JOURNAL OF SUSTAINABLE MINING 14 (2015) 30–37

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/jsm

JOURNAL OF SUSTAINABLE MINING

Possibility of convergence measurement of gates in coal mining using terrestrial 3D laser scanner

Radovan Kukutsch[*], *Vlastimil Kajzar, Petr Konicek, Petr Waclawik, Jiri Ptacek*

Institute of Geonics AS CR, Institute of Clean Technologies, Ostrava, Czech Republic

ARTICLE INFO

Article history:
Available online 21 August 2015

Keywords:
3D laser scanning
Point clouds
Mining
Geotechnical monitoring
Convergence measurement

ABSTRACT

The application of laser scanning technology has increased recently in many different branches. The presented paper deals with an application of this technology in the mining environment. To verify the spatial changes (movements and deformations) of mining works this technology was deployed *in situ* at the selected mining workplace in the Czech part of the Upper Silesian Coal Basin. The main purpose of 3D laser scanning at Lazy Mine was to monitor the deformation of the roadway before approaching the longwall face on the selected tailgate. From the results of performed 3D scanning used it was possible to accurately define and quantify the floor lift area in front of the approaching coalface, observe measurable tilt of middle wooden props, capture documentable changes in floor dinting during the period between campaigns and monitor the deformation of steel arch support, confirming the influence of additional stress away from the goaf of previous longwall.

1. Principles of laser scanning technology

Laser scanning excels in the ability to determine spatial coordinates of any spatial objects without contact, such as buildings, structures, interiors, space, terrain, etc. This technology is characterised by exceptional speed, accuracy, complexity and safety. The scanned objects are then visualised using specialised software in the form of point clouds. Subsequently it is possible to perform a wider range of analytical tasks and also generate models of these objects (Stroner et al. 2013).

The wider utilization of this technology underground is in cave rooms, not only in the Czech Republic, but also abroad (Buchroithner & Gaisecker, 2009; Cosso, Ferrando, & Orlando, 2014). Considering its use in underground mining, as well as geotechnical and geological practice, this technology may find a wider application to solve the following tasks – capture the course of underground mining works and create as-built documentation, assess stability conditions of mining workplaces, monitoring of deformation and convergence, implementation of large volumetric calculations of various characters, extension of evidence (e.g. accidents, damages), use in the design activities, basis for construction and reconstruction activities, collision awareness, mine site protection etc. Scanning costs are variable, cannot be accurately quantified and depends on the specific type of project. The purchase price of the device and the corresponding software (from 30 000 up to 100 000 EUR) plays a crucial role.

* *Corresponding author*. Tel.: +420 59 69 79 242.
E-mail address: radovan.kukutsch@ugn.cas.cz (R. Kukutsch).

Peer review under responsibility of Central Mining Institute in Katowice.
http://dx.doi.org/10.1016/j.jsm.2015.08.005

Unfortunately, the use of this technology in mining environment is still limited and more in ore mines than in coal mines. As it is known from the available resources, this technology is used for the documentation of corridors and infrastructure by room and pillar mining methods. In the case of longwall mining, the use of the laser scanner is very rare (e.g. DMT GmbH or Measurement Devices Ltd. UK).

In the case of coal deposit, a safety is a primary concern of any mine. A laser scanner can identify and record any cracks and fissures, compare these data to previous scans, and identify any areas of concern. This is an enormous contribution to mine safety and a safe work environment.

On-going 3D documentation of the mine can prevent a mine collapse, as it instantly detects any alterations in local rock strata, so that appropriate security measures can be taken well in advance. Construction work underground, such as the digging of a new coal mine, is also made easier and safer by the use of laser aided 3D documentation.

Our knowledge of the use of laser scanning are based on *in situ* testing in mining works of an already closed polymetallic deposit in Zlate Hory (Olomouc Region, Czech Republic). Within realised surveying campaigns, it was possible to verify the possibilities of using this technology especially for documentation of the current technical condition of the mines and their real spatial definition (Kuda, Kajzar, Divíšek, & Kukutsch, 2014). To verify the spatial changes (movements and deformations) of mining works this technology was deployed *in situ* at the selected mining workplace in the Czech part of the Upper Silesian Coal Basin. The laser scanning method was applied in an active coal mine within the Czech Republic for the first time ever.

2. Lazy colliery case study

2.1. Geological properties

Seam No. 4 with a thickness of up to 6 m lies about 800 m below the surface in the lower part of Sedlove Member and is mined by the longwall in the explored area (No. 23 in Fig. 1). The entire sequence of the lower part of the Sedlove Member is dominated by solid layers of sandstone, conglomerates and sandy siltstones. Less solid rock layers (siltstone and mudstone) occur only very rarely in the immediate vicinity of coal seams. The vertical distances between seams are tens of metres. The characteristic features of the mined seams in the Sedlove Member are their relatively large thickness (up to 8 m) and horizontal variation.

The main tectonic elements in the explored geological block are the anticlinal structure and fault B. The anticline divided the block into two different parts. The western limb of the anticline dips 10°–20° to the west whereas the eastern limb dips 10°–15° to the east. The southern branch of major fault A separates the explored area to the north and the tectonic fault C to the south. Internal fracturing and dislocation in the geological block are not too extensive except for the numerous tensile fractures of N–S direction in the hinge area of the anticline. From a geomechanical aspect, it represents a significant destress area.

The characteristic lithological profile of the overburden of seam No. 4 in which the explored longwall was mined is shown on the right side of Fig. 1. Interbeds of seams No. 2 and No. 3 as well as interbeds of seams No. 3 and No. 4 are

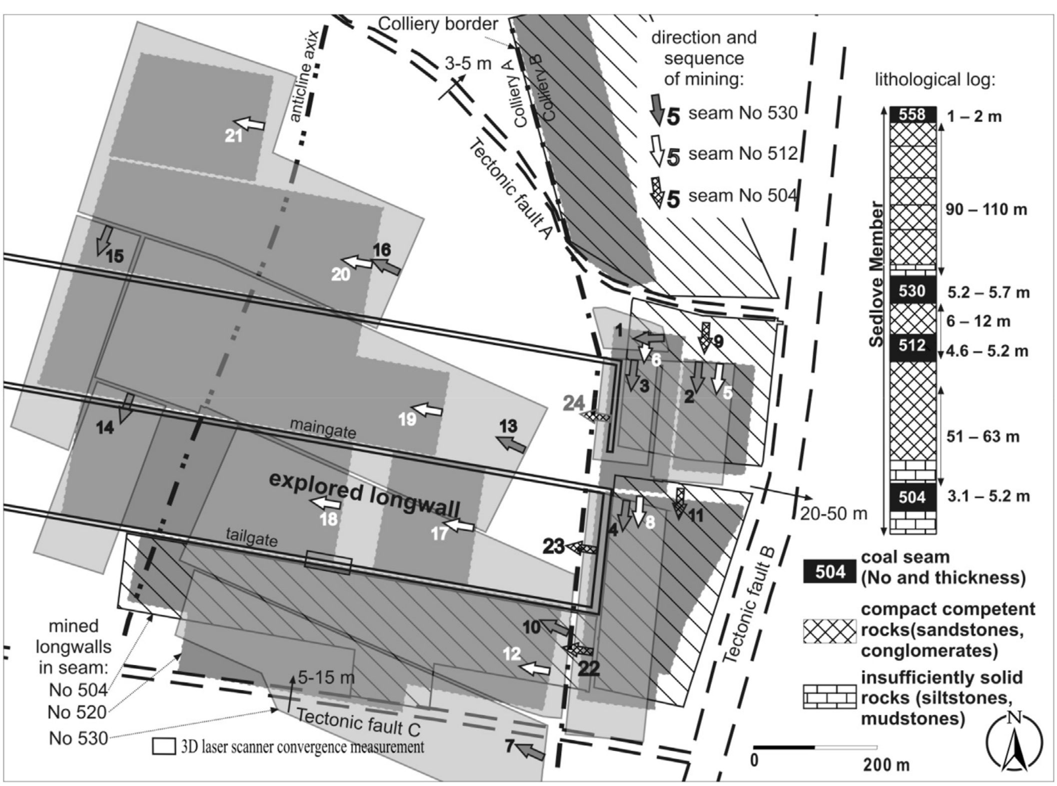

Fig. 1 – History of mining and lithological log of the rock mass in area of explored longwall.

composed of fine-to-medium-grained siltstones and sandstones, with a predominance of sandstones (Konicek, Ptacek, Waclawik, Soucek, & Kukutsch, 2013; Konicek et al., 2014).

2.2. *Geomechanical conditions in the explored area*

The influence of the mine edges of seams No. 2 and No. 3 in the overburden were considered from a geomechanical aspect (Konicek et al. 2013, 2014). This is necessary to identify the deciding factor for stress strain distribution in the explored area, although the influence of the upper seams (seam No. 1 and higher) must be accepted. For stress strain distribution it is necessary to consider the mining in the next colliery, B (east of the explored area – see Fig. 1). Because of differential time and spatial mine advance in both collieries and non-observance of the old mining rules (the use of natural borders to determine the mining area), there is a high concentration of stress along the mine edges in the overburden east of the explored area (in the former mine B field). These stress concentrations were combined with additional stress because of the above-mentioned mine edges in the overburden, which created a complicated stress field which influenced mining activity in the entire geological block. The high stress level primarily affected the first stage of longwall excavation – the face, starting from the crosscut – and there was no controlled caving.

The first panel (face No. 22) was already mined out south of the explored longwall No. 23 in seam No. 4. Additional stress caused by this goaf caused a stress concentration in the southern part of the explored panel. We had to consider the additional stress added by residual pillars in seams No. 2 and No. 3, too. They were left in the overburden at a perpendicular distance of about 50 m and 80 m respectively.

3. Laser scanning technology application purpose

The purpose of 3D laser scanning at Lazy Mine was to monitor the deformation of the tailgate in stationing from 400 m to 500 m during advancing of the longwall face (Fig. 2).

Traditionally convergence measurement is performed by measuring tape or laser rangefinder. More sophisticated solution is to create a convergence station where measurements are performed not only between points within one profile, but also between different profiles. Neither of these methods, it is not as comprehensive as convergence measurements by using a laser scanner. Convergence monitoring was focussed on part of the tailgate impacted mainly by additional stress from an unmined left pillar in overburden seam No. 3 (see Fig. 1). Cases where the scanned area is in the immediate vicinity of the coal face, have not been found from any available sources.

This part of the tailgate was selected due to impact of additional stress from unmined left pillar in seam No. 3 and mining of previous longwall (No. 22 in Fig. 1). Approximately half of the above-mentioned monitoring section was located under the unmined pillar in seam No. 3 and the aim of scanning was to reach a complex deformation of this section in the 3D view (slip yokes of steel arches of support, deformation of ceiling and side arches of steel arch support, swelling of floor rocks, deformation of middle wooden props, etc.).

Support design parameters of the investigated gate can be described as follows:

- Subparabolic profile SP 14 (4.0 m high and 5.58 m wide).
- Steel arch spacing (0.5 m).
- Strengthening of steel arch support by cable bolts (length 9 m) with spacing of 1 m and loading capacity of 420 kN. High cable bolts were combined with short steel beams; strengthening of steel arch support by wooden props with spacing of 1 m.

We note that our section was not scanned immediately after excavation (Fig. 3), but at the time when the investigated tailgate section was impacted by additional stress from the advancing longwall face, so we got the default state. Thus, the initial state does not correspond with the state after the excavation and the profile gate is therefore smaller. However, analogous comparison and evaluation is possible.

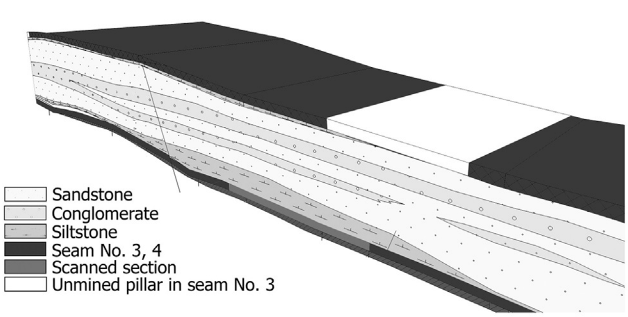

Fig. 2 – Geological model.

4. Scanning experiment description

Used Leica ScanStation C10 device is a compact pulse scanner with dual-axis compensator, featuring high speed scanning (up to 50 000 points per second), high surveying precision and long-range beam. The device uses the green laser beam with wavelength of 532 nm. Based on the intensity of reflected beam, the device can distinguish different types of planes within the point cloud. There is a possibility of scanning in the full field of view (except space below the scanner). ScanStation C10 is able to measure on distance up to 300 m in ideal reflectivity conditions. The shortest distance of detection is 0.1 m. The device is also complemented by integrated digital camera.

In total, three campaigns were planned; the first two were successfully realised at a distance of 94 and 46 m ahead of the longwall face. This two scanning campaigns were performed in 14 days interval. Another one campaign planned in the immediate proximity of the longwall face had to be cancelled due to unfavourable conditions for scanning (significantly reduced gate profile, high dustiness, high induced seismicity, etc.).

To achieve the most uniform density of point cloud, covering a selected 100 m long section, a series of scans

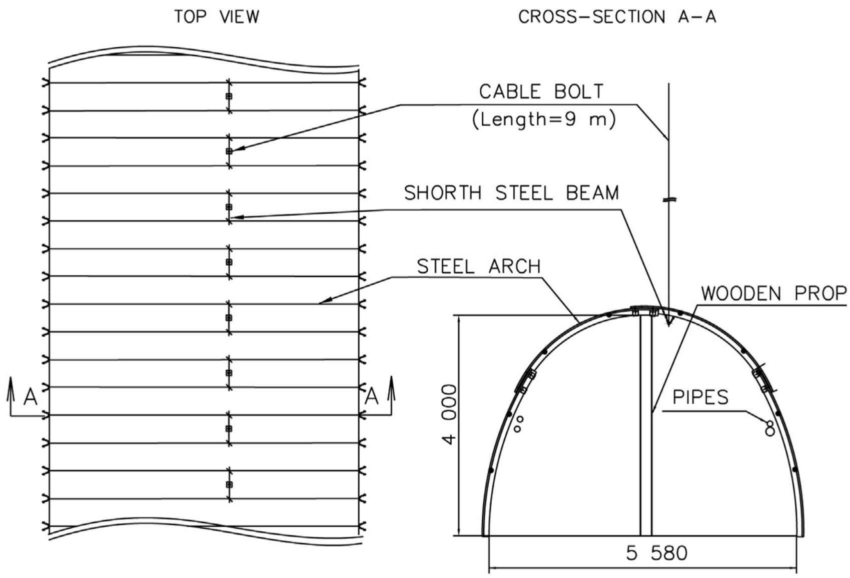

Fig. 3 – The original state after excavation (length in mm).

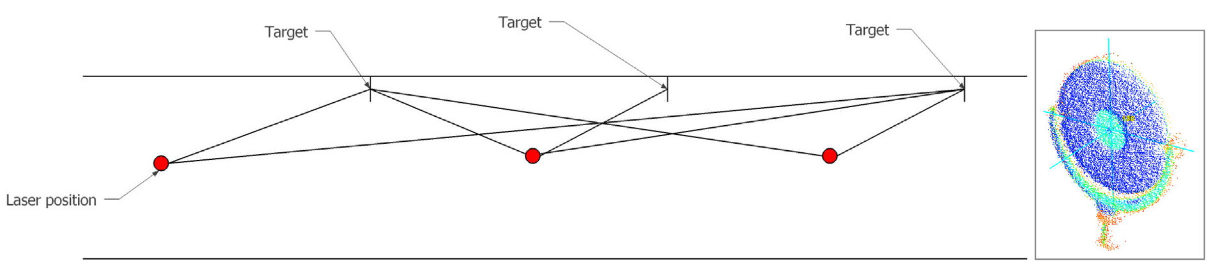

Fig. 4 – Principle of target visibility and focus (left) and scanned target point cloud (right).

spaced at 15 m was realised (Fig. 4). It was desirable to scan in the shortest possible and strictly necessary time due to work in a hazardous environment (classified in the third level of rockburst risk).

To facilitate the subsequent post-processing of the final scans, a set of special scanning targets (see Fig. 4) were deployed on fixed position and, before each scan, accurately spatially targeted. These targets join partial point clouds into a single unit in post-processing. These are 6 inch circular targets coated with a highly reflective layer, precisely defined centre and the possibility of rotating in both planar axes. It allows focussing the target from any visible position. In mining conditions, characterized by poor light condition and high dustiness, is sometimes very difficult to focus on targets due to increasing distance from the scanning position and low resolution of integrated camera and display. In order to compare clouds of points from different scanning campaigns, it is also necessary to place the targets in the equal positions.

The scanning resolution was set at 10 cm/100 m (scan time ca 7 min). From each scanning position, a point cloud of

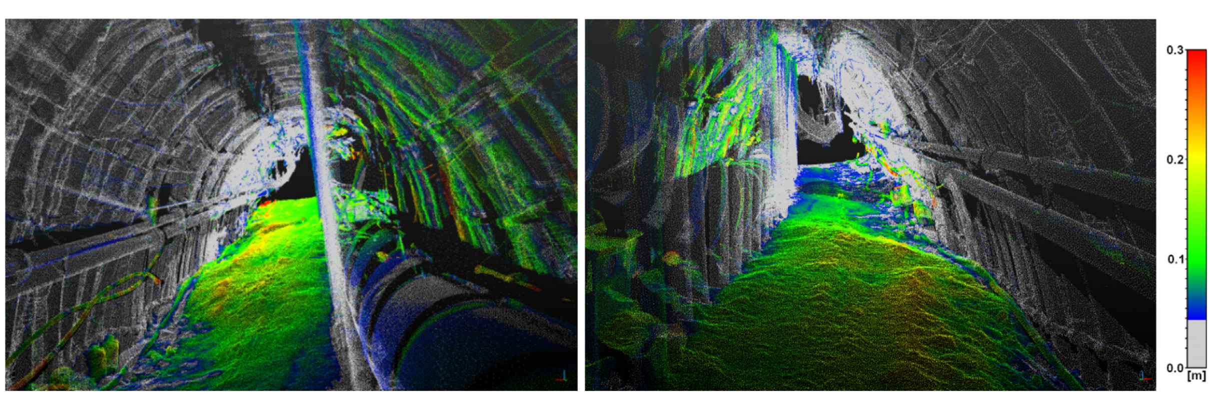

Fig. 5 – Detailed evaluation of spatio-temporal changes (14 days) on the part of the studied section.

approximately 15 million spatial points was obtained. The scanner determines always the spatial coordinates of each of measured points relatively to its current position. The connection to the used geodetic system was not strictly necessary for purposes of this testing task and point cloud was registered relatively to the first one.

Used method of aiming targets is very time consuming. It seems that scanning without targets, using the so-called "scan and go method", when the whole scanning process is limited to the transferring and positioning the device without focussing on targets might be an alternative. Its use, however, entails more complicated post-processing with manual point clouds registration.

5. The results of post-processing

Post-processing of obtained data was realised using specialized software (Leica Cyclone and CloudCompare). In the Cyclone software registration of individual clouds and referencing of the resulting clouds with respect to each other was carried out. Further processing took place using the open-source software CloudCompare. At first, point clouds were subsampled to optimal density. Then, subsequently, a comparison of both point clouds and graphical visualisation of the resulting spatio-temporal changes were performed (see Fig. 5).

As evident from the images, there was a deformation of mining works, especially from the goaf of the previous coalface, which was previously mined. There is also visible floor lifting that towards the coalface reaches up to 30 cm. In two monitoring profiles, changes of the height and width were observed – greater with the approaching longwall and lesser with the mining work profile. The metric expression of profile comparison is shown in Table 1.

Table 1 – Results of profile comparison.

	Distance to longwall face [m]	Height [m]	Width [m]
Profile 1 (stationing 460 m)			
Primary state		4.00	5.58
1. campaign	94	2.61	2.85
2. campaign	46	2.50	2.75
3. campaign	12	cancelled	cancelled
Profile 2 (stationing 410 m)			
Primary state		4.00	5.58
1. campaign	94	2.24	2.53
2. campaign	46	1.92	2.22
3. campaign	12	cancelled	cancelled

In terms of spatial resolution scanning, the closer the scanned object is the closer the points defining the object are to each other. The device is able to distinguish different points in mutual distance of 1 mm. The indicated 3D accuracy of measured points is 6 mm which means that the real distance between the device and the object is 4 mm. The angular accuracy is 60 μrad (see Fig. 6). More accurate determination of accuracy is the matter of repetitive and comparative measurements and statistical evaluations. However, the range in millimetres is more than adequate for the wide-variety of utilization requesting the accuracy in centimetres (Kajzar, Kukutsch, & Heroldová, 2015).

Within the graphical comparisons mining work profiles were compared in 2D and 3D view (see Fig. 7 and Fig. 8).

The principal findings from a comparison of the two scanning campaigns are as follows:

- The area of interest is at a distance of 107 m in front of the coalface (stationing 460 m) which registered primary signs of floor swelling with an increasing trend in the height difference of about 30 cm within the scanned section.
- Observe measurable tilt of middle wooden props (up to 10 cm).
- There was a reduction in the height of the mine working by 11 cm (respectively 32 cm from the primary state).
- There was a reduction in the width of the mine working by 10 cm (respectively 31 cm from the primary state).

6. Strengths and weaknesses of the method, findings from scanning

Scanning at Lazy Mine belongs to our most demanding ever conducted. The difficulty of scanning can be unfolded on several levels, namely on technical parameters, specifics of the mining environment and of course safety, including explosion hazard.

6.1. *Technical parameters*

The laser scanner Leica belongs to one of the most robust scanners on the market, as far as the accessories are concerned. Transportation to the site had to be dealt with using a special back construction, since the distance to the workplace, crossing several belt conveyors, moving between tracks and moving over rugged floor, excluded the possibility of classical scanner transfer with a transport container.

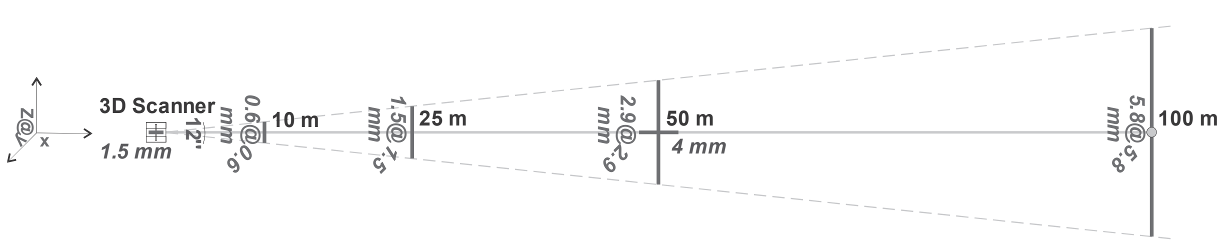

Fig. 6 – Schematic overview of the basic measurement errors for ScanStation C10 (Kuda et al., 2014).

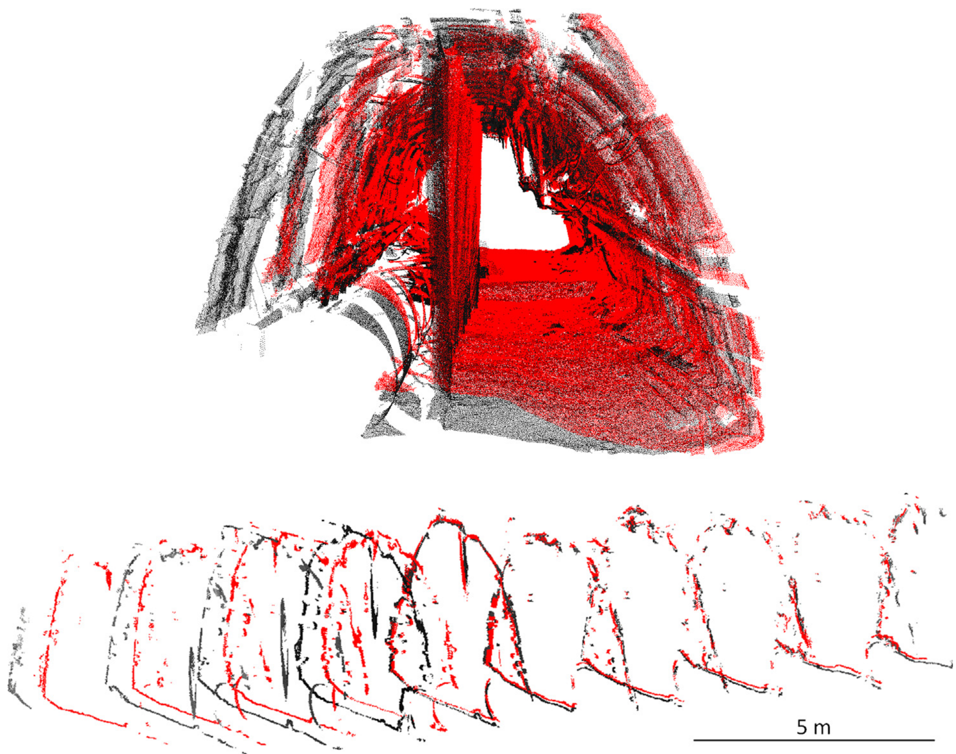

Fig. 7 – Point clouds of both campaigns overlap (red × grey) with significant spatial changes.

6.2. *Specifics of the mining environment*

The active mine environment is completely different from closed or conserved mine environments, i.e. conditions in which we tested the use laser scanning before (Kuda et al. 2014). Darkness, dust, high humidity and high temperature limit device deployment underground.

The most limiting factor in active coal mine is dustiness. The fine dust could damage delicate and precise laser optics. In addition, low visibility affects the speed of scanning. With decreasing visibility, performance of device also decreases. Conditions of reduced light in respect to the darkness and dustiness causes poor targeting. The targets are highly visible to a distance of 10–15 m.

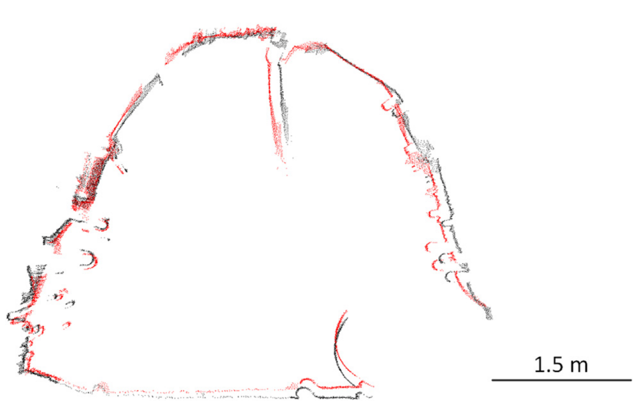

Fig. 8 – 2D view of profile comparison.

The fogging scanner optics due to high humidity and temperature is also a problem. Waiting time for temperature equalisation may be more than 30 min.

It should be pointed out, that the authors are fully aware that the used device is not primarily designed for direct using in mines and in similarly extreme conditions. Therefore its use was accompanied by series of preventive precautions (preventing the penetration of the dust into the device, condensation on the device, etc.).

Another problem is the technology in mining works. The larger is the object in front of the scanner, the greater is the area behind the objects that will not be scanned. The same applies to the distance of that object. The closer the object is to the scanner, the greater the area that will not be scanned. These problems are evident in the vicinity of coalface, when due to deformation and decreasing of the mining work profile everything is in close range to the scanner (see Fig. 9).

6.3. *Explosion hazard and safety*

Leica ScanStation C10 is not a typical representative device intended for mine environment. Assessment whether the devices can be used in a specific case is a question for the safety manager of the mine. Disposable use of the laser in mines in the Czech Republic is allowed of pursuant to an exemption from safety regulations, but in strict compliance with other safety conditions (CO, CO_2, CH_4 measurement, regular reporting to inspection service etc.).

Scanning was carried out in part under the unmined pillar of the seam No. 3, which in the conditions of the thick Sedlove

Fig. 9 – Focussing the centre of the target on the scanner display (left); low profile of mining works (right).

Member negatively impacted the gate condition of mining works. The present tailgate was impacted by significant deformations of steel arch support, broken middle wooden props and numerous ceiling bursts. This phenomenon can be described as acoustic effect of the rock mass.

The great advantage of this device is that the resulting point cloud may be processed by a variety of metrical tasks (height and width measurements, deformation measurements, the calculation of area, volume, etc.) without requirement to repeated visit of the risky mining works.

7. Summary

From the obtained results of 3D scanning used to assess the movement and deformation of the scanned roadway section, the following conclusions were deduced. It is possible to:

- accurately define and quantify the floor lift area in front of the approaching coalface,
- observe measurable tilt of middle wooden props,
- capture documentable changes in floor dinting during the period between campaigns,
- monitor the deformation of steel arch support, especially the right side and ceiling arches, confirming the influence of additional stress away from the goaf of previous longwall.

As mentioned in the paper, laser scanner has a wide range use in the mine. It is only to consider the purposes of its use. There is an uncertainty about its use in places with high dustiness near the source of pollution (longwall, drilling rig etc.) or in other places with a high safety risk (rocks fall from the ceiling, roof fall, rock bursts, outburst etc.). Although the weaknesses of this survey method were reflected, it is possible to eliminate or minimise them in the future. On the other hand, our conclusions, requirements and recommendations are based on the basic safety requirements which involve scanning in the absolutely necessary and shortest time.

Acknowledgement

This article was written in connection with project Institute of clean technologies for mining and utilization of raw materials for energy use, reg. no. CZ.1.05/2.1.00/03.0082 supported by Research and Development for Innovations Operational Programme financed by Structural Founds of Europe Union and from the means of state budget of the Czech Republic and in connection with project Institute of clean technologies for mining and utilization of raw materials for energy use – Sustainability program, identification code: LO1406 supported by the National Programme for Sustainability I (2013–2020) financed by the state budget of the Czech Republic.

REFERENCES

Buchroithner, M. F., & Gaisecker, T. (2009). Terrestrial laser scanning for the visualization of a complex dome in an extreme Alpine cave system. *Photogrammetrie-Fernerkundung-Geoinformation, 4*, 329–339.

Cosso, T., Ferrando, I., & Orlando, A. (2014). Surveying and mapping a cave using 3D laser scanner: the open challenge with free and open source software. *ISPRS – International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, xl-5*, 181–186.

Kajzar, V., Kukutsch, R., & Heroldová, N. (2015). Verifying the possibilities of using a 3D laser scanner in the mining underground. *In Acta Geodynamica et Geomaterialia, 12*(1(177)). ISSN 1214–9705.

Konicek, P., Ptacek, J., Stas, L., Kukutsch, R., Waclawik, P., & Mazaira, A. (2014). Impact of destress blasting on stress field development ahead of a hardcoal longwall face. In L. R. Alejano, Á. Perucho, C. Olalla, & R. Jiménez (Eds.), *EUROCK 2014-Rock engineering and rock mechanics: Structures in and on rock masses. Proceedings of EUROCK 2014, ISRM European regional symposium* (pp. 585–590). London: CRC Press, Taylor and Francis Group, Balkema.

Konicek, P., Ptacek, J., Waclawik, P., Soucek, K., & Kukutsch, R. (2013). Control of rockburst risk in hardcoal longwall mining – a case study. In *Proceedings of the International symposium of the International society for rock mechanics, EUROCK 2013, Wroclaw, Poland, 21–26 september 2013* (pp. 745–750). A. A. Balkema.

Kuda, F., Kajzar, V., Divíšek, J. A., & Kukutsch, R. (2014). *Application of the terrestrial laser scanning in geoscience research (in Czech)* (p. 53). Ostrava: Institute of Geonics AS CR. ISBN 978-80-86407-50-0.

Štroner, M., Pospíšil, J., Koska, B., Křemen, T., Urban, R., Smítka, V., et al. (2013). *3D scanning systems (in Czech)* (p. 396). Prague: Czech Technical University.