Using SLAM-based Handheld Laser Scanning to Gain Information on Difficult-to-access Areas for Use in Maintenance Model

T. Makkonen[a], R. Heikkilä[a], P. Tölli[b], F. Fedorik[a]

[a]Construction Technology Research Center, University of Oulu, Finland
[b]First Quantum Minerals, Pyhäsalmi Mine, Finland

E-mail: Tomi.Makkonen@oulu.fi, Rauno.Heikkila@oulu.fi, Filip.Fedorik@oulu.fi
Pekka.Toelli@fqml.com

Abstract

Laser scanning is the de-facto system to collect large amounts of geometrical information, especially indoors. Total stations are usually used for accuracy and information-rich results. However, in some cases the target area is not suitable for using a terrestrial laser scanner. For instance, too cramped or difficult-to-access space can be a limiting factor. In complex cases, standard scanning methods are usually time-consuming, leading to unexpected costs and sometimes scanning can be omitted for time and cost reasons.

Simultaneous location and mapping (SLAM)-based rapid laser scanning could be considered as a practical method to perform scanning in poorly accessible spaces. In this paper, we present results obtained using a ZEB1 handheld SLAM-based laser scanner to ~1440 m depth in a mine shaft in Finland while standing on the roof of the moving elevator, for very fast data collection in an extreme environment.

In a scanning time of approximately one hour, we collected and archived 120 million data points. Compared with standard tripod lasers, the accuracy was low, but could be improved using positioned targets. The method also gave an imperfect model which required manual correction. Considering the rapid maturation of SLAM-based systems, the method can be seen a promising tool to collect laser point data in difficult-to-access areas in the near future for maintenance model applications. These systems already work well enough when speed is required over accuracy and in cases where the environment is too difficult to use standard total stations, as in the case presented in this paper.

Keywords –

mine shaft; BIM; laser scanning; SLAM; maintenance model

1 Introduction

This study is an extension of previous work in which we studied the practicality of using simultaneous location and mapping (SLAM)-based rapid laser scanning for mine inventory model purposes [1]. The case presented in this paper is probably one of the most difficult possible: a very long narrow space (elevator shaft), rain due to water leaking from rocks, moisture on the walls and a relatively fast moving platform. The latter made it impossible to scan the full 360º, and instead about 270º were scanned while going down and another 270º while going up. The expectations for perfect results were very low; the intention was rather to test the limits of current performance of rapid laser scanning systems. However, the results were better than expected and using the same elevator shaft later should give us a great baseline to compare the advances in SLAM rapid laser scanning in upcoming years.

In Finland, YIV2015 [2] and COBIM2012 [3] specifications are used in infrastructure and building specifications, but the mining sector applies specific regulations. Mine shafts must be regularly inspected, as required by national standards, for instance the U.S. Code of Federal Regulations for Mineral Resources (U.S. Government Publishing Office). At Pyhäsalmi Mine in Finland, a mine elevator shaft used for personnel transport is inspected at least once every three months. At least four inspectors must use a specific inspection platform under or on the roof of the car, with one person in the car with radio connection to an operator of the elevator at surface level. Hence, five people are needed in the elevator and one on the surface. The radio operator and inspectors must have a clear connection, causing no misunderstanding that can lead to critical situations. The inspection takes about one hour and during this time the elevator is disabled for other uses.

Thus improving the inspection method and procedure in Pyhäsalmi Mine consists of: reducing the man hours needed, shortening the inspection time to free up the elevator for other uses and finding and responding to changes and faults more frequently than every three months. This can be achieved by finding ways to generate a maintenance model.

2 Laser scanning with SLAM

One of the promising candidates for performing specialist tasks such as shaft monitoring is applying laser scanners with SLAM capabilities. SLAM-based laser scanners usually include, in addition to the laser scanner part, an inertia measurement unit (IMU) that records angular rate and specific forces. In addition, they can use other positional data in sensor fusion, e.g. GNSS location or odometer information, if available, in mathematical calculation of simultaneous location and scanning.

The commercial name of the SLAM-based laser scanner tested in this study is ZEB1 (Figure 1), but the entire system, developed by CSIRO, is called Zebedee. Tutorials and video presentations on the device can be obtained from CSIRO [4], Geoslam [5] and 3D Laser Mapping [6]. The handheld laser scanner generates a 3D map automatically while measurement is being performed. Thus for instance a whole tunnel network (or whole building) can be scanned with only one continuous measurement. The main parts of the ZEB1 are a spring-mounted 2D laser, data logger and inertia measurement unit (IMU). The range typically used for scanning is 15-20 m, scan rate 43200 points per second, noise ± 30 mm and field of view horizontally 270º. The moved-around vertical field of view is approximately 120º. Post analysis of data is performed at dedicated servers in the cloud. Details of the construction and design parameters are available elsewhere [7]. The accuracy of ZEB1 in a mine environment has previously been tested at Kemi Mine [8]. Some differences between total station and SLAM-based rapid laser scanning are listed in Table 1.

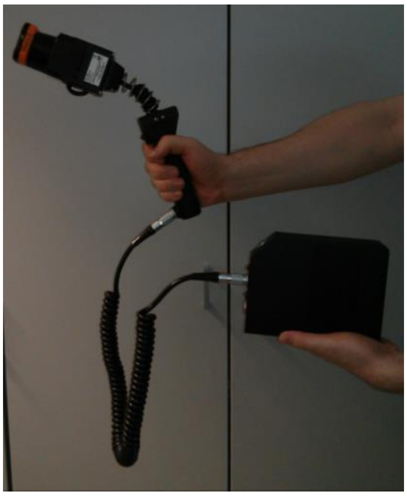

Figure 1. The ZEB1 SLAM-based laser scanner.

Table 1 Differences between total station and SLAM-based handheld rapid laser scanning

Total station	**SLAM-based rapid laser scanner**
Needs setting up and referencing per measurement location	Is ready to go from the start. However, requires closed loop path, so that measurement is started and stopped at the same location
Is required to stand in one location without distributions	Measurement device is moved around, and location is auto-generated relative to the environment
Accuracy and noise are good	Accuracy and noise are low compared with total station
No drift error	Drift error, which is halved by closing the measurement loop
Scanning speed slow in cramped space because it needs setting up per scan location. For narrow spaces, many measurement locations are needed	Very fast, because measuring device can move around while continuously measuring
Not economical in general in cramped space, because needs long time to set up to measure from multiple places with referencing. Also needs skilled workforce	More economical in cramped space, because is faster to perform and skill cap is low
With working reference networks combining point clouds gives great results, without references needs referencing first	Currently does not use reference points ‘inside’ the measurement. This is also a disadvantage if accuracy is the main goal, over speed

3 Rapid laser scanning experiment in Pyhäsalmi Mine shaft

A laser scanning experiment using ZEB1 was performed at Pyhäsalmi Mine, Finland, in an elevator shaft called Timo's Shaft. The length of the shaft is approximately 1440 m and the diameter is 5 m, and it had never been laser-scanned previously. The laser scanning measurements were performed during a regular inspection. While the inspectors were standing on the roof of the car, laser scanning was performed at the highest point of the elevator system. This gave a relatively obstruction-free view to the wall of the shaft (Figures 2 and 3). The operator waved the ZEB1 up and down in one position at about 1 Hz frequency, to scan well over half (270º) of the tunnel when going down. After the elevator started to ascend, the position was rotated 180º to face the opposite wall, resulting in overlapping point clouds (approximately 90º overlap both sides) covering the entire shaft wall.

The elevator speed was regulated to 1 m/s, giving a time from ground level to bottom of about 25 minutes and another 25 minutes back up. The total measurement time was about an hour, including time needed for preparation.

The conditions were demanding for laser scanning, since water penetrating through the rocks resulted in a constant rain in the shaft for the first 1000 m. There was no rain cover in use and therefore the rain wet the glass in the measuring glass head, but also the rock walls, resulting in shiny surfaces. Furthermore, rain itself is not suitable for laser measurement, as it obscures the path of the laser rays [9].

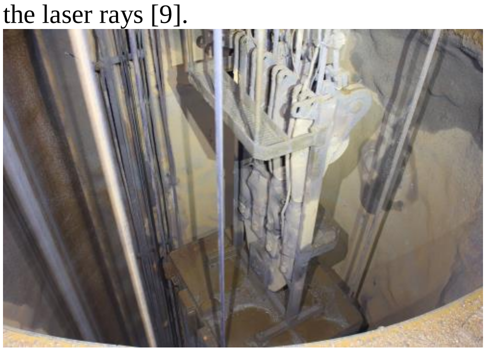

Figure 2. Measurement position, the highest platform in the image.

Figure 3. Overall image of the measurement position in relation to the upper part of the elevator.

4 Results of measurements in the mine shaft

A graphical expression of the point cloud obtained from the measurements is presented in Figure 4. It shows the point cloud of the whole shaft on the left and detailed shaft from the highest point of the elevator to the first level. The point cloud was made from 120 million points in *ply* format. The calculated approximation for point density during movement of 1 m/s was 2778 points per square metre, meaning that points were separated by 2 cm. Because the measurement method involves hand movements during scanning, this value can vary significantly, depending on the orientation of the measurement head.

Compatibility of the measured point cloud with the mining software Surpac was achieved using a Matlab script to convert *ply* format to native Surpac *str*. An example of data for *str* covering the first three measured points is given in Table 2.

After measurement, the collected data were sent for post processing in Geoslam, where SLAM-based data fitting failed completely twice, but gave results at the third attempt. The best result obtained is presented in Figure 4. Complete success was not achieved, as part of the point cloud failed to match measurements between 252 and 434 m, as shown in Figure 5. As can be seen, the results, represented by two half-cylindrical rings, did not overlap correctly. A correction procedure was applied for part of the shaft to test the accuracy and possibility of improving the results obtained. The two overlapping rings were first classified, resulting in two separate point clouds, by using time stamps as shown in Figure 6. Given the vague shape and asymmetry of the clouds, automatic alignment was not possible. Registering points manually was also too difficult to achieve suitable accuracy.

Table 2 Example of *str* format for the first three measured points

0.000,	0.000,	0.000,	0.000,	0.000,	0.000
1,	3.622,	-1.643,	-75.120,		
1,	3.723,	-1.430,	-75.187,		
1,	3.739,	0.820,	-75.469,		
0,	0.000,	0.000,	0.000,		
0,	0.000,	0.000,	0.000,	END	

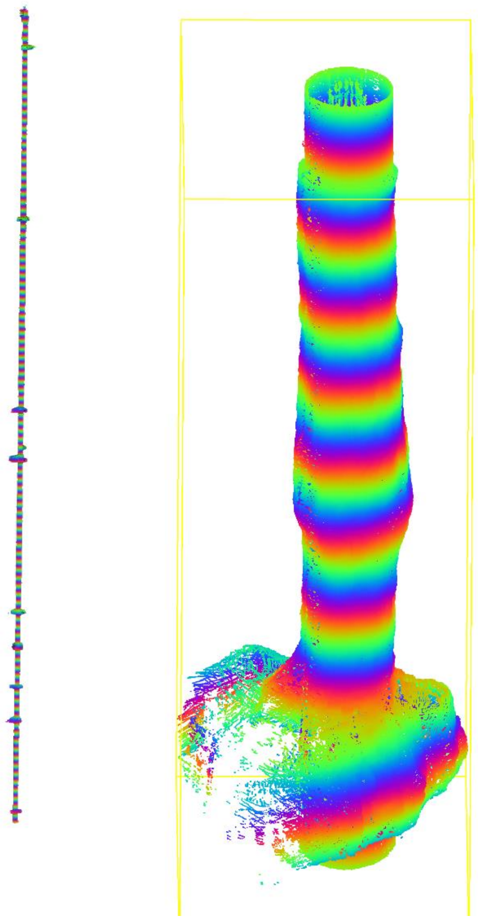

Figure 4. Left: The whole scan of the 1440-m Timo's shaft. Right: Upper part of the scan.

To solve the problem, five cables were segmented out of both clouds and automatically aligned (Figure 7). The transformation matrix was then applied to the point clouds, resulting in the new point cloud in Figure 8. The quality of the results was confirmed by comparing computed distance of overlapping parts (Figures 9 and 10), with mean error 37 mm and standard deviation 19 mm.

The quality of SLAM-generated results was studied by using part of the scan, from 130 m depth. Here the rock surface was characteristically more similar than for most of the tunnel's uneven bare rock surface. Although the time difference between up and down scans was among the greatest, measurement in this location was still systematically similar to the basic procedure. Repeated time classification was used to generate two separate point clouds and the differences in the overlapping area were studied. The resulting mean distance error was 27 mm and the standard deviation 17 mm (Figures 11 and 12).

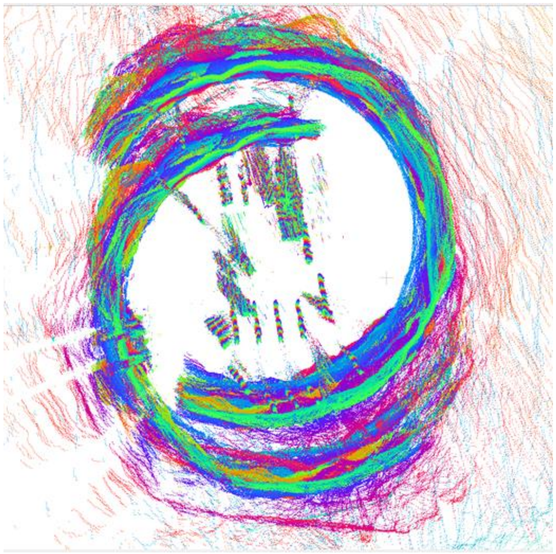

Figure 5. Poorly shaped SLAM-generated point cloud between 252 and 434 m.

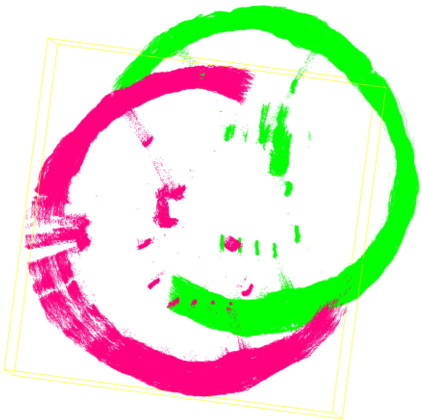

Figure 6. Two separate point clouds, classified using time stamps.

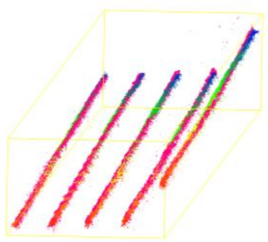

Figure 7. Aligned cables to generate the transformation matrix.

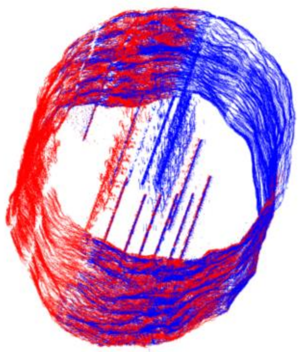

Figure 8. Semi-manually merged point clouds.

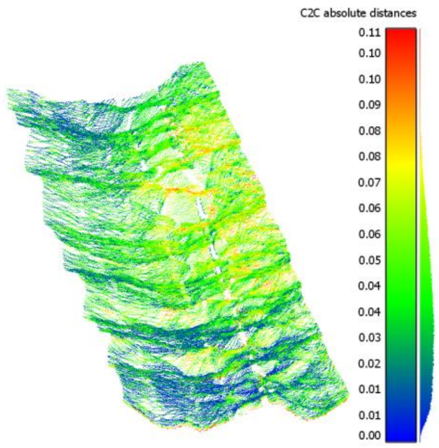

Figure 9. Distance error (m) in merged point clouds after transformation.

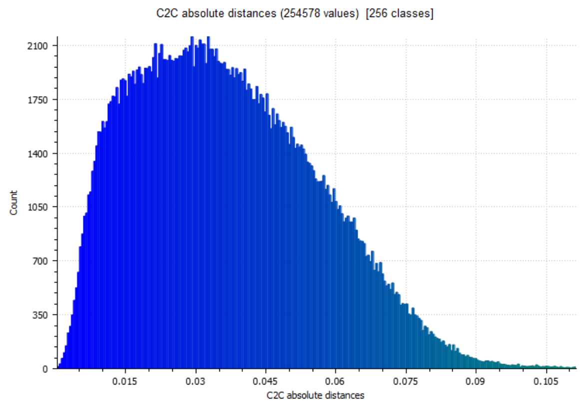

Figure 10. Histogram of distance error (m) for manually corrected point cloud.

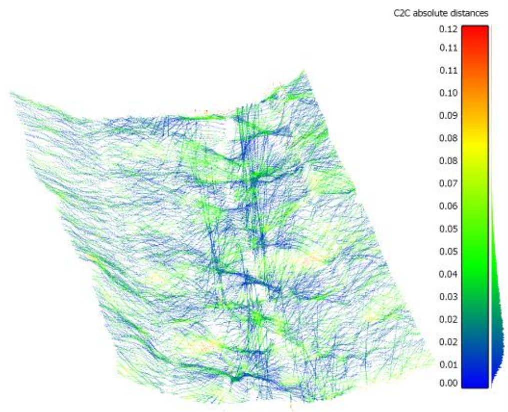

Figure 11. Distance error (m) in SLAM algorithm-generated point cloud, comparing time stamp-classified clouds.

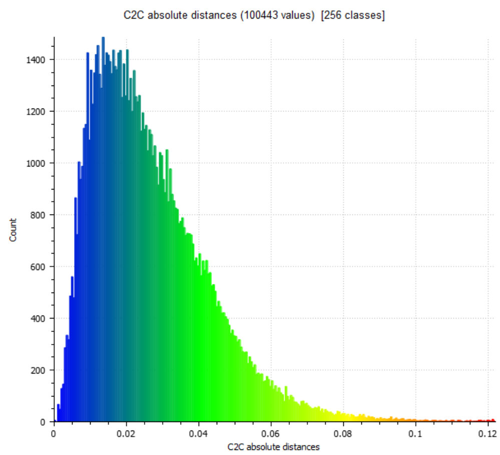

Figure 12. Histogram of SLAM algorithm-generated point clouds, comparison of time-classified up and down scans (m).

5 Discussion and conclusions

This measurement experiment in extreme conditions demonstrated the potential of SLAM-based scanning systems to generate point clouds. The SLAM generation of laser scanners is not fully mature yet, but shows promise for future automated elevator-shaft monitoring and maintenance model generation. In its current state, the system is not ready yet for the demanding task it was given in this paper.

It should be noted that the scanning can most likely be improved greatly, even using the same equipment. The most significant change results-wise could be the scanning pattern, as only 270º of the shaft wall were scanned, while a whole 360º scan would have been preferable. This could be achieved using automated movements of the scanner, or designing better, more systematic movement in the handheld method, whereby more of the cylindrical shape is covered. The most efficient way would probably be a laser scanner system fixed to the elevator with a uniform circular moving mechanism.

Nevertheless, the results suggest that applying the laser scanner for mine shaft point cloud generation has much potential, e.g. the method is extremely fast and does not require wide spaces to perform. Noise value for mean distance error of 27 mm and a standard deviation of 17 mm in an automatically generated point cloud is already acceptable for some usages. The results obtained seemed to be unaffected too much by rain and humidity condensing on the device, but it is probably advisable to protect the scanner from falling rocks and/or other elements and to prevent rain and humidity from influencing the measured results. Results from our earlier work [1] also support use of rapid handheld laser scanning in difficult-to-access areas. In that study scans were performed in an old, cramped hoisting tower (Figure 13), a steep stairway to an evacuation shelter and even places where the operator had to crawl through a small hole.

In future work, analysing positional measurement errors and finding more efficient methods to obtain point clouds will be the main goals. On achieving accurate scanned results to monitor a shaft, a statistical method and a suitable number of scans should be determined. Hence, continuous scanning and applied statistical techniques might allow development of SLAM-based point cloud measurements of sufficient quality for maintenance monitoring.

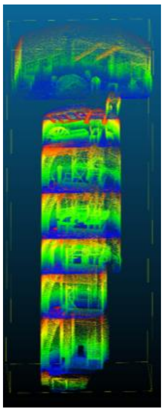

Figure 13. Rapid laser scanning results of a hoisting tower – cross-section of the whole tower [1].

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