Some technologies for underground space mapping

Baltic Sea Underground Innovation Network (BSUIN)

Interreg Baltic Sea Region
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Contents

1. BSUIN project introduction

The aim of the Baltic Sea Underground Innovation Network (from now on BSUIN) project is to make the underground laboratories (from now on U.L.s) in the Baltic Sea Region (BSR) more accessible for innovation, business development and science by improving the information available about the U.L.s and their operation principles and opportunities therein. In addition, the BSUIN project aims to collect the safety protocols of each U.L. and the experiences of their respective users to aid further development.

BSUIN is a collaboration project between 13 partners from eight (8) BSR countries. Besides project partners, 17 associated partners contribute to achieving the project goals.

The BSUIN project is participated by six (6) U.L.s from the BSR area. Each of the U.L.s will be characterised and presented to potential customers in order to attract developing innovative activities and effectively activate the use of those laboratories. These six underground laboratories by name are:

1. Callio Lab, Pyhäsalmi mine, Finland
2. Äspö Hard Rock Laboratory, Oskarshamn, Sweden
3. Reiche Zeche, TU Freiberg Research and Education mine, Germany
4. Lab development by KGHM Cuprum R&D centre, Poland
5. Khlopin Radium Institute Underground Laboratory, Russia
6. Ruskeala Mining Park, Russia

The project's main outcome is a sustainable network organisation, which will disseminate technical, marketing, operational quality, training, and other information about the BSR ULs.

The project is funded by Interreg Baltic Sea funding cooperation. Its duration is 36 months with a total budget of 3.4 M€.

2. Content of present document

2.1 Document justification

The purpose of this document is to provide an insight into different scanning methods for underground spaces. The focus is on the usability of the selected methods for the different purposes of creating accurate point clouds for equipment installation, facility design, or just for creating general models of the existing infrastructure. The current document is based on the scanning measurements done at Callio Lab (Pyhäsalmi Mine, Finland).

2.2 Content description

This work aims to give a summary of

- The history and the need for underground scanning of facilities (Section 3)
- The comparative scanning at Callio Lab (Section 4)

The last chapter will summarise the main points of this report.

3. Scanning of underground spaces

Extraction of minerals from the lakes or dedicated mines is among the oldest technical practices created by humankind. A topic closely related to mining itself is mine surveying. The mine surveyers and their expertise have been well valued. The historical mine maps provide a glimpse of the past. The rising interest in old mine sites and the treasures within the old mine maps have become more and more valuable for mining companies.

3.1 Why is scanning important? Historical background of underground cavity mapping/scanning?

The earliest documented mine surveys are dated back to ancient Rome two centuries B.C. The historical works include, e.g. the construction of an underground drainage gallery to the lake Fucino between 41 to 54 B.C. [1].
The earliest survey instruments based on laser distance-measuring became available in the 1960s with commercial success, following in the 1970s using lasers in engineering surveying and construction industry [2]. Today, laser-based instrumentation is standard in various applications. Since the end of the 20th century, huge technological progress has provided the ability to rapidly and accurately survey complex locations virtually in their entirety. In the context of the mining industry, laser scanning was first applied in optimising open-pit mining. Open-pit applications were soon followed by managing underground spaces, deformation monitoring, and optimising spray concrete reinforcements.

3.2 An underground building information model

Laser scanning opens possibilities to the generation of underground building information models. In ongoing mining projects, scanning can be utilised, for example, in data collection of current mine infrastructure. Scanning also allows the mapping of abandoned or historical mines. If combined with an autonomous platform (e.g., drone), there is also a possibility to map areas that are hard to reach or deemed too dangerous for human operator. For example, the produced models can be utilised in structural design, space planning, and generation of 3D demonstration and marketing materials of available facilities.

3.3 Measurement techniques used in this study

Three different laser scanning techniques and devices were tested to demonstrate their ability to produce data for different usage cases related to underground facilities (Figure 1). Two of the devices, Geoslam Zeb-Horizon and Leica Pegasus Backpack, represent modern mobile mapping solutions as either handheld or wearable device. The Z+F Imager 5006 represents a more traditional static mapping device. General information for each device is provided below:

1) Geoslam Zeb-Horizon
  - Device type: handheld scanner (mobile mapping)
  - Positioning: SLAM-technique
  - Georeferencing: known reference points
  - Device cost: ~70 000 €
  - Hourly rate for professional work: ~95 €/h

2) Leica Pegasus Backpack
  - Device type: wearable backpack (mobile mapping)
  - Positioning: GNSS, inertia and SLAM-technique
  - Georeferencing: GNSS or known reference points
  - Device cost: approx. ~270 000 €
  - Hourly rate for professional work: ~150 €/h

3) Z+F Imager 5006
  - Device type: terrestrial laser scanner (static mapping)
  - Positioning: GNSS, inertia, point cloud matching, tachymeter measurements
  - Georeferencing: known reference points
  - Device cost: approx. ~80 000 €
  - Hourly rate for professional work: ~100 €/h

Figure 1. A) Geoslam Zeb-Horizon handheld mobile mapping device (Image: geoslam.com). B) Leica Pegasus Backpack wearable mobile mapping device (Image: leica-geosystems.com). C) Z+F Imager 5006 terrestrial laser scanner. In a typical field application, the scanner is usually mounted on a sturdy tripod, not included in the image (Image: zf-laser.com).

All the measurement techniques can be utilised by a non-professional after a short introduction to the devices' proper use. However, if the measurement data needs to be georeferenced to a local coordinate system, an experienced surveyor is needed to measure the required reference points on site. The Geoslam Zeb-Horizon requires that the mapping is done in a closed-loop, i.e., the mapped route starts and ends in the same location. The georeferencing for Zeb-Horizon is done via a pair of reference targets measured with a tacheometer (theodolite). For Leica Pegasus and Z+F Imager, the georeferencing can utilise multiple reference targets measured with tacheometer. Generally, the more targets are used, the more accurate the data is.

Sufficient software skills to post-process the raw measurement data to a more useable format can be obtained in 1–2 days of training. Postprocessing of the raw measurement data typically relies on commercial software provided by the laser scanner manufacturer or retailer. However, further analysis and manipulation of the post-processed point cloud data can be done with both commercial and/or open-source software. Some examples of open-source software are CloudCompare [3] and different tools based on PDAL (Point Data Abstraction Library) [4] or PCL (Point Cloud Library) [5].

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4. Test measurements in Callio Lab facilities

The measurement techniques were tested in the CallioLab facilities in Pyhäsalmi underground mine. The test circuit was approximately 200 meters long (Figure 2), with the width of the corridor varying from approx. 5 to 9.5 meters. The mobile measurements were performed by composedly walking a closed loop with the device in hand (Geoslam) or back (Leica Pegasus). Since there is no GNSS connection available in the underground, the Leica Pegasus was started already on the surface to get a proper GNSS time signal before descending to the CallioLab facilities.

The static measurements were performed by moving the Z+F Imager to multiple static positions. The approximate scanning time is roughly 1.5 minutes per position, or 2.5 minutes when shifting the scanner to a new position is included. If the positioning is done by tachymeter registration to reference points, the total time is roughly 5 minutes per position.

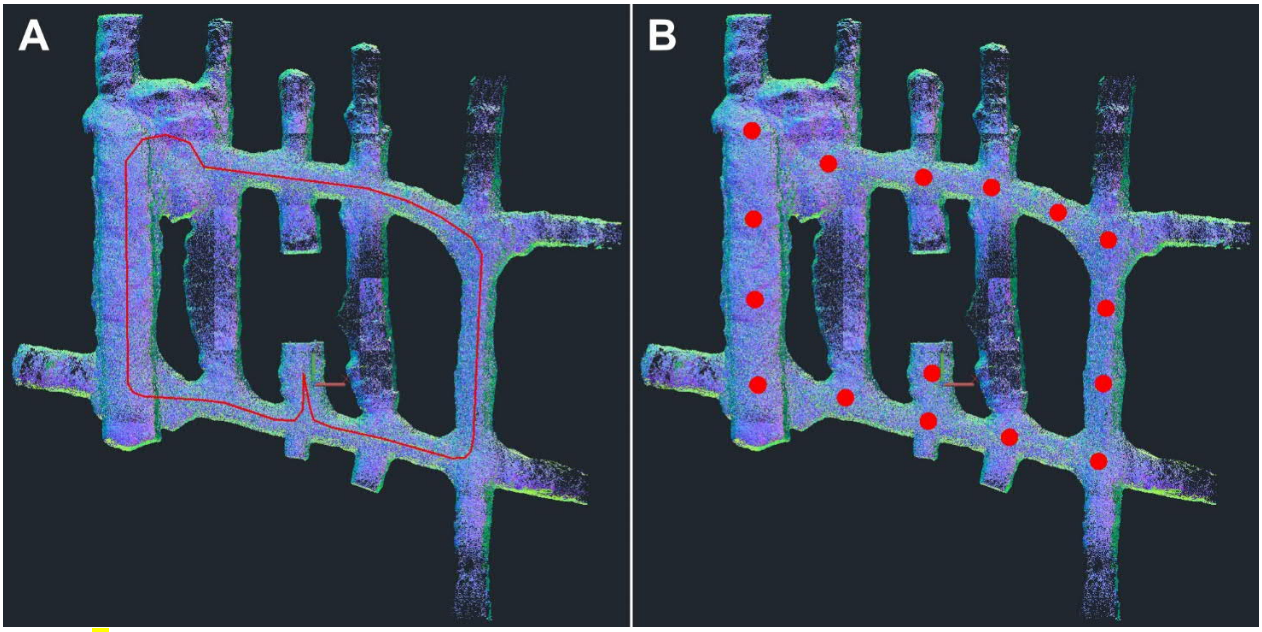

Figure 2. A) Approximate circuit for the mobile scanning techniques (Geoslam Horizon and Leica Pegasus), and B) locations for the static scanning (F+Z Imager).

The clearest differences between the mobile and static mapping techniques were the duration of measurements and the resulting data accuracies and noise (Table 1). The mobile techniques were clearly faster than the static Z+F Imager (25 min vs 120 min). However, since the test circuit was comparably small and the total measurement durations were relatively short compared to the time required for preparations and travel, there were negligible differences between the costs.

Naturally, when the measurement area gets larger, economies of scale begin to play a role, and the mobile techniques become more cost-efficient.

Table 1. Techniques utilised in the CallioLab test circuit.

Technique	Duration [min]	Accuracy [cm]	Noise [cm]
Geoslam Horizon	25	5–50	5–10
Leica Pegasus Backpack	25	5–10	2–5
Z+F Imager 5006 (tacheometer registration)	120	1	< 1
Z+F Imager 5006 (point cloud matching)	60	1–5	< 1

Another key difference is the resulting data accuracy and noise. The static Z+F Imager clearly provides more accurate and less noisy data with both tacheometer registration and point cloud matching-based measurements compared to the mobile techniques. With tacheometer registration, the static method provides constant accuracy throughout the mapped area. With point cloud matching, the accuracy drops further away from the measurement location from the reference points. The accuracy obtained with tacheometer based registration is sufficient for structural design and building information models. However, it is possible also to utilise point cloud registration if absolute positioning is not that critical. Both methods are more than sufficient for space planning and marketing materials.

The data provided with mobile mapping is less accurate, and without any noise suppression applied in postprocessing, the high level of noise is clearly visible in the data (Figure 3). The absolute accuracy of the data products gets worse the further away the location is from the reference points. However, the internal accuracy is still quite good. The noise can be suppressed in postprocessing by, for example, subsampling the point cloud (Figure 4). However, some surface details are necessarily lost during the subsampling, although one might argue that a lot of details are already obscured by the noise.

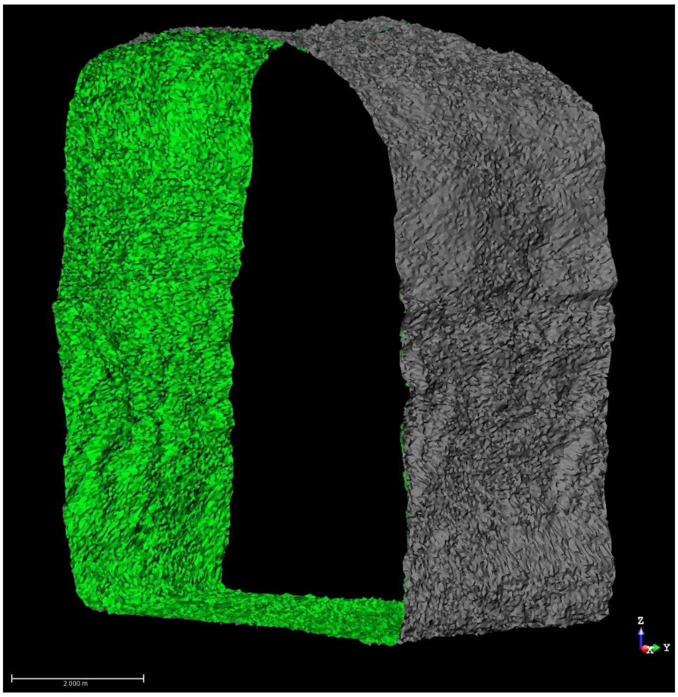

Figure 3. Triangulated mesh from mobile Geoslam measurements without data subsampling. The data noise is clearly visible on the meshed surface.

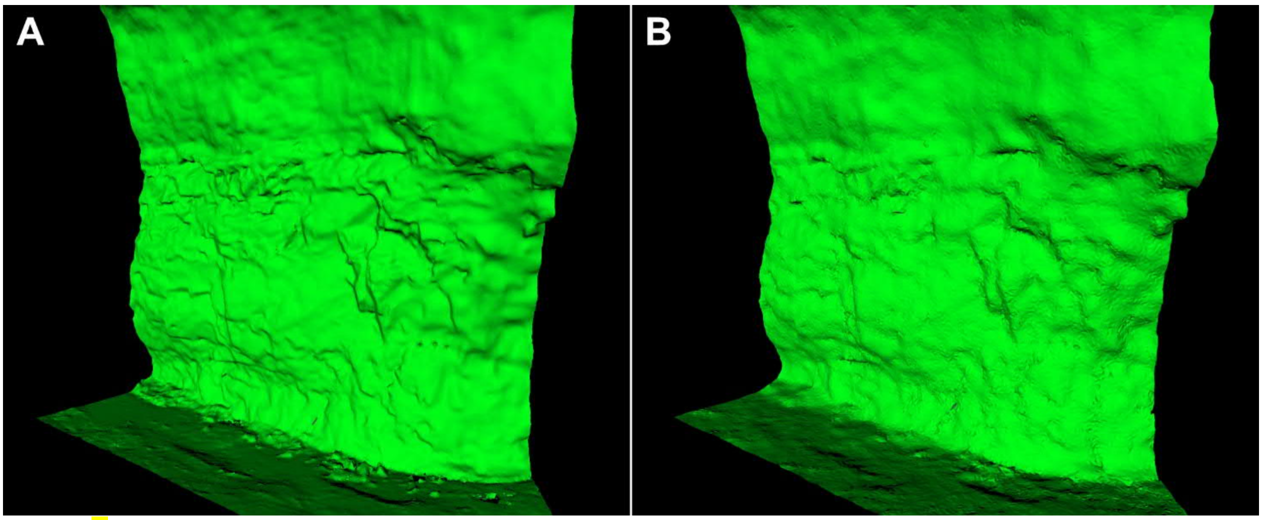

Figure 4. A) Triangulated mesh generated from static measurements with negligible signal noise. B) Triangulated mesh from mobile Geoslam measurements subsampled to 5 cm pixel density. Subsampling mitigates excess noise; however, some details are lost.

The higher noise level and lower accuracy obtained from the mobile mapping techniques matter, depending largely on the use case and requirements placed on data quality. In cases such as subway construction, the tolerances are small, and only static measurements can provide sufficiently accurate and detailed data. For more general space planning and an area showcasing, mobile mapping methods can provide more than suitable data (Figure 5).

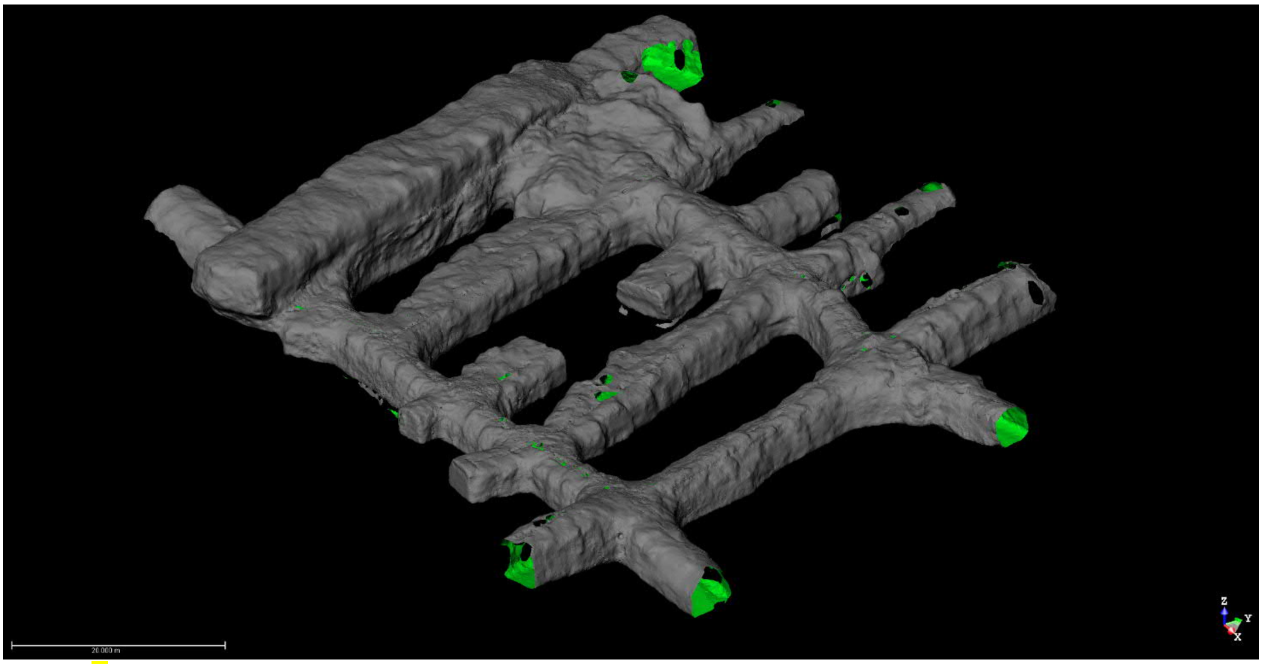

Figure 5. Final meshed dataset of the CallioLab facilities test run based on the GeoSlam data.

5. Summary and Conclusions

Both static and mobile laser scanning applications were tested at the Callio Lab facilities in Pyhäsalmi mine, Finland. The new mobile mapping techniques have a clear advantage in the measurements' speed, but the obtained data accuracy and noise are not on par with more traditional static methods. The mobile mapping provides sufficient data for general space planning, area showcasing and marketing materials. In contrast, static measurements can also provide data for structural design and building information model applications where high data accuracy is critical.

From the underground laboratory opeator point of view all the underground surveying tools require experts, basically mine surveyors, to assists in the underground mapping. This is especially important of the surveyed area is planned to be included into the general plan of the underground faiclity. If the aim is just on providing illustrative 3D-models based on the laser-scanned point clouds then independent, in relative coordinate-system located maps and 3D models are possible to be created and used.

References

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