# The Applicability of the Rapid Handheld Laser Scanner to Underground Tunnel Surveying

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**Abstract -**

**Laser scanned point clouds are important part of the modern work processes in mine industry. Inertia corrected handheld laser scanners are new type of apparatus commercially available from the year 2013 to gather point clouds. These devices are fast to use as the person scanning can walk when holding the device and the map is then automatically produced, however the resulted point cloud is most likely not as accurate as it is with standard industrial laser scanner.**

**Having major advances in fast and easy scanning and a drawback of not so great accuracy might do the usage of the attained point cloud non trivial in industry. Based on experiments accuracy of the ZEB1 handheld laser scanner from Geoslam Ltd is studied in three underground field experiments.**

**Obtained RMSE varied between 0.15 – 0.43 meters. It's important to remember that these results are not mostly about accuracy of the ZEB1 (Zebedee) but about the accuracy of the whole measurement chain of personnel, measurement devices and the coordinate system used in the mine.**

**Scanning speeds in experiments were astonishing from 5 to 13.5 tunnel meters per minute.**

**Keywords -**
**handheld laser scanner; point cloud; accuracy; tunnel**

## 1 Introduction

Handheld laser scanner generates a 3D map automatically during measurement, thus for example whole tunnel network (or whole building) can be scanned with only one continuous measurement. The scanning speed can loosely defined as a slow walking speed as scanning is performed by holding scanner in hand and walking around the desired area, while simultaneously waving spring supported laser sensor.

The commercial name of the device we tested is ZEB1, but the name of the whole system developed by CSIRO is Zebedee. Tutorials and video presentations about the device can be found from the CSIRO[1], Geoslam[2] and 3D Laser Mapping[3].

In Figure 1 the measurement device is presented. The main part of the ZEB1 are spring mounted 2D laser, data logger and inertial measurement unit (IMU). Typical range for scanning is 15-20 meters, scan rate 43200 points per second, noise ± 30 mm and field of view horizontally 270º when moved around vertical field of view is approximately 120º. Data analysis is done as a post analysis at dedicated servers in the could.

For deeper understanding about the construction and design parameters reference [4] is highly recommended.

Simultaneous localization and mapping (SLAM) [5] is the method to generate 3D maps from the surrounding simultaneously when making the scan. Every new scanned point extends the 3D map. Place recognition using ZEB1 is presented in [6].

Very simplified way to describing map generation is: Scanned points start to accumulate and form shapes. So that for example when wall is scanned, it will take a shape of a plane. This plane is then extended and used as a reference to other measurements. IMU provides extra sensor information for this to happen.

## 2 Experiments and setup

Laser scanning experiments was performed in Kemi Mine, Finland approximately 500 meters below the surface. Three test tracks were prepared: Loop, Trick and Marathon (Figures 4, 5, 6).

Every reference point was measured in Kemi Mine coordinate system using total station.

**Figure 1**. ZEB1

Targets were custom made as seen in Figure 2 and 3. The polystyrene ball's diameter was 25 cm and standard laser target was mounted to it. Custom target were used because standard geometric targets we had were too hard to locate from the noisy data collected.

**Figure 2**. Custom made target in Trick experiment area

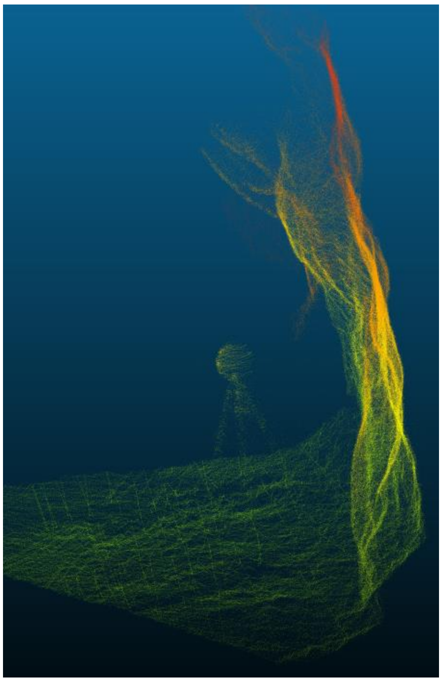

**Figure 3**. Custom made target in point cloud

## 2.1 Experiments

### Measurement 'Loop' MEA1 and MEA1

A map of the Loop experiment is shown in Figure 4. The size of the area is about 80x72 m. The main method to use ZEB1 is to create loops. Every time measurement paths cross a correction can be made. Total of ten points were measured using total station and then scanned (one was later removed from the results).

Two separate measurements were made. First one clockwise (MEA1) and second counter clockwise (MEA2) starting both times near point D. The path was really demanding as there was a drop of 4 meters between points D to E through narrow passage and lots of open space from F to D. E to A was smaller tunnel and A to F was larger tunnel for traffic.

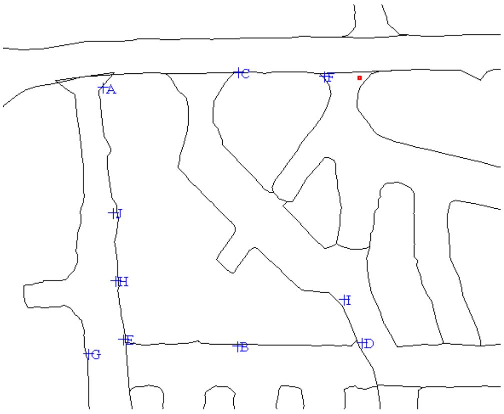

**Figure 4**. Experiment Loop. MEA1 clockwise D-B--D and MEA2 counter clockwise D-I--D.

**Measurement 'Trick' MEA3 and MEA4**

A map of the Trick experiment is sown in Figure 5. The size of the area is about 5.5 x 34 m. The purpose was to study work process after tunnel end rock blasting. Ten points were measured starting near A then walking a bit past H and returning back to A. This measurement was repeated two times (MEA3 and MEA4).

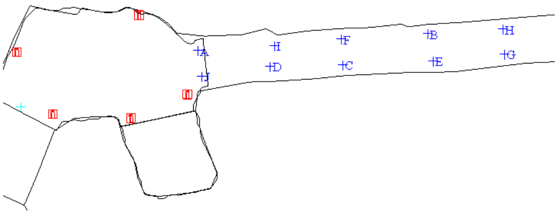

**Figure 5**. Experiment Trick. MEA3 and MEA4 similar path A-H-A middle of the tunnel

**Measurement 'Marathon' MEA5**

A map of the Marathon experiment is shown in Figure 6. The size of the area is about 145 x 170 m. The purpose of the measurement was to see how longer distances will affect to the accuracy and also to study drift error. Figure 7 shows the location around F to E.

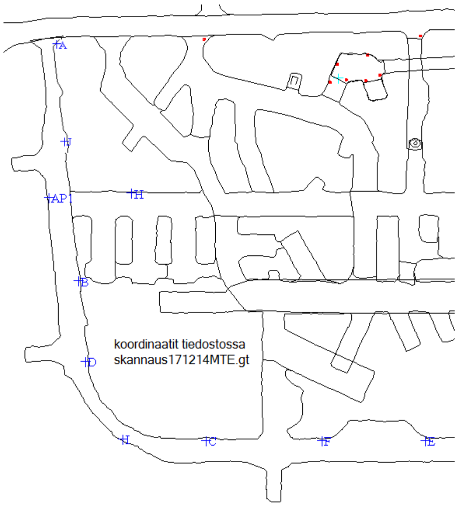


**Figure 6**. Experiment Marathon. MEA5 started from A to E and back to A.

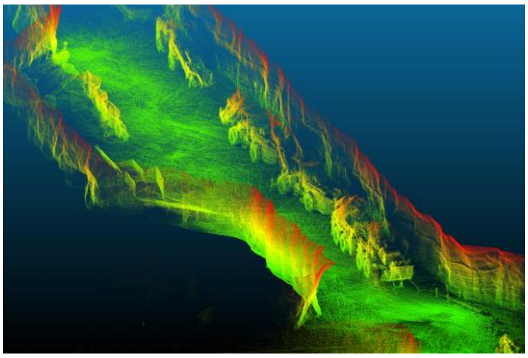

**Figure 7**. Part of the tunnel in experiment Marathon.

## 2.2 Coordinate transformations and error analysis

From point could spherical targets were extracted using fminsearch [7] with fixed radius and compared with measurements done in Kemi Mine coordinate system from total station measurements.

For direct comparison six parameter LSQ fit (Least Squares fit) was used, where 3 transformations and 3 rotations were the variables. This method was used in all three experiments Loop, Trick and Marathon.

From experiments Loop and Marathon point A was omitted, leaving 9 points to study. Root mean square error and standard deviation was calculated. LSQ fit was done using all the points obtainable, so nine point was used for transformation except for Trick full ten points was used.

To study errors, especially drift error, special case was formed around experiment Marathon. Only three points (AP1, H and B) were used to make transformation. The theory being that only ZEB1 is making the localization and drifting away when distance is growing. Because z-errors (height) were very small around intended points compared to xy errors LSQ fit performed really poorly and so Helmert transformation fit was decided to use.

Helmert transformation was done separately in xy-plane for two linear transformations and one rotation around z. This combined transformation was then studied.

Scalar error was calculated for every experiment. From measured reference points distance between every measure point was calculated and then compared to results from the laser scanning.

## 3 Results

In Figures 8,10,12 the planar xy error is presented as arrows pointing from the reference points. Separate axis are for position of the reference point (black left and bottom) and for the error (red top and right).

Error in z-direction is shown for the experiments in Figures 9,11 and 13. The y-axis corresponds to the Figures 4, 6 as follows 1=B, 2=C … 9=J and to the Figure 5 1=A, 2=B … 10=J.

Scalar error, the distance between reference points compared to the laser scanned distances is presented in Figures 16,17 and 18.

Finally error data are interpreted as a one number results presented in tables. Table 1. shows the root mean square error (RMSE), varying between 0.15 – 0.35 m, when laser scanner positions are transformed to Kemi Mine coordinate system using 6 parameter LSQ fit. All reference points and measurement points are used to for the fit. Error is given x,y,z direction as well as the 3D error *d* as a square root of the sums of the errors x, y and z directions.

Table 2 and Table 3 standard deviation and maximum errors are calculated similarly to Table 1. Calculated standard deviation values are between 0.6 - 0.18 meters.

Scalar errors are given in Table 4. Distance between reference points was calculated and then compared to results obtained from laser scanning and error then presented. Four values presented per experiment are: RSME, standard deviation, BIAS as an average error and maximum error. RSME value calculated is between 0.13 - 0.44 meters.

Table 5 shows a case where only three reference points (Figure 6: AP1, H and B) were used as a xy-reference and all points were used as a reference point for z-direction. RSME, standard deviation and maximum error are given. RSME value calculated is 0.23 meters.

Time estimation and speed of the scanning are presented in the Table 6. Loop experiment was the fastest to do as there were no back and forth measurement path needed to complete the loop, resulting 13.5 meters of tunnel scanned in a minute.

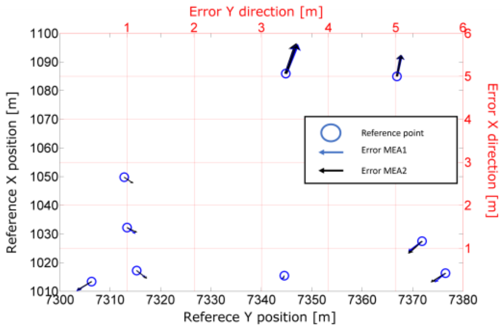


**Figure 8**. Loop errors in LSQ fit MEA1 and MEA2 in xy-direction are drawn as arrows pointing from the reference points.

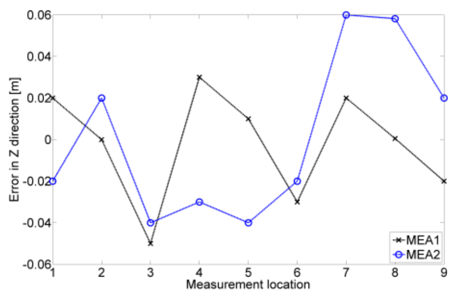


**Figure 9**. Loop errors in LSQ fit MEA1 and MEA2 in z-direction.

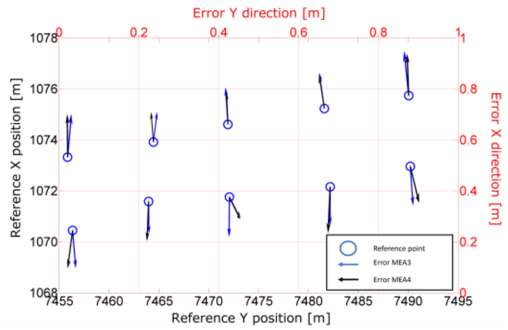


**Figure 10**. Trick errors in LSQ fit MEA3 and MEA4 in xy-direction are drawn as arrows pointing from the reference points.

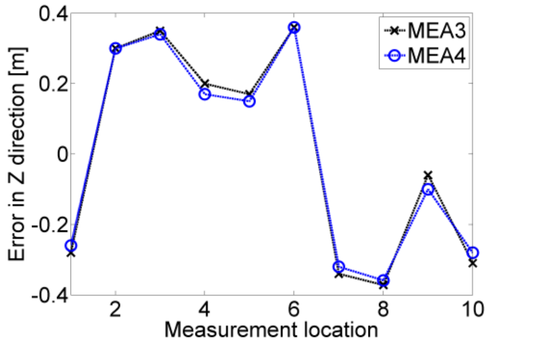

**Figure 11**. Trick errors in LSQ fit MEA3 and MEA4 in z-direction.

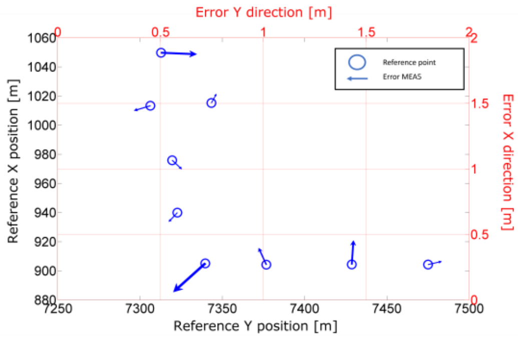

**Figure 12**. Marathon errors in LSQ fit MEA5 in xy-direction are drawn as arrows pointing from the reference points.

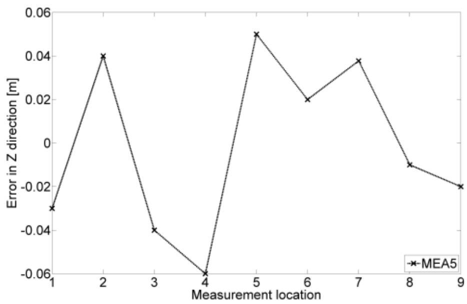

**Figure 13**. Marathon errors in LSQ fit MEA5 in z-direction.

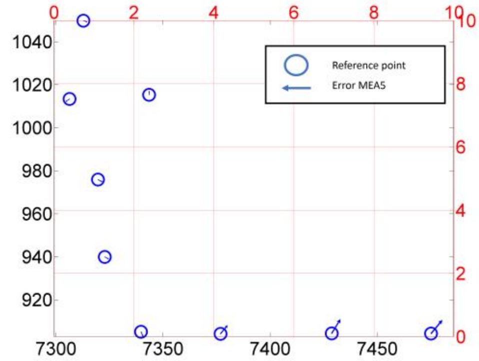

**Figure 14.** Marathon errors in three parameter no scale Helmert transformation plane fit MEA5 in xy-direction for reduced number (three) of reference points.

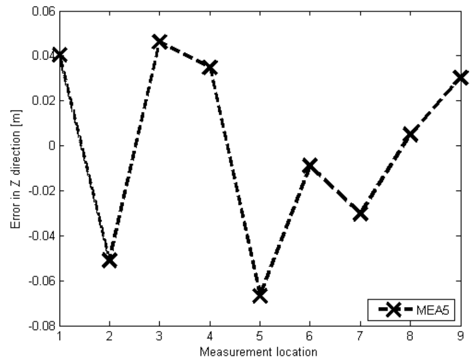

**Figure 15.** Marathon errors in one parameter no scale Helmert transformation fit MEA5 in z-direction using all reference points.

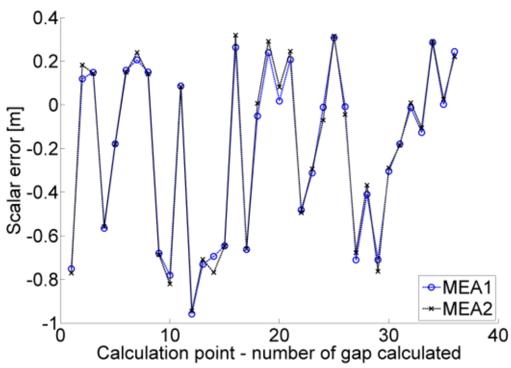

**Figure 16.** Loop distance error between scanned points MEA1 and MEA2 no fit.

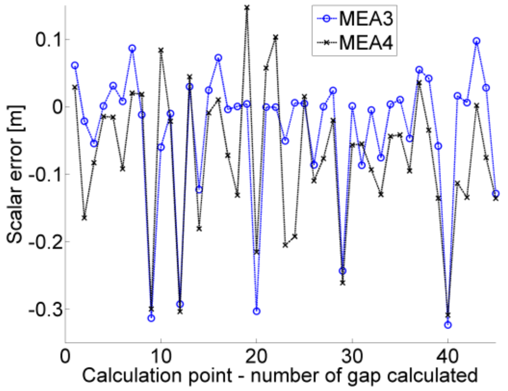


**Figure 17**. Trick distance error between scanned points MEA3 and MEA4 no fit.

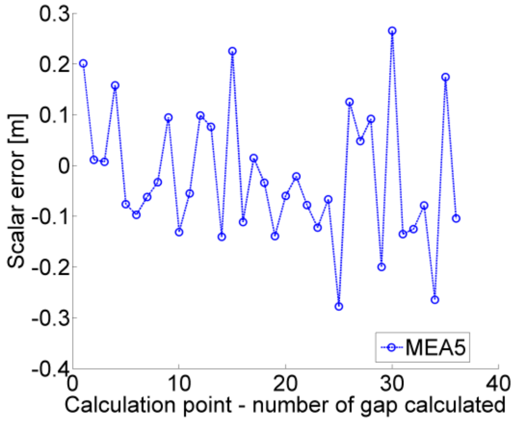


**Figure 18**. Marathon distance error between scanned points MEA5 no fit.

Table 1. RMSE values LSQ fit

| Experiment | x(m) | y(m) | z(m) | *d(m)* |
|---|---|---|---|---|
| Loop | 0.32 | 0.14 | 0.03 | 0.35 |
| Trick | 0.15 | 0.04 | 0.28 | 0.32 |
| Marathon | 0.10 | 0.11 | 0.03 | 0.15 |

Table 2. Standard deviation LSQ fit

| Experiment | x(m) | y(m) | z(m) | *d(m)* |
|---|---|---|---|---|
| Loop | 0.32 | 0.14 | 0.03 | 0.18 |
| Trick | 0.15 | 0.04 | 0.28 | 0.07 |
| Marathon | 0.10 | 0.11 | 0.04 | 0.06 |

Table 3. Maximum errors LSQ fit

| Experiment | x(m) | y(m) | z(m) | *d(m)* |
|---|---|---|---|---|
| Loop | 0.70 | 0.20 | 0.06 | 0.72 |
| Trick | 0.18 | 0.11 | 0.37 | 0.41 |
| Marathon | 0.19 | 0.22 | 0.06 | 0.25 |

Table 4. Scalar errors - distance between points – no fit

| Experiment | RSME | σ | BIAS (m) | max (m) |
|---|---|---|---|---|
| Loop | 0.44 | 0.39 | -0.20 | 0.96 |
| Trick | 0.12 | 0.11 | -0.06 | 0.32 |
| Marathon | 0.13 | 0.13 | -0.02 | 0.28 |

Table 5. Marathon only 3 reference points on plane and all for z-direction. Helmert transformation fit.

| Marathon | x(m) | y(m) | z(m) | *d*(m) |
|---|---|---|---|---|
| RSME | 0.23 | 0.18 | 0.04 | 0.30 |
| σ | 0.21 | 0.13 | 0.04 | 0.07 |
| max | 0.43 | 0.35 | 0.07 | 0.54 |

Table 6. Scanning speed approximated.

| Experiment | ~length (m) | duration (min) | ~Scanning speed (m/min) |
|---|---|---|---|
| Loop | 290 | 21.5 | 13.5 |
| Trick | 40 (back and forth) | 8 | 5 |
| Marathon | 305 (back and forth) | 45 | 6.5 |

## 4 Conclusion and discussion

The handheld laser scanner system showed great potential in practical measurements. First of it was really easy to use and it was ready to go when picked up and started. Second and most important strong point was the speed to do scans; for example in Loop experiment scanning speed of 13.5 meters per minute was reached. No reference points are needed, if something is behind a corner, the automatic 3D map generation (SLAM) makes it possible to just walk around and behind the corner simultaneously scanning.

In the light of Table 5 the system seems to be exceptionally accurate in z-direction (RSME 0.04 m when 305 meter distance was travelled). This might mean that 6 parameter LSQ is not really optimal, but 4 parameter (3 translations and one rotation) is better choice. Other results (LSQ) in this paper can't be used to determine z-accuracy as both x and y axis are rotated.

Trick and Marathon showed good results RSME values between 0.12 – 0.13 m. Loop experiment gave the poorest results (RSME = 0.32 m) while we were expecting this measurement to be the most accurate in theory. No explanation is yet to be found for this.

These kind of fast laser measurement systems using SLAM, performing around 10 m/min scanning speeds (see Table 6), will be used widely in near future, but the jobs they perform might not be the same than standard industrial lasers are doing right now. There is need to study and find correct and possible new ways to use these point clouds in mines as well as buildings.

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