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Structural recognition and rock mass characterization in underground mines: A UAV and LiDAR mapping based approach

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Abstract

The current geotechnical challenges in underground mines create the necessity for tools that can make safe and quick geological and geotechnical assessments, especially in hazard zones such as open stopes, in environments that are increasingly deep and confined. The purpose of this work was to test and validate the use of a new technology called Hovermap (HM). This tool combines the autonomous management of a drone (UAV) with the ability to generate 3D surface representations using LiDAR. This research shows the results of two case studies. The first case study is a comparison of data collected with Hovermap of a medium-quality scan with traditional methods such as Cavity Monitoring Surveys (CMS) and Core Logging to assess surface quality representation for geotechnical purposes. The results showed discordance between the RQD calculated with HM data and RQD calculated with traditional methods. Nevertheless, the origin of the problem is clear, and the solutions are also displayed. Once these results were validated, a second case study was performed with a higher quality scan and easier structural visualization for structural identification. The results were analysed to estimate the potential for use in underground mines for stability analysis. Furthermore, a series of drone flight parameters were estimated to perform scans depending on different purposes, such as velocity and wall distance and Sample Effort Variable (SEV).

1 Introduction

Because the first and most important step to be undertaken in any type of rock engineering project is to maintain safety and engineering standards, infrastructure required for civil use and mining where humans lives are involved (Bolkas et al. 2018) must be carefully assessed. Mapping and analysis of natural structures in the rock mass (RM), then, becomes essential for underground projects.

In Sub-Level Stoping and other types of underground extractions, geotechnical analysis provides the input for the entire design process of stopes and drives (Goodman 1989; Slob et al. 2007; Villaescusa 2014) and is involved in all extraction process stages. The features of geological structures and their characteristics within the rock mass are incorporated in 2D maps and more recently in 3D-structure models, which are used to predict RM behaviour and the possible influence of structures in construction and operation. Unfortunately, a detailed description of some of these factors can only be obtained through visual inspection on exposed surfaces. Nevertheless, more recently, data acquisition has utilized semi-autonomous and fully-autonomous drones, providing data from previously inaccessible areas.

1.1 Overview of traditional mapping techniques in underground mines

1. Core logging: Geotechnical information about the RM is initially obtained during the exploration stage. The standard method used for orebody delineation involves diamond drilling in combination with core logging, to collect information about the general geotechnical conditions and identify the principal structures. Some disadvantages of this procedure are the bias problems produced by geologists performing the logging, core loss in heavily fractured rocks, wash out of infill material, and drill deviation. These problems can lead to an important loss of representativeness.

2. Window or Cell Sampling and Scanline: The background and measurement technique of cell sampling is essentially the same as for scanline, but the sampling domain is two-dimensional. For both, the process basically involves in one case the count of structures cross an imaginary line and in the other the count of structures contained inside an imaginary rectangle. Shortcomings of this method include the lack of information about the orientation, frequency or qualitative characteristics. Both scanline and window sampling have the limitation of the data collection technique, limited by the safety standards.

3. Photogrammetry: This technique is the process of constructing maps or 3D models of real world objects or scenes of underground tunnels and caves based on distance measurements from photographs. Currently, this remote sensing method is used in mining for stability studies and structural mapping, specifically development of Discrete Fracture Network (DFN) models across all the sections with exposure of rock faces (Benton et al. 2017; Rogers et al. 2017; Lato et al. 2013). Photogrammetry has some clear advantages over traditional field sampling techniques: it is possible to perform it at a safe distance from hazardous conditions and it can generate a permanent geometric record for future analysis.

1.2 LiDAR sampling techniques overview CMS

With LiDAR, a laser fires a rapid pulse of light at the surface and a sensor measures the time the reflected pulse takes to return to the origin. From this process, the laser can generate tens to hundreds of thousands of referenced 3D locations in a short interval of time (more than 220,000 measurements per second) building a high-resolution virtual 3-dimensional point cloud. After processing, this information can be supply an accurate image of the surface measured for a given location (Lato et al. 2010; Riquelme et al. 2014).

LiDAR has been applied in mining operations, specifically in open pit mines where the visualization and manipulation of point clouds allows for performance assessments, rock mass characterization, and identification of hazards (Cacciari & Futai 2016; Lato 2010; Slob et al. 2007). For underground mining, the applications have been limited to geotechnical data collection in tunnels and places with partial access, such as stopes, with the potential to add efficiency and accuracy to this task with an instrument called CMS (Lato et al. 2010)spacing and roughness. The line-of-sight property of static Lidar scanners results in occluded (hidden.

1.3 Hovermap: A tool for mapping in unexpected places

The Hovermap (HM) was developed by the Commonwealth Scientific and Industrial Research Organization's (CSIRO) Data61 as a new alternative for 3D-mapping tasks. It is a self-contained LiDAR mapping mounted on top of a drone to map 3D spaces and objects in 360°, autonomously using the Simultaneous Localization and Mapping (SLAM) algorithm.

Figure 1 Hovermap, LiDAR tool mounted at the bottom of the drone

The key benefit is that drones (Figure 1) replace humans in the task of collecting field data, avoiding risk and reaching places previously inaccessible. This tool represents important progress but its application has just begun to be tested on site. The core of our research is to test the ability of this tool to provide useful information to understand, assess and predict the rock mass behaviour.

2 Methodology

To achieve the purposes of this work, evidence from scans obtained with HM in underground mines using 3D point clouds from stopes will be compared with characterization data to assess whether the quality of the information collected with this technology can replicate that characterization data. To make this comparison, two case studies will be presented, each with special conditions to widen the scope of assessment. The first case study, carried out in stope "A" corresponds to a medium-quality scan in terms of structurally simple visual recognition obtained with HM. This scan can be compared against information captured with traditional methods such as CMS and Core Logging. The second case study is performed in stope B concentrated on the structural identification with a point cloud that presents a high quality. The results were analysed to estimate the potential to be used in underground mines for stability analysis, and a series of drone flight parameters were estimated to perform scans depending on the purpose, such as velocity, wall distance and SEV (Sample Effort Variable).

The structural identification and principal feature extraction such as Dip, Dip Direction, Persistency, etc. were carried out with a Sirovison beta test. This software was designed for geotechnical applications on open pit tasks obtaining results that allow Discrete Fracture Network construction with photogrammetry. The beta test provided is an improved version used for the first time in this research, which enabled the work with point clouds and underground environments.

2.1 First case study

Stope "A" (Figure 2) is part of an SLS extraction in the north of Queensland, Australia. It is 320 m (base) deep, with dimensions of 20m (length) × 23 m (width) × 68 m (height), presenting an RQD average of 82, resulting in good stability and performance. The information available allowed a comparison between the data calculated by the company with core logging against the extraction of geological structures and RQD calculation from the HM point cloud.

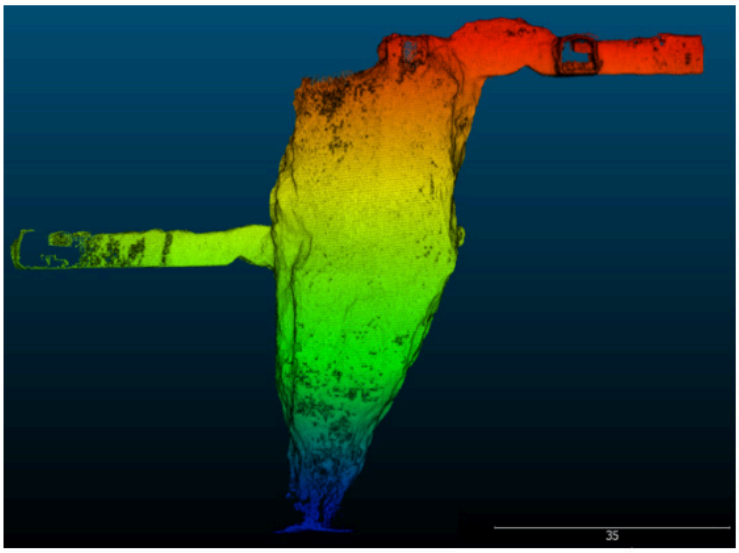

Figure 2 Complete point cloud Stope A, case study 1. Lateral view

The RQD was calculated following Equation 1 and with input of geotechnical information in addition to parameters calculated in the structural recognition stage carried out with Sirovision such as spacing. The software provides the spacing information used in the RQD estimation through the Jv factor (Equation 1).

$$RQD = 110 - 2.5\ x\ Jv \tag{1}$$

Where the Jv factor is represented by Equation 2:

$$Jv=1S1+1S2+1S3+\cdots+1Sn \quad (2)$$

The variables $S1$, $S2$, $S3$ and Sn represent the average spacing for each one of the joint sets respectively.

It is important to mention the structural recognition can be carried out when there is a clear visualization of structures and their planes. With these characteristics, Sirovision can estimate the main features and classify the GS according their Dip/Direction into families.

2.2 Second case study

This case study is with stope "B" with dimensions of 30m (length) × 12 m (width) × 30m (height). It is an SLS extraction stope (Figure 3) from a mine situated in the province of Ontario, Canada. The main characteristic of this stope is the clear visualization of geological structures in the HM point cloud, presenting structural deficiencies in the Hanging Wall (HW) and Roof making it a good candidate to demonstrate the potential of UAV-LiDAR scan quality.

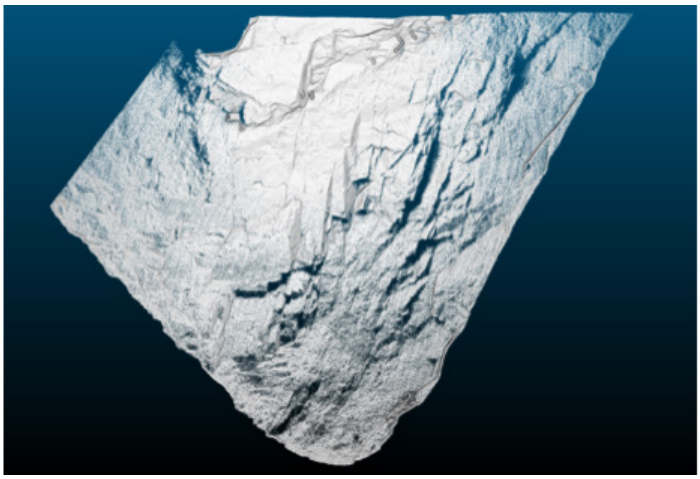

Figure 3 Hanging wall point cloud, Stope B, Case 2. Frontal view

The first stage of this case study was to determine the principal features of the geological structures. The analysis and comparisons were performed in the HW, determining planes and traces (Figure 4) utilizing Sirovision. The results enabled the joint sets to be determined, manually choosing the groups of structures that would form the families with the tool "Define Set Orientation." For each set defined, a list of information was obtained including the spacing to determine the RQD using the Jv factor (Equation 1 and 2).

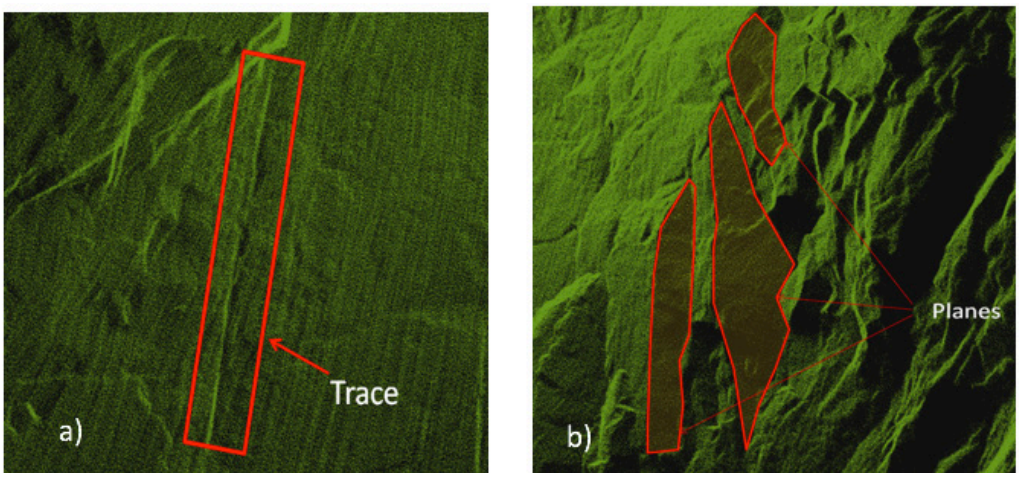

Figure 4 Sirovision 3D visualization with zoom, a) Trace in the HW and b) Planes in the HW

2.3 Case 1 and Case 2: Comparison of resolution

The difference between the quality of the point clouds and their surface representation suggested the need for further analysis and comparison to determine the best HM flight features for geotechnical purposes.

2.3.1 First analysis

A trajectory analysis comparing the HW of both cases was carried out because there was a disparity in terms of the structural visualization in areas with a similar point density (number of points per square meter), which suggested differences in the flight pattern and scan construction.

The flight patterns and point clouds of both case study A and case study B were analysed evaluating the distances from walls, velocity, and structural visualization.

2.3.2 Second analysis

A surface of 119 m^2 with good structural resolution in the HW from Case 2 was selected to determine three features that set up an efficient scan flight for geotechnical purposes:

1. Distance (m): Trajectory or total length described by the drone during a particular flight time.
2. Pattern (sec/m): The diagrams or shapes in which the flight can be performed above the surface, considering the time, distance and area involved. The pattern was calculated by multiplying the total time of flight by the distance; all that was then divided by the area scanned.
3. Range (m): The perpendicular distance between the drone and the surface under analysis. A higher range indicates a larger area of measurement but at the same time a higher distance from the surface.
4. Sampling Effort Variable (sec/m^2): A measure of how much effort or time should be applied on a surface (area). The Sampling Effort Variable is calculated dividing the Pattern by Range.

3 Results

3.1 Results case study 1

3.1.1 Structural Recognition

In the HW analysis with Sirovision, it was possible to recognize 39 structures between planes and traces concentrated in the centre of the wall (Figure 6 a)). The structures were classified in three main joint sets. The plot of the poles and main planes formed by the selected GS is shown in the Figure 6 b).

Table 1 Joint sets estimated with Sirovision in the HW, case 1

Set	Type	Dip (°)	Dip Direction (°)	Max persistence (m)
J1	Red	78.4	37.7	15.4
J2	Aqua	65.4	352.7	9.7
J3	Blue	74.8	287.3	11.9

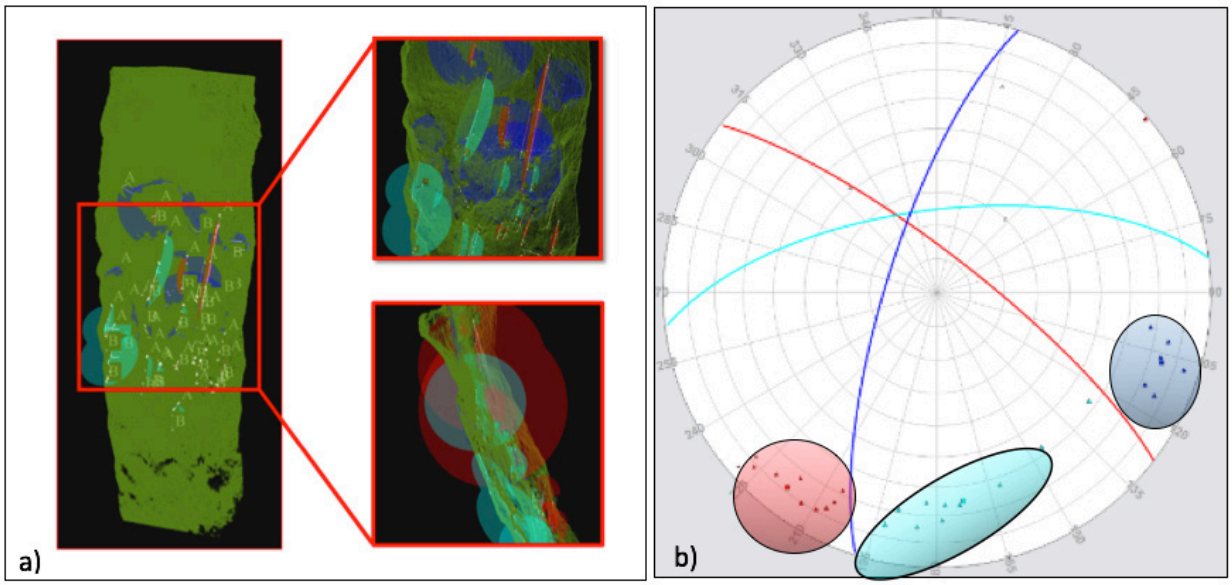

Figure 5 **a) Joint set visualisation; and b) Plane pole concentrations estimated with Sirovision**

The structural information in the HW was corroborated with data registered by the mine's core logging. For example, Figure 6 shows a principal structure identified during the drilling campaign using core logging on the left, and this same structure observed in more detail with a more prominent projection from the point cloud analysis is shown on the right. On the other hand, there are several structures, which were localized with HM that are not included in the mine geological model a situation generated from the scale effect, as only the main structures are documented during the drilling campaign.

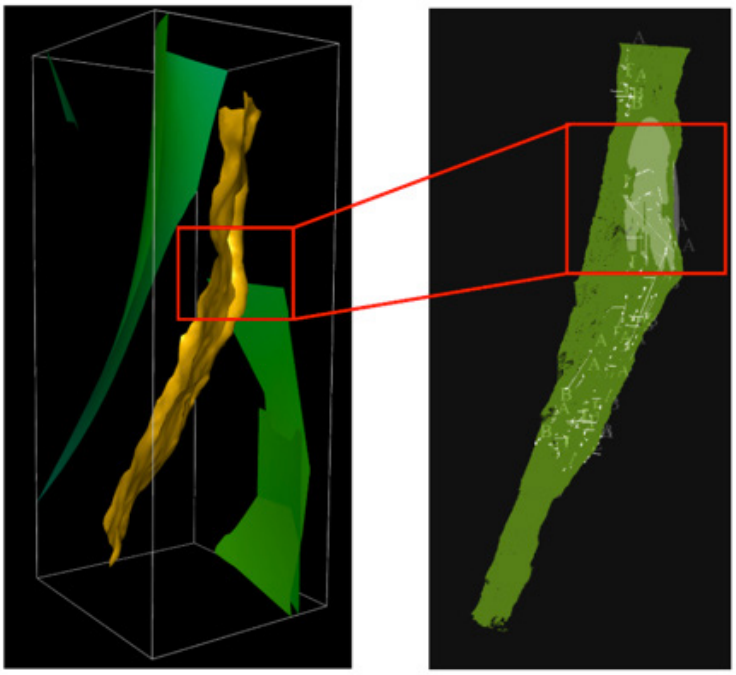

Figure 6 **On the left, the hanging wall and the structures (green planes) identified during core logging; on the right, the structure at the back was identified in the point cloud.**

A link between the data obtained with core logging and HM can be observed, specifically in the area where the RQD is in a range between 20 and 40 % (red windows), which concurs with a high fracture frequency in the same zones on the HM scan (Figure 8). However, there is a difference between core logging and HM results at the wall bottom, where the quality of the RM tends to decrease according to the core information. The difference is caused by the impossibility of structural recognition (HM scan) in the area due to the presence of noise and a lower surface resolution representation.

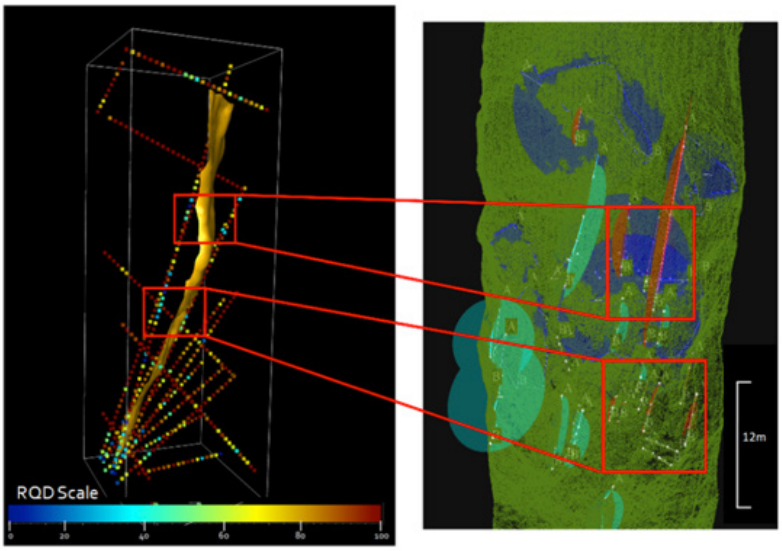

Figure 7 Relation between the RQD estimated with core logging (left) and the structures found in the point cloud.

Calculating Equation 1 and 2 with a Jv factor of 5.33, the RQD is 97%. Though the RQD measured with core logging was 82%, this 15% difference could be produced by the absence of structural information at the bottom of the wall, a zone that presents a low RQD.

Another point to keep in mind is that for this type of measurement (RQD), mining companies consider a volume around the wall of approximately 5 meters of width (2.5 meters behind the wall and 2.5 meters in front) to calculate the integration of structures, which run parallel to the wall, an impossible task utilizing only HM.

3.2 Results case study 2

3.2.1 Structural recognition

With the structural analysis made with Sirovision, 4 main joints sets were determined using more than 80 structures to estimate the families, identifying structures of up to 20 cm. It is important to mention that this selection of families was not automatic; after the structural recognition, Sirovision plots the concentration of pole planes and allows for automatic or manual selection of groups.

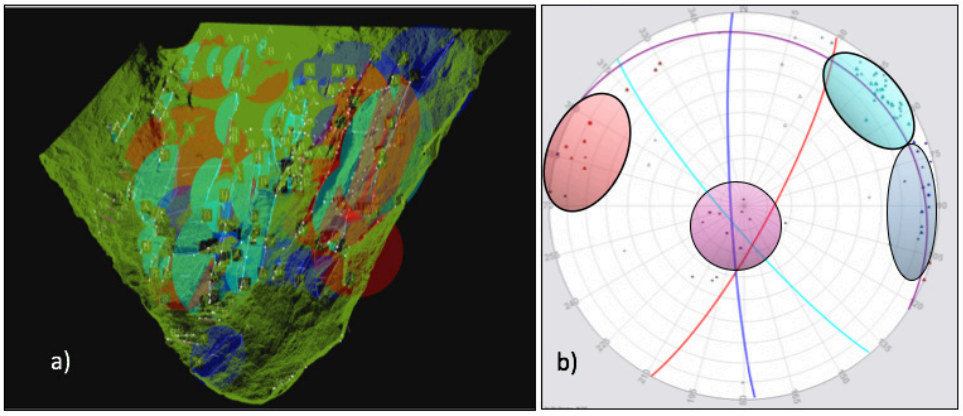

Figure 8 a) Joint set visualization; and b) Plane pole concentration estimated with Sirovision

The combination of HM and Sirovision enabled the recognition of traces and the determination of planes in a low-density area, increasing the accuracy of the results. With this additional information, the analysis acquired greater representativeness; it was possible to obtain a better characterization of each set, calculating the spacing, persistency, orientation and maximum persistency.

Table 2 Joint sets estimated with Sirovision in the Hanging wall, Case 2

Set	Type	Dip (°)	Dip direction (°)	Max persistence (m)
J1	Aqua	81.9	229.5	9.011
J2	Red	78.9	118.5	12.433
J3	Blue	84.4	266.6	6.863
J4	Purple	13.4	32.3	2.966

3.3 Case 1 and case 2: Point clouds difference

3.3.1 First Analysis

Densities were compared as a first step to understand the difference between the HM scan qualities in both cases studies. It is important to mention in Case 1, the scan set up involved the alignment of two point clouds from two different access points to remedy a shadow present in the first measurement.

Figure 9 Case 1 (a) in the red square shows the concentration of points per square meter in a range of 3,000 – 10,000 points. The average point density shows that Case 2 b) has twice the number of points per square meter as Case 1. This difference becomes evident when considering that for Case 1 the range of density under study represented a higher concentration while for Case 2 the same interval of evaluation or range represented a lower concentration with an average over 30,000 points per square meters (as shown in the red square).

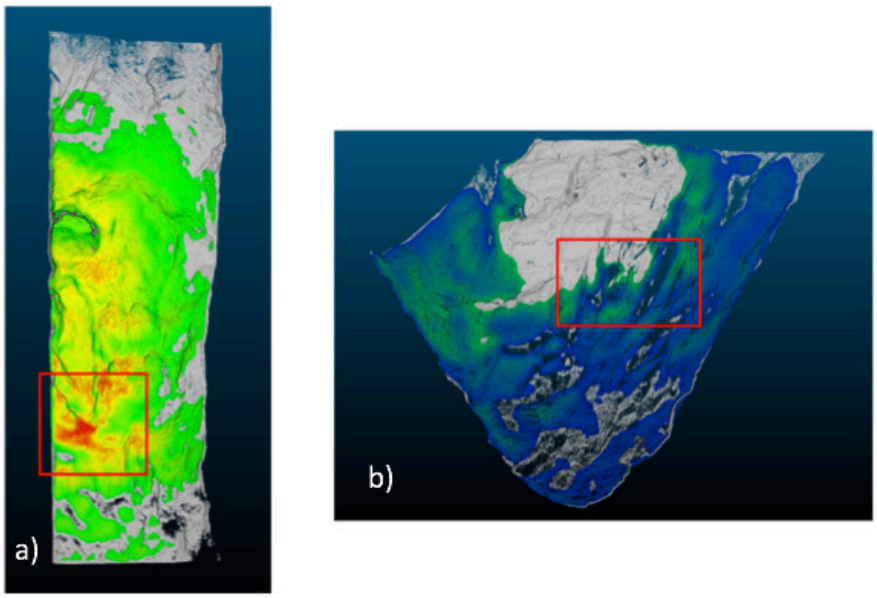

Figure 9 Point density a) HW Case 1; b) HW Case 2. Zones with the similar density represented by red squares

The results show the influence of more factors in the scan results. For example, in Figure 9 the coloured surface inside the red frames for both cases has the same density of points, but the quality and detail is completely different, and this is even more pronounced for Case 2 as that zone is in middle of the area with the best structural representation.

To continue with the analysis, the drone trajectories with their velocities and distances from the wall were examined for both cases:

a) Case 1:

This point cloud has a high presence of shadows in the HW, occasioned by the drone position during the procedure, generating angular occlusion and angular deviation as the drone only entered the stope for a few seconds and did not go inside or closer to the walls.

To avoid the problems of angular occlusion and angular deviation, the drone should fly around the stope, getting a visibility angle of 360° and taking a trajectory close to the walls.

b) Case 2:

The drone trajectory was entirely dedicated to scan the stope from inside. The main feature of the trajectory should consider that the drone flies around the stope and gets as close to the walls as possible and then returns to its point of origin. The quality of the scan is related to the velocity and distance from the walls during the drone flight. A low velocity will increase the density, but the way to obtain the most useful data for geotechnical purposes is to fly near the walls.

Finally, the study reveals an optimum quality of scan with a flight velocity between 0.13 - 0.2 meters per second, and a distance from the wall between 3.6 – 4.5 meters. With this velocity and distance from the walls, easy visual recognition of structures and details to characterize them can be obtained.

3.3.2 Second analysis

A deeper analysis enables the determination of the four flight parameters during the three different tracks (time intervals). Table 6 summarizes the results of the study.

Table 3 Track analysis results, Case 2

Trajectory	Distance	Time	Pattern	Range	SEV
Track 1	6.87	31	1.78	5.75	0.31
Track 2	6.02	40	2.01	4.92	0.41
Track 3	4.32	30	1.08	5.74	0.19

In terms of scan quality, Track 3 showed an optimum performance while the opposite occurs with Track 2. These results were corroborated with the Sample Effort Variable (SEV) calculated for each track demonstrating the important relation between velocity, wall distance and time spent during the scan. The SEV as the factor, which measures how much effort or how much time should be applied on a surface (area); this is calculated dividing the pattern by the range or distance from the surface, which in this case would be the walls.

4 Conclusions

Using a combination of UVA and LiDAR inside stopes in underground mines provides important input in terms of extra information and safety, especially for complex tasks such as inspection and rock mass characterization, by enabling information to be obtained from places where people have not previously been able to access.

Nevertheless, some points must be considered to obtain the most useful data for geotechnical purposes:

1. HM with any type of UVA and LiDAR should not replace the core logging technique, but rather it should be used as complement to corroborate information obtained, increase the accuracy and detail of the DFN, assess the blasting effects and with that predict the behaviour of a specific mine sector.

2. In order to obtain data for geotechnical purposes, it is important to program the flight so as to ensure a flight velocity between 0.12 – 0.2 meters per second, a wall distance of no more than 5 meters, and a flight pattern to avoid angular occlusion. As the velocity mentioned is low, it is also useful to maintain a constant velocity and include some static points in the pattern at the places of most interest.

The case studies shown here demonstrate the potential of this instrument to be utilized as a new source of information in underground mines to further improve data collection and with it mine safety.

References

Benton, DJ, Seymour, JB, Boltz, MS, Raffaldi, MJ & Finley, SA 2017, 'Photogrammetry in underground mining ground control — Lucky Friday mine case study', in J Wesseloo (ed.), Proceedings of the Eighth International Conference on Deep and High Stress Mining, Australian Centre for Geomechanics, Perth, pp. 587-598.

Bolkas, D, Vazaios, I, Peidou, A & Vlachopoulos, N 2018, 'Detection of Rock Discontinuity Traces Using Terrestrial LiDAR Data and Space-Frequency Transforms'. Geotechnical and Geological Engineering, vol.36, no. 3, pp. 1745-1765.

Cacciari, PP & Futai, MM 2016, 'Mapping and characterization of rock discontinuities in a tunnel using 3D terrestrial laser scanning '. Bulletin of Engineering Geology and the Environment, vol. 75, no. 1, pp. 223-237.

Goodman, RE 1989. Introduction to rock mechanics, vol. 2, Wiley New York.

Lato, M, Kemeny, J, Harrap, RM & Bevan, G 2013, 'Rock bench: Establishing a common repository and standards for assessing rockmass characteristics using LiDAR and photogrammetry'. Computers & Geosciences, vol. 50, pp.106-114.

Lato, MJ, Diederichs, MS & Hutchinson, DJ 2010, 'Bias Correction for View-limited Lidar Scanning of Rock Outcrops for Structural Characterization'. Rock Mechanics and Rock Engineering, vol. 43, no. 5, pp. 615-628.

Lato, M 2010, 'Geotechnical applications of LiDAR pertaining to geomechanical evaluation and hazard identification', Thesis (PhD, Geological Sciences & Geological Engineering. Queen´s University.

Riquelme, AJ, Abellán, A, Tomás, R & Jaboyedoff, M 2014. 'A new approach for semi-automatic rock mass joints recognition from 3D point clouds'. Computers & Geosciences, vol. 68, pp. 38-52.

Rogers, SF, Bewick, RP, Brzovic, A & Gaudreau, D 2017, 'Integrating photogrammetry and discrete fracture network modelling for improved conditional simulation of underground wedge stability', in J Wesseloo (ed.), Proceedings of the Eighth International Conference on Deep and High Stress Mining, Australian Centre for Geomechanics, Perth, pp. 599-610.

Slob, S, Hack, HRGK, Feng, Q, Röshoff, K & Turner, AK 2007, 'Fracture mapping using 3D laser scanning techniques'. in LR e Sousa & CON Grossmann (eds), 11th congress of the International Society for Rock Mechanics : the second half century of rock mechanics, 9-13 July, 2007, Lisbon, Portugal. Taylor & Francis / Balkema, Leiden, The Netherlands, pp. 299-302.

Villaescusa, E 2014, 'Geotechnical design for sublevel open stoping', CRC Press.

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