DETERMINING THE SHAPE AND VOLUME OF ENCLOSED SPACES AND UNDERGROUND MINES BY MOBILE LASER SCANNING

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Abstract

In this paper [1] handheld laser scanner GeoSLAM ZEB-REVO for ungerground mine surveying was studyed and useage for drawing plans of buildings. Author was able to participate in resourch group from the Tallinn University of Technology to study Estonia underground mine surveying methods to improve and modernize their technologies. Two chambers were visited and and one chamber was scanned with mobile handheld laser scanner as well as statical laser scanner for reference data. For data analysis the program 3D Reshaper was used to georenerence point clouds, to make cross sections for calculating area of pillars and making 3D models to calculate volume of the excavated mineral resources. The results were compared to the mining surveyors' data as well. Total area of the pillars measured with GeoSLAM ZEB-REVO was 0,5% bigger than the reference data, mine survyors' result was 1,8% smaller. In the other chamber mine surveyors total area was 1,8% bigger than GeoSLAM data. So measuring underground mine with laser scanner the results are objective and more complete. Volume of the excavated mineral resources was 0,7% smaller with GeoSLAM and also from mine surveyors compared to the reference data. In summary the differences between laser scanners were small and therefore handheld laser scanner is suitable instrument for surveying underground mine, it is small, accurate, easy to use, timesaving and one person can handle it. Handheld laser scanner was also used to study the possibility of using it for drawing plans of the rooms of the buildings, results showed that this area need more study, but some cases it is possible and comfortable to use it.

Introduction

Mobile laser scanning technology is commonly used in the field of geodesy, but mostly still in outdoor situations, where the surveyor's location can be determined by GNSS (Global Navigation Satellite System) signals. Some mobile laser scanning instruments that do not need satellites and can be used as indoor surveying method have been developed such as uGPS Rapid Mapper [2, 3], Trimble Indoor Mobile Mapping Solution (TIMMS), MineFly [3], or TILT Ranger [4]. Their's working methods are a somewhat different, but they do same thing – use mobile laser scanning method to survey indoor situations.

In the beginning of year 2019 Division of Mining of Department of Geology in Tallinn University of Technology in association with Road Engineering and Geodesy Research Group of Department of Civil Engineering and Architecture and with the company Hades Geodeesia OÜ studied surveying technologies in an Estonian mine to improve and modernize mine surveying methods in order to make surveyors' work easier, more accurate and faster. In Estonian mining industry laser scanning technology and UAV (Unmanned Aerial Vechicle) are not used, they use levels, total stations and laser distance meters for surveying today. Although laser scanning technology has been studyed widely for surveying and because it is accurate, detailed and controllable [5], it should be used in our mine industry as well.

In this paper the author studied handheld laser scanner GeoSLAM ZEB-REVO (Fig 1) as indoor surveying instrument in particulary for mine industry but also for buildings for making drawing plans or 3D models from the point clouds.

Fig 1. The author with handheld laser scanner in the underground mine of Estonia

Instruments and data

In this work it was used three laser scanners, terrestial laser scanners Faro Focus^{3D} X330 and Riegl VZ-400 were used for reference data, and mobile laser scanner GeoSLAM ZEB-REVO (technical data in Table 1).

Table 1. Specification of GeoSLAM ZEB-REVO, Faro Focus^{3D} X330 and Riegl VZ-400

Specification	**GeoSLAM ZEB-REVO** [6]	**Faro Focus^{3D} X330** [7]	**Riegl VZ-400** [8]
Maximum range	Up to 30 m in optimal conditions, usually 15-20 m	0,6 m to 330 m	1,5 m to 600 m
Field of view (vertical/horizontal)	270° / 360°	300° / 360°	60° + 40° = 100° to 360°
Measurement speed	100 line p/s 43 200 p/s	976 000 p/s	120 line p/s 122 000 p/s
Scan range noise, ranging error	± 30 mm	± 2 mm	± 3mm
Laser safety classification	Laser Class 1	Laser Class 1	Laser Class 1
Laser wavelength	905 nm	1550 nm	Near infrared (750 nm – 1 nm)
Operating conditions	Temp 0°C to 50°C Humidity <85% RH	Temp 5°C to 40°C	Temp 0°C to 40°C Humidity <80%
Weight	Scanning head 1 kg, carry case and contents 4,1 kg	5,2 kg	9,6 kg
Dimentions	Scanning head 80x113x140 mm	240x200x100 mm	Ø180x308 mm
Battery life	Approximately 4 h	4,5 h	

GeoSLAM ZEB-REVO is based on SLAM (Simultaneous Localization And Mapping) algorithm that takes 2D laser scanning data and IMU (Inertial Measurement Unit) data connecting them to 3D point cloud [9, 10]. There is detailed instructions how to use this instrument and how to get best result with it, there are basics rules to follow in [6].

Data for this paper was collected from Estonia underground mine (Fig 2) in 29.11.2018 and 21.02.2019 from two different chambers. Mine is situated in the east of Estonia and was opened in 1972.

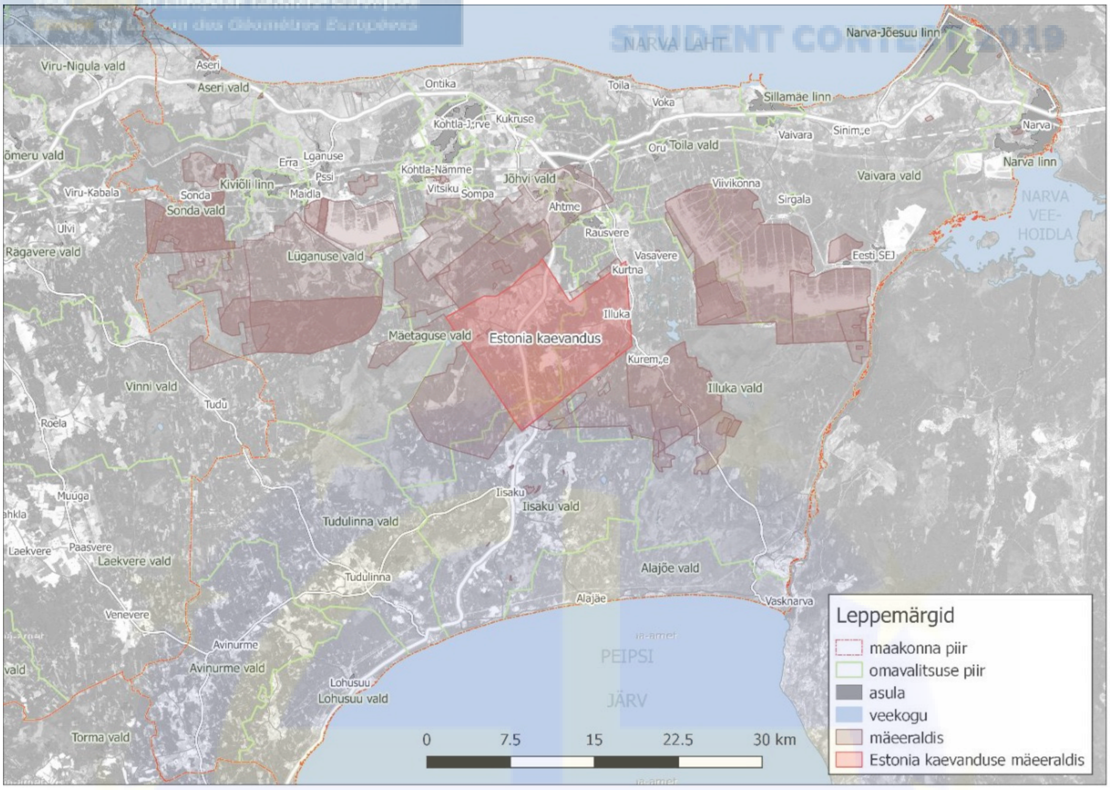

Fig 2. Estoninan mine [10]

Underground mine depth is 20 to 70 m, they use room and pillar mining method where pillars are left to support roof of the mine rooms (Fig 3).

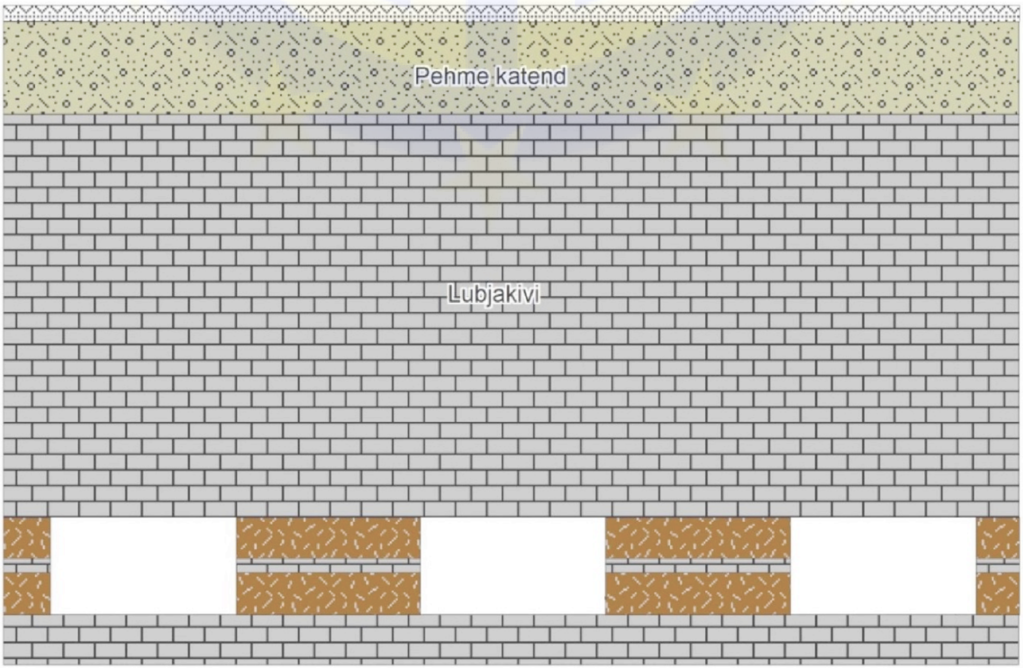

Fig 3. Plan of room and pillar mining method (from top are ground, limestone and underground mine with pillars to support roof of the rooms)

Data for buildings was collected from the Land Board building in 28.06.2018 and from asupermarket in Estonia in 11.02.2019.

Surveying underground mine

In Fig 4 is a plan of chamber nr 1214. The control area (yellow on the plan), ca 5200 m^2 was scanned by terrestial laser scanner Faro Focus^{3D} X330 from 23 positions in 1,5 hours, ca 14 500 m^2 (yellow and blue together) was scanned by handheld laser scanner in 40 min.

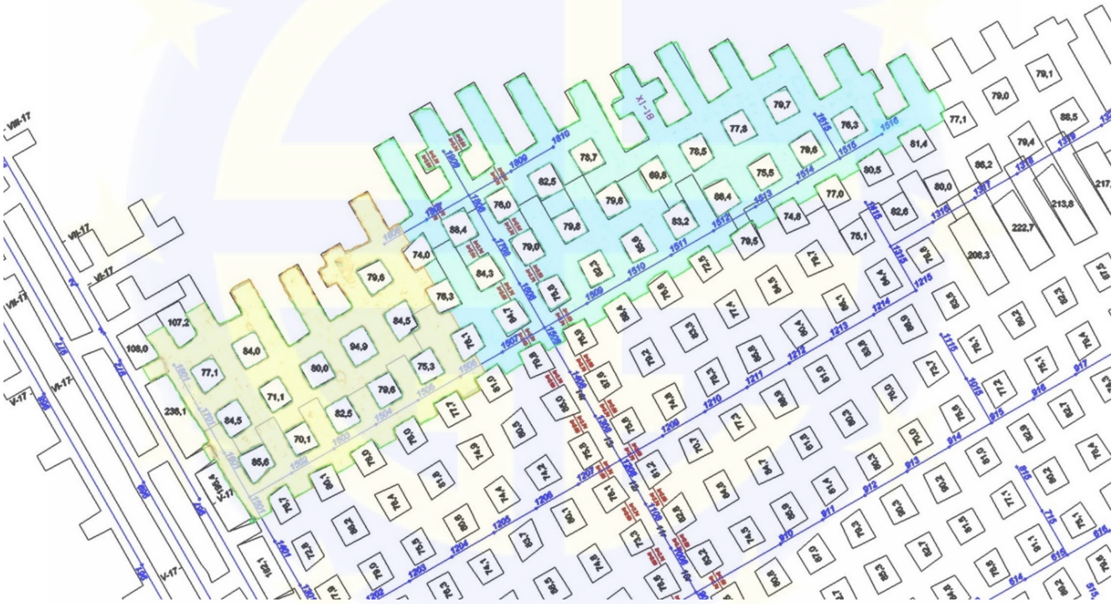

Fig 4. Plan of chamber nr 1214. Yellow area is the control area that is measured with Faro Focus^{3D} X330 and yellow with blue area is measured with GeoSLAM ZEB-REVO. Dark blue numbers are points from mining sureveyors survey network that was used as location of scanning targets.

Handheld laser scanner GeoSLAM ZEB-REVO point cloud is not as perfect as Faro Focus^{3D} X330, but it is enough for underground mine, for example in Fig 5 there can be seen gaps in the mine roof and timber structures to support it.

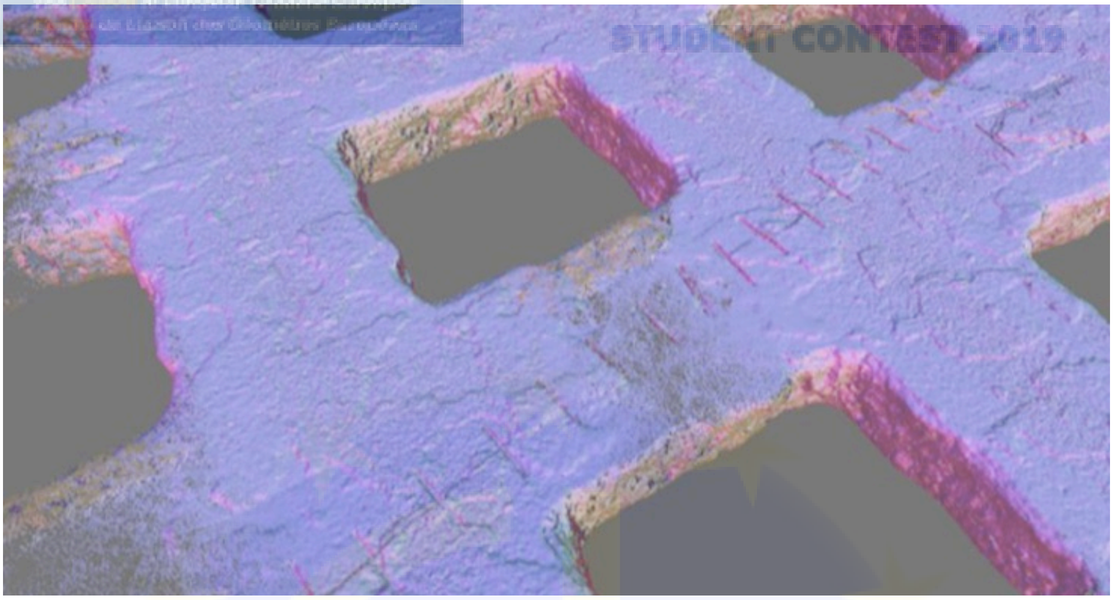

Fig 5. Underground mine, ceiling with caps and timber structures to support it.

Noise from the Faro scanner in 5 cm is 1-3 cm depending on location, points are situated equally and systematically. GeoSLAM point cloud points has not systematical distribution, noise is from 3 to 5 cm (Fig 6).

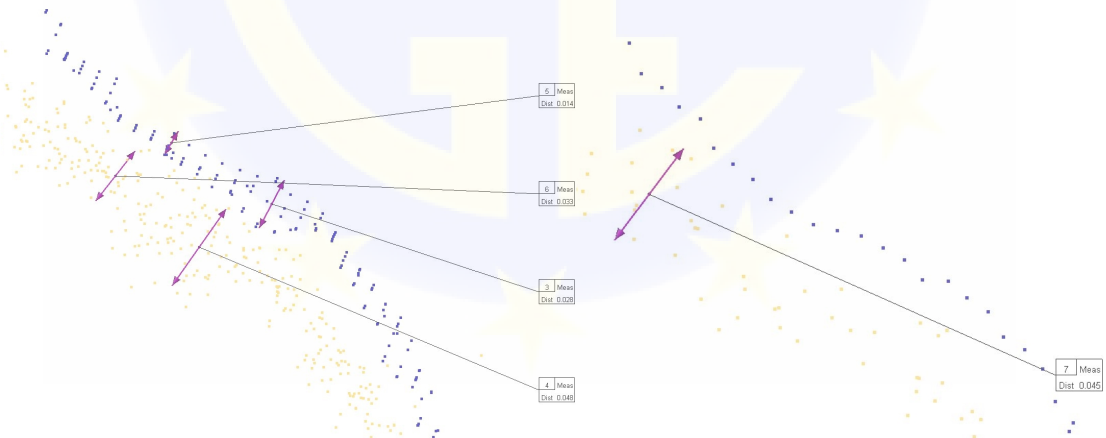

Fig 6. Yellow is the point cloud from GeoSLAM ZEB-REVO, blue is from Faro3D X330. Faro's noise in 5 cm is 1-3 cm, GeoSLAM's 3-5 cm. On the right figure noise in 1 cm from Faro is one row of points and GeoSLAM noise is about 4,5 cm.

Mine surveyors have a survey network in the rooms of underground mine, coordinated points are marked with numbers (Fig 4 dark blue numbers). The same points were used for scanning to georefererence point clouds, for that the spherical targets (tennis balls) were secured to the roof (Fig 7).

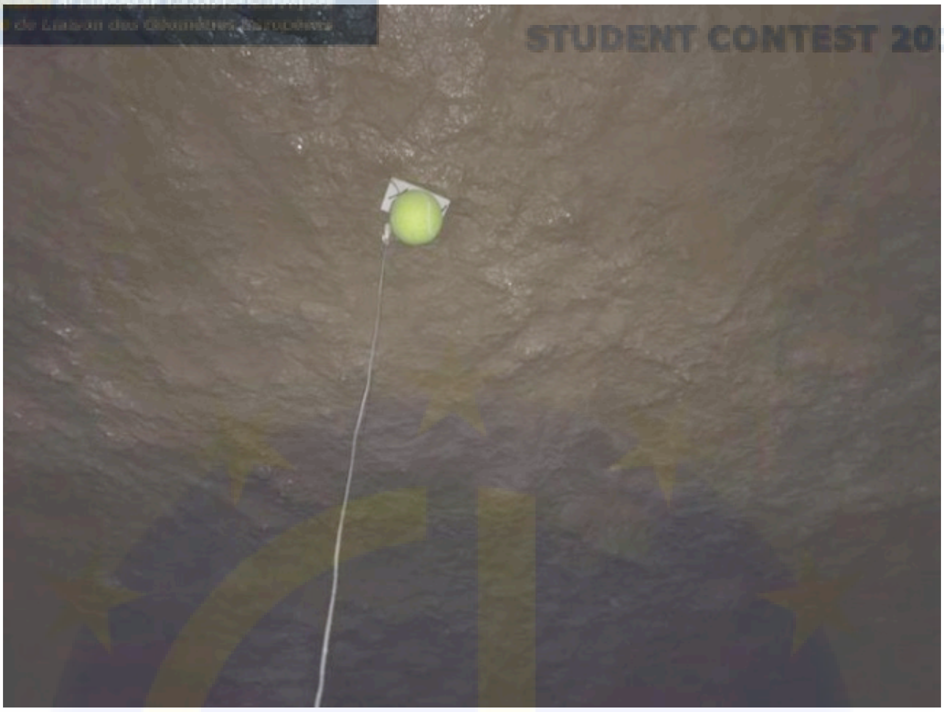

Fig 7. Tennis ball as scanning target on the roof of the underground mine

These targets were located in point clouds and replaced by virtual targets with equivalent parameters. So all point clouds were georeferenced.

Comparing point clouds from Faro and GeoSLAM in 3D Reshaper the *Bet fit registration* was used. Maximum differences were 5 cm in hight and 2 cm in plan (Fig 8).

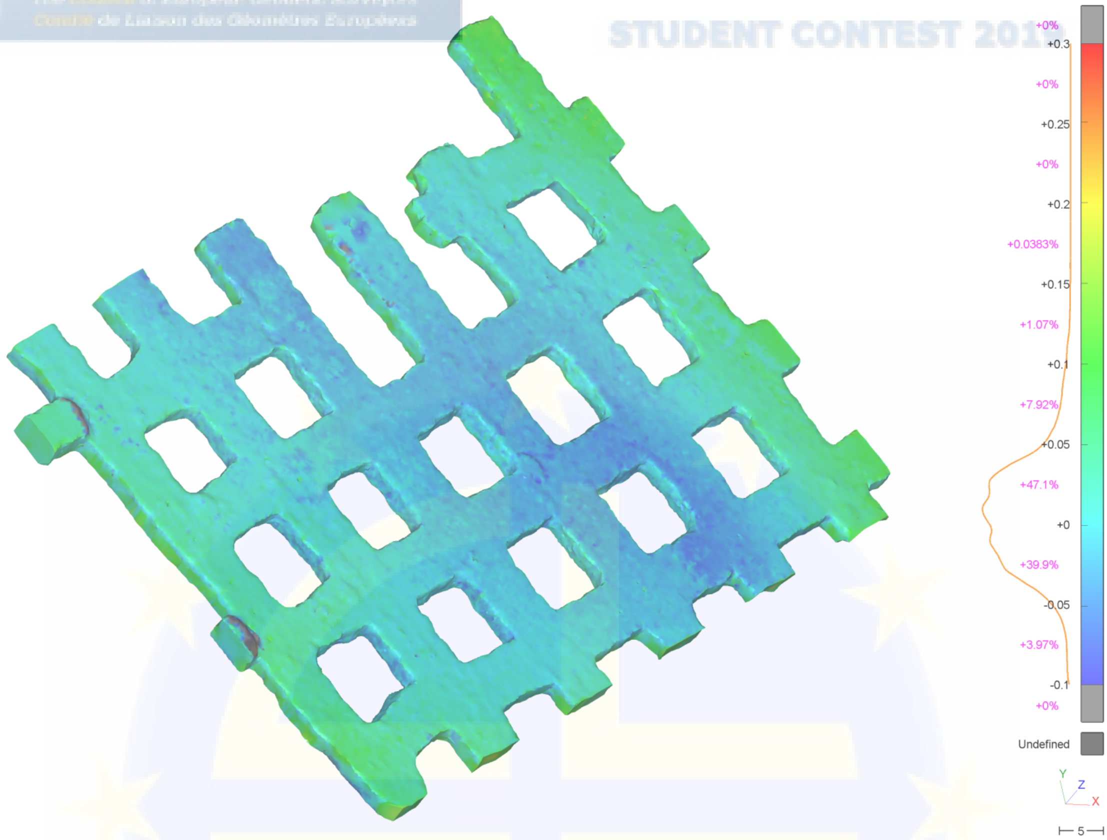

Fig 8. Comparisation of the 3D models of Faro and GeoSLAM in the control area. In green area the Faro surface is higher than GeoSLAM (most differences are +/- 0,1m)

Pillar and room method leaves pillars to support underground mine roof and chamber stability is sustained. Measurements and locations of the pillars are very important. The size of the pillars are measured in 1,6 m high from the underground mine ground floor with laser distance meters, for the location it is measured distances to the points of the survey network. Final shape and location of pillars will be drawn out in CAD-based program called CREDO (Fig 9).

To compare point cloud to the mine surveyors measurements, in the surface from the point cloud the cross section was made at the same high (1,6 m) and was calculated area of the pillars. In the Fig 9 there are 13 pillars in the control area. On the right corner with white color there is shape of mine surveyors measurements, red and green are Faro and GeoSLAM results. The areas and locations of pillars are very similar.

Fig 9. Pillars and their areas from Faro (red line), GeoSLAM (green) and mine surveyors' (black and white on the picture on black background) data.

Surveyors' total area of pillars was 1,8% smaller than the Faro's results, which means that the volume of excavated mineral resources exceeds the data Faro presents. GeoSLAM total area was 0,5 % bigger than Faro's area and surveyors total area was 2,3 % smaller than GeoSLAM area (Table 2).

Table 2. Comparison of area of pillars in chamber 1214 and 1707.

Pillars / Areas (m²)	Faro, m²	GeoSLAM, m²	Mine surveyors, m²
Chamber 1214			
Total area, m²	1068,0	1073,6	1048,8
Difference from Faro data, m²		-5,6	19,2
% form Faro data		0,5	1,8
Difference from GeoSLAM data, m²			24,8
% from GeoSLAM data			2,3
Chamber 1707			
Total area, m²		1013,2	1031,7
Difference from GeoSLAM data, m²			18,5
% from GeoSLAM data			1,8

In another chamber, 1707, additional measurements using previously described methods were conducted, the results are esimated in the table 2. Mine surveyors' data show 1,8% bigger area than GeoSLAM. As in one case the area was bigger and the other case it was smaller therefore it can be assumed that while measuring pillars with traditionals methods is subjective, scanning results are objective because of the evenly spaced point cloud.

It is important to calculate the volume of the excavated mineral resources. Volumes measured by mining surveyors and the GeoSLAM data are 0,7% smaller from reference data. Comparing handheld scanner data to mine surveyors data, volume from surveyors is 0,04% bigger. In the other chamber is difference between GeoSLAM and surveyors 0,2% (Table 3).

Table 3. Comparison of volumes

	Faro, m^2	**GeoSLAM, m^2**	**Mine surveyors, m^2**
Chamber 1214			
Volume of the control area, m^3	11 067,7	10 984,2	10 988,5
Difference from Faro data, m^3		83,6	79,2
% form Faro data		0,7	0,7
Difference from GeoSLAM data, m^3			4,4
% from GeoSLAM data			0,04
Chamber 1707			
Volume (m^3)		29 187, 6	29 140, 5
Difference from GeoSLAM data, m^3			47,1
% from GeoSLAM data			0,2

Results between statical laser scanner, handheld laser scanner and laser distance meter are small and more than 10 times less than it is allowed in Estonian laws [12].

To estimate the measuring results from handheld laser scanner GeoSLAM ZEB-REVO it is able to see trajectory of movement of 2D laser of this measuring device and it can be added to the point cloud. In Fig 10 and 11 red circle in left up corner refers to the beginning and the ending of the closed loop beginning with blue line and ending with red. Arrow points to the loop, one spherical target was attached to the ceiling and surveyor was taking circle around that target.

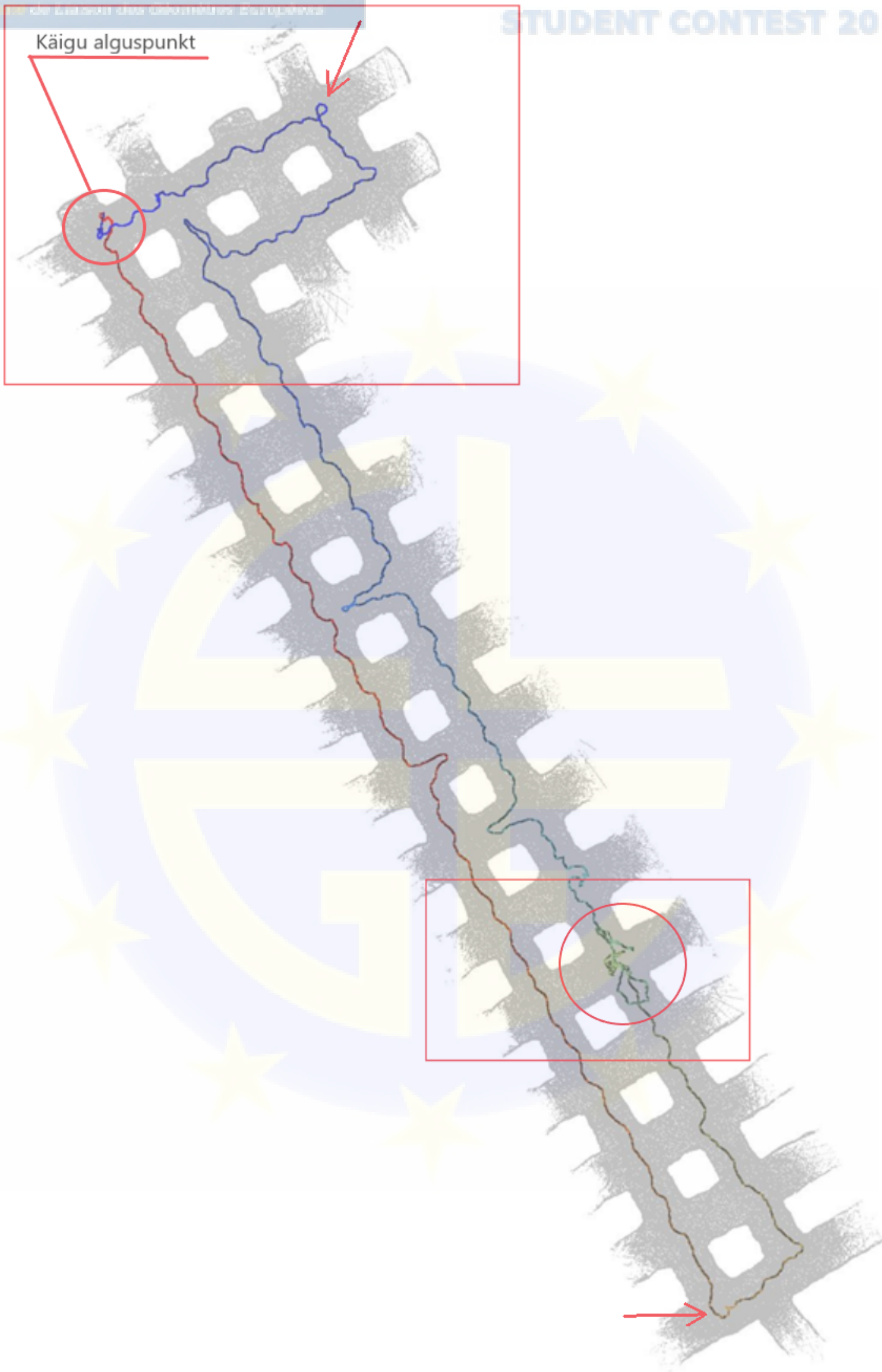

Fig 10. Point cloud with trajectory from GeoSLAM ZEB-REVO

Beside the movement of surveyor the trajectory also show the range of measurement of this device, the further away the less data points have been measured.

Fig 11. Point cloud with trajectory from GeoSLAM ZEB-REVO, zoomed out from Fig 10

In the center (in Fig 10 and 12) there is another circle that indicates the place where surveyor moved around standing people to demonstrate their existence in later calculated point cloud.

Fig 12. Point cloud with trajectory from GeoSLAM ZEB-REVO, zoomed out from Fig 10

Similar trajectory can be added to illustrate the conditions of the scanning (Fig 13), discerning situations in which the SLAM algorithm works better and finds more jointed points than others. Better conditions are marked as blue and poor conditons are red.

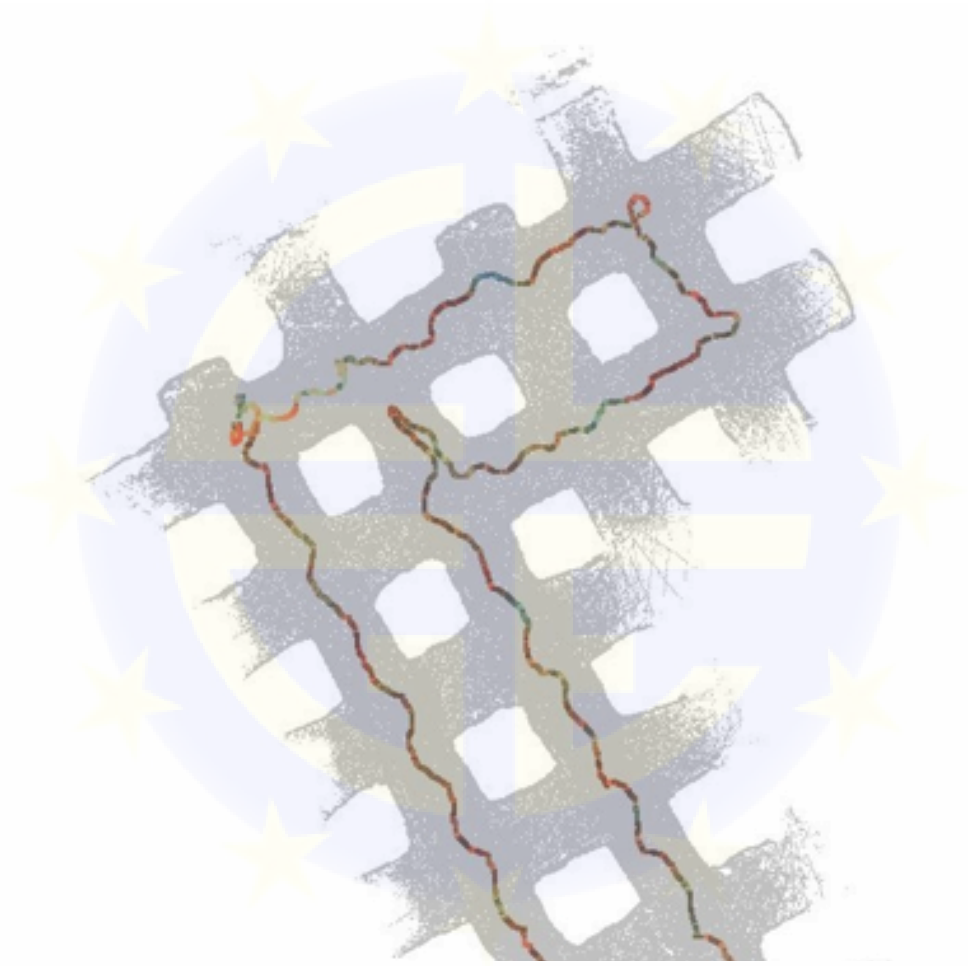

Fig 13. Point cloud with trajectory from GeoSLAM ZEB-REVO, conditions of scanning

Measuring the buildings

In this paper rooms of two building were scanned and handheld laser scanner was compared to statical scanners.

In the supermarket, smaller rooms and storages were scanned, reference data was scanned with statical laser scanner Riegl VZ-400. There was measured ca 950 m^2 in

32 positions about 2 hours. With handheld laser scanner it took about 15 minute. Fig 14 is the scanned area from GeoSLAM.

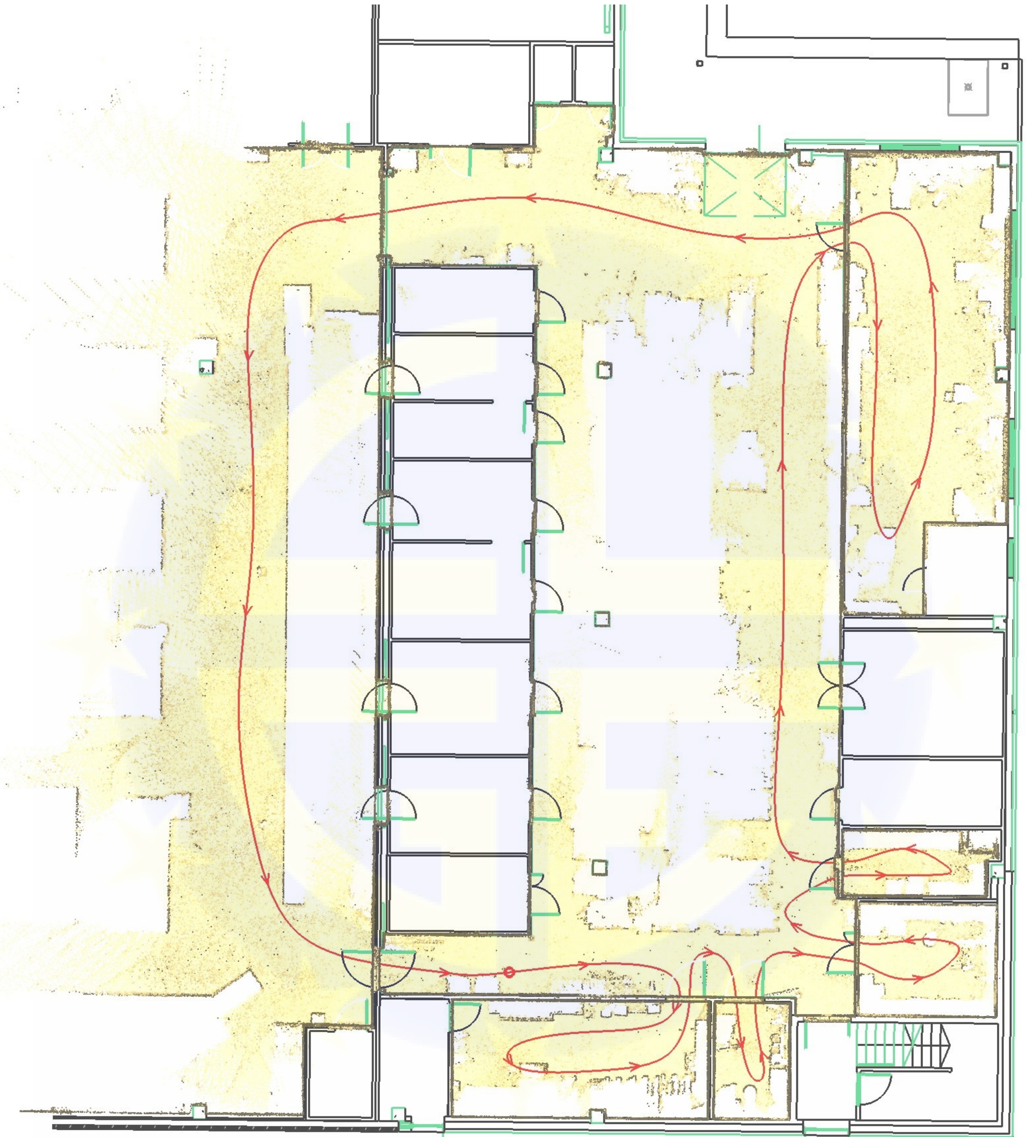

Fig 14. Plan of the scanned area of GeoSLAM ZEB-REVO with yellow. Trajectory is added from author.

For the walls, roofs and floors determined from the point cloud best approximation of equivalent planes were constructed in the 3D Reshaper program. With these planes it was possible to compare accuracy between two point clouds. In the height of 1,6 m a cross section was made and the widths, lenghts, and heights of the rooms were measured and areas were calculated. The results are estimated in table 4.

Table 4. Data of rooms from Riegl and GeoSLAM measured in the supermarket

	Riegl VZ-400 (m)	ZEB-REVO (m)	Difference (m)
Distances			
Min (m)	0,40	0,40	-0,104
Max (m)	29,16	29,14	0,021
Standard deviation (m)	8,47	8,46	0,028
Average (m)	8,46	8,47	-0,003
Median (m)	4,91	4,90	0,001
MSE (m)			**0,028**
Areas			
Min (m^2)	2,41	2,39	-0,007
Max (m^2)	3,47	3,47	0,019
Standard deviation (m^2)	0,44	0,45	0,010
Average (m^2)	3,12	3,12	0,001
Median (m^2)	3,45	3,46	-0,003
MSE (m^2)			**0,010**

MSE (Mean Square Error) of distances was 0,028 m. MSE of areas was 0,010 m2. Data of measured rooms hints good results, but lacks statistical significance because of the small sample sizes.

In the Land Board building (Fig 15) three floors were measured, whole together 23 rooms to compare their's areas. Reference data was from Faro^{3D} X330 laser scanner.

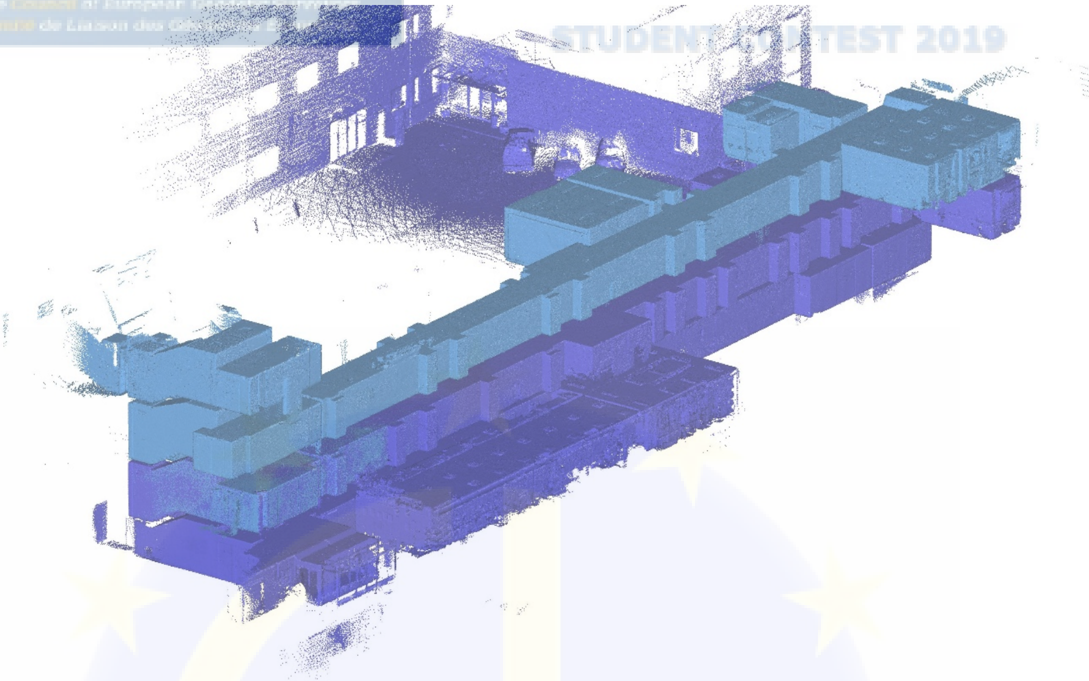

Fig 15. GeoSLAM ZEB-REVO point cloud from Land Board building

The greatest difference between GeoSLAM ZEB-REVO point cloud and Faro point cloud was 0,08 m^2. Mean square error (MSE) was 0,04 m^2 (Table 5). The greatest approximate error is 0,1 m^2, this is the accuracy of the area of the drawing plan, so this approximated number may influence the total area of the rooms.

Table 5. Comparison of rooms in the Land Board building from 3 floors

	Area of Faro (m^2)	**Area of GeoSLAM (m^2)**	**Difference (m^2)**
Min	2,38	2,39	-0,07
Max	190,76	190,79	0,08
Standard deviation	42,48	42,48	0,04
Average	39,72	39,72	0,00
Median	25,80	25,83	-0,02
Summary	873,73	873,77	-0,04
Difference from the reference data was 0,004 %			

Difference between point clouds on the whole building gives 80% of points of GeoSLAM ZEB-REVO are limited within 4 cm.

Conclusions

Handheld laser scanner GeoSLAM ZEB-REVO is suitable instrument for mine surveyors, it is accurate, fast, easy to handle and only one person is needed to operate the device. Point clouds can be collected to one complete database and can always be retrieved and reanalysed. Handheld laser scanners can improve the surveying methods in underground mines and modernize mining survey in general in Estonia and why not elsewhere.

Using a handheld laser scanner for making drawing plans or 3D models one has to be ready to make extra measurements to insure the accuracy of results. On the basis of results from data in this paper handheld laser scanner is a suitable instrument for measuring small rooms, for longer or wider rooms additional measurements using a known-good method have to be taken to trust the results. Proper measuring technique is very important working with handheld laser scanner, improper usage may cause errors or drifts of point clouds. Detailed measuring instructions for getting the most accurate results have been issued and should be adhered to.

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