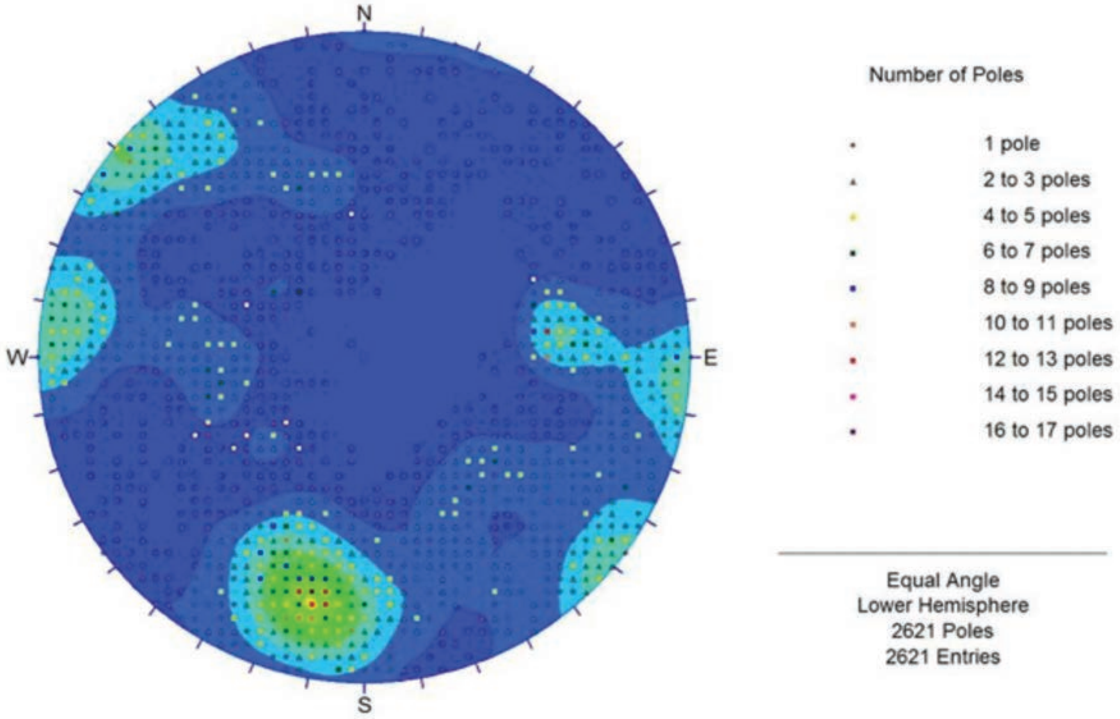


Figure 9. *Discontinuity analysis of Split-FX data in DIPS.*

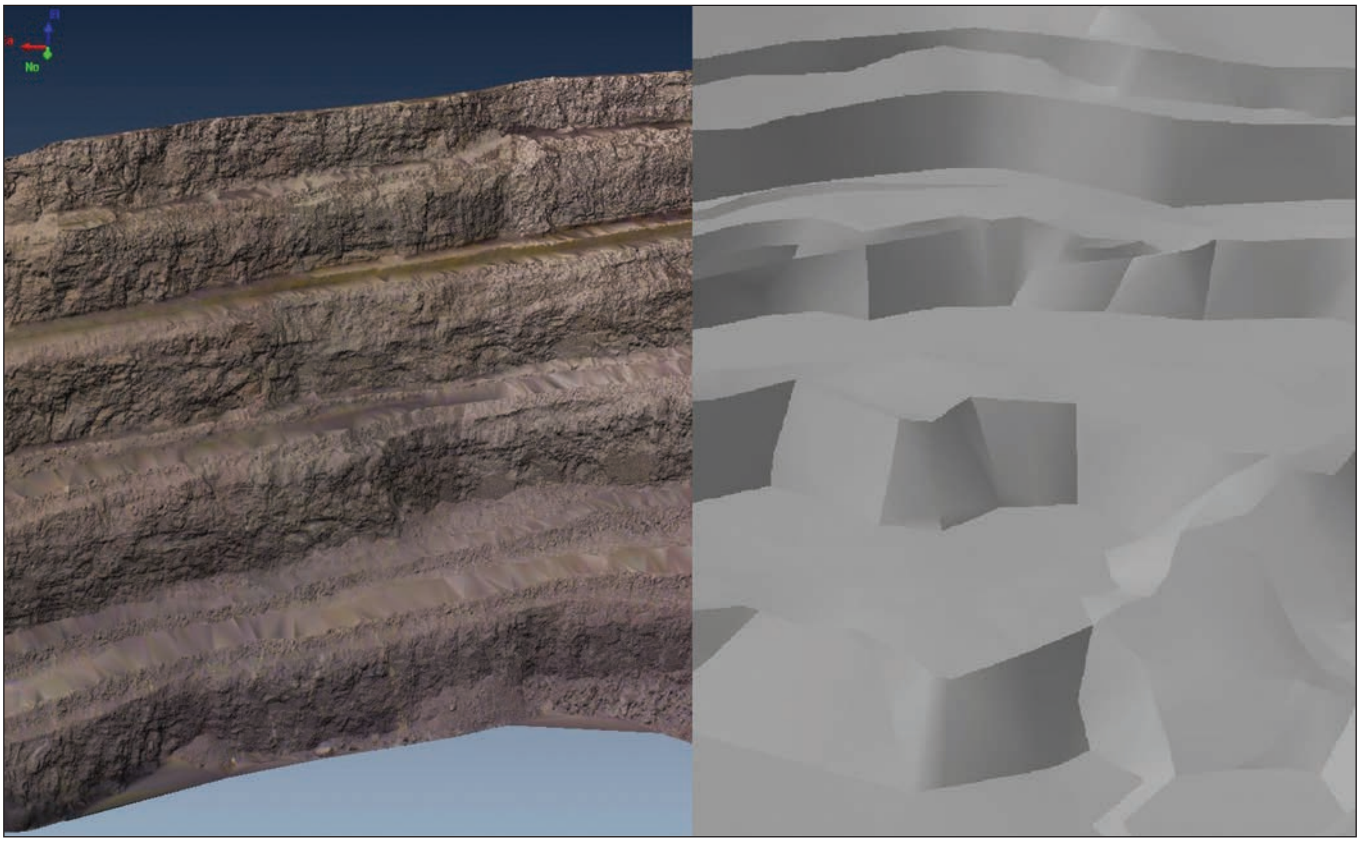


Figure 10. *Recent LiDAR survey alongside a traditional topographical survey for the same faces in a quarry.*

crest and toe face survey from a reflector-less total station survey. Cross sections generated through these highly detailed face surveys and analysed in RocFall enable a more accurate prediction of where rock-fall is likely to occur and where it is likely to land in future rock-fall events. This ensures that the engineering geologist can design rock-traps and rock-fall barriers to the correct dimensions for that particular face rather than being designed to generic design criteria that may be deficient or conversely may be overly conservative.

As well as providing an accurate face profile for rock-fall analyses, successive LiDAR surveys can be compared to provide monitoring data. Figure 11 shows a comparison between LiDAR scans of a quarry face prior to and post a rock-fall event. By colouring the 'cut' areas in red (original location of fallen rock) and the 'fill' areas in green (final location of the rock-fall); the source, primary impact distance, roll-out distance and volume of the rock-fall can be determined. Determining the characteristics of this rock-fall would have been difficult on narrow benches and from this range with traditional survey techniques.

In addition to monitoring rock-masses and calculating where and what volume of rock-fall has occurred, LiDAR scanning is also suited to monitoring movements in overburden slopes, tip slopes, wind erosion of sand faces or coastal retreat where traditional walk-over surveying (GNNS) or the emplacement of fixed reflectors or markers for theodolite techniques would be unsafe to undertake.

Figure 11. *Comparison of pre and post rock-fall event LiDAR surveys. Red denotes areas of 'cut' and green denotes areas of 'fill'.*

CONCLUSION

Remote systems in the form of long-range high-resolution LiDAR scanning and photogrammetry in conjunction with point-cloud analysis software now enables the extractive industry geologist to collect a significantly larger data set, more safely and to interpret the data more accurately than by traditional hand-based systems alone.

FUTHER DEVELOPMENTS

At the time of the EIG Conference, QuarryDesign had been trialling a fixed-wing UAV. Since September 2012, QuarryDesign have trialled a number of fixed-wing and multi-rotor UAV's (quad-copters, hex-copters and octo-copters) and as a result of those trials have acquired an Octo-copter. It is anticipated that this paper will be continued at the 2014 EIG to include the benefits of using multi-rotor UAV's for remote geological and geotechnical Surveying.

REFERENCES

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