NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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THE USE OF SLAM TECHNOLOGY IN UNDERGROUND MINING OPERATIONS

Bachelor's thesis
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1. INTRODUCTION

The environment of underground spaces is challenging for both the construction and the exploitation of natural resources. The unpredictable behavior of the rock and the conditions of underground spaces makes access and staying in it difficult and dangerous. This is the reason why the development of new methods and unmanned systems for the rapid and safe execution of mapping is increasingly important. However, the in-situ characterization of the rock mass and the mapping of the space are the most important steps in data collection, which are then input elements for numerical analysis, design and modeling of surfaces.

The underground mapping was performed with visual methods and analog recording, which are time consuming, inaccurate, subjective, difficult and sometimes dangerous. With the development of technology, these methods were largely replaced by theodolites and total stations, eliminating many difficulties and saving time. However, even these techniques there were many difficulties, mainly in terms of the time of field work and computations, the risk of the work, as well as the limited amount of information produced. In recent years, a technological breakthrough came in the form of 3D scanning methods. The technology is based on the dense recording of millions of points per second of the surrounding space, producing detailed three-dimensional information regardless of light conditions, something that would be impossible with classical geodetic methods. The 3D scanning technique is highly efficient, fast, with low field workload, remote control capability and the ability to receive a wide variety of data simultaneously. The disadvantages of this method are the huge data volume, data processing time, relatively high cost of the equipment and the need of high computational power.

The aim of this project thesis is to investigate the state-of-the art method of simultaneous localization and mapping 3D scanning, or otherwise SLAM technology and the possibilities of its application in surveys of underground works. SLAM technology (Simultaneous Localization and Mapping) refers to the 3D scanning of objects in the moving space, while having the ability to self-position the instrument in the unknown scanning environment.

2. 3D LASER SCANNING

Laser scanners are instruments that can determine the position of points in three dimensions relative to a local reference system by measuring the distance, vertical and horizontal angle. The measurement principle is similar to that of a total station with the difference that the optical aiming device is absent. In essence, it is a device that has the ability to record the environment as it really is, meaning geometrically is correct with great accuracy and in some cases with its true color and its real place in space.

3D laser scanning has many advantages and therefore great possibilities of application in different engineering projects related to the mine engineering practice, such as the following:

- Characterization of rock mass
- Forehead blasting quality control

- Deformation monitoring
- Improve input data for numerical modeling
- Remote inspection and analysis

There are different types of scanners for capturing objects of various sizes, and these can be categorized according to the technology they use, such as time-of-flight scanners , triangulation and interferometric scanners.

Scanners can be of **static type**, which remain stable during the scanning process. The advantages of this category include high accuracy and high point density. Another requirement of the static scanners is the use of known reference points and targets to allow for registration and georeferenced. Whilst static scanners have a great advantage in accurately capturing the environment, the time required to collect data and process point clouds, due to their static nature, make the method cumbersome and time consuming in underground environments.

The need for a faster and easier-to-use method has led to the development of **dynamic/kinematic scanners**, which combine the features of static scanners with the difference that the need for reference points is not essential. Therefore, the registration of all point clouds is performed during system movement. Kinematic scanners are usually mounted on a mobile platform or held in the hand. Therefore, to determine their trajectory in an unknown environment usually requires more complex additional positioning systems, such as GPS receivers and inertial INS systems, which can increase the acquisition cost. Examples of such scanners are airborne laser scanners, scanners built into a mobile laser scanner, or an unmanned aerial vehicle (UAV), even handheld scanners as SLAM technology scanners (Quintero et al., 2008) have emerged.

All scanners require multiple scans to map an environment or objects. For the processing of point clouds there is a variety of algorithms depending on the desired result, with the most basic procedures being the alignment and georeferencing of clouds. When the scan object cannot be scanned in its entirety from a single location but needs to be scanned from multiple locations, then independent point clouds are created but located in the scanner's arbitrary reference system. The process of registration is required for their transformation into a single coordinate system. However, even then the point clouds have arbitrary coordinates. The point clouds become part of a known coordinate system, either national or local with the georeferencing process

3. SLAM TECHNOLOGY

The SLAM method was first developed by Durrrant-Whyte and Leonard (2006), who relied on the previous work of Smith and Cheeseman (1985). SLAM (Simultaneous Localization and Mapping) technology refers to the 3D scanning of objects in space on the move, while having the ability to self-identify the instrument in the unknown scanning environment. There are many variants and combinations of receivers in the system, such as inertia modules, color cameras, satellite tracking system, etc. SLAM uses sensors to collect visible data (camera) and / or invisible data (RADAR, SONAR, LiDAR) with the basic data to be collected using the inertial unit (IMU) (GIS Resources, 2020).The SLAM technique is usually combined with photographic sensors (e.g. cameras), range sensors (e.g. radar) and Lidar or depth cameras (e.g. Microsoft Kinect). Depending on the sensors used, it can be categorized as Visual SLAM, Lidar SLAM and RGB-D SLAM, which are the three most widely used SLAM techniques.

The SLAM technique is an important development in locating and mapping underground projects (e.g. mines), as well as in route planning and autonomous navigation of mining equipment. Its main advantages are the high speed of data recording, the digital format of the data, the possibility of combining with many sensors, the possibility of remote data reception and the possibility of locating the location of the scanning system without additional auxiliary devices in space.

Compared to other imaging methods it has an increased cost but the choice to implement the SLAM sensors may be in many cases the only way of mapping and recording.

4. STUDY AREA AND APPLICATION

The practical part of the work focuses on the application of SLAM technology in an underground magnesite mine. The mine is one of the 10 mines located in the wider area of Pelion in North Evia and is now inactive. It has a length of the central corridor of 290 meters and a large number of transverse excavations. In the mine the supporting elements are minimal as the rock allows unsupported openings. The aim of this application is the use of SLAM technology in real conditions and the study of its basic capabilities, in contrast to the traditional methods.

4.1 Magnesite products and uses

Magnesite (MgCO3) is a magnesium carbonate mineral, similar to limestone, but much rarer. It has a white to white-yellow color, is relatively soft, absorbent and chemically inert. Magnesite in its original form does not have many applications, but when baked, carbon dioxide is released and magnesium oxide remains, where it acquires different properties depending on the temperature. The products of magnesite treatment are caustic and dipyrous magnesia.

Figure 4.1: The applications of magnesite and its processing products (www.orykta.gr)

Magnesite in the area has emerged as a replacement product, from the action of water and the alteration of peridotite. In image 4.2 such a case occurs inside the central mine adit, with the magnesite having formed between the layers of peridotite.

Figure 4.2: Creation of magnesite as a replacement deposit

When the degree of conversion is small, the stocks meet in the form of irregular veins within the mass of peridotite and are called "stockwork", with their exploitation being superficial. On the contrary, when the degree of conversion is large, the stocks are found in veins (felons), with its thickness being of the order of a few meters (eg 2-3 meters) (Figure 4.3).

Figure 4.3: Research drilling carrot (Pelion Area)

5. PROCESSING OF MEASUREMENTS AND CONCLUSIONS

Both topographic equipment and a 3D laser scanner with SLAM technology were used for the mapping. The topographic equipment was a total station and a GNSS receiver for the realization of a traverse along the main corridor of the mine and the georeferenced in the Greek geodetic reference system EGSA '87. The "ZEB-HORIZON" mobile scanner of the GeoSLAM company was used to map the mine, using SLAM technology.

The purpose of scanning data processing is to obtain information about the mine site. the specific aspects that were examined include:

- ✓ The comparison of 3D data with the real image of objects
- ✓ The tour in the 3D space of the mine
- ✓ Exporting cross sections through 3D data

- ✓ Volume calculation of parts of the mine
- ✓ Extraction of structural elements (slope angle and direction of slope angle) of the mine

Figures 5.1-5.3 below show some results from data processing.

The point cloud from the SLAM produced a very dense product which is very close to reality, even if there is no built-in camera in the scanner for capturing color images.

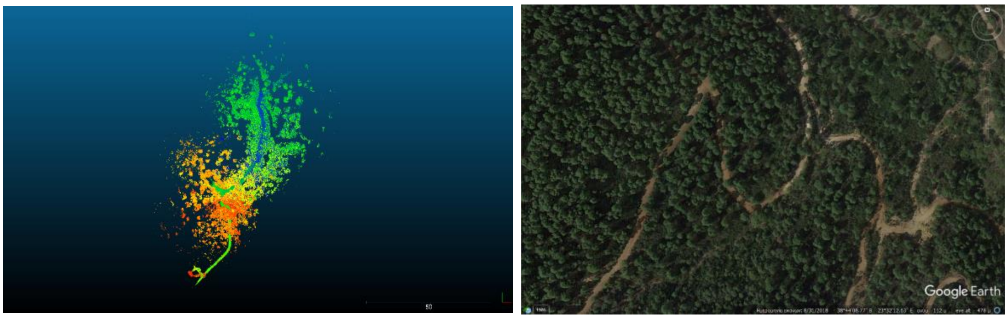

Figure 5.1: Correlation of 3D and satellite data

From the data, it was examined to derive cross-sections either from the point cloud or from the triangulated mesh data. It was seen that the geometry of the cross-sections is captured more accurately and with less noise in the case of the triangulate mesh compared to the point cloud.

the calculation of the area in the cross-sections was performed in two ways. The first method estimated the area using appropriate software tools directly on the point cloud. The second method estimated the area using mathematical surface adjustment by least squares., the two methods gave close results . This is justified since the surface adjustment method is more approximate. However both methods are considered reliable for calculating the area of a section.

Regarding the volume calculation of parts of the underground corridors that the results suggest that in the case of simple geometry with a few edges it is proposed to measure directly from the cloud of points and with the help of mathematical surface adjustment. In the case of complex geometry the method of using the triangulated mesh with mathematical surface approximation is proposed and carefully choose the mathematical surface adjustment method.

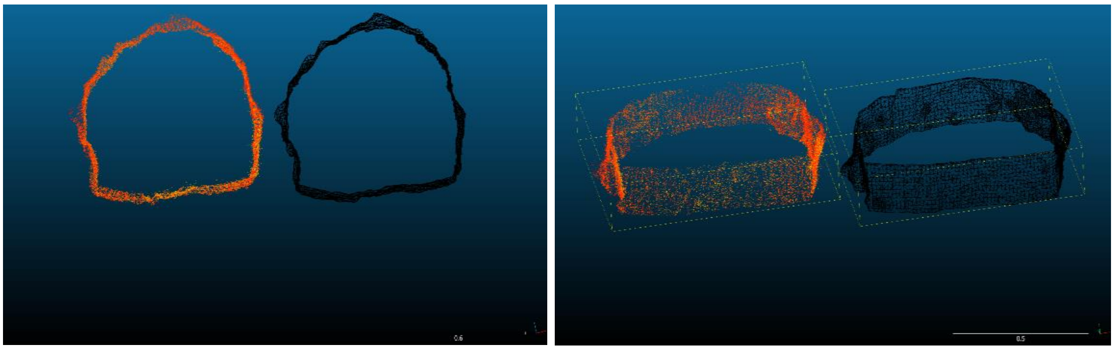

Figure 5.2: Cross section in the form of a point cloud and in the form of a grid

Another aspect that was considered , was the estimation of essential parameters such as orientation and azimuth direction. The plane adjustment method and the digital geological compass method, provided by the software, are used for the extraction of the above parameters of the mine. The results show that the differences between the two methods are not significant, provided that the positions of the compasses are carefully selected. Specifically, the differences regarding the dip angles are negligible while the differences regarding the dip direction are greater, thus emphasizing the sensitivity of the geological compass method.

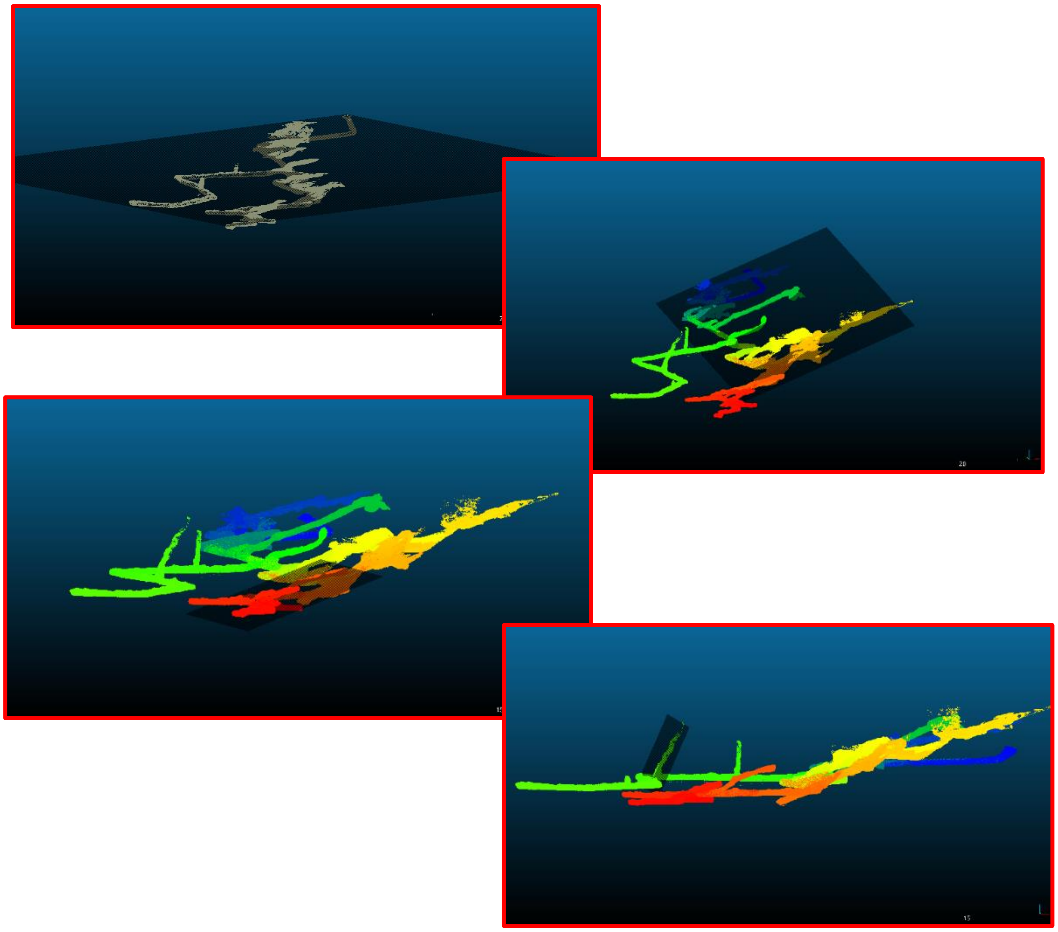

Figure 5.3: Slope and slope direction of basic mining levels

6. Conclusions - Suggestions

The conclusions reached regarding the 3D data , the software used in this work and the data processing are as follows:

- The volume of the collected data was very large (for scanning a section of 100 meters the volume of data can reach up to 5Gb) due to the high density during scanning. As a result there is need for a computer system with high specifications in both RAM and card graphics.
- The point scanning rate is given by the scanner manufacturer and is equal to 300.000 points / second, while the point density (points / m^2) is not constant but

depends on the scanner speed. Slower speed means more density and more detail.

- Obtaining data with the handheld scanner SLAM technology was very simple and fast compared to traditional methods,. Indicatively, the time required to scan 290 meters of main corridor and approximately 200 meters of transverse excavations was one hour.
- An integral part of the scanning process is the establishment of reference points inside the mine required for the registration process.
- Due to the fact that the scanner during data acquisition did not close the loop, at the end of the main corridor (290 m) there was a drift error of 1 m, which was verified by comparing the 3D scan with the reference points placed in known places into the mine.
- For the processing of the data, a reduction of 20-50% was made both for reasons of computing power and for reasons of achieving a better result in some cases.
- As for the processing of triangulated mesh surfaces there are no powerful processing tools in the Cloud Compare software, so for their processing is recommended other open access software (e.g. MeshLab).
- the definition of cross sections using triangulated mesh was more accurate and detailed than the representation through the point cloud.
- The calculation of cross-sectional areas with the approximate method of surface adjustment and with the analytical method offered by the software provides similar results, with the differences up to 0.5 m^2.
- The calculation of the volume in the cases of simple geometry is done efficiently either with the help of mathematical surface in the point cloud or directly on the point cloud with the help of the appropriate software tool. The difference between the two methods is in the order of 1.5 m3 in a total volume of 25 m^3 (deviation 6%). The volume calculation through the triangulated mesh had difference from the two previous methods by 16% and 10% respectively.
- The volume estimation in cases of complex geometry is proposed to be performed with the help of the triangulated mesh and adaptation of a mathematical surface under specific conditions. The difference between the two methods is about of 4%, while their difference from the calculation of the volume directly from the point cloud is about of 16% and 20% respectively.
- Regarding the estimation of basic structural parameters, 4 basic ones were distinguished, of which 1st is the level of main corridor. Structural elements of dip angles and dip direction were more easily and effectively exported by the method of mathematical surface adjustment. In contrast, the method of digital compass is prone to errors due to non-proper use of the tool. However, by carefully using the compass tool, maximum differences occurred between the two methods are 4^o for the dip angle and 17^o for the dip direction.

From this project, interesting suggestions for future research are:

- The study of capturing high-risk underground spaces with the help of SLAM technology and the use of a drone.
- Dealing with algorithms of SLAM technology in order to minimize the error of merging point clouds. The registration error is very important because it acts cumulatively and affects the final scanning accuracy.
- The study of SLAM technology in an outdoor environment and the comparison with static scanners in terms of speed, efficiency and accuracy.

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