New methods and equipment for 3D laser scanning, mapping and profiling underground mine cavities

SN Ahmed *Clickmox Solutions Inc., Canada*

JD Gagnon *Clickmox Solutions Inc., Canada*

MN Makhdoom *Clickmox Solutions Inc., Canada*

R Naeem *Clickmox Solutions Inc., Canada*

J Wang *Clickmox Solutions Inc., Canada*

Abstract

In this paper methods related to 3D laser scanning and profiling underground mine cavities that are radically different from the traditional cavity monitoring systems are presented. The traditional systems suffer from many drawbacks including long scan time, only stationary scan capability requiring point cloud stitching, long set up time, bulky systems and low point cloud density. V-Scan3D offers a highly versatile scanning system that is fast, is capable of performing both mobile and stationary scans and is lightweight and compact. Simultaneous Localization And Mapping (SLAM) software enables the mobile scans and generation of 3D maps. This paper discusses case studies related to their use in real mining environments and how it dramatically increases safety and scanning efficiency.

Keywords: CMS, Cavity Surveying, Underground Mine Scanning

1   Introduction

Cavity surveys are routinely performed in underground mines for various reasons including excavated rock mass measurements, monitoring of cavity geometry and its geological features and identification of potentially dangerous rock mass conditions. These cavities include stopes, mine drifts, ore passes and other underground openings.

Most mines use Cavity Monitoring Systems (CMS) for this purpose. These systems are composed of a single laser, which is continuously rotated at two angles to measure distances of obstructions around the laser head (Teledyne Optech, 2017). In general, time-of-flight measurements are performed where the return time of the laser pulse is measured with reference to a precise trigger (Amman et al, 2001). The distance is then calculated by multiplying this time with the velocity of light. Half of this distance gives the distance of the obstruction from the laser source. All such point collected during the scan are collectively called a point cloud. This point cloud is used to create wire mesh of the cavity surface, which can then be used to create a solid surface and thus calculate volume of the cavity. An important part of this process is to register the CMS with respect to the mine coordinate system. This is generally done before the scanning is performed through a process that involves mounting prisms at previously surveyed points. Once the system has been registered, the scanning process is started, which for most instruments takes between 6 to 10 minutes. It is worth mentioning that to effectively scan the cavity, the system must be inserted into the cavity and held stationary at a point where the possibility of shadows is minimized. This is done by mounting the scanner head on a boom and pushing the boom into the cavity. Since a typical CMS scanning head with battery weighs over 10 kg, the process is seldom performed by one person and generally requires two or more surveyors working together. In terms of effectiveness, ease of use and total scanning time, this method has following drawbacks.

- The complete scanning process including registration may take one hour or more.

- The system may miss portions of the cavity due to obstructions.

- System is heavy and therefore requires more than one person to perform the survey.

- Point cloud density is low.

- System must be kept stationary during scans.

In this paper a new light weight and compact 3D laser scanning system that overcomes the drawbacks of traditional CMS is proposes.

2 New approach to cavity scanning

A new methodology and system to perform underground mine cavity scanning has been developed. It overcomes the drawbacks mentioned earlier and allows more accurate, faster and cost effective monitoring of mine cavities. The new method involves a system that is light enough to be mounted on aerial drones and is capable of performing both stationary and mobile scans. The mobile scanning capability allows the system to scan areas that are blocked by obstructions in traditional CMS. This also significantly reduces the set up and scanning time.

In this system the intensity of reflected light is also measured allowing deduction of geological features, such as cracks and faults, from the data gathered. Furthermore, reflected surfaces on surveyed points can be used to register the point cloud during post processing, thus eliminating the need to perform the usual time-consuming pre-scan registration.

3 System description

The V-SCAN3D system consists of a 2D scanning laser head on a rotating platform (see Figure 1). A mirror in the scanning laser head rotates to allow scanning at a frequency of 40 Hz. The laser head itself is rotated at different frequencies depending on the mode of scanning.

Figure 1   V-SCAN3D

The system works on time-of-flight measurement principle described earlier in this paper and in addition measures intensity of the reflected light.

The system is capable of performing both stationary and mobile scanning. The mobile scanning is accomplished through a Simultaneous Localization And Mapping (SLAM) algorithm, which allows feature-rich underground mine cavities to be mapped with the system on a mobile platform, such as aerial drone. The plastic enclosure version of V-SCAN3D weighs only 650 grams and can therefore be mounted on mid-size aerial drones suitable for underground mines.

For stationary scans, the system takes less than 40 seconds to perform a complete scan. This should be compared with at least 6 minutes scan time with the traditional CMS. A complete 40 second scan by V-SCAN3D captures more than 1.7 million points. This should be compared with less than 60,000 points captured by traditional CMS equipment in one 6-minute scan (Teledyne Optech, 2017).

4   Tests and results

A number of tests in the lab and mine environments were performed to understand the effectiveness and limitations of the system. Results of some of these stationary and mobile scanning tests are presented here.

4.1   Stationary scanning

In order to measure accuracy, precision and resolution, 51 mm wide reflective tapes on a board separated by 40 mm, 15 mm and 5 mm were used as shown in Figure 2.
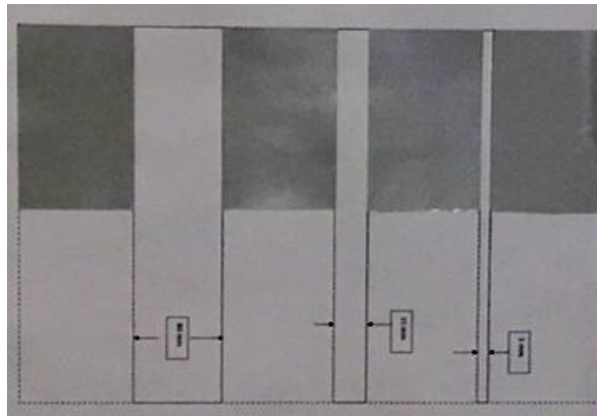

Figure 2   Set up to measure accuracy, precision and resolution

The scanning was performed at distances of 1 m, 2.5 m, 5 m and 10 m. The resulting point clouds were colorized with respect to reflected light intensity with CloudCompare software. In this way the reflected tapes turned up red in the visualization window of CloudCompare. It should be noted that measurements were done not only of these tapes but also of other structures captured in the scans. Figure 3 shows the point cloud generated at a distance of 1 m from the board. It is apparent that all the tapes can be resolved at this distance. However, the resolution becomes poorer at larger distances. Tests at mine sites have revealed that objects that are as close as 2 cm from each other can be resolved at a distance of 5 m from the source (see Figures 4 and5).
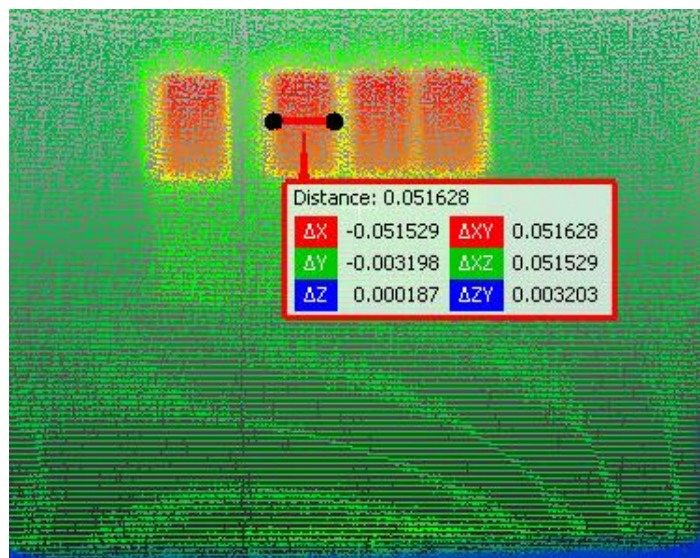

Figure 3   Point cloud at a distance of 1 m from the board

Table 1   Results of measurements

Distance (m)	Actual (mm)	Measurements (mm)			Mean (mm)	SD (mm)	Precision (mm)	Accuracy (%)
		1	2	3				
1	51	51.6	50.2	51.8	51.2	0.87	0.50	0.4
2.5	264	261.7	267	267.7	265.5	3.28	1.89	0.6
5	908	905.7	909	901.6	905.4	3.71	2.14	0.3
10	264	262.7	270.6	266.2	266.5	3.96	2.29	0.9

Table 1 shows that the system shows a precision in length measurement of about 2 mm with better than 1% accuracy at a distance of up to 10 m from the laser source. This shows a great level of accuracy since most drifts in underground mines are 5m x 5m arch back type and a control point on the drift wall can be identified easily in the resulting point cloud. This can be seen in Figure 4 as well where a control point has been identified and circled.
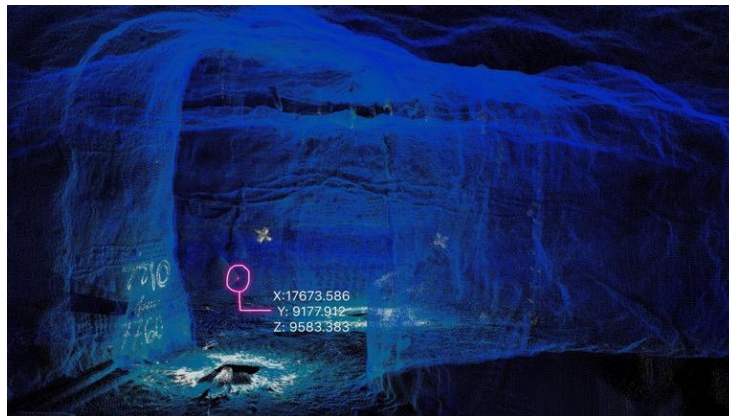

Figure 4   A surveyed point identified in the point cloud captured by V-SCAN3D

Figure 5 shows the point cloud generated with V-SCAN3D at a mine site. The details in the point cloud can be used by geologists to identify rock conditions such as large cracks and faults. This point cloud was generated in less than one minute.
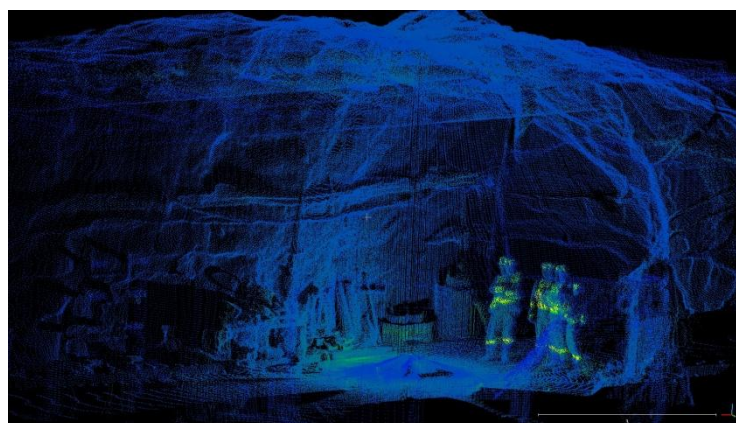

Figure 5   Point cloud of a mine drift captured by V-SCAN3D

It was also investigated if V-SCAN3D can be used to perform stationary scan of a stope. In some cases the stopes are small enough so that the scanner can be inserted into the cavity with a post or a cable. This method is similar to how scanning is done by traditional CMS equipment. Figure 6 shows the scan of a stope by inserting the scanner with a post into the cavity.
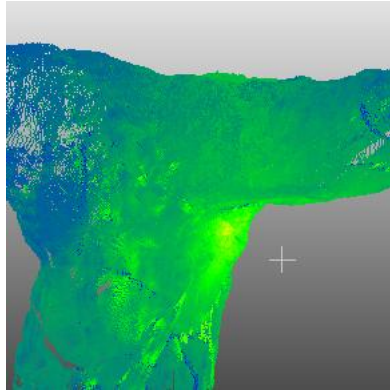
Figure 6 Point cloud of an underground mine stope captured by V-SCAN3D

Next, the use of the system to map mine drifts by performing multiple stationary scans and manually stitching them together was investigated. Figure 7 shows a mine drift scanned in this way with the scanner on the MineFly drone. The drone was flown and landed at certain distances from the operator and stationary scans performed. It should be noted that a part of the drift was inaccessible and traditional CMS from the entry point would have most probably missed the parts circled in the figure.
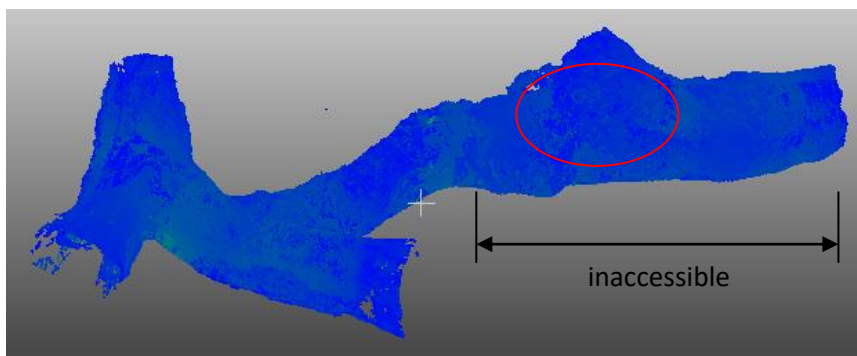

Figure 7 Multiple stationary scans merged together during post processing

4.2 Mobile scanning

In many situations the areas to be scanned and mapped are not only inaccessible but also too large to perform stationary scans. In these cases use of traditional CMS may introduce shadows as the system is kept at one position during scans. In such situations mobile scanning can be performed using SLAM algorithm. To test this the V-SCAN3D with SLAM capability was used to perform mobile scans in different underground mines. For this the scanner was mounted on mine ground vehicles and two different drones: Tilt Ranger and MineFly.

Figure 8   V-SCAN3D mounted on the Tilt Ranger drone developed by Inkonova, Sweden

For the tests with scanner mounted on a ground vehicle, the real-time version of the scanner, VM-SCAN3D, was used. This system generates the point cloud in real time using SLAM algorithm. Result of one of the tests at an underground mine is shown in Figure 9. The vehicle was continuously moved between the drifts with the scanner running. The point cloud was then downloaded from the system at the end of the scans and used to generate wire mesh shown in the figure.
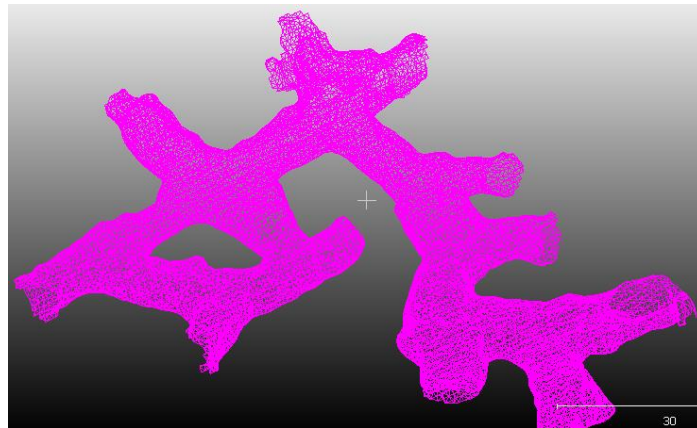

Figure 9   Wire frame of mobile scan performed by VM-SCAN3D (real-time version) mounted on an underground mine vehicle

Figure 10 shows the wire frames of a stope scanned with traditional CMS equipment (Teledyne Optech, 2017) and V-SCAN3D mounted on the Tilt Ranger drone. The drone-based mobile scanning took less than 2 minutes and involved flying the drone in and out of the stope with the scanner running in SLAM mode. It is obvious that the scan performed by V-SCAN3D is more detailed than the one performed by the traditional CMS scanner.
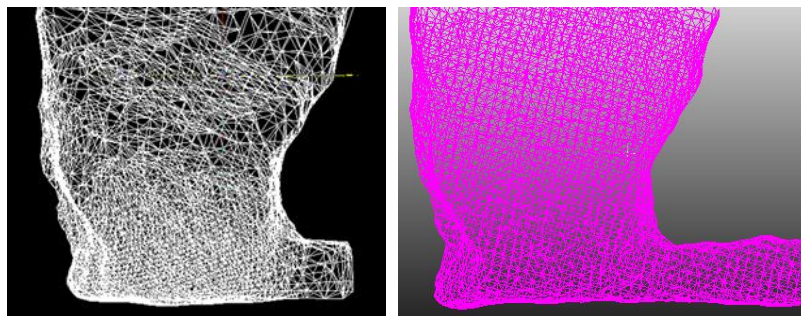

Figure 10 Wire frame of scan performed by (left) traditional CMS equipment and (right) by V-SCAN3D mounted on Tilt Ranger drone

Figure 11 shows the wire frame of a large stope scanned with V-SCAN3D mounted on Tilt Ranger drone. The drone was flown in and out of the stope with the scanner running in SLAM mode.

It should be pointed out that MineFly drone has an optional collision avoidance system. However, the guards around both MineFly and Tilt Ranger are capable of saving the propellers during low-impact collisions with walls. The Tilt Ranger has a longer operational range and could also be flown in non line-of-sight situations during these tests.
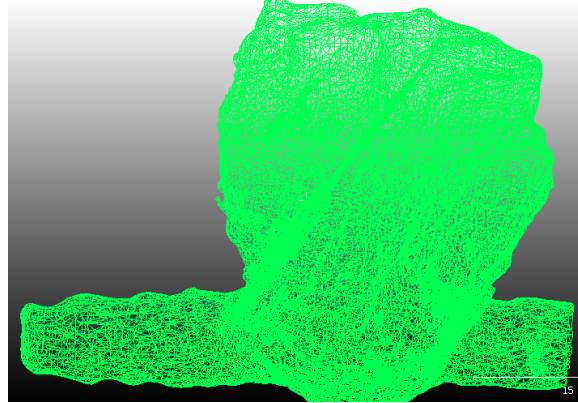

Figure 11   Wire frame of a large stope scanned by V-SCAN3D mounted on Tilt Ranger drone

5   Conclusion

The tests performed in this study validate the hypothesis that fast, lightweight and compact 3D laser scanners having stationary and mobile scanning capabilities can be more effectively used to scan underground mine cavities as compared to traditional CMS scanning equipment. Such systems allow more robust, accurate, quick and safe scanning and mapping of stopes, ore passes, drifts and other underground mine openings. Mobile scanning systems based on ground and aerial vehicles are highly effective in scanning and mapping hard-to-access and inaccessible areas in underground mines and do not suffer from shadowing effects. The high point cloud density obtained from such systems can also be helpful in deducing geological information about rock surfaces.

Acknowledgement

References

Amann, M-C, Bosch, T, Myllyla, R & Rioux, M 2001, 'Laser ranging: a critical review of usual techniques', *Opt. Eng.*, vol. 40, no.1, pp. 10–19.
CloudCompare [GPS software]. 2016. Retrieved from http://www.cloudcompare.org/
Teledyne Optech 2017, 'CMS V500 Cavity Monitoring System', Available at www.teledyneoptech.com.