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New methods for modern technology for the evaluation of spatial parameters of underground structures

Nove metode za sodobne tehnologije ocenjevanja prostorskih parametrov podzemnih objektov

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Abstract

The process of acquiring geometric data within geosciences is usually limited by predetermined observation points, anthropogenous or naturally exposed visible objects. With the classical geodetic methods for measuring the underground construction's location of observed points are being determined systematically or on spots where manifestations of natural or anthropogenic influences are expected according to professional interpretations. Activities in rocks cannot be entirely predicted. At the same time the problem is often in insufficient accuracy and inadequate plans after implemented activities or excavations, which are often a reference or in null condition for further management with the construction.

The solution for comprehensive three-dimensional measurement with high metric accuracy is 3D terrestrial laser scanning technology. The direct result of such data capture is condensed to be a crowd of spatially located points – a point cloud, which describes the accurate shape of the complex engineering object building with some primary data processing. The raster of scanning is definable and adjusted to the demands and can reach also millimetre spans. Monitoring and the analysis of deformations detected on visible watched surfaces is one of the applications of the mentioned technologies. Besides the deformation analyses, a method for 3D registering of the fractures was developed and consequently predicted of optimal excavation progress. The application is introduced with one epoch in the case of underground excavation of Doline with the capture of Fracture Targets (FT) and the simulation of the progress of excavation.

Key words: 3D model, deformation monitoring, terrestrial 3D laser scanning, quarry, fractures

Izvleček

Pri pridobivanju geometrijskih podatkov v geoznanosti smo navadno omejeni na preddoločene opazovane točke ali antropogene ali naravno izpostavljene vidne objekte. Čeprav se lokacija opazovanih točk v podzemnih prostorih s klasičnimi geodetskimi metodami določa sistematično oz. na mestih, kjer se po strokovnih interpretacijah pričakujejo manifestacije naravnih ali antropogenih vplivov, v kamnini točnih dogajanj nikoli ne moremo zagotovo napovedati. Prav tako se pogosto pojavlja problem nezadostne natančnosti in pomanjkljivih načrtov po izvedenih delih oz. izkopih, ki so pogosto osnova za nadaljnje upravljanje objekta.

Rešitev za celovito tridimenzionalno izmero z visoko mersko natančnostjo je tehnologija s 3D terestričnim laserskim skeniranjem. Neposredni rezultat tovrstnega zajema podatkov je zgoščena množica prostorsko lociranih točk – oblak točk, ki z nekaj primarne obdelave opisuje natančno obliko kompleksnega inženirskega objekta. Raster skeniranja je določljiv in prilagojen zahtevam ter lahko dosega tudi do milimetrske razpone.

Ena od metod, ki se nanašajo na omenjeno tehnologijo, je nadzor in analiza deformacij, zaznanih na vidnih opazovanih površinah. Poleg deformacijskih analiz smo razvili metodo za 3D kartiranje razpok in posledično napovedovanja optimalnih napredovanj. Metoda je predstavljena s terminsko izmero podzemnega kopa Doline z zajemom t. i. tarč za razpoke (FT – ang. fracture targets) in simulacijo napredovanja.

Ključne besede: 3D model, nadzor deformacij, terestrično 3D lasersko skeniranje, kamnolom, razpoke

Introduction

The main goal of the project is to set and test methods for inventorying and documentation of underground structures. Methods are also related to monitoring and prediction of deformations. The identification of deformation and impact of fractures on yield in progressions are evaluated qualitatively and quantitatively.
All operations and methods are based on technology TLS (terrestrial 3D laser scanning) in combination with the existing methods. The described methods are tested on cases of volumetric, deformation, fracture mapping and estimation of impact on yield and costs, planning progressions and operational dynamics in the quarry. The focus was on methods for monitoring of deformation on the safety pillars and fracture mapping. Fracture mapping methods were primarily focused on planning of yield.
The methods are verified on the case of the Doline quarry (Marmor Sežana, PLC.) as a user, with MAGELAN skupina Ltd. as a provider of technology and FNSEA as the "know-how".

Methods

Terrestrial 3D laser scanning

TLS is considered to be an effective measuring method of comprehensive spatial data, describing the geometry of the visible objects' surfaces. In a very short time, instrument systematically produces millions of measurements, with a dense crowd of geo-located points as a direct result.[1] Already after a single capture and primary processing (registration in filtration) these "point cloud" data accurately define a high detailed shape of the measured object. With the secondary treatments, the gathered data is useful in many engineering applications.

Instrument characteristics

In order to achieve maximum accuracy with the discussed technology, we chose a pulse based terrestrial 3D laser scanner Leica Scan-station C10 and performed starting with a "null" epoch measurement of Doline quarry (Marmor Sežana PLC).
The pulse based instrument consists of a transmitter/receiver of infrared laser pulses and scanning optics. The distance of measurement is based on the time-of-flight of the laser pulse to travel and reflect from the surface of interest. The location of each point is acquired in a polar coordinate system. The horizontal and vertical angles are modified by the scanning device using an internal system of rotating mirrors.
Compared to conventional surveying methods, a TLS shows a very high data acquisition speed (up to 50 000 points/s). Technical characteristics of the Scan-station C10 supplied by the

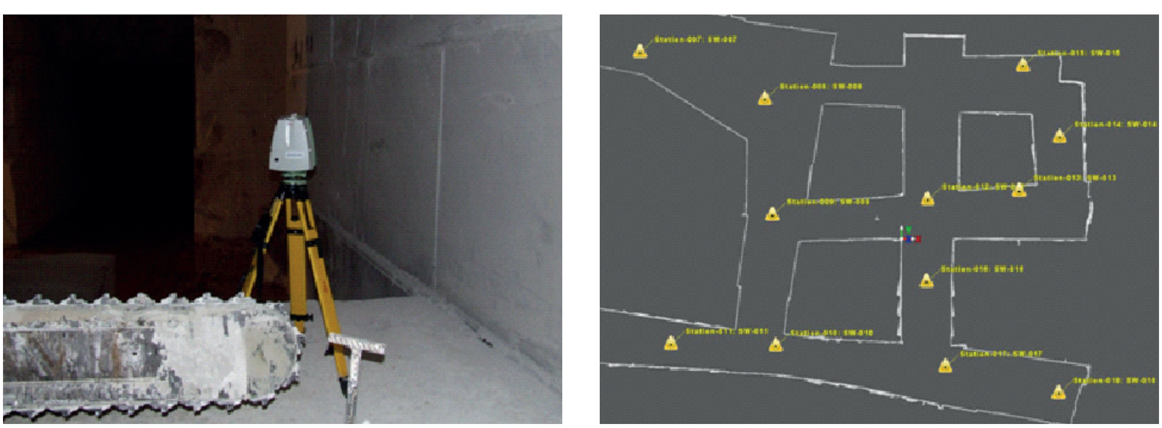
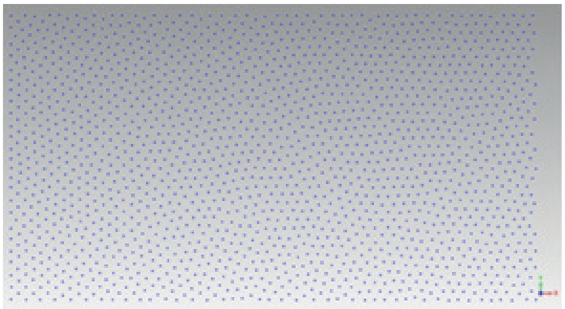


Figure 1: *Photo from the field work - 3D terrestrial laser scanner (left), a scheme of scan positions inside the quarry (right).*

[1]Registration: For a complete measurement of the object, more scan positions are usually required. Each scan position has its own coordinate system. Registration means the transformation of all scan positions into a uniform coordinate system.

[2]Filtration: The scanning often covers the surface, some of which is not the subject of interest (mechanization, vegetation, people, etc.). This disturbing object called "noise" should be within the primary treatment to remove. This process is called filtration.



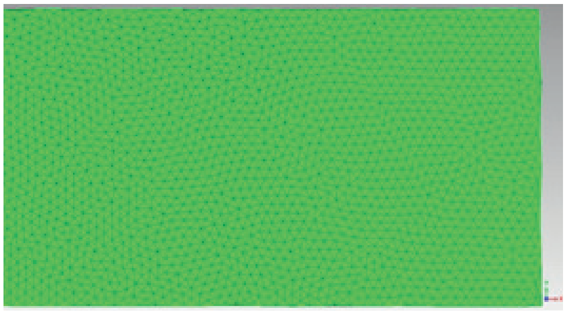


Figure 2: *Schematic illustration of triangulation; point based model (left), surface triangulated model (right).*

manufacturer show high maximum range (up to 250 m for 90 % surface reflectivity) and high point accuracy.

More than 289 million points was measured, which were converted into desired and useful data by computer processing. The basis for all the methods described below is the georeferenced point or surface 3D computer model, generated with the procedure of triangulation (Figure 2).[2]

The methods are related to improvements and additions to the technical documentation, which is currently regulated by the legislation:

Site plans

Site plans are an integral part of the mining technical documentation (floor plans and vertical profiles). After the completion of one-day scanning, our method provided detailed plots of profiles in any direction and in any location. Plansare written in the classical CAD format and are intended for use by all operatively involved professionals, therefore users can individually select plot location of the specified profile.

Fracture mapping

We verified the method for 2D and 3D vectoring of visible fractures in the quarry. The advantage of our method is the fact that in one epoch (1D scanning) all visible fractures on the wall, floor and ceiling can be measured. In the secondary processing of data, measured fractures can be mapped in both 2D and 3D technique. The method provides a comprehensive inventory of visible fractures and represents an effective tool for exploitation planning. As well as site plans, the fracture lines are adjusted in classic CAD form.

In our survey team, we are in the early development of the methods with FT targets (C & C "Fracture Targets") for the measurement of the dip and dip direction of fractures. FT targets are solid slats which are wedged in the unfilled fractures (Figure 3). 3D scanning captures geometric data of wall surfaces as well as the FT surface. Points that hit the FT define the plane from which we get hold of the data of the dip and dip direction of the discontinuity.[3]

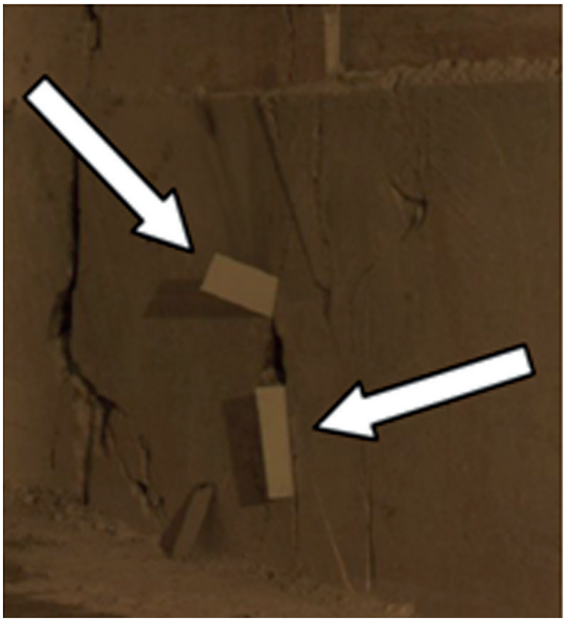


Figure 3: *Photorealistic coloured point cloud, which defines a wall and two FT.*

At the head of progression, where excavations with the method of breaking the block are carried out, there are visible discontinuities. With the TLS semi-automatic and remote sensing, documentation of the geometric properties of visible fractures is possible.

Deformation monitoring

Currently the method of deformation monitoring with TLS is the only method, which provides accurate and comprehensive control of all quarry surfaces. Given the fact, that it is a method of remote sensing, we can identify deformations even on areas with difficult or no access in critical locations such as high walls, ceilings, and dangerous areas. The result of the method is illustrated by numerical and graphical deformation analysis and, in that way contributes to the timely and optimal precaution.[4]

Leveling

The levelling method was used to graphically illustrate the relative and absolute floor level. The raster of measured points reaches up to centimetre ranges. Large utility of such methods is reflected in identifying the locations of water accumulation and controlling of the horizontal progressions.

Codification and dimension analysis

The shape ofthe quarry is measured up to the very smallest detail and presented three-dimensionally. In this way, optimal dimensioning and placement of machines in the quarry can be analysed and pre-planned. A computer model represents a "freeze state" on the day of theepoch measurement. With simple and tailor-made views, the user has direct access to geometric information of the quarry through his personal computer.

Results

3D models, 2D plans

Already with the primary processing of measured data, a point based 3D model of the quarry can be generated. Such models serve as a metric lining for generating site plans and the production of the interactive 3D viewer.

Such plans can be plotted at any location and in any direction (horizontal, vertical, diagonal). The plans are designed for conventional CAD operational planning.

Just like any random selection of the location of transverse and longitudinal profiles, free choice of horizontal/floor plans is possible.

An elevation image is added to the floor plan, which is also one of the products of the TLS method. The elevation image illustrates the levelling data; however the raster of measured points is achieved in centimetre grid ranges. With this data we could identify the locations of water accumulation. The elevation image is also equipped with a colour scale, representing the corresponding absolute or relative elevation.

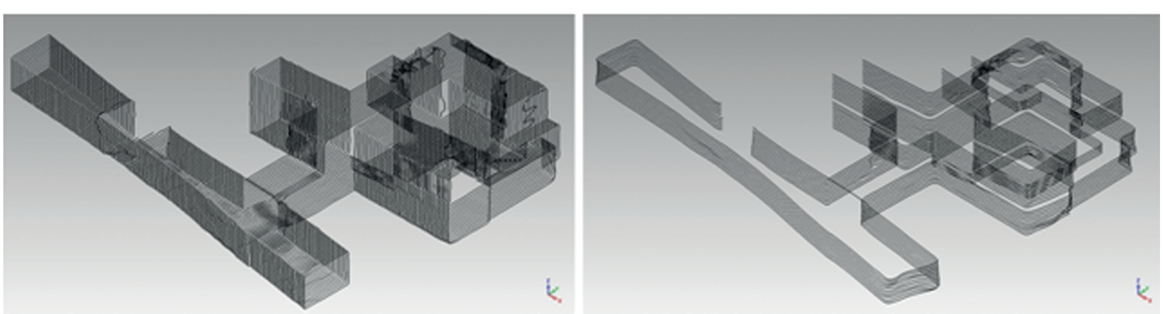


Figure 4: *Vertical and horizontal cross sections, generated from point cloud or 3D model.*

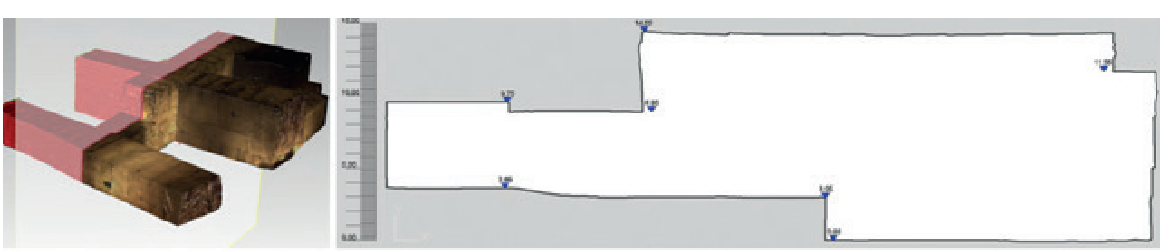


Figure 5: *Location on a selected section of the 3D model (left), CAD plotting profile (right).*

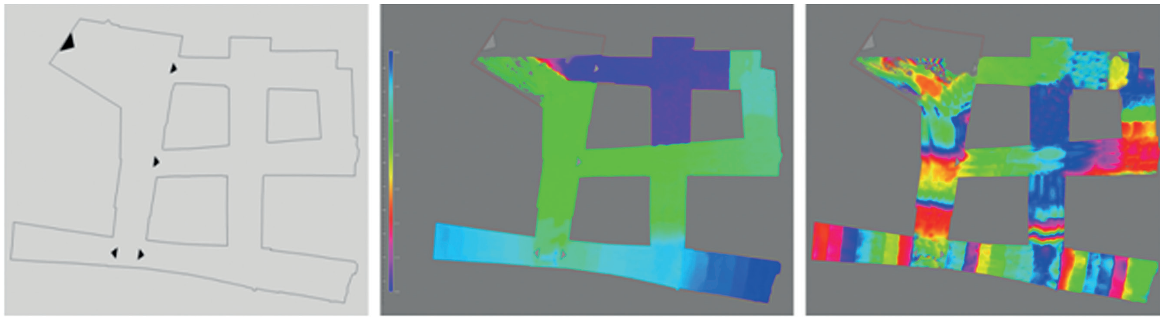


Figure 6: *Site plan of Doline quarry, elevation-coloured view.*

With the process of triangulation, a point model was converted to a surface model format. From the surface model, we obtained the volume data of the quarry, while it also served as a reference surface for the analysis of deformation in future epoch measurements. Figure 7 (left) shows a detailed 3D model of the Doline quarry. Figure 7 (right) shows one of the first and simpler uses – the calculation of the volume of the quarry.

All plansand 3D models are constructed in real dimensions. This meanst hat the geometric condition of the quarry is transferred to a digital format. This way is suitable forreviewing and performing measurements through the personal computer, rather than as field work.[5]

Deformation monitoring

To demonstrate the monitoring of deformation, a "null" epoch measurement and the simulation of the following epoch on the characteristic areas were used. An analysis of the deformation was executed on the case of the wedge slip on the ceiling (Figure 9) and scaled slip on one of

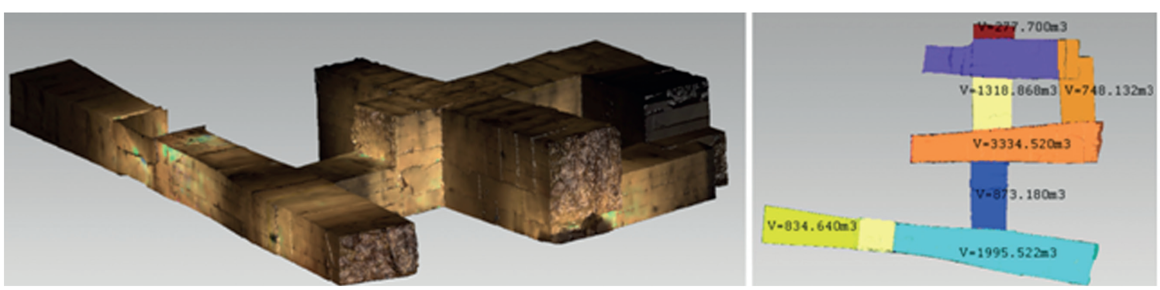


Figure 7: *A 3D computer model of the Doline quarry (left), quarry segmentation of spaces with volume calculations (right).*

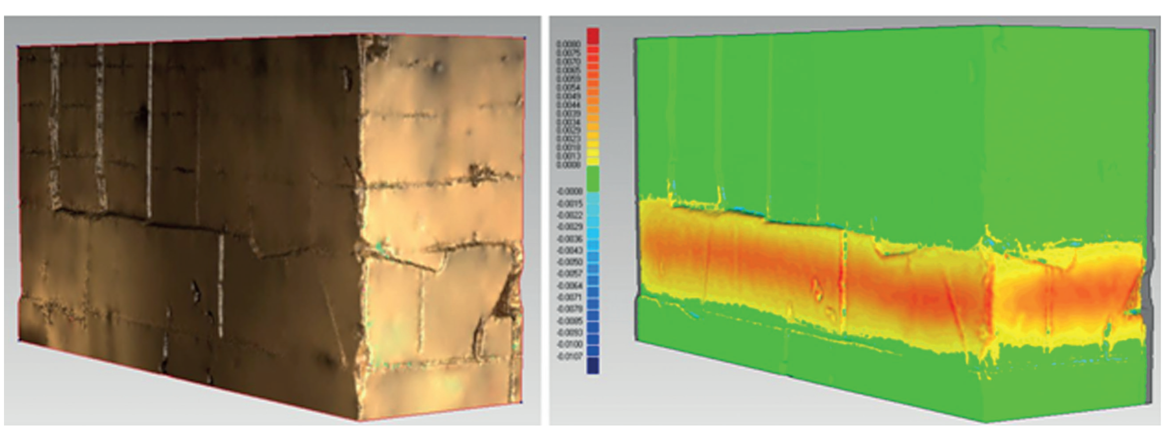


Figure 8: *A 3D model of two sides of the safety support pillar (left), 3D illustration of the analysis of deformations on the pillar walls in the horizontal direction (right).*

the walls, where these kinds of problems have already occurred (Figure 8). An analysis and visualization of deformations on the security pillar was also made with case of simulation of the swelling of rocks (Figure 8).
Since the data acquisition with TLS is performed with an extremely high raster of scanning, it is possible to detect surface deformation in millimetre ranges. Currently, TLS technology represents the only tool for this kind of monitoring and effective complement method for the conventional 2D monitoring of stress states, allowing the analysis of deformations, which are detectedon all visible surfaces through out the monitored object.

The deformation analysis was also performed on a wider area, namely on the longer wall outside the quarry (Figure 11). The discrepancies between the two epochs are demonstrated with colour and numerical analysis.

Fracture mapping

Along with the scanning instrument, the surface of the observed object is also simultaneously photographed with the integrated camera. This method enables the production of orthogonal photosthat represent a metric projection plane for fracture mapping within 2D vector format (Figure 12).

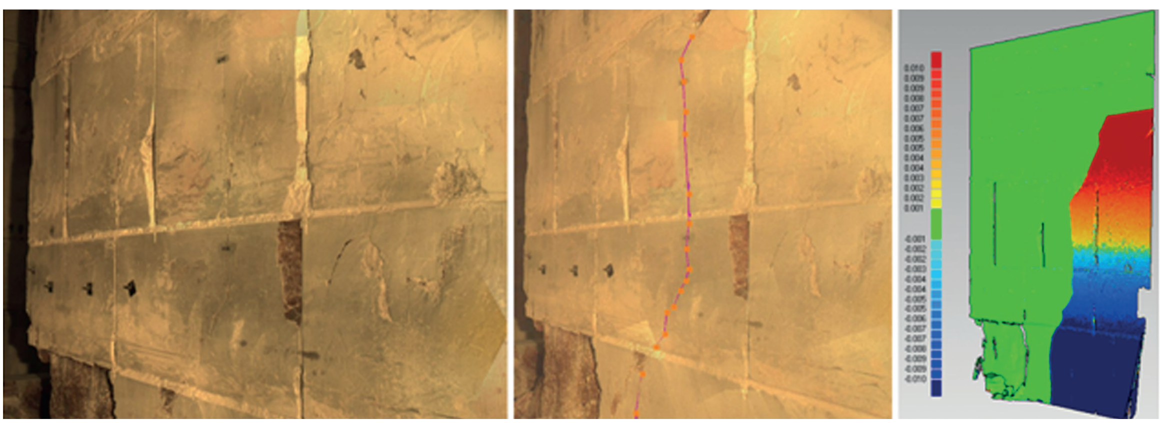


Figure 9: *The support system with safety anchors on the critical region (left), mark of already visible and observed fracture (centre) and illustration of the perception of slipping.*

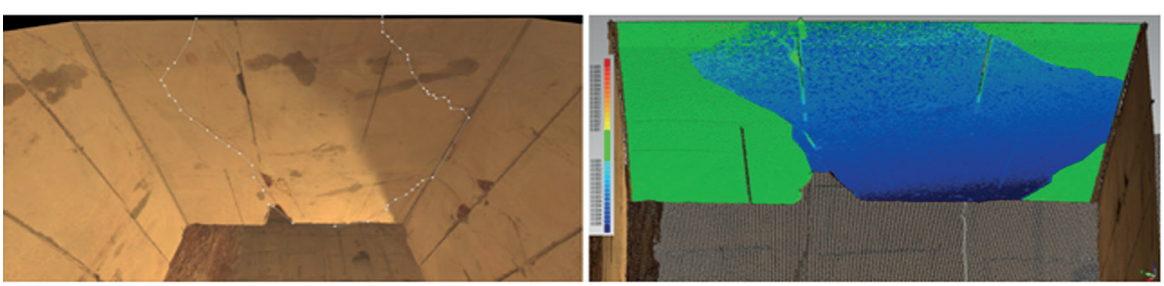


Figure 10: *Outlines of fractures (left) and visualization the perception of the slipping on the ceiling (right).*

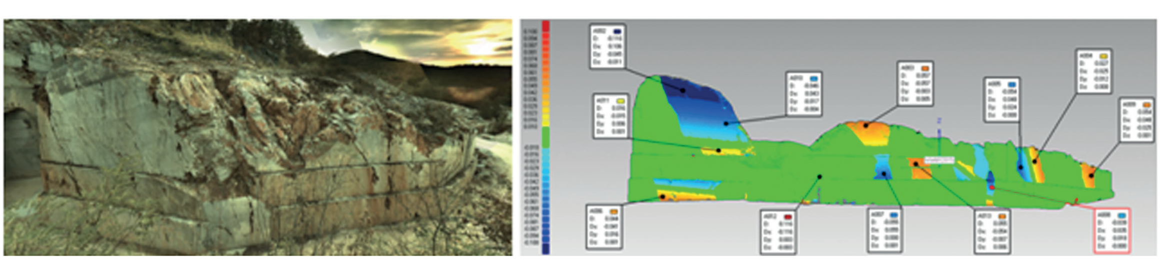


Figure 11: *Photo of the quarry Doline exterior wall of the (left) the deformation analysis of the wall (right).*

The 3D mapping of fractures on the photo-realistic coloured model, which as such represents a projection surface, was also produced. Figure 13 (left) illustrates direct spatial mapping of visible fractures.

Both cases of mapping enable export of the lines in standard CAD formats, allowing the use of date to all of the professionalsin the quarry.

In the field of fracture mapping, we are developing methods for further detecting the strike and dip direction of fractures in which solid slates could be jammed. One of the first results of such methods is demonstrated in Figure 14 (right), where a blue plane is illustrated (the wall), and two smaller planes are generated from points that lie on the situated slates.

Figure 12: *2D mapping of fractures based on orthogonal photos.*

Figure 13: *Fractures as vectors, photograph of situated FT.*

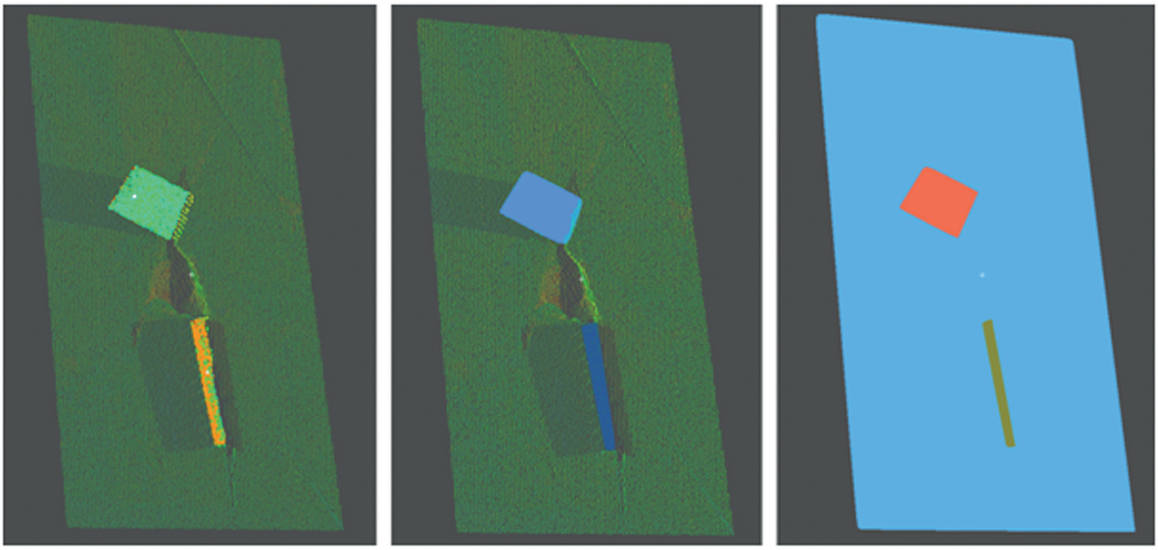


Figure 14: *Scans of walls and two of situated FT (left), modeled planes, which define the dip and dip direction of the fracture (middle), modeled wall and FT planes (right).*

Discussion

As mentioned above, the direct result of the TLS measurements is a photo-realistically coloured point cloud, which defines the spatial model of an object. This model represents an easy and interactive source of geometric information that can be accessed by all the experts (geologists, miners, geo-mechanics, etc.) via personal computer. This type of real-time access to information enables time saving and does not impede the work of the employees and the machines in the quarry.

The great advantage of TLS is also reflected in the non-contact measurements, which enables that the measurements do not influence the status of the observed object. With the non-destructive measuring methods, surfaces which are difficult to reach or dangerous can be measured. Relative distances, which would otherwise be very difficult or even impossible to measure, can be measured as well.

In one day of scanning of the Doline quarry, extensive geological inventory works and geodetic measurements were carried out. In both processes (geological and geodetic), our methods reduced the impact of human error (systematic and random error operator is void). After fieldwork measuring there is no insufficient and inaccurate data. This means that there is no wasting of time or returning to the terrain. The latter could in some cases also be too late, since work processes in the quarry cannot be stopped and wait for a repeated measurements, because of economic reasons.

As the TLS measurements work, processes in the quarry must be stopped or limited, because micro vibrations and dust element adversely affect the outcome of the measurements. Regarding the quality of the end product, measurements are made in very short time. Comparable results cannot be achieved with conventional methods.

Conclusion

The research project evaluated and the tested methods base on TLS. On the basis of the null and the simulation of second epoch measurement, advanced methods were demonstrated. Its demonstrated results can be useful in other engineering objects (e.g. tunnels, excavations, construction pits, hydroelectric stations, landfills, landslides, retaining walls, plants and industrial infrastructures etc.[6]

For example, in tunnelling and building of other underground constructions, the utility of the methods reflects in the possibility of deformation monitoring, measurement of deviations between built and planned, while thickness and regularity of primary and secondary of concrete support system layer could also be measured.[7] In case of these applications, the research continues.

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