The use of TLS technology in the inventory of damage to building objects resulting from the impact of underground mining exploitation

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Słowa kluczowe: terrestrial laser scanning, mining damage

SUMMARY

The aim of the article was to assess the suitability of terrestrial laser scanning for documentation of damage to building objects caused by underground mining exploitation. For this purpose, there was created a 3D model of a single-family house in Rybnik, affected by the impact of underground exploitation of the Coal Mine “Chwałowice”. Point clouds created with the help of stationary and hand-held scanners have been applied. The representation made it possible to detect numerous columns and cracks in the facades of the buildings and to measure their geometric parameters. On this basis, conclusions were drawn on the advantages and disadvantages of the presented method.

PODSUMOWANIE

W artykule dokonano oceny przydatności naziemnego skaningu laserowego dla potrzeb inwentaryzacji uszkodzeń obiektów budowlanych, spowodowanych podziemną eksploatacją górniczą. W tym celu, w oparciu o chmury punktów utworzone z użyciem skanerów stacjonarnego i ręcznego, wykonano trójwymiarowy model budynku jednorodzinnego, położonego w Rybniku, w zasięgu wpływów eksploatacji górniczej KWK ROW Ruch ”Chwałowice”. Zobrazowanie pozwoliło na rejestrację licznych szczelin i spękań w elewacjach budynków oraz pomiar ich parametrów geometrycznych. Na tej podstawie sformułowano wnioski dotyczące zalet i wad prezentowanej metody.

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1. INTRODUCTION

Underground mining works are not indifferent to the environment, landscape or building structures on the surface ground. In highly urbanized areas, which include, e.g. the Upper Silesian Coal Basin, the problems involving the deformation of mining areas are of particular importance, since they often bring about serious damage to buildings, often eliminating them from further use. Making inventory of damage done to buildings, and in special cases their monitoring, is a complex task. Simple photographic documentation does not provide metric information, while classic geodetic surveys may turn out to be insufficient or ineffective, e.g. in the case of numerous, propagating cracks. The problem may be solved by the technology of 3D terrestrial laser scanning (TLS) – with the use of both stationary and handheld equipment. Measurements made in this way provide multi-criteria and accurate data on the deformation and damage to buildings.

The objective of the work is to present the possibilities of using TLS technology to assess the degree of damage caused in a single-family building subjected to the influence of underground mining exploitation, based on the example of actual measurements of a building located in the mining area of Coal Mine ROW Ruch "Chwałowice". The carried out imaging allowed to identify numerous gaps and cracks in the facade of this building and to measure their geometrical parameters. On this basis, conclusions were drawn regarding the advantages and disadvantages of the presented method.

2. CAUSES OF MINING DAMAGES AND THEIR IMPACT ON BUILDING OBJECTS

Mining damage is understood as all movements of rock mass as well as a collapse or uplift of the surface ground of mining area, effected by underground mining activities and contributing to incurred losses of property owners (Misa R., 2015). The damage visible on the facades of buildings is mainly in the form of gaps and cracks, which are the result of stresses affecting surface objects in the deformation process of the surface ground subjected to the influence of mining exploitation. These stresses are mainly the result of the impact of extreme in time principal horizontal deformations and extreme in time main curvatures created in a developing subsidence trough and acting on the building structure.

Figure 1 presents the distributions calculated with the application of the program EDBJ by prof. J. Białek (Białek J., 2003) of extreme in time principle tensile and compressive deformations which will be generated on ground surface above the exploitation of three successively exploited horizontal longwalls with a height of 1.0 m, located at a depth of 400m. Similar distributions will have extreme in time concave and convex main curvatures.

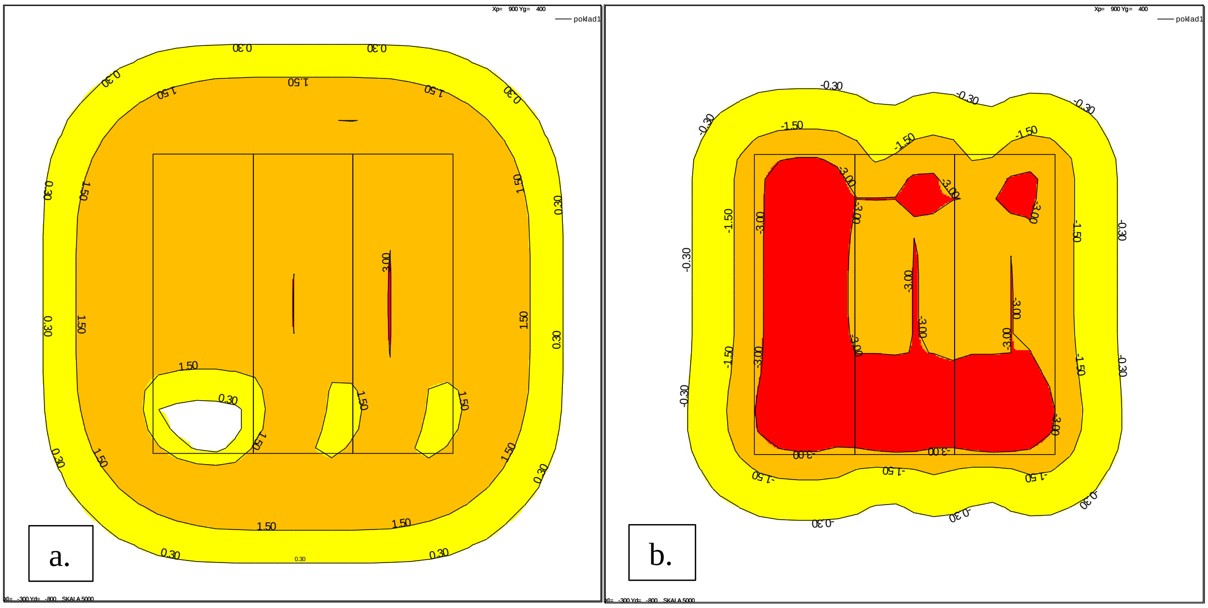

Fig. 1. Distributions of extreme in time principle tensile (a.) and compressive (b.) deformations calculated with the EDBJ program (source: own study)

Figure 1 shows that outside the exploited field, higher values will be adopted by the extreme in time principle tensile deformations and convex curvatures, and inside this field - extreme in time principle compressive deformations and concave curvatures.

The damage to the facade of a residential building with a typical structure, resulting from the impact of horizontal deformations and curvatures greater than its strength, will be manifested, among others, in the form of (Misa R., 2015):

- vertical scratches,
- diagonal scratches,
- warped door and window openings.

Exemplary cracks in the facade of a building located in the edge part of the subsidence trough (i.e. subjected to tensile deformation and convex curvature) are shown in Figure 2.

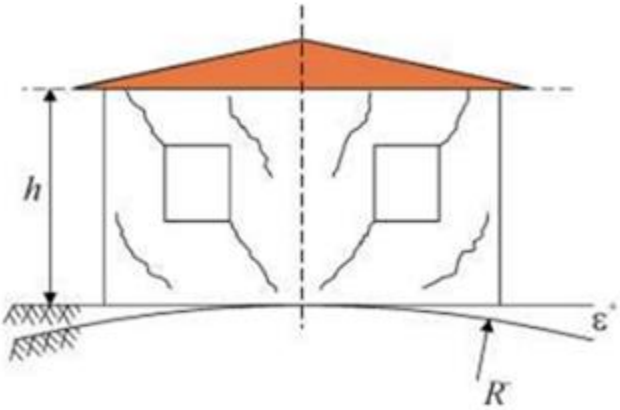

Fig. 2. Cracks in the facade of a building located in the edge zone of the trough (source: Misa R., 2015) (ε - tensile deformation, R - convex curvature)

3. CHARACTERISTICS OF THE TLS METHOD

Terrestrial Laser Scanning (TLS) is a technology that allows to obtain information about the shape and dimensions of objects. It is based on a fast determination of XYZ coordinates of a very large number of points (from several thousand to even several million per second) and on creating the so-called point clouds. Such a spatially oriented cloud allows for the development of a three-dimensional model of the scanned object with high precision, with the possibility of measuring various angular and linear quantities (e.g. length or inclination of objects) (Janus J., 2016).
The scanner determines the XYZ coordinates of points in any given system in a way analogous to the measurement of terrain details using the polar method - based on (Janus J., 2016):

- vertical and horizontal angles - their values are determined on the basis of the position of rotating mirrors that distribute a laser beam over objects around the instrument,
- the distance of the measured point from the scanner, determined in the same way as in laser rangefinders, e.g. in electronic tachymeters.

The interface of the instrument, usually based on the Android system, allows the user to define the parameters of the performed scans, such as the quality of imaging, the number of repetitions of a single point measurement, or the resolution of the point cloud, i.e. the actual distance between adjacent points of the point cloud. For example, a resolution of 3 mm / 10m means that for an object located at a distance of 10m from the scanner, the distance between the adjacent points of the cloud mapping its surface will be 3 mm.

4. CHARACTERISTICS OF THE TESTED OBJECT AND FIELD STUDIES

For the purpose of assessing the suitability of the TLS technology for inventorying the damage to objects, a three-dimensional numerical model was made of a single-family building located in Rybnik, in close proximity to Coal Mine ROW Ruch Chwałowice (Fig. 3), i.e. in the area that is strongly influenced by underground mining. The necessary field studies were carried out on October 12, 2021.

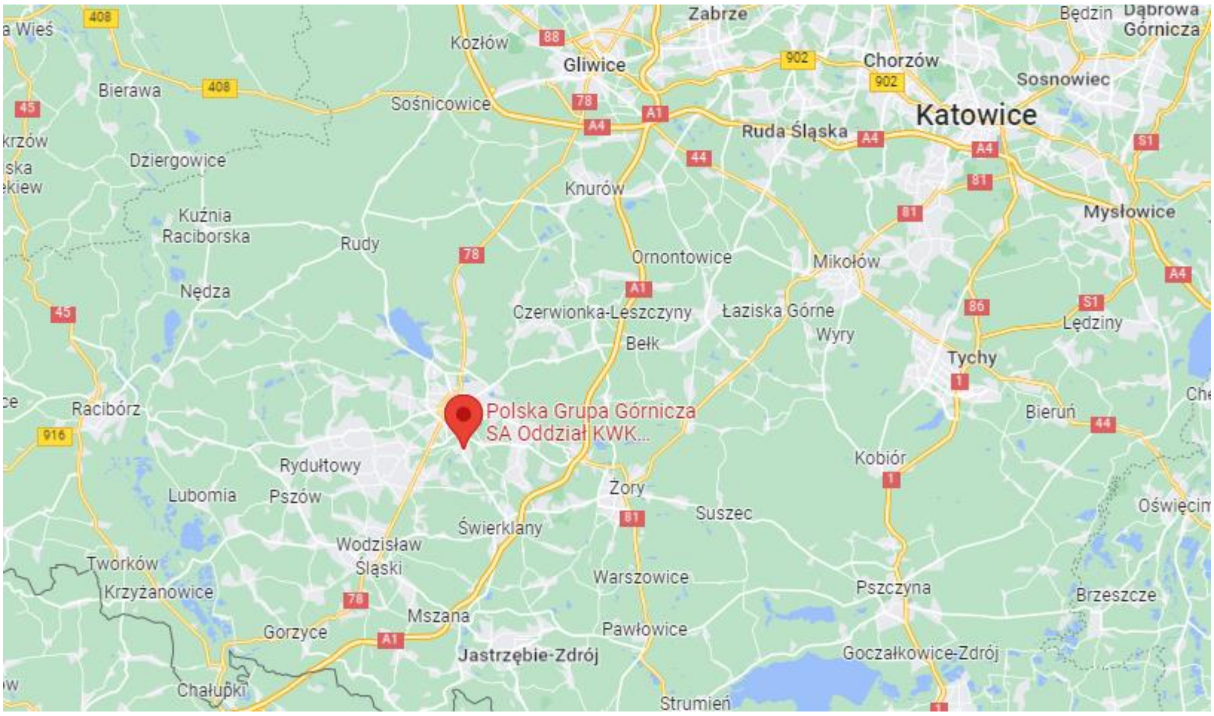

Fig. 3. Location of the tested object (source: Google Maps)

The object in question consists of a residential part, a utility room and a barn, once used for the needs of a private farm (Fig. 4). Within the area of the property there are numerous shrubs and low trees, and in close vicinity, on a high embankment, there is an express road. The facades of the buildings are covered with numerous, clearly visible cracks, and large-sized gaps were also found in many places.

After the completion of the field interview, it was decided to arrange 8 scanner stands so that it would be later possible to combine the scans automatically (i.e. common aiming direction was ensured and they were placed at short distances from each other) and to cover the entire facade. Due to a large number of characteristic scenery elements, which could become common points for several scans, the idea to place additional measurement signals was abandoned.

At each stand, the instrument performed in turn:

- a rough scan of the area around the stand,
- a detailed scan of the objects,
- a panoramic photo of the area around the stand, helpful e.g. with cameral processing of the scans.

After completing the process, an inventory of larger gaps in the façade was also made with the use of a handheld scanner.

Fig. 4. General view of the tested object, obtained after data processing from a stationary scanner (source: own study)

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5. CHARACTERISTICS OF THE USED MEASURING APPARATUS

To make the model of the entire building, the scanner FARO® Focus S350 was used (Fig. 5). It enables to scan up to a million points per second, located even 350 m away from the stand of the instrument, both in the field and indoors. It also provides a distance measurement accuracy of ± 1 mm and a high precision angle measurement. It is adapted to work in temperatures from -20^{o}C to + 55^{o}C, and also, owing to the IP54 tightness class, in dusty conditions, high humidity or with short-term splashes of water on any side of its housing. The optical system of the device is equipped with the HDR function, which allows to accurately capture the scanned surfaces even in poor lighting conditions. Additionally, the instrument is equipped with a GNSS module, which enables spatial orientation and automatic merging of the scans. It also makes it possible to mount the scanner on the unmanned aerial vehicle and capture, for example, objects located at greater heights (www.vpi-polska.pl, www.tpi.com.pl).

Fig. 5. Stationary scanner FARO® Focus S (source: www.faro.com)

The gaps of larger size found on the facade of the building were inventoried using the FARO® Freestyle 2 handheld scanner (Fig. 6), which allowed to capture surfaces placed 0.4 - 10m away with the error of distance measuring of only 0.5 mm / 1 m. The scanner enables the registration of up to 220 thousand points per second, and like a stationary instrument, it has an HDR function that allows to work in dim light. The course of the registration of points can be followed in real time on a smartphone screen, which also allows to control the instrument. The created point cloud can be combined with data from a stationary scanner.

Fig. 6. Handheld scanner FARO® Freestyle 2 (source: www.develop3d.com)

6. DEVELOPMENT OF THE ACQUIRED POINT CLOUDS AND THE OBTAINED RESULTS

The point cloud obtained from the work of the stationary scanner was processed into a 3D model of the tested object, using the software FARO® SCENE. The processing comprised, among others:

– initial, automatic data processing – e.g. removing shadows or elements that were not clearly visible on the scans, recorded with low precision (points being away from the cloud with a too large distance),
– registration - mutual orientation of the scans from the individual stands and combining them together (this stage is also performed automatically by the program's algorithms),
– extracting from the model the outline of the buildings under study - by adding the so-called clipping boxes, i.e. cuboids, inside which only the desired objects were placed, excluding the surrounding vegetation, etc.

In effect, a high-quality imaging was obtained. The image was also devoid of vegetation fragments that would reduce clarity (Fig. 7).

Fig. 7. Three-dimensional model of the object after the processing of point clouds (source: own study)

The created model very clearly shows cracks and scratches in the building's facade. Their irregular course was reconstructed ensuring the preservation of the smallest details (Fig. 8). The cyclically created studies, combined with the function of linear and angular measurements offered by the software FARO® SCENE, allow to carry out precise observation of the propagation of the shape and size of almost any damage to the object.
For the most extensive gaps, which pose the greatest threat to the structure of the object, models with increased accuracy were also made, using the data obtained with a handheld scanner, which were then processed in the FARO® SCENE Capture program (Fig. 9).

Fig. 8. Cracks in the building wall - model created on the basis of data from a stationary scanner (source: own study)

For the most extensive gaps, which pose the greatest threat to the structure of the object, models with increased accuracy were also made, using the data obtained with a handheld scanner, which were then processed in the FARO® SCENE Capture program (Fig. 9).

Fig. 9. Cracks in the walls of the building - models created on the basis of data from a handheld scanner (source: own study)

The processing of point clouds was largely the same as in the case of a stationary scanner. The created models made it possible to measure the geometrical quantities characterizing the cracks, such as: vertical dimension, horizontal dimension, total length and width. The program makes it possible to precisely outline individual sections of the crack and determine their dimensions (Fig. 10.).

Fig. 10. Determining the dimensions of the gaps in the building facade. (source: own study)

7. SUMMARY AND CONCLUSIONS

As it has been demonstrated in the research, the TLC technology may be useful in the inventorying process involving the impact of mining damage to building structures. The obtained accuracy of the point cloud at the level of 7 mm / 10 m (i.e. a 7-mm distance between adjacent cloud points at a distance of 10 m from the stationary scanner) allows for very precise documentation of the occurrence, location and shape of any cracks and gaps on the walls of buildings. A still higher precision of imaging is offered by the handheld scanner, which allows for the positioning of details of the object with a precision of up to 0.5 mm / 1 m. Other advantages of the TLS technology attesting its advantage over classic methods include:

- cross-sectional, continuous nature of the collected data - the scan allows to recreate the shape and geometrical parameters of the entire body of the building, as opposed to traditional measurement techniques which provide only discrete information. It also facilitates the determination of useful parameters, such as the angle of inclination of the structure or the size of free-form deformations.
- simple visualization of the obtained data - in the form of a clear, easy and quick-to-generate 3D model. The software FARO® SCENE allows to view any part of a building from different perspectives. This significantly facilitates the comparative analysis of the condition of the object in time intervals and the observation of damage propagation.
- significant reduction of the measuring time and processing time of the results, allowing for more frequent inventory works.

The disadvantages of the presented measurement technique include:

- obstruction along the path of laser beam caused by environmental elements (plants, vehicles, devices, etc.). This blocks the beam from reaching the desired surface, which is manifested by the presence of blanks in the 3D model. The need to maintain a perfect aiming direction should therefore be especially taken into account when designing the location of the stands of the instrument.
- reduced density of the point cloud for details located at greater heights, which eliminates the TLS method from inventorying slender or multi-story objects. In this case, the solution may be to mount the scanner on the unmanned aerial vehicle. The cloud obtained in this way is fully compatible with the measurement results obtained on the ground.

In conclusion, we can state that due to significant improvement in accuracy, which goes hand in hand with saving time and labor, the terrestrial laser scanning technology can be widely used for the documentation of the impact of mining exploitation on surface ground objects.

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