DALHOUSIE UNIVERSITY

Department of Civil and Resource Engineering

Evaluation of a Short-Range 3D Laser Scanner for Change Detection and Discontinuity Characterization

By:

Farzaneh Hamedi Azad, PhD Student, Dalhousie University

Navid Bahrani, Assistant Professor, Dalhousie University

Submitted to:

Dr. Naeem Ahmed, Clickmox Solutions Inc.

September 2019

Table of Contents

Executive Summery

Clickmox Solutions Inc. develops products and provides services to the underground mining industry in the areas of robotics and 3D laser scanning. Clickmox is looking into expanding the application of their 3D laser scanner, Versa3D, to deformation monitoring and discontinuity characterization for geomechanical mine design. Through several meetings, Dr. Bahrani and Dr. Ahmed of Clickmox developed a research project to answer the following questions:

- What is the accuracy of Versa3D under controlled laboratory conditions and how should it be operated to achieve such accuracy?
- Can Versa3D be used to map discontinuities and obtain orientation data as part of geomechanical mine design?

This report provides a summary of an NSERC Engage project supported by Clickmox and conducted by Dr. Bahrani's research group on the application of Versa3D for change detection and discontinuity characterization. In this regard, a series experiments were conducted to better understand the limits of applicability of Versa3D under laboratory and field conditions. In the first part of this project, the accuracy of Versa3D for change detection and deformation monitoring was investigated. For this purpose, repeated scanning was performed before and after a foam board of a given thickness was attached to a wall. The open source point cloud post-processing software CloudCompare was used to analyze the scan data to determine the thickness of the foam board. The results were compared with manual measurements using a caliper. In the second part of the project, a wedge-shape model was made from foam boards and scanned from different distances. Similar investigation was conducted on an outcrop. In both cases, CloudCompare was used to post-process the point clouds and determine the dip angles of the modeled and real discontinuities. The results were then compared with manual measurements using geological compass. It is concluded from the results of this project that Versa3D can be used to detect changes or deformations of 6 mm and more and discontinuity dip angles with an accuracy of 2° from a distance of up to 3 m from the target. This suggests that Versa3D is a suitable tool for surveying applications in most underground mine drifts.

1. Introduction

Remote sensing refers to the activities of recording, observing and perceiving (sensing) objects or events from remote places (Weng, 2013). The two common remote sensing techniques include digital photogrammetry and laser scanning. Digital photogrammetry is a measurement technique that uses light rays captured by a standard digital camera. The technique fundamentally requires two images of the same object taken from different locations. The digital photogrammetric software uses a stereo pair of photos and automatically locates common points in both images to determine camera location and orientation, and the three-dimensional (3D) coordinates of these common points. A processing software uses these coordinates to construct a 3D digital terrain model (DTM) of the scene. Laser scanning is also a measurement technique, which operates by firing pulses of laser light in a known direction. The distance to the target is calculated by measuring the time for the light to travel out to the target and back to the instrument (time-of-flight method). By firing a large number of pulses in a regular pattern, the scanner creates a 3D DTM of the scene.

The 3D DTMs generated from either technique are highly suitable for geotechnical studies. One of the main applications of remote sensing techniques in geotechnical engineering is data collection for rock mass characterization, where detailed information on geometrical characteristics of discontinuities are obtained. Such information is useful for the analysis of structurally controlled instabilities in both surface and underground excavations. Other applications of the remote sensing techniques include rockfall and landslide hazard assessment and change detection and deformation monitoring in tunnels and rock slopes (Walton et al., 2014). Some of the operational applications of remote sensing techniques in mining include volume calculation of blasted rock, tunnel profile generation, support installation quality control, and potential leakage location mapping (Fekete et al., 2010).

The objective of this project is to investigate the applications of a short-range 3D laser scanner, Versa3D (by Clickmox) for change detection and rock discontinuity characterization. In this regard and to further investigate the accuracy of this system, a series of scans were performed under controlled laboratory and field conditions and the results were compared with accurate manual measurements. It was found from the results of this investigation that Versa3D is a suitable tool for surveying and profiling underground excavations and can potentially be used to map discontinuities and monitor deformation in mine drifts.

2. Versa3D

Versa3D consists of a two-dimensional (2D) scanning laser head mounted on a rotating platform (Figure 1). The laser head can rotate with different speeds depending on the required point cloud intensity (Ahmed et al., 2017). Its light weight and compact structure allow it to be mounted on a mid-size drone, making it suitable for underground surveying applications. The system works on the time-of-flight measurement principle and in addition, measures the intensity of the reflected light (Ahmed et al., 2017). Further information about the technical specification of Versa3D is provided in Table 1.

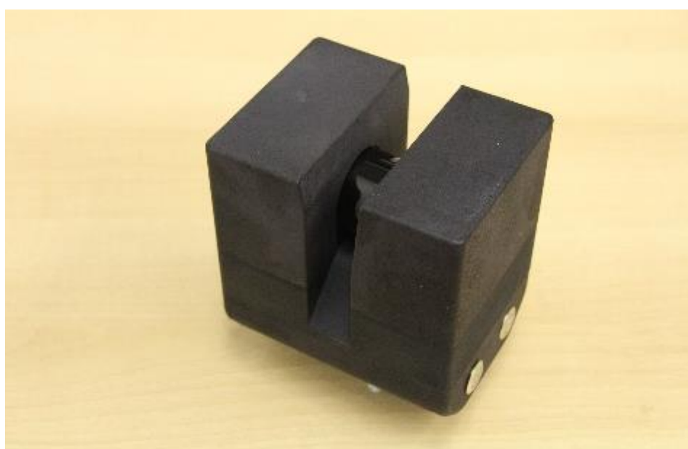


Figure 1 Versa3D laser scanning

Table 1 Technical specifications of Versa3D

Parameter	Value	Parameter	Value
Range	0.06 m up to 60 m	**Storage Temperature & Humidity**	-30 deg C to +70 deg C
Laser Wavelength	905 nm (invisible)	**Vibration Resistance**	10 to 55 Hz
Startup Time	Approx. 10 sec	**Shock Resistance**	196 m /sec^2 of 2 min for 30 min
Surrounding Intensity	< 2 mm	**Weight**	< 970 g
Field of View	270 deg	**Material**	Polycarbonate & Aluminum
Angular Resolution	0.25 deg	**Dimensions**	(130 x 90 x 126) mm
Ambient Temperature & Humidity	-10 deg C to +50 deg C	**Mountable To**	Tripods, Ground Vehicles & UAV

3. Research Methodology

A series of experiments were designed and conducted under controlled laboratory and field conditions to explore the applications of Verca3D in geotechnical engineering. Experimental work in this project comprises 3D laser scanning and conventional manual measurements. This is aimed to study the accuracy of Versa3D under the stationary mode for change detection, deformation monitoring and discontinuity characterization in underground excavations.

A series of scans were performed at designated scan stations and scan speeds. The scanning point clouds were analyzed and compared to the manual measurements. It should be noted that in order to better capture different features, the scanner must be located at a point where the possibility of occlusion and orientation bias are minimized. Occlusion occurs when the scanner is not able to capture parts of an object because it is obscured by protruding features. When the vertical line-of-sight of the scanner is parallel to a discontinuity, there is a potential for orientation bias (Figure 2) (Sturzenegger & Stead, 2009).

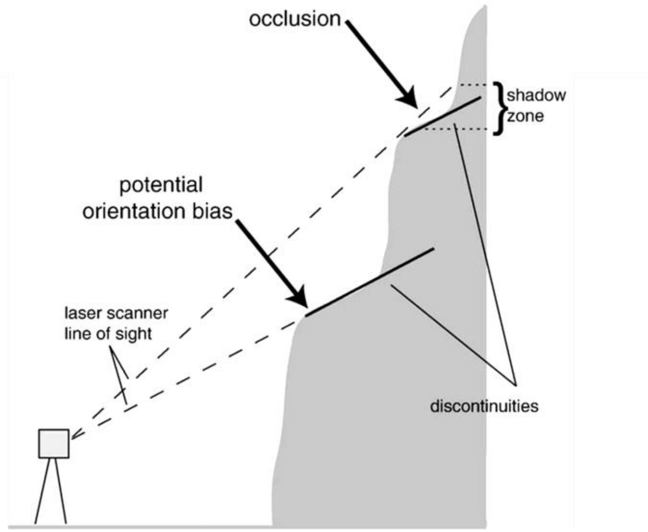


Figure 2 Illustration of occlusion and orientation bias (after Sturzenegger et al., 2007)

Covering all the features by scanning the object from different positions helps reduce these issues. In this case, having distinguishable reference points are of great help when post-processing scanning point clouds. Therefore, one or more reflective tapes, which are easy to find in the point clouds, were placed at different places around selected objects. The locations of reflective tapes depend on the size of objects and the distance between the scan stations. The reflective tapes were used along with other known features to register (align) two or more point clouds.

3.1 Change Detection

In order to determine the accuracy of Versa3D for detecting changes in the geometries or locations of objects, a series of scans were conducted before and after a foam board of a known thickness was attached to a wall. The comparison between the two point clouds were used to measure the thickness of the foam board and the results were compared with the actual thickness of the foam board measured using a caliper. Figure 3 shows an image of the experiment including a foam board with a known thickness attached to a larger foam board (called ‘base surface’). A reflective tape was attached to the wall close to base surface for registration purposes.

Figure 3 Change detection experiment setup showing foam board of a known thickness attached to a larger foam board (base surface)

Different scanning speeds result in different point cloud density; e.g., a complete 16-second scan captures about 600 points while a 2-minute scan results in about 5 million points. A comparison between different scanning speeds at a certain distance from the foam board with a thickness of 22 mm is shown in Figure 4. In this project, all scans were conducted with the slowest speed (i.e., 135 seconds).

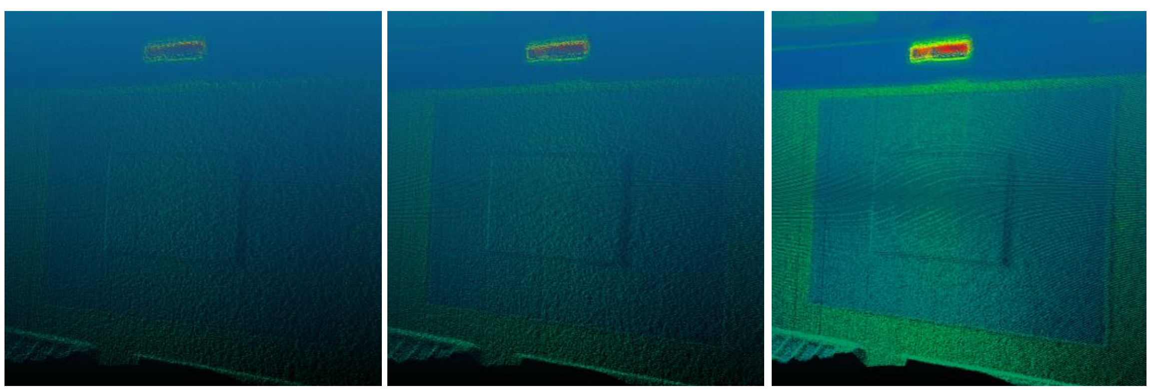


Figure 4 Point clouds of the foam board obtained from three different scan speeds: a) fast (16-second scan); b) medium (60-second scan); and c) slow (135-second scan)

Initial scanning was conducted at four stations (S) in front of the base surface at distances of d_1 = 50 cm, d_2 = 100 cm, d_3 = 200 cm and d_4 = 300 cm. Then, the smaller foam board was attached to the base surface and scanning was conducted from the same stations.

Three foam boards with thicknesses of t_1 = 6 mm, t_2 = 11 mm and t_3 = 22 mm were used for this purpose. Figure 5 illustrates a schematic view of the experiment set up showing the position of the scanner relative to the foam board and a top view of the experiment showing the scanning stations.

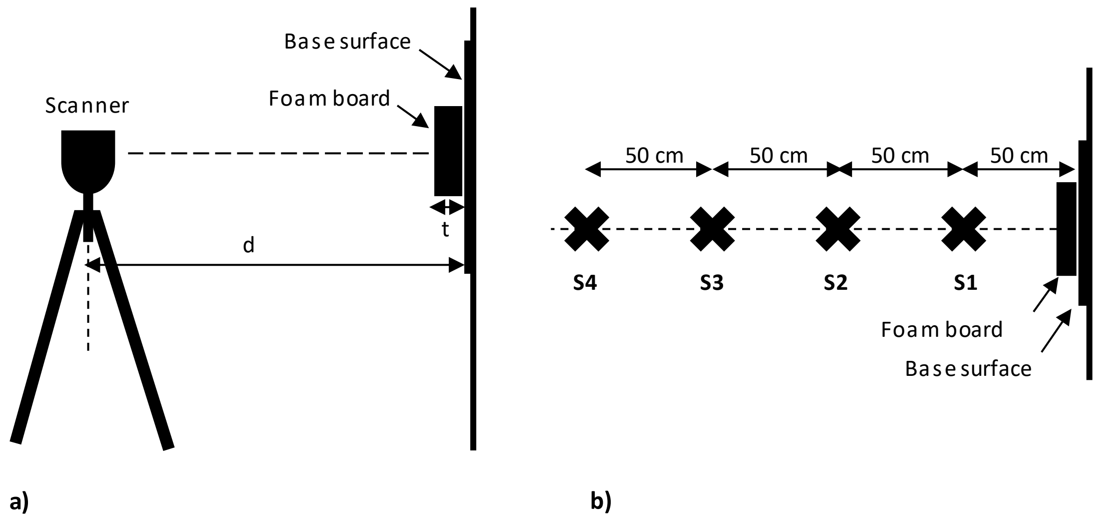


Figure 5 Schematic view of the change detection experiment: a) position of the laser scanner relative to the foam board; and b) top view of the scanning stations

The point clouds obtained from the scans taken at each station before and after attaching the foam board were then registered (i.e., aligned) in CloudCompare, which is an open source 3D point cloud post-processing software. The thickness of the foam board was then calculated using two methods (i.e., plane fitting and cross-section methods), and the results were compared with actual thicknesses of the foam boards measured using a caliper.

Another series of experiments were conducted by scanning the foam board from four stations located along a line at 45° (S45) from the center line of the base surface, as shown in Figure 6. In this case, each pair of point cloud (e.g., S1 and S45-1) from scanning the foam board were first registered (i.e., aligned and merged) to create a single point cloud. The resulting point cloud was then registered with the initial point cloud of the base surface to determine the thickness of the foam board in CloudCompare using both plane fitting and cross-section methods. The thicknesses of the foam boards obtained from the analysis of point clouds were then compared with those measured using a caliper.

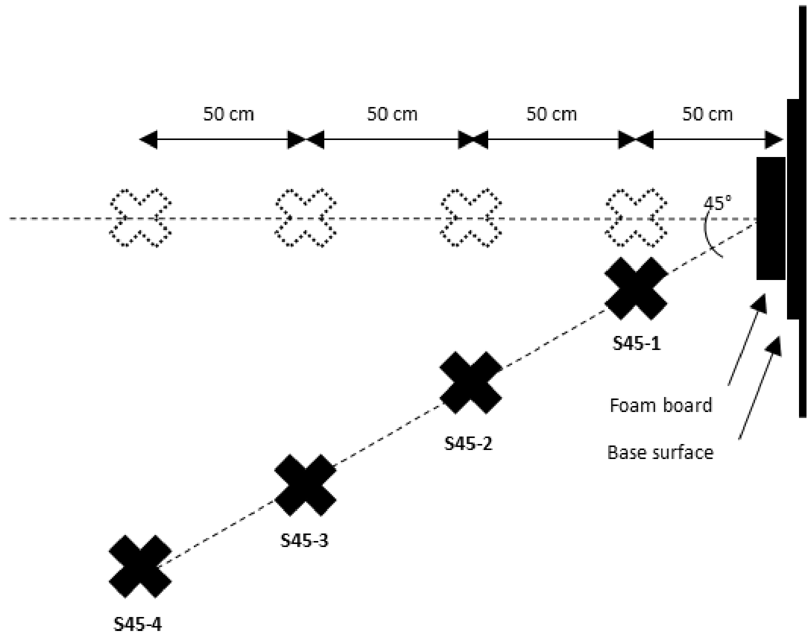


Figure 6 Plan view of the scanning stations in the second series of experiments

3.2 Discontinuity Mapping

A common application of laser scanning in geotechnical engineering is mapping geological discontinuities and obtaining their orientations (Martin et al., 2007). Measuring the orientation of discontinuities using the geological compass may not be accurate due to either the presence of magnetic field or the size of the compass relative to the extent of discontinuities (Ross-Brown, 1973). Moreover, traditional field mapping techniques (i.e., scanline and window mapping) are time consuming and present numerous safety and measurement problems near the face of high and steep slopes and shallow tunnels with rock fall hazard potential, and in deep and burst-prone mines. In these conditions, laser scanning offers a reliable tool to measure the orientation of discontinuities on much larger surfaces from remote locations providing more meaningful estimation of discontinuity mean orientation (Sturzenegger & Stead, 2009).

3.2.1 Lab investigations

A wedge-shape model consisting of five planar surfaces (i.e., P1 to P5) representing discontinuity surfaces was made from foam boards. A 3D view of the model is provided in Figure 7. The wedge model was attached to a vertical wall and the dip values of the planes were measured using a geological compass. The model was scanned at the slow speed mode (i.e. 135 seconds) and two reference points on both sides of the base surface were used for point cloud registration. In order to evaluate the capability of Versa3D to map discontinuities, the model was scanned at different distances from the model. A schematic view of the position of the scanner relative to the wedge model is shown in Figure 8.

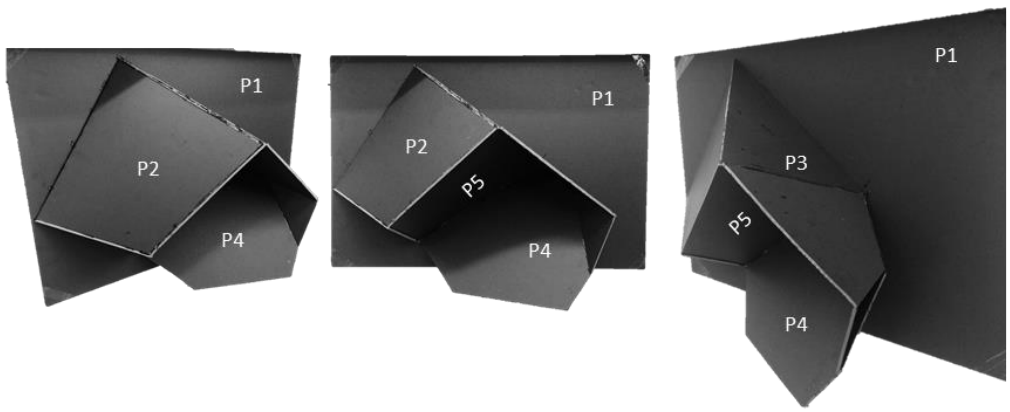


Figure 7 3D views of the wedge model

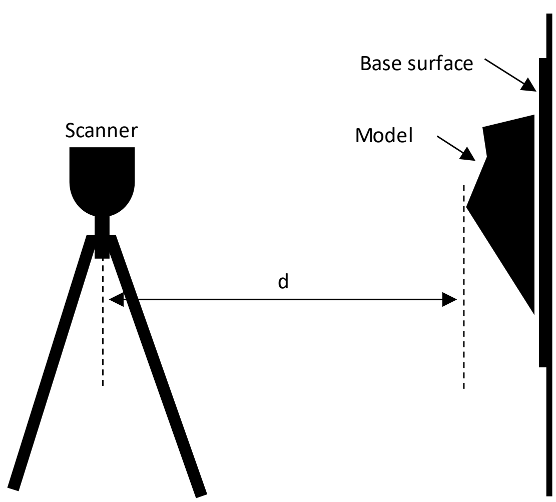


Figure 8 Schematic view of the position of Versa3D relative to the wedge model for discontinuity orientation measurement

Two series of experiments were conducted to determine the orientation of the modelled discontinuities from the scan point clouds: 1. Single scan, and 2. Multiple scans. In the case of single scan, the wedge model was scanned at different stations (i.e., SW1, SW2, SW3 and SW4) and the point cloud from each scan was used to determine the orientations of the modelled discontinuities (Figure 9). In the case of multiple scans, the point clouds from SW1 and SW2 and then SW3 and SW4 were registered and the resulting point clouds were used for determining the orientations of the modelled discontinuities. Note that the purpose for registering (combining) point clouds obtained from two stations was to prevent and/or minimize the occlusion and orientation bias. Figure 9 shows the locations of the scanning stations relative to the modelled wedge. The distance between the wedge model and SW1 and SW3 is d_1 = 200 cm and d_2 = 300 cm, respectively, and the distance between SW2 and SW4, and SW1 and SW3 is d_3 = 200 cm, respectively.

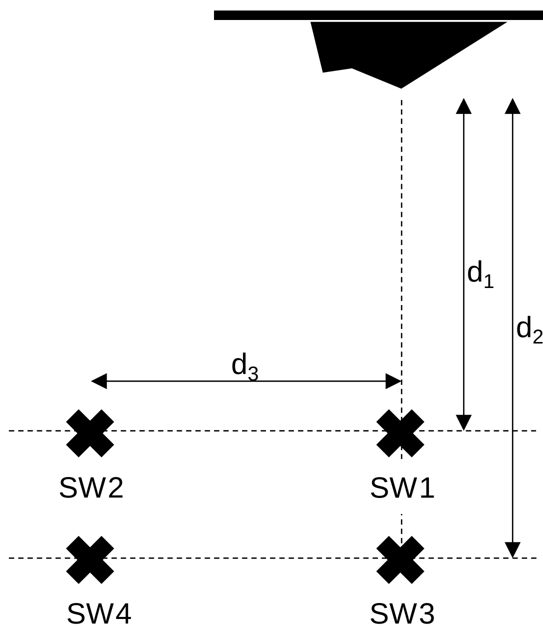


Figure 9 Plan view of scanning stations relative to the wedge model

Orientation measurements including the dip values of the modelled discontinuities were first conducted for the single scan taken from all scanning stations, and the results were compared with those obtained from multiple scans (i.e., registering SW1 with SW2, and SW3 with SW4). The dip values determined from the results of single and multiple scans were then compared with those measured manually using the geological compass. Figure 10 presents a view of the wedge model and the reference points used for point cloud registration.

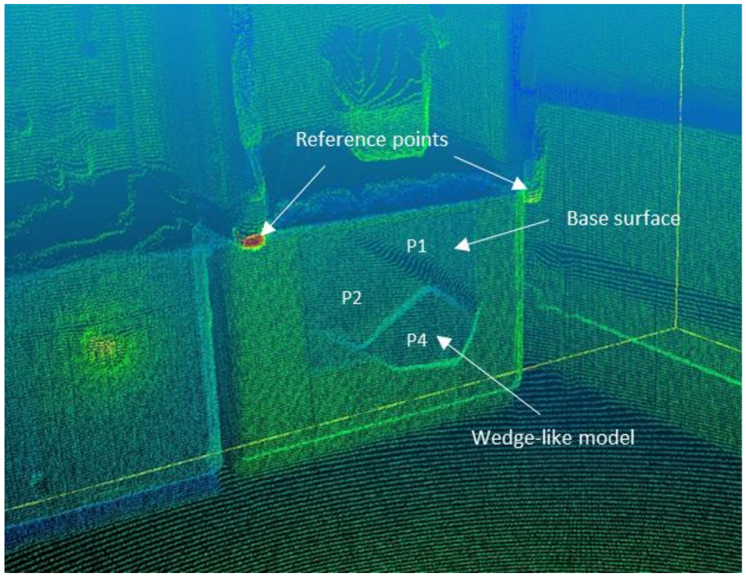


Figure 10 Point cloud of the wedge model

3.2.2 Field investigations

To further investigate the limits of applicability of Versa3D for mapping discontinuities a rock outcrop was selected and scanned under the slow speed mode. Figure 11 shows a picture of the outcrop. As shown in this figure, eight discontinuity surfaces (RF1 to RF8) belonging to four joint sets were identified and their orientations were measured using a geological compass. Several reference points were placed at different locations on or near the rock surface to improve the point cloud registration process.

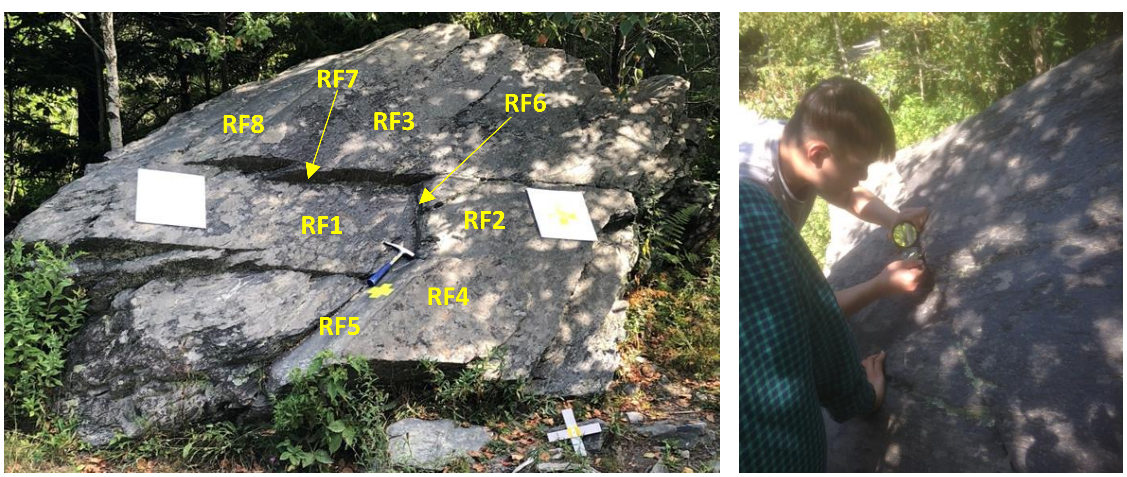


Figure 11 Rock outcrop showing the joint surfaces and their orientation measurements using geological compass

Figure 12 shows the plan view of the twelve stations from which the rock surface was scanned, and Figure 13 illustrates examples of the point clouds of the rock outcrop from three stations: SR2 = 1 m, SR6 = 2 m and SR10 = 3 m. Similar to the previous analyses, the discontinuity orientations (i.e., dip angle) were determined from the results of single and multiple scans. The discontinuity dip values were determined by using the plane fitting method in CloudCompare, and the results were compared with manual measurements using the geological compass.

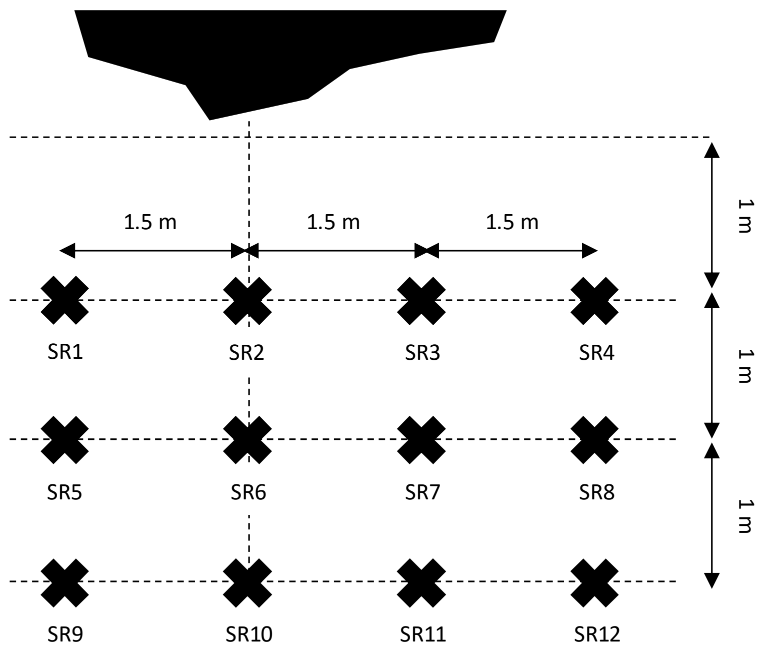


Figure 12 Plan view of scanning stations relative to the outcrop

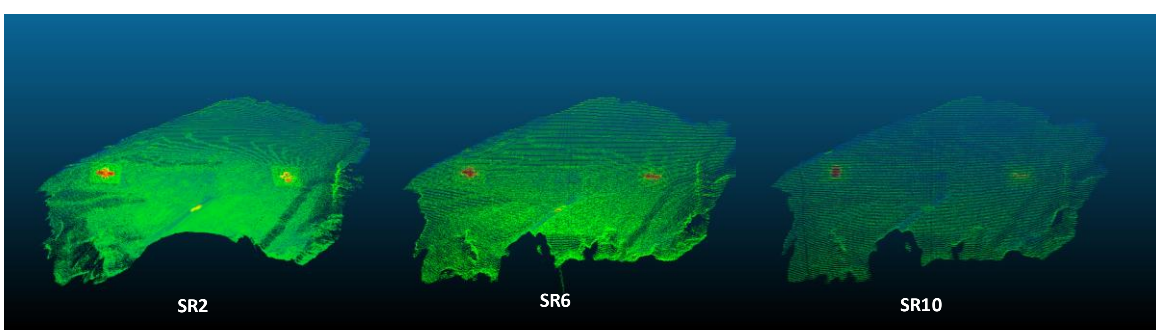


Figure 13 Point clouds of the rock outcrop from three stations: SR2, SR6 and SR10

4. Point Cloud Data Analysis

The following steps are usually taken in CloudCompare before analyzing point clouds for change detection and discontinuity characterization:

- Point cloud registration (in case of multiple point clouds)
- Noise filtering
- Segmentation

Registration: Registration means aligning two or more point clouds from scanning an object from different locations. Point cloud registration can be done manually or automatically depending on how far and how well the two (or more) point clouds are aligned.

Noise filtering: Once the point clouds are registered and properly aligned, the noise filtering feature is used to reduce the noise and remove the outliers from the scan data. Noise filtering locally fits a plane to the point cloud and removes the points that are too far from the fitted plane.

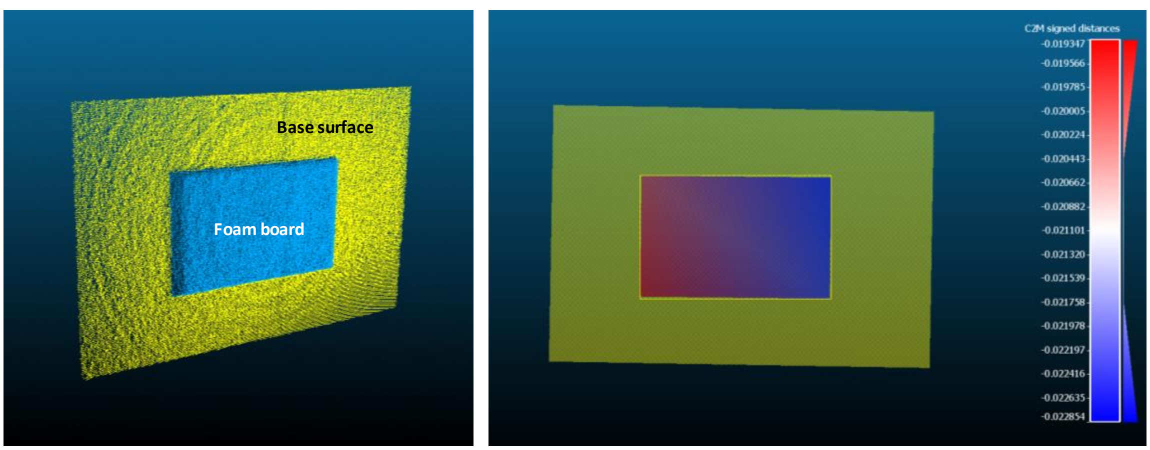
Segmentation: Segmentation is used to obtain a better view of the scan and remove unnecessary parts of a point cloud. Segmentation is a process where the area of interest (e.g., the area around the base surface), in the point cloud is cut out and separated from the rest. The resulting point cloud is then used for further processing (e.g., change detection or discontinuity characterization).

4.1 Change Detection

Two methods are proposed to determine the thickness of the foam board in CloudCompare. One is to find the distance between two planes fitted to the foam board and the base surface, called the plane fitting method. In this case, it is required to separate the foam board from the base surface in the point cloud by the segmentation tool, and then fit planes to both the base surface and the foam board. The second method, called the cross-section method, is based on obtaining cross-sections of the foam board in the point cloud and use any CAD software to measure the thickness of the foam board. The following provides further information about these two methods.

4.1.1 Plane fitting method

CloudCompare can be used to fit planes to surfaces identified in a point cloud. Various pieces of information such as the normal and the dip and dip direction of the fitted planes can be extracted from this analysis. The first step after removing the unnecessary parts from the point cloud was to identify and segment the foam board and the base surface from the rest of the point cloud (Figure 14a). This resulted in two separate point clouds. Then, by using the plane fitting tool in CloudCompare, two planes were fitted to the two point clouds, and the distance between the two planes was calculated. Figure 14b shows the calculated distance between the two planes in gradient color. The mean value of the distance between the two planes was interpreted as the thickness of the foam board.



a) **b)**

Figure 14 a) Segmented point clouds showing the base surface and the foam board; b) fitted planes to the point clouds showing the distnace between the two planes in gradient color

4.1.2 Cross-section method

Extracting cross-sections from a point cloud may not be a good representative of a smooth surface due to the inherent noise in the point cloud. A tool in CloudCompare, called the Statistical Outlier Removal method, was used to remove the noise from the point cloud. This method is based on the computation of the distribution of the distance of a point to its neighbor. For each point, the mean distance to all its neighbors is calculated. By assuming that the resulting distribution is Gaussian with a mean and a standard deviation, all points whose mean distances are outside an interval defined by the global distance mean and standard deviation can be considered as outliers and trimmed from the dataset. A comparison of the point cloud before and after smoothing is presented in Figure 15.

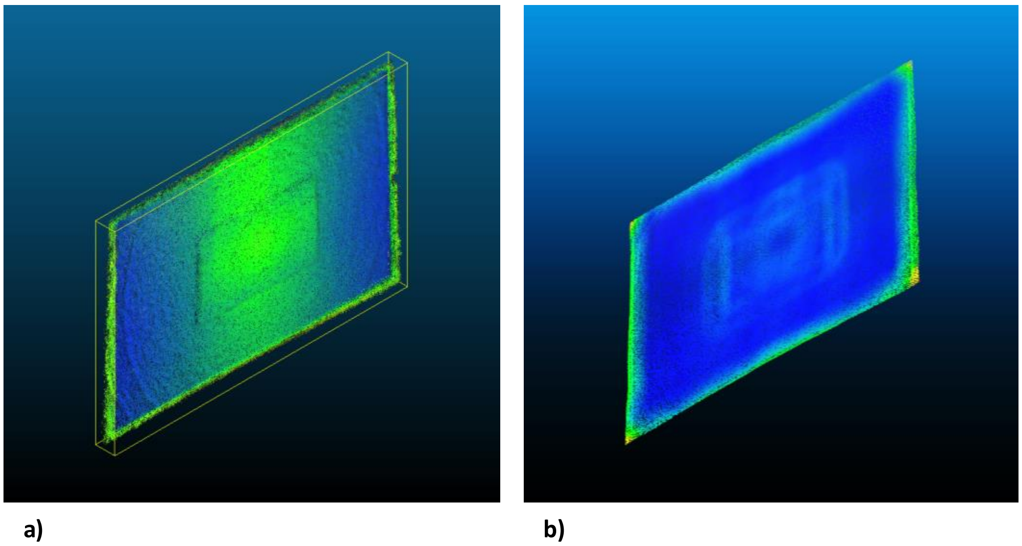


Figure 15 Point cloud of the model: a) before; and b) after smoothing

The Statistical Outlier Removal method was first used to remove the noise from the point clouds of the foam board. For this purpose, several cross-sections with a spacing of 2 cm were generated in CloudCompare and exported to AutoCAD to re-generate the geometry of the foam board. The average thickness of the foam board was then calculated by dividing its area over its length. Figure 16 illustrates the top view of the cross-sections of the 6 mm thick foam board.

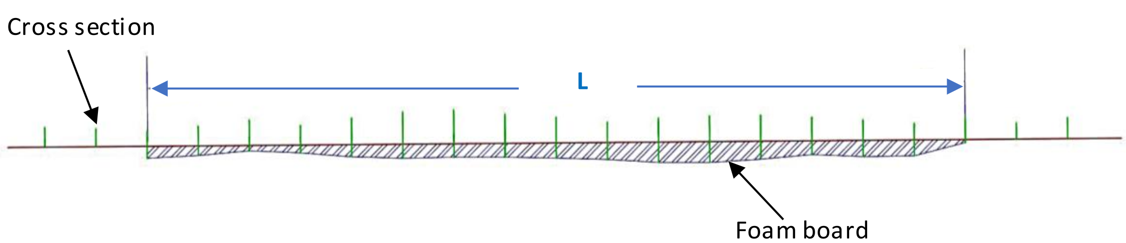


Figure 16 Top view of the extracted cross-sections of the foam board

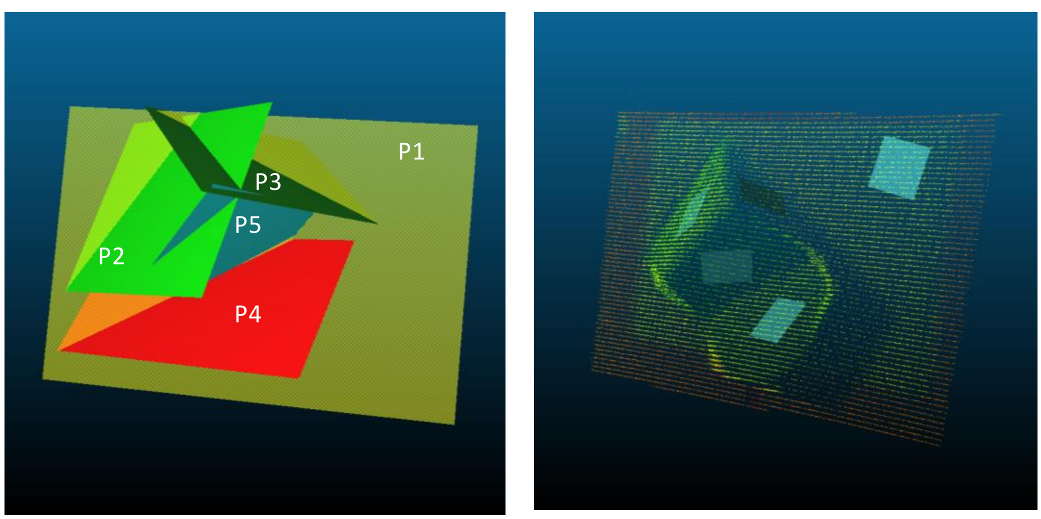
4.2 Discontinuity Orientation Measurements

4.2.1 Automatic plane detection method

The automatic shape/plane detection algorithm in CloudCompare was used to detect surfaces in the wedge model. Factors that may influence the results of this approach include the shadow zones and the density of point cloud. Five surfaces of the wedge model were chosen and measured by the geological compass and the results were compared with those automatically detected in CloudCompare.

4.2.2 Manual plane detection method

The automatic plane detection algorithm may not always detect all surfaces, and in some cases, may detect surfaces that are not real discontinuities. Therefore, it is suggested to compare the results of manual and automatic plane detection methods. To better understand the difference between the two methods, the manual plane detection method was used to determine the orientations of the surfaces in the wedge model. This was done by identifying the surfaces in the point cloud, manually selecting a point on each surface, and fitting a plane to them to obtain their dip values. Figure 17 shows the planes fitted to the surfaces in the wedge model using automatic and manual detection methods.



a) b)

Figure 17 Plane detection using: a) automatic; and b) manual methods in CloudCompare

5. Results

5.1 Change Detection

Figure 18 illustrates the results of change detection analysis from the point clouds using plane fitting and cross-section methods in CloudCompare. In this figure, the mean, the minimum and the maximum thicknesses of the foam boards obtained from post-processing the point clouds (i.e., bars) are compared with their actual thicknesses measured using a caliper (i.e., dashed lines). It is concluded that the plane fitting and cross-section methods provide comparable results for all foam board thicknesses scanned from small distances (i.e., d1 and d2). However, the cross-section method provides more reliable results for foam board thicknesses of 6 mm and 11 mm scanned from greater distances (i.e., d3 and d4). Note that the 6 mm thick foam board could not be identified in the point cloud from the scans taken at d3 and d4, therefore its thickness could not be determined using the plane fitting method. For the same reason, the thickness of the 11 mm thick foam board could not be determined from the analysis of the point cloud from the scan taken at d4 using the plane fitting method.

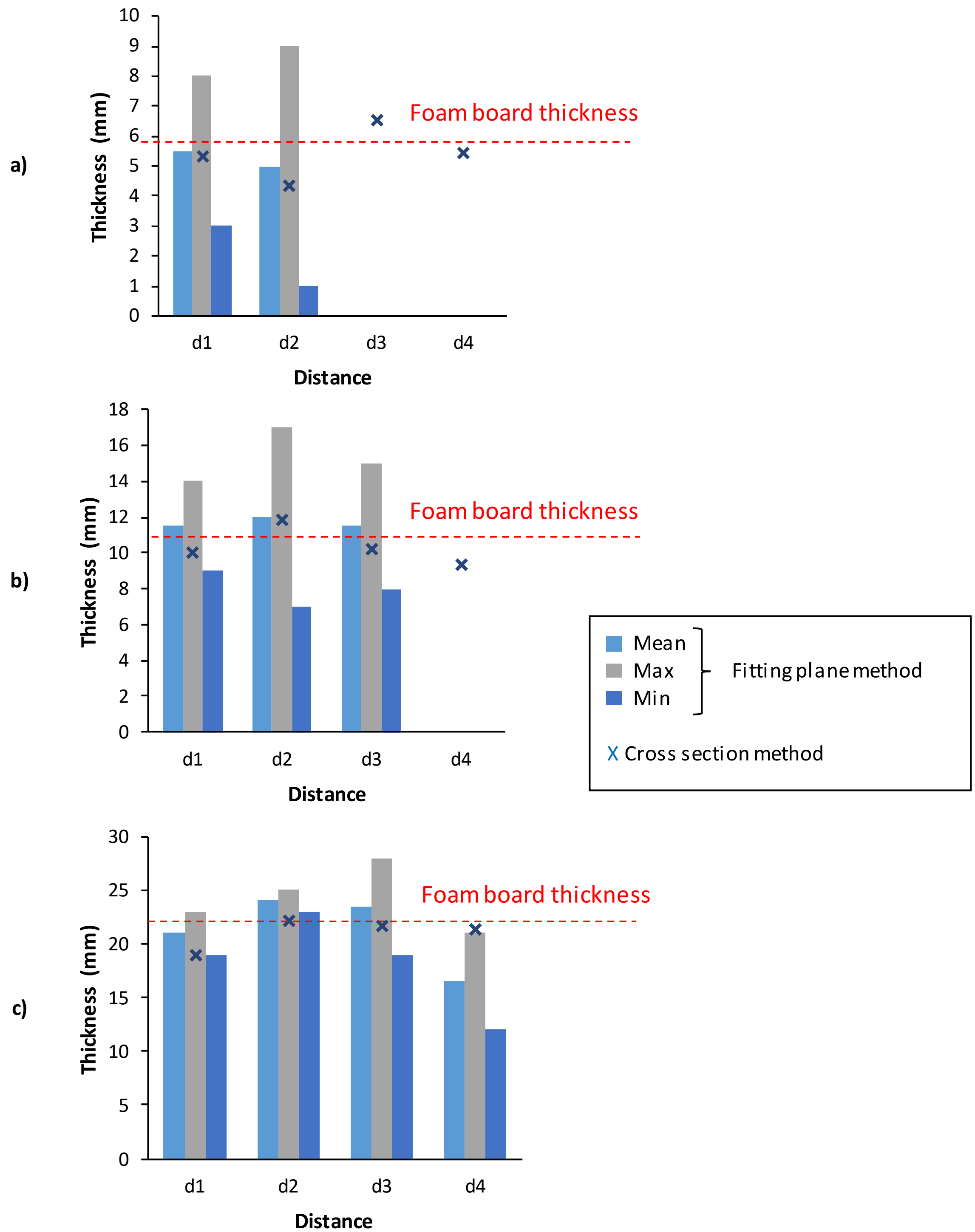


Figure 18 Thickness calculation for foam boards scanned at different distances via plane fitting and cross-section methods: a) 6 mm; b) 11 mm; and c) 22 mm thick foam boards

A comparison between the accuracy of measurement methods for the thickness of the foam boards scanned at four distances is presented in Figure 19. Accuracy highlights potential systematic errors and evaluates how close each measured value is to its associated real values (Sturzenegger & Stead, 2009). The difference between true and measured value is called the 'residual'. The measurement accuracy is evaluated by calculating the 'residual absolute value', as suggested Sturzenegger and Stead (2009). The residual absolute value in this analysis is defined as the difference between the thickness of the foam board obtained from post-processing the point clouds (i.e., measured value) and that obtained using the caliper (i.e., true value). The overall trend in Figure 19 shows an increase in the residual absolute value with increasing the distance between the scan station and the object (i.e., foam board) in the plane fitting method. This value is less than 3 mm for all distances in the cross-section method. The residual absolute values in the plane fitting method seems to be affected by the thickness of the foam board and the distance between the scan station and the foam board. However, the measurement accuracy in the cross-section method seems to be independent of the board thickness and the scanning distance to the object.

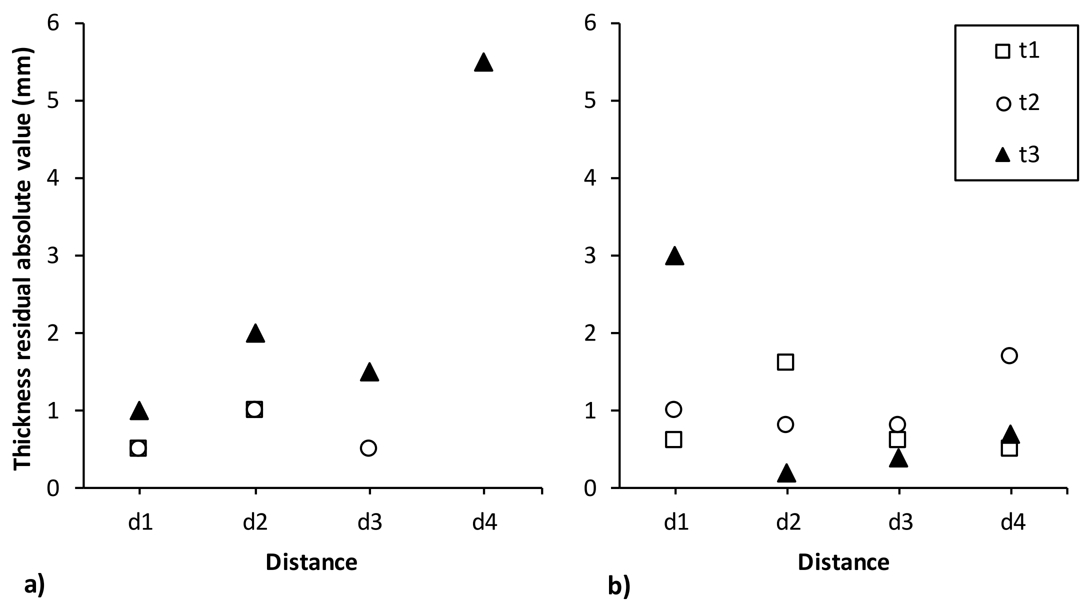


Figure 19 Thickness residual absolute values estimated for each foam board for: a) plane fitting; and b) cross-section measurement methods

5.2 Discontinuity Mapping

5.2.1 Modeled discontinuities

The dip values of the surfaces in the wedge model obtained from single and multiple scans are plotted in Figure 20 and compared with the dip values measured using the geological compass. This figure shows that the dip values from the manual and automatic plane detection methods are in a good agreement with manual measurements. The results indicate the applicability of both approaches in mapping rock discontinuities. However, in the case of rough surfaces or poor scans, the automatic plane detection method might not be able to capture all surfaces. Therefore, the manual plane detection approach should always be used independently or along with the automatic method.

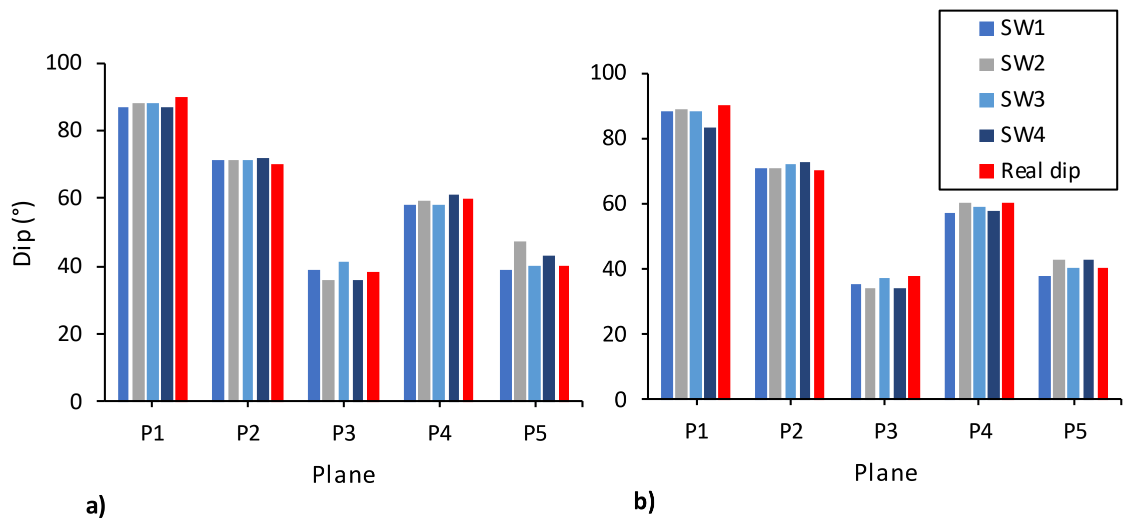


Figure 20 Dip values from single and multiple scans taken from stations SW1 to SW4 using: a) automatic; and b) manual plane detection methods

The residual absolute values for the dip angles obtained from both single and multiple scans (i.e., registering SW1 and SW2, and registering SW3 and SW4) are plotted in Figure 21. The dip residual absolute values were calculated for both automatic and manual plane detection methods and are compared with the average values. The results in this figure indicate that the dip absolute residual values are not influenced by the number of scans (single and double) nor the distance of the scanner from the objects. However, low absolute residual values in the automatic plane detection method suggest that the calculation of the dip values obtained from this method is more accurate than those from the manual method.

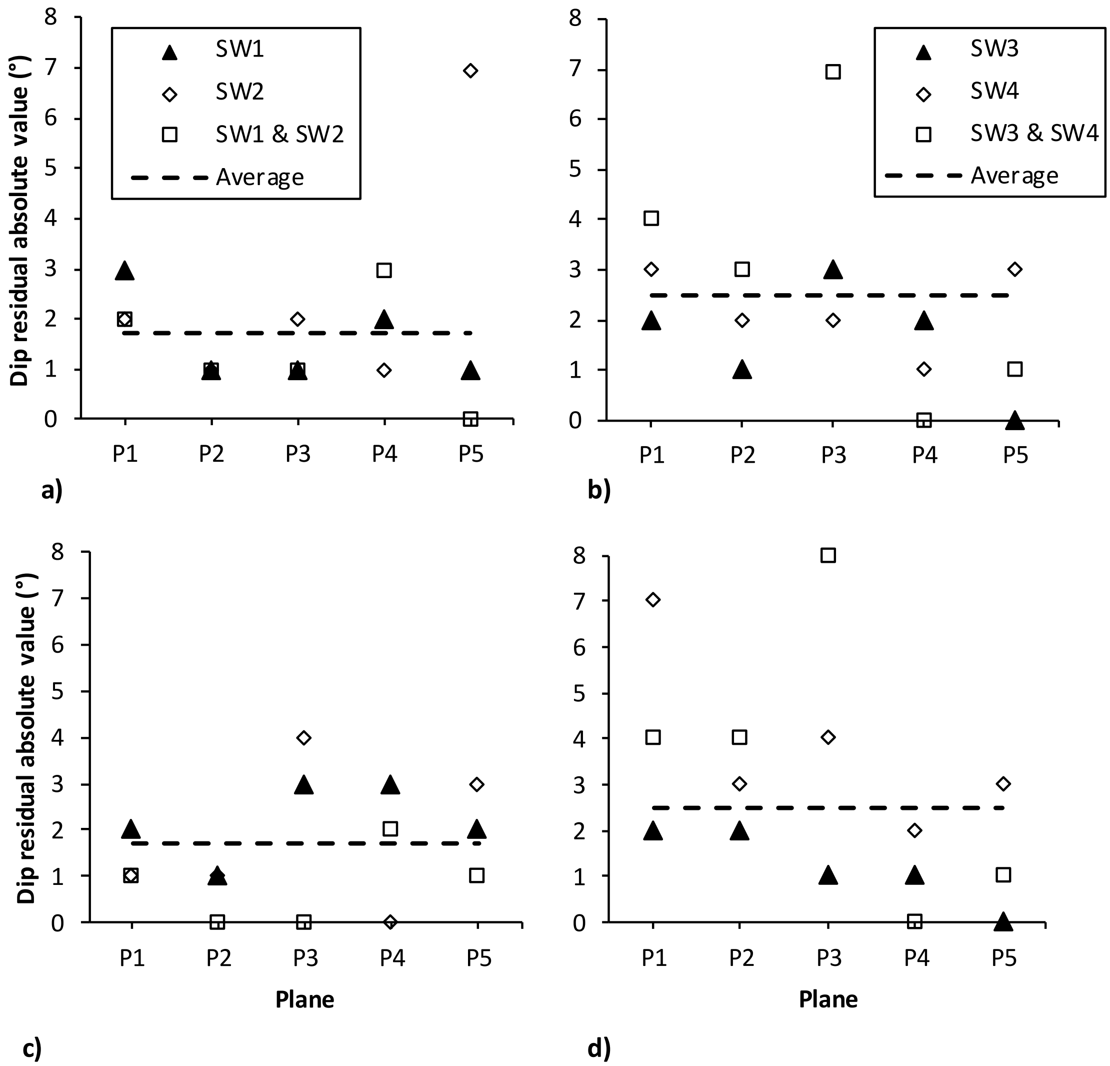


Figure 21 Dip residual absolute values for: a) automatic plane detection (2 m distance); b) manual plane detection (2 m distance); c) automatic plane detection (3 m distance); and d) manual plane detection (3 m distance)

5.2.2 Rock discontinuities

Using the manual plane detection method, the dip angles of the rock surfaces were obtained and plotted in Figure 22a. This figure shows the results from single scans taken from SR2, SR6 and SR10 and a combined scan by registering the point clouds from scanning at SR9, SR10, SR11 and SR12. The dip values measured using the geological compass are also shown in this figure (yellow squares). It can be concluded from the results presented in this figure that the dip angles of rock discontinuities obtained from single and multiple scans using the manual plane detection method in CloudCompare are close to manual measurements using the geological compass. The dip residual absolute values and their averages are plotted in Figure 22b. It is concluded that Versa3D can capture the dip values of rock discontinuities with an accuracy of 2 degree from a distance of up to 3 meters using the manual plane detection method in CloudCompare.

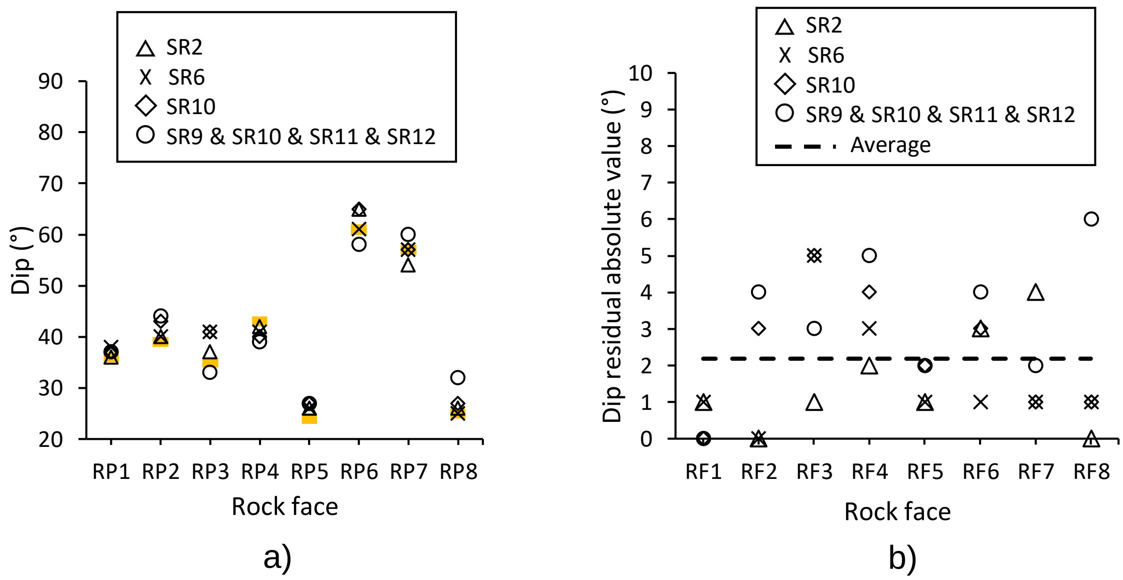


Figure 22 a) Dip angles of rock discontinuities obtained from laser scanning using the manual plane detection method in CloudCompare (measured dip angles are plotted as yellow squares); b) dip residual absolute values obtained from laser scanning using the manual plane detection method in CloudCompare

6. Other Applications

Based on the results of preliminary investigations presented in this report, Versa3D seems to be a practical tool mapping and monitoring objects from a distance of up to 3 m. To investigate other applications of this scanner, a hallway representing a long closed spaced environment such as a mine drift was scanned. Furthermore, Versa3D was used to capture the progressive deformation and geometry of a cylindrical Carbon Sandwich Liner (CSL) during axial loading.

6.1 Scanning of a Hallway

In order to evaluate the performance of Versa3D in scanning a long indoor environment representing an underground mine drift, a hallway was scanned at 13 scan stations. A top view of the hallways and the scan stations are illustrated in Figure 23. This figure shows the main hallway (Hallway 1) with six scan stations (i.e. S1 to S6) and a second hallway (Hallway 2) scanned at six stations (i.e. S2, and S7 to S12). To cover all the features along Hallway 2, scan stations were chosen at 1.5 m distance from each other. Registering all the scan point clouds in Hallway 1 and 2 resulted in a 3D view, which is shown in Figure 24.

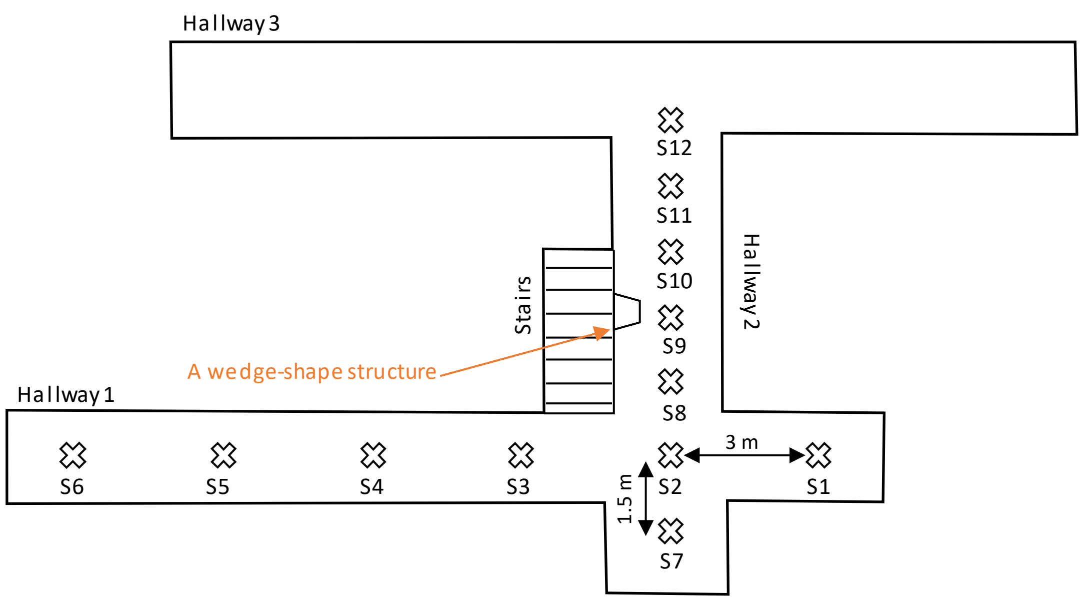


Figure 23 Plan view of the building/ hallways and scan stations

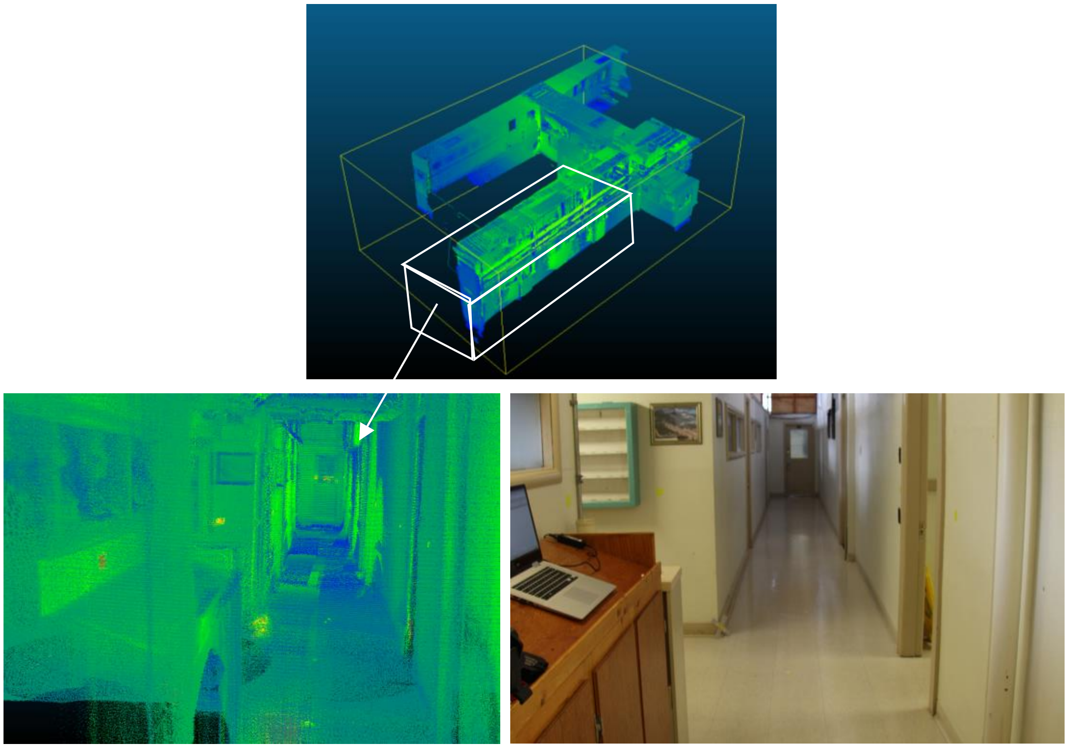


Figure 24 3D view of the hallways (top image) and a view of Hallway 1 in scan and real images (bottom images)

In underground environments, having distinguishable reference points for the purpose of point cloud registration is of great importance. For this purpose, several reference points of various shapes were made from reflective tapes and placed at different locations along the hallways, as shown in Figure 25.

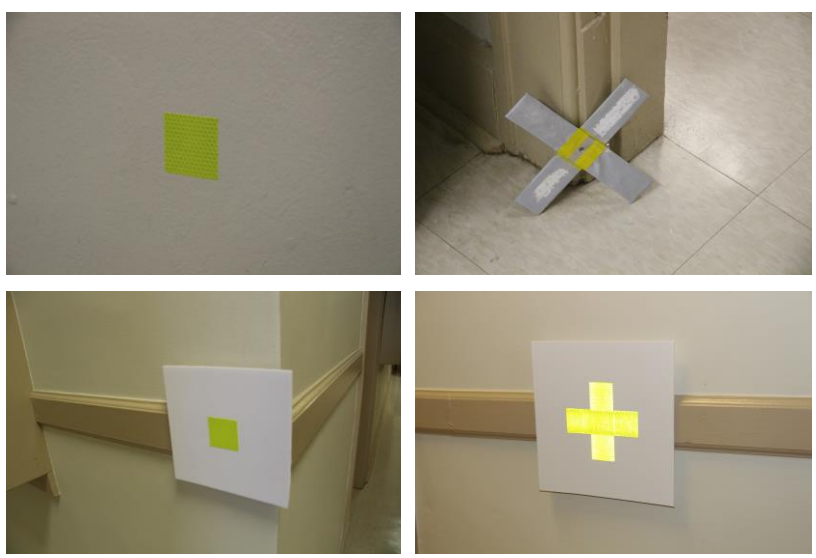


Figure 25 Reference points used for registering point clouds

In order to study the influence of the distance between the scan stations on the registration process and the results, a vertical section of Hallway 2 was obtained from the point clouds. Figure 26 presents a 3D view of Hallway 2 and a cross-section passing through a wedge-shaped structure.

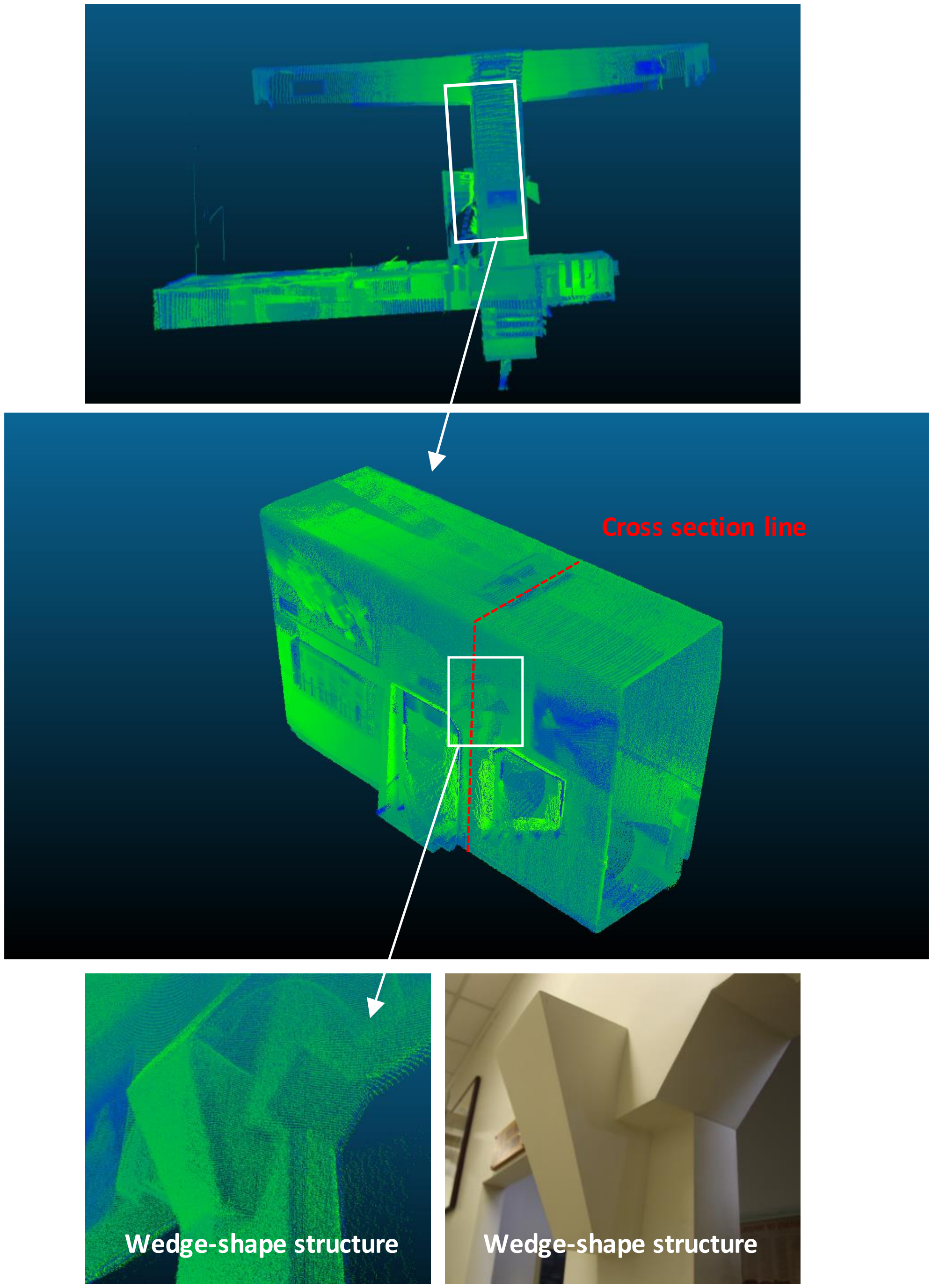


Figure 26 Scan and real images of a wedge-shaped structure in Hallway 2

A comparison between the vertical sections obtained from merging point clouds with scan station distances of 1.5 m and 3 m is provided in Figure 27. As shown in this figure, both cross-sections capture the overall geometry of the structure where the cross-section was taken. However, the geometries of some features near the corners of the cross-section obtained from laser scanning with scan station distance of 1.5 m deviate from the actual geometries of those features. The reason for this is not known but could be related to the level of noise, which is higher when the distance between the scan stations is smaller, as more point clouds need to be registered.

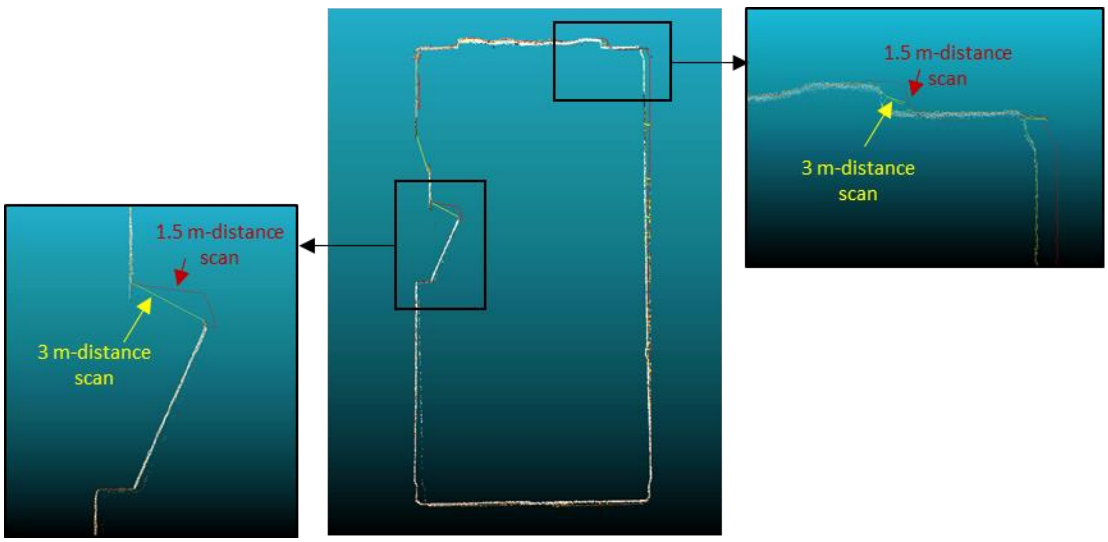
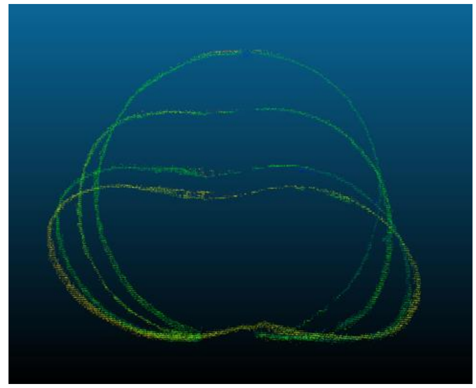


Figure 27 Comparison between the cross-sections obtained from registering point clouds from 1.5 m and 3 m distance scans

6.2 Progressive Deformation of Carbon Sandwich Liner (CSL) during Axial Loading

As discussed in this report, change detection and deformation monitoring are two common applications of 3D laser scanning in civil, geotechnical and mining engineering. To further investigate the capability of Versa3D for change detection and deformation monitoring, a cylindrical Carbon Sandwich Liner (CSL) was scanned during axial loading. For this purpose, the slowest scan speed (i.e., 135 seconds) was selected and the CSL with a thickness of 10 mm was scanned from a distance of 50 cm before and after the test (Figure 28). To better understand the change in the geometry and progressive deformation of the CSL during axial loading, scanning was also performed two times during the test. Figure 28 illustrates how the geometry of the CSL changes during the axial loading.



a) b)

Figure 28 a) Test set-up for axial loading of a Carbon Sandwich Liner (CSL); b) progressive deformation of the CSL during axial loading captured by Versa3D

7. Conclusions and Recommendations

3D laser scanning is a rapidly evolving technology which is being used as a tool for rapid data collection in various engineering disciplines. Some of the common applications of 3D laser scanning in mining and geotechnical engineering include mapping geological discontinuities for rock mass characterization and monitoring the deformation of excavation walls under various mining-induced loading conditions. In this project, Versa3D, which is a compact short-range 3D laser scanner, was examined as a potential tool for change detection and discontinuity characterization in underground mine drift.

In the first part of the project, Versa3D was evaluated for its accuracy in detecting small changes. For this purpose, foam boards of various thicknesses (6 mm, 11 mm and 22 mm) were attached to a wall and scanned at different distances (up to 3 m) from the wall. Scanning was conducted before and after attaching the foam boards to the wall. The comparison between the two point clouds was used to identify and measure the thickness of the foam board. Two methods in CloudCompare including the plane fitting and cross-section methods were used for this purpose, and the results were compared with actual measurements using a caliper. It was found that the cross-section method provides a more reliable estimation of the thickness of the foam board, and that Versa3D can be used to capture changes of 6 mm and more from a distance of up to 3 m.

In the next step, a model of rock discontinuities in the form of a wedge was made from foam boards, attached to a vertical wall and scanned from different distances and angles. Both automatic and manual plane fitting methods in CloudCompare were used to determine the dip values of the wedge surfaces, and the results were compared with those from manual measurements using a geological compass. Further investigations were conducted by scanning a rock outcrop and mapping its discontinuities. It was found from the results of both laboratory and field investigations that Versa3D can be used to map discontinuities and obtain their dip values with an accuracy of 2 degrees up to a distance of 3 m from the object using the automatic plane fitting method in CloudCompare.

Future research will consider investigating the application of Versa3D in detecting joint traces. Preliminary investigations can be carried out under controlled laboratory conditions by creating slots of various thicknesses on the foam boards, representing joint traces or openings. In the final step, it is suggested to test this scanner for deformation monitoring along mine drift and pillars. This will involve scanning two parallel drifts making up the pillar in an underground mine. For this purpose, laser scanning will be conducted at two stages in the mining cycle: 1) During the mine development stage (i.e., drift advance); and 2) During the mine production stage, (e.g. due to excavation of nearby stopes). Stage 1 will involve repeated scanning of individual drifts after each round of drift advance. Once both drifts are completely excavated, scanning of the drifts will be continued after each round of stope excavation. The results of deformation monitoring using laser scanning can be checked against drift convergence monitored using the tape extensometer.

Acknowledgements

The authors would like to acknowledge the in-kind contribution by Clickmox Solution Inc. through the NSERC Engage Grant. The technical support from Dr. Naeem Ahmed, Jieyu Wang, and Justin Gagnon is greatly appreciated. Prof. Pedram Sadeghian and Anita Shiny Kanagaraj of Dalhousie University are also thanked for providing access to their lab and allowing scanning the Carbon Sandwich Liner during their experiments.

References

Ahmed, S. N., Gagnon, J. D., Makhdoom, M. N., Naeem, R., & Wang, J. (2017). New methods and equipment for three-dimensional laser scanning, mapping and profiling underground mine cavities. In Proceedings of the First International Conference on Underground Mining Technology (pp. 467-473).

Fekete, S., & Diederichs, M. (2013). Integration of three-dimensional laser scanning with discontinuum modelling for stability analysis of tunnels in blocky rockmasses. International Journal of Rock Mechanics and Mining Sciences, 57, 11-23.

Martin, C. D., Tannant, D. D., & Lan, H. (2007, May). Comparison of terrestrial-based, high resolution, LiDAR and digital photogrammetry surveys of a rock slope. In Proc. 1st Canada–US Rock Mechanics Symp (pp. 37-44).

Ross-Brown, D. M. (1973). Design considerations for excavated mine slopes in hard rock. Quarterly Journal of Engineering Geology and Hydrogeology, 6(3-4), 315-334.

Sturzenegger, M., & Stead, D. (2009). Close-range terrestrial digital photogrammetry and terrestrial laser scanning for discontinuity characterization on rock cuts. Engineering Geology, 106(3-4), 163-182.

Walton, G., Delaloye, D., & Diederichs, M. S. (2014). Development of an elliptical fitting algorithm to improve change detection capabilities with applications for deformation monitoring in circular tunnels and shafts. Tunnelling and Underground Space Technology, 43, 336-349.

Weng, Q. (2013). -Introduction to Remote Sensing Systems, Data, and Applications. In Remote Sensing of Natural Resources (pp. 28-47). CRC Press.