Aplication of Selected Geodetic Methods in Opencast Quary with Aim of Their 3d Model

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Summary

Now, there are several geodetic methods suitable for 3D objects documentation, such surface mine works for example are. These methods differ mainly in its principles, but also as to used apparatuses. Among the mostly used methods are tachymetry, GNSS and terrestrial laser scanning. GNSS method is nowadays the mostly used method of space data collecting, because of its sufficient accuracy and low costs. On the other side, the laser scanning is modern, but also expensive, and consequently rarely used method, suitable for precise documentation of the object. The choice of the suitable method often depends on requirements on data processing and output preparation for example if it is necessary to use the obvious, or specialized expensive software (cloud data processing at TLS). The utility of these methods in mine work conditions was assessed in Sedlice quarry. Results of the process of mine surface 3D modeling on the basis of data gained by geodetic measurements depend mainly on the type and density of input data, but also on the interpolating /modeling/ method itself. The paper aims to present modern geodetic methods of data collecting, and analyze the quality of created 3D models.

Keywords: tachymetry, GNSS, laser scanning, quarry, 3D model

Introduction

Considering the multifunctional exploitations of modern geodetic apparatuses (GPS, laser scanner, etc.) for different applications we are often confronted with the problem of incorrect localization or incorrect 3D coordinates of spatial data determination. This fact is closely bound to problems of geoobjects 3D models creation on the basis of measured space data. This is basically caused by the ignorance of principles and utilizability of the measuring technology, resp. by ignorance of modeling method principles used for geoobjects 3D modeling. It is necessary to consider whether it is suitable that activities like eg. surveying - localization of events by Global navigating satellite systems (GNSS) or modeling of spatial objects and events might be done by unauthorized and professionally incompetent persons missing necessary professional knowledge.

Geodetic Measurement Of The Extraction Wall In Sedlice Quarry.

The spatial data on real world objects can be without unnecessary financial costs gained from different secondary sources (map, database, etc.), but primary data should be collected by specific geodetic methods. The step that should be carefully considered is the choice of appropriate technology that will be used for three-dimensional data collection [1]. Except of the aspect of costs, one should consider the efficiency of the used method (apparatus), and notably its accuracy. The collection of spatial data in terrain is a technologically and professionally demanding process. The errors made in this period of the project solving are transferred into further following periods, and so negatively influence all other results and conclusions. Because of this, the period of data collection planning is extraordinary important, as well as following choice of the data collection method. The choice of the data collection method depends mainly on:

- Specific task to be solved,
- Size of locality (object) to be mapped,
- Accessibility of the locality (object),
- Required accuracy of gained data,
- Time available for data gathering,
- Type of output we receive (picture, cloud of points, etc.),
- Cost requirements of data collection and pro cessing.

The paper aims to prove technical possibilities of modern geodetic apparatuses. To prove possibilities of selected geodetic methods – tachymetry, GNSS and laser scanning at space data collection, and later compare and evaluate the quality and accuracy of 3D models of measured objects (in our case – quarry wall) created from these measurements.

Description of the area of interest

To present possibilities and utilizability of selected geodetic methods, as the model example, the quarry wall in Sedlice quarry (Figure 1, 2, 3) was chosen. The dolomite deposit Sedlice lies in extravilan of cadastre area of the Sedlice village (Fig. 1) approximately 1 km far from Sucha village. The quarry is accessible by panel road connected with the III. class state road below the Sucha Dolina village Lubovec direction. The mine activity covers the area of 314 912m2. Quarry extraction has started by 1982. Basic dimensions of extraction area are 700m x 500m. The base of the deposit is determined in the altitude 400m a.s., and its highest point lies in the level 501,5m a.s. The extraction area of Sedlice quarry is managed by VSK Mineral ltd. in Kosice.

The surface of the chosen quarry wall (Fig. 3) represents a relatively irregular body with dimensions 80m (length) x 40m (width) x 20m (height).

Method of data collection and their processing

The measurement of the object / quarry wall was realized in forenoon hours at ideal meteorological conditions. He quarry wall was aligned using above mentioned three methods by following apparatuses:

- GNSS apparatus Leica GPS 900 CS (Fig. 4) [2],
- Universal measuring station LeicaFlexLine TS 02 (Fig.5) [3],
- 3D laser scanner Leica ScanStation c 10 (Fig. 6) [4].

With the aim to measure the quarry wall, the net of detailed points was built up, that serve as stations for apparatuses, ev. orientation. Points were stabilized in a transitory way and measured by GNSS method. Their coordinates X and Y were determined in the coordinate system of the Uniform trigonometric cadastral net – S-JTSK, and the Z coordinate in the altitude system Balt after adjustment – Bpv [14]. Quarry wall

Fig. 1 Geographic position of the area of interest

Rys.1 Położenie geograficzne obszaru

Fig. 2. Sedlice quarry

Rys. 2 Kamieniołom Sedlice

was gradually measured by each of selected geodetic methods and gained data were subsequently processed using software equipment Leica GEO Office [5], ev. in the Real Works [6] program. Totally on the quarry wall we measure by the method of:

- GNSS 389 points,
- Electronic tachymetry using UMS 467 points,
- Terrestrial laser scanning app. 2 000 000 points.

Measurement of the object by GNSS apparatus Leica GPS 900 CS

GNSS measurement of the quarry wall was realized by the receiver Leica GPS 900 CS using RTK method. Points of the wall (edge and foot of the wall) were aligned in regular interval app. 3 – 5 m and the levels of slices were measured in the net app. 5x5m. Density of points was higher at places with more pronounced morphological changes, enable so the best possible characteristic of the object. The wall itself - its vertical part, was not measured, because GNSS method doesn't allow such measurements. Totally, 389 detailed were measured.

Measurement of the object by electronic tachymeter Leica FlexLine TS 02

Measurement of the quarry wall by tachymetry was realized using universal measuring station Leica FlexLine TS 02 by prism less measurement of detailed points on the wall itself, on the level of slices,

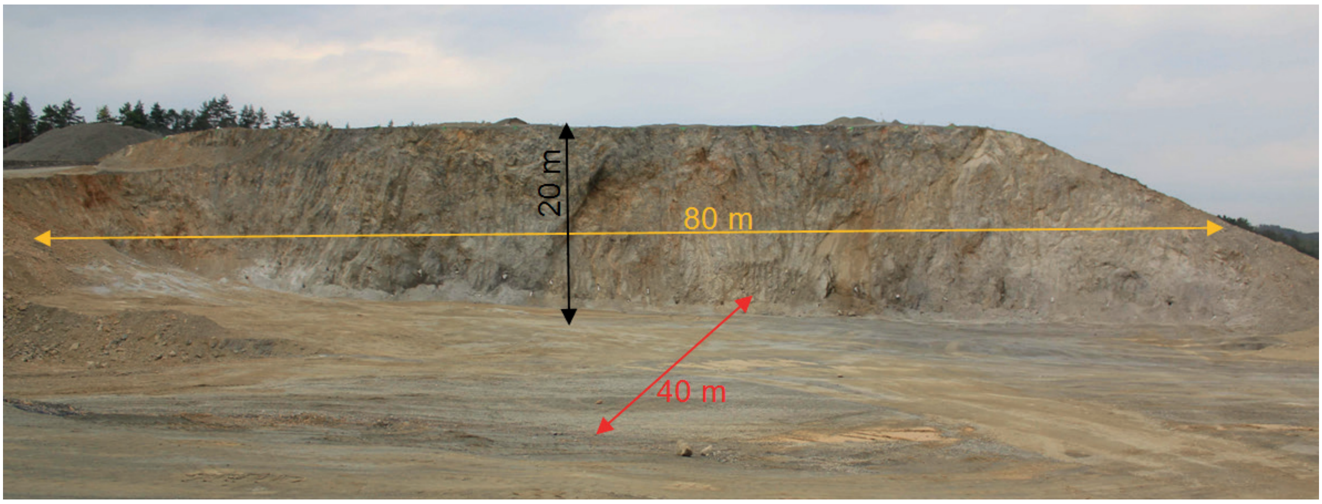

Fig. 3 Quarry wall in Sedlice quarry

Rys. 3 Ściana kamieniołomu Sedlice

Fig. 4 GNSS apparatus Leica GPS 900 CS

Rys. 4 Urządzenie GNSS Leica GPS 900 CS

Fig. 5 Universal measuring station Leica FlexLine TS 02

Rys.5 Uniwersalna stacja pomiarowa Leica FlexLine TS 02

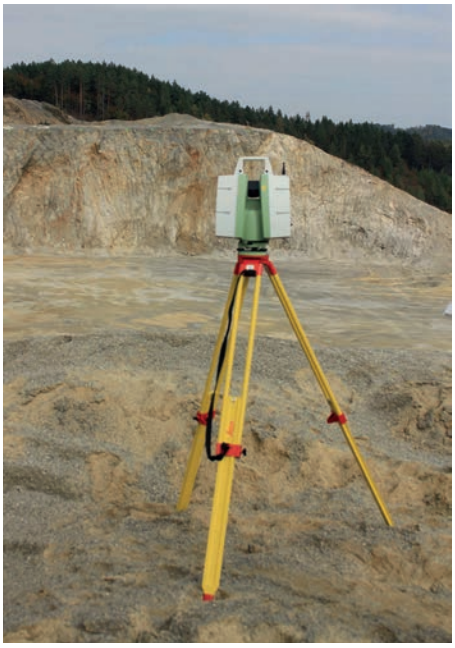

Fig. 6 3D laser scanner Leica ScanStation C 10

Rys. 6 Skaner laserowy 3D Leica ScanStation C10

as well points on the edge and foot of the wall. Object points (edge and foot of the wall, the wall itself and slices) were measured from one stand point in the regular net app. 3x3m and the levels of slices were measured in the net app. 5x5m. Higher point density was applied at places with more pronounced morphological changes aiming to receive the best reflection of shape characteristics of the object. Totally, 467 detailed points were measured.

Measurement of the object by terrestrial laser scanner Leica ScanStation C10

Measurement of the object using TLS Leica ScanStation C10 was realized from one stand point. Scanner war set up for scanning with point density app. 5x5cm at distance 80m. Point cloud containing app. 2 000 000 points was the result of the measurement. This set was further edited using Leica Cyclone software. Later, points of the set were reduced for the density 10x10cm. In global data set after correction, cutting and elimination of useless points consists of app. 165 000 points.

Construction Of The Extraction Wall Space Model

Interpolating methods used for modeling of the terrain surface.

Also, in the process of modeling it is trendy to make use in complex different computerized programs, mainly their modeling procedures and tools. The terms model and modeling are in the field of geodesy and cartography encountered in connection with 3D models constructions of terrain, as well as of different objects created by men [7]. The data software processing has contributed to improvements and better elaboration of mathematic principles of modeling methods. Their implementation into different processing software is on the appropriate user level, and nowadays it is possible in one software very efficiently process gained data and create the needed model in a relatively short time [8]. Special software (Surfer, ArcGIS and others) today commonly offered include the possibility to choose from different interpolating methods with the possibility of setting up different parameters of interpolating process [9] [12]. In spite of this, many professional modeling systems, mainly CAD software (MicroStation, Auto CAD and others) still make use of "classical" interpolating method - triangulation with linear interpolation. Triangulation has several methods- "mutations", elaborated with elimination of their weak aspects [13]. The best known method id for example: Delaunay's triangulation.

Delaunay's triangulation

By the end of 19 century, Peter Gustav Lejeune-Dirichlet presented, that the given set of points in 2D space can be divided into convex cells by the criterion of their approximation to identified points. Then, Georgy Fedoseevich Voronoi derived the concept of the elementary polyhedron. Consequences of this new approach enable to enlarge Dirichlet's results into 3D platform. The concept of Voronoi's diagram was therefore presented as a set of points corresponding with the criterion of approximation towards identified points in the given space.

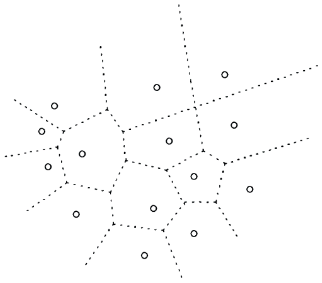

Fig. 7 Voronoi' diagram [10]

Rys.7 Schemat Voronoi' [10]

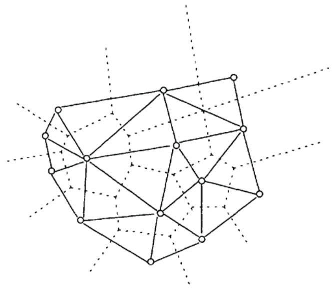

Fig. 8 Delaunay's triangulation [10]

Rys.8 Triangulacja Delaunaya [10]

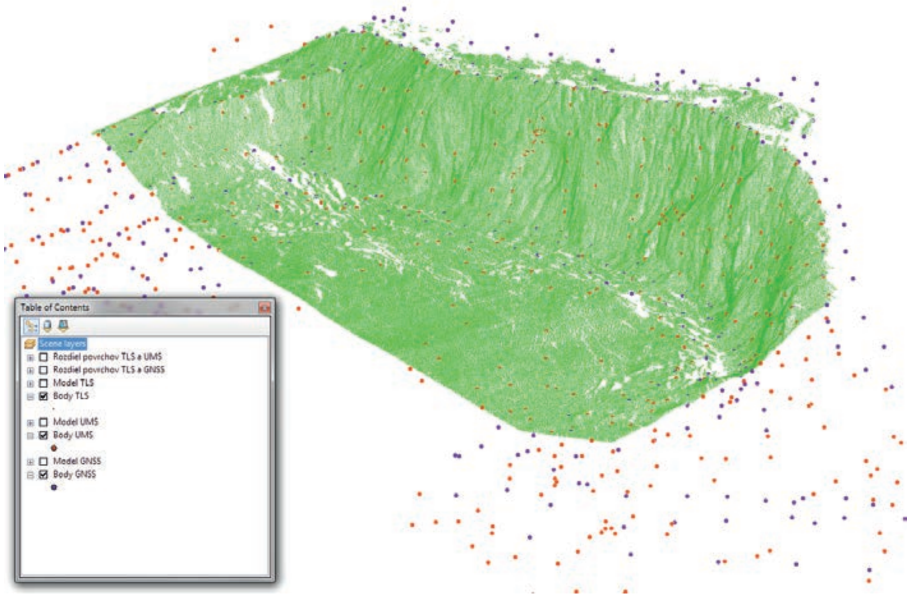

Fig. 9 Point measured on the quarry wall by TLS method (lightest gray), UMS (darker gray) and GNSS (darkest gray)

Rys. 9 Punkt pomiaru na ścianie kamieniołomu metodą TLS (najjaśniejszy szary), UMS (ciemniejszy szary) i GNSS (najciemniejszy szary)

In thirties of 20. century, Boris Nikolaevich Delone (Delaunay) has proved, that on the basis of Voronoi's diagram it is possible to derive on the principle of duality the specific type of triangulation, with the characteristic trait of criterion of empty circle (globe). In the seventies, Lawson comes with the idea of shifting the common diagonal of two adjacent elements with resulting higher efficiency of Delaunay triangulation. The fact that Delaunay triangulation may be derived from any triangulation using this local modification, that makes maximal the minimal angle between two edges of the element, is the further contribution. But the algorithm of Delaunay's triangulation was implemented only in eighties, granted to the development in the field on information technologies [10].

The method of data processing and 3D model creation

To create 3D models of the quarry wall and their visualization, the platform of GIS software ArcGIS by company ESRI [9] was used. Measured data were into the ArcGIS imported as point themes and subsequently symbolized as 3D points (Fig. 9). Using modeling tools of 3D Analyst extension and on the basis of given points by triangulation all three surfaces were generated in the format TIN. Creating TIN models, all obligatory connecting lines of points /break lines/, which in the terrain represented the edge and the foot of the slope, were considered in the process of modeling.

3D model of data gained by terrestrial laser scanner Leica ScanStation C 10

TIN model from data gained by laser scanning was created from 165 000 points, and so represents the most precise model of the surface of the quarry wall (Fig. 10).This model was used in following comparisons as a base – referential model for the assessment of accuracy of further two models.

3D model of data gained by electronic tachymeter Leica FlexLine TS 02

TIN model from data gained by electronic tachymeter was developed by triangulation of 467 points. Contrary to TIN model from TLS data this model is created by triangular net with visibly larger triangles in which corners points were measured - picture 11. Points used for model construction represent points on the edge and the foot of the wall, points on the wall itself and points on the levels of slices. Considering that almost 500 points were aligned and that points were measured at all parts of the wall, one may suppose that this model should be relatively precise. Of course, the accuracy of the model is not influenced only by the sum of points, but also by their correct localization on the wall, edge and foot. If the surveyor will not select representative - characteristic points on the object, what may happen at prism less measurement (surveyor due to relatively big distance from the documented object mustn't correctly identify all points characteristic for the complex morphology of the object), the ensuing model will not be representative.

3D model of data gained by GNSS apparatus Leica GPS 900 CS

TIN model developed from data gained by GNSS (Fig. 12) is, similary as the model from data by UMS,

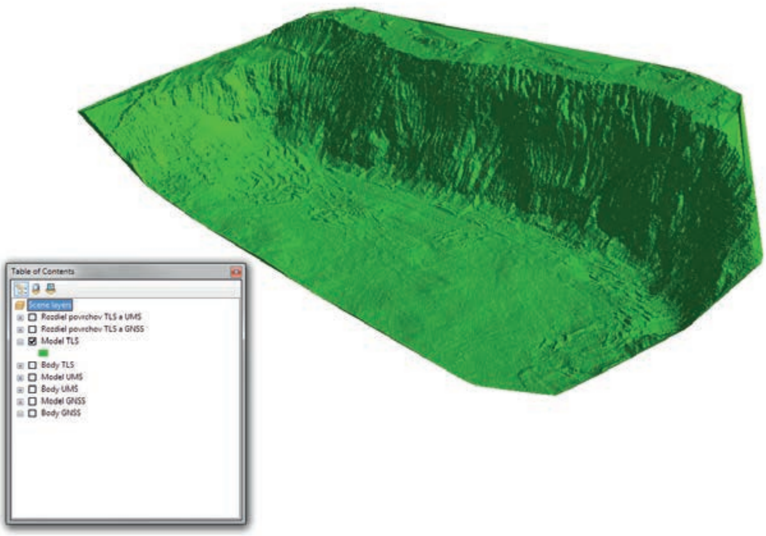

Fig. 10 3D model from data by TLS

Rys. 10 Model 3D na podstawie danych z TLS

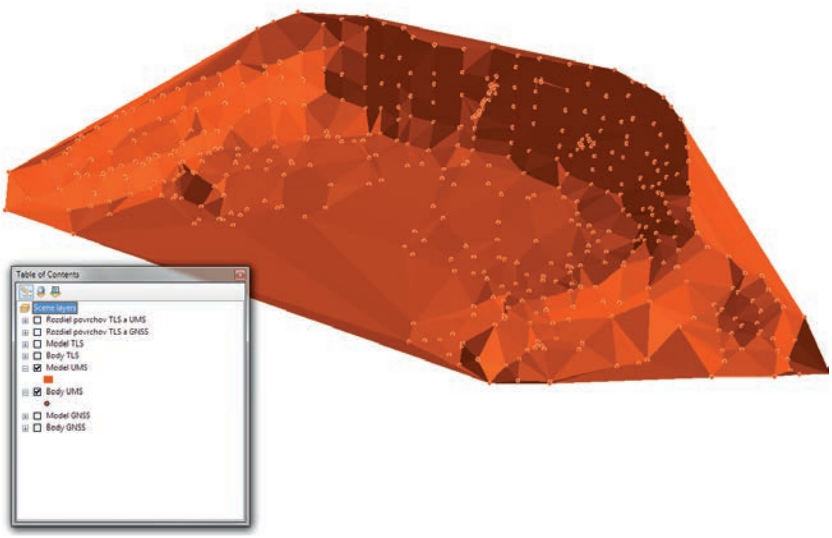

Fig. 11 3D model from data by UMS

Rys. 11 Model 3D na podstawie danych z UMS.

created by irregular triangular net. Because points are not measured on the wall itself its shape is too generalized. The model has been basically developed through connecting of points at the foot and edge of the wall with vertically elongated shape. So there is the assumption that this model will not be representative enough, because in its creation the points of the wall vertical part cannot be used. The advantage of data collection by GNSS is that the surveyor physically traverses the whole terrain and selects places where he will situate the detailed point according to the terrain-object morphology, and so we may assume, that the ensuing model will relatively appropriately documented terrain [11]. This of course is valid only if the whole terrain is accessible and doesn't contain parts undocumentable by, as high and steep slopes GNSS method, etc.

Evaluation Of Results

Evaluation of suitability, accuracy and efficiency of used geodetic apparatuses and methods.

- GNSS

Data collection using GNSS apparatus Leica GPS 900 CS at measurements in RTK represents a relatively quick and cheap way of 3D data collection. Gained spatial data are comparing with data from other two apparatuses are burdened by the highest inaccuracy. The declared accuracy of RTK method by use the SKPOS service is: in the horizontal direction 2 cm and in the vertical direction 4 cm [2].

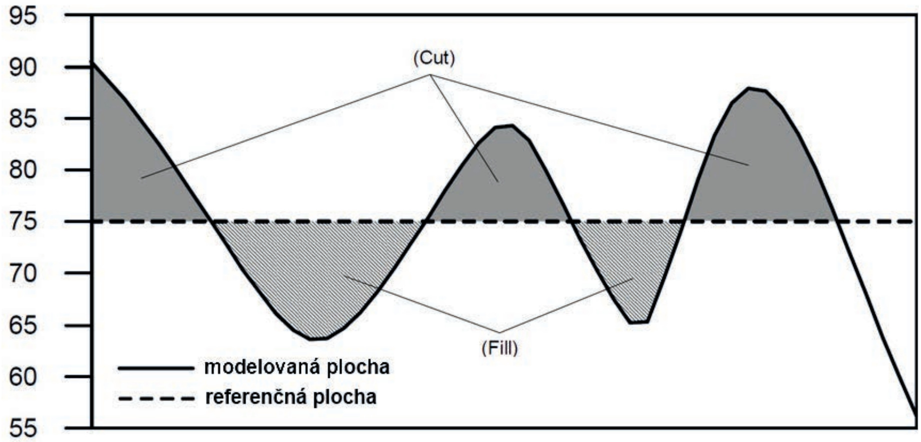

Fig. 13 Principle of comparing the two terrain models based on the volume difference (cut/fill)

Rys. 13 Zasada porównania dwóch modeli terenu na podstawie różnicy objętości (otwór/wypełnienie)

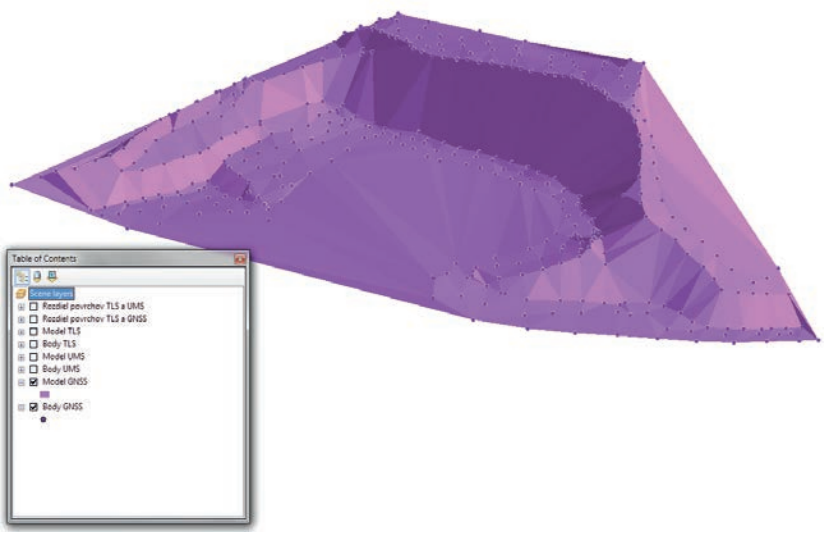

Fig. 12 3D model from data by GNSS

Rys. 12 Model 3D z danych GNSS

The process of measurements of detailed points is very simple. Its length corresponds directly to the number of points we intent to measure.

- UMS

Using universal measuring stations it is possible to gain simultaneously very precise data on the position and height of aligned points. Time requirement of direct terrain measurements is principally longer than at GNSS. UMS LeicaFlexLineTS02 represents the ideal apparatus for all types of tasks, where the stress is on the accuracy and simplicity of operating [3].

- Laser scanning systems

Laser scanning is in the last five years the most rapidly developing field, and its applications has found the extensive exploitation also in geodesy, where the interest is on the detailed documentation of the surface of objects, ev. terrain. AS to their positioning and height accuracy, results of this method are sufficient for detailed documentation of close bodies, where at short distances the measuring error is in the range of mm. [4].

Summarizing gained results, we set up a simple table presenting the efficiency of used geodetic methods and apparatuses (Tab. 1). The efficiency was assessed from the point of view of accuracy, speed, and cost of each method (apparatus) considering the size of documented area. On the results of analysis we may conclude that the cheapest the method of GNSS is. GNSS method is at present the mostly used method for collective gathering of spatial data, just because of its relatively low costs and sufficient accuracy of gained spatial coordinates.

The classic methods with a acceptable ratio "cost/efficiency" include the digital tachymetry exploiting UMS. The accuracy of this technology substantially exceeds GNSS, and its price in last year is continually falling down. Modern robotized UMS by their efficiency (granted for prism less technology of length measurements) are about approaching TLS, while their price is in comparison with TLS substantially lower.

Laser scanning is ideal for precise documentation of the object (building, rock massive), and eventual monitoring of its transformation (deformation of the body, erosion, ect.), but costs are very high, and the work with the scanner and processing software requires the experienced professional.

Comparison of spatial models and evaluation of the accuracy of geodetic methods

To quantify the difference of both TIN areas we used the volumetric analysis cut/fill. This analysis makes analytic calculation of space volume between two areas – referential and modeled reaching the volume cut/fill, and subsequently determines its difference. Such quantification of the deviation of two areas comes out from the following assumptions:

- part of the modeled area will be below, and the other above the referential area (Fig. 13),
- global space volume below and global space volume above the referential area should be as low as possible,
- difference of both volumes - cut/fill – space below and above the referential area should approach zero.

Comparison of TIN models from data gained by TLS and UMS

In the ArcGIS platform, the analysis of overlapping of models from data gained by TLS and UMS (Fig. 14) was realized. Results of analysis are presented in the picture 15, and point out to the fact that the substantial part of the model made on the basis of measurements by UMS is above the referential area – model created from data gained by TLS. This part is in the picture 15 represented by blue color, and a brown color depicts the area bellow the referential area. It results from volume calculation, that the volume above the plane is 129m3 and the volume above the plane is 341m3. The difference of both volumes

Tab. 1 Evaluation of efficiency of used geodetic methods.

Tab. 1 Ocena skuteczności stosowanych metod geodezyjnych.

Method	Accuracy	Speed	Cost	Size of documented area
GNSS	*0,01 – 0,1 m*	**	*€*	*OO*
UMS	*0,002 – 0,05 m*	*	*€€*	*O*
Laser scanning systems	*0,002 – 0,05 m*	****	*€€€€€*	*O*

is + 2012m3, what is the volume by which the TIN model from UMS data shift over the TIN model from data TLS.

Comparison of TIN models from data gained by TLS and GNSS

Similarly, as in previous analyses, also at evaluating models from data by TLS and GNSS, the analysis was realized in ArcGIS platform using the method cut/fill. Pictures 16 and 17 compare both models. It is visible that the error is lower, and the model relatively appropriately represents the quarry wall. The highest deviation is, as we have supposed, on the vertical wall, which cannot be measured. Analysis cut/fill resumes that the volume below the area is 264m3 and the volume above is 232m3. The difference of both volumes is -32m3. This result is really sufficient, and proves that the geodet carefully chose characteristic points at the object, and so the model comparing with the previous one is representative with low error.

Discussion

Comparison of gained results disapproves original assumptions that alignment of the object using UMS should bring confronting with GNSS more precise results. It results from assumption that surveyor will professionally measure the object – will choose points that will characterized it concisely so

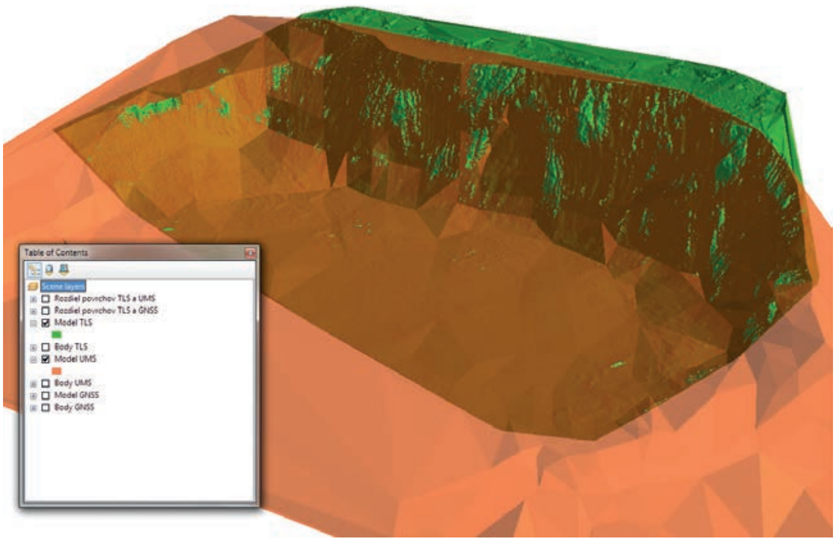

Fig. 14. Mutual overlapping of the TIN model from TLS (light gray) and TIN model from UMS (dark gray) data.

Rys. 14 Wzajemne nakładanie modelu TIN z TLS (jasny szary) i model TIN z UMS (ciemny szary) danych.

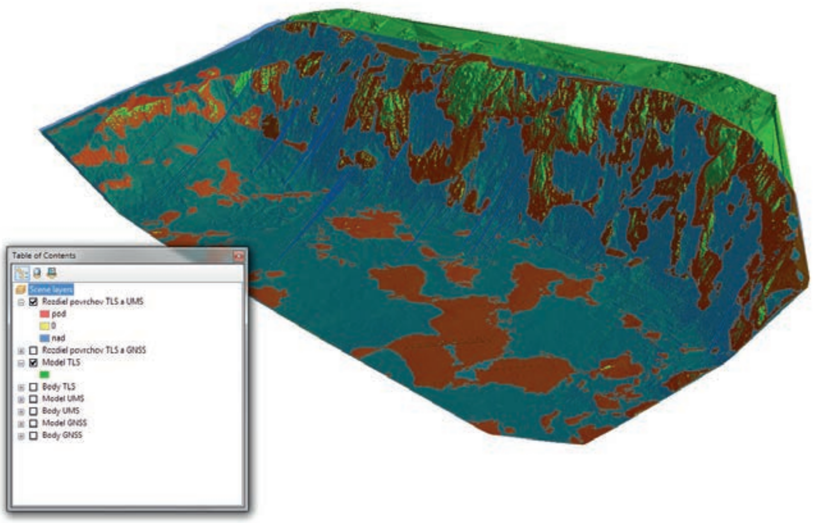

Fig. 15 Analysis of overlapping of TIN models from TLS and UMS data.

Rys. 15 Analiza pokrywania modeli TIN z TLS i danych UMS.

the resulting model will be representative. In our case, the error probably has occurred in the process of data gathering, where the object wasn't identified correctly – characteristic points on the object, and so the resulting model doesn't represent the reality sufficiently. The definite conclusion is clear, and so that the process of identification of characteristic points in the terrain (for needs of modeling its shape properties) should be based on experience and knowledge of the surveyor, ev. the surveyor and helping worker (when the work is done by the reflecting prism and pole). The helping worker must choose appropriate point on the object, ev. surveyor will navigate him to always choose characteristic points. The accuracy of determination of these points will then depend mainly on the accuracy of geodetic apparatuses. Considering the type of the apparatus used the accuracy of measured detailed points determination in the position is – mean coordinate error equal or less than 25mm, and as to height – mean error of height determination is equal or less than 40mm.

At the object modeling itself, points that were inappropriately chosen will project into the shape of unreal surface, which differs from the real one by some deviations. In our case, the simplest mode was chosen – comparison of generated surfaces and their analysis by the method cut/fill. However this way of the assessment of the model quality is only approximate,

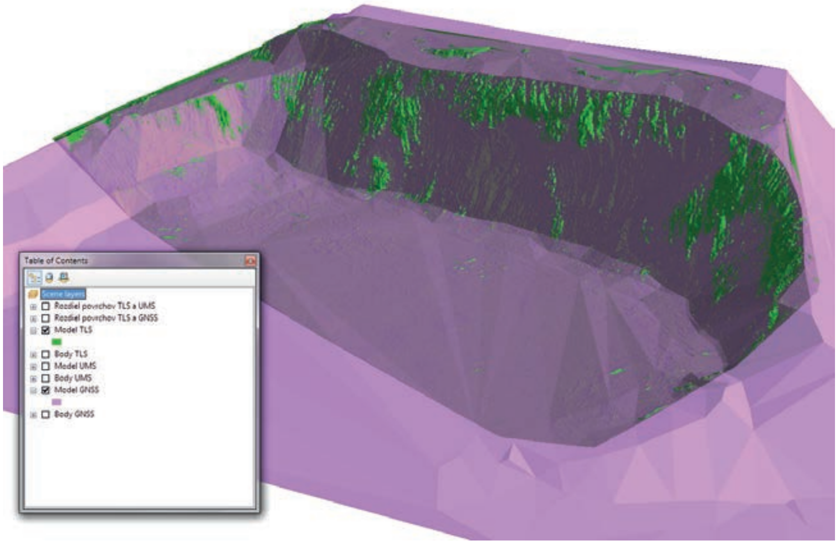

Fig. 16 Mutual overlapping of TIN model from TLS (light gray) and TIN model from GNSS (darker gray) data.

Rys. 16 Wzajemne nakładanie modelu TIN z TLS (jasny szary) i modelu TIN z GNSS (ciemny szary) danych.

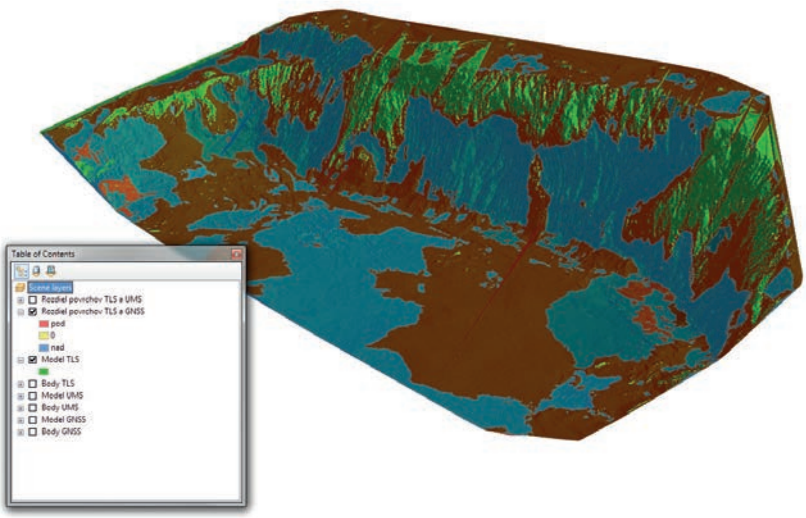

Fig. 17 Analysis of overlapping of TIN models from TLS and GNSS data

Rys. 17 Analiza pokrywania się modeli TIN z TLS i GNSS danych because doesn't give absolute results, and may state only the difference between surfaces in the shape of the volume of the body that appeared between them. The surface with the smallest cut and fill is the most precise one, and the surface with the greatest cut and fill is the less precise one.

One can see that in spite of efficient technology that enable precise measurement of the object by contact less way we may reach unrepresentative results. Just in this connection many expert committees open the issue of professional expertise of "lay" surveyors: "It is necessary to have the qualified and professionally proved personnel for serving geodetic apparatuses? When modern apparatuses are sophisticated enough to have a simple service, so anyone, even without deep geodetic knowledge can manage it." On the basis of these results the answer is definite, "Yes, not only it is necessary to have professionally advanced, but also the experienced personnel able to proceed appropriately in solving any problem". When we underestimate this phase of the process of solving the geodetic task – terrain collection of data, all other results will be burdened by an errors and we will reach inaccurate results what was documented by this paper.

Conclusion

Presented methods of 3D data collection for purposes of mining practice have their definite advantages, but also important disadvantages. In selecting the most suitable method for geodetic alignment of the given object in given conditions one must consider a lot of parameters entering the process of decision making. Main criteria of this process always are:

- Reason of application of gained results,
- Needed accuracy and needed detailes of resulting model,
- Time requirements of measuring and receiving of results,
- Cost acceptability of technology,
- Size of documented area,
- Technologic possibilities themselves.

Summarizing information presented in this paper we may resume that GNSS method is at present the most obvious method for mass collection of spatial data granted for its relatively low costs and sufficient accuracy of gained spatial coordinates. On the contrary, terrestrial laser scanning is the ideal choice for precise object documentation (building, rock massive), and for monitoring of its eventual transformation (deformation of the body, erosion, etc.), but the operation costs are very high and the work with the scanner and processing software requires an experienced expert. Classical methods reaching acceptable results include tachymetry using UMS. The accuracy of this technology substantially overweights the GNSS and its cost is gradually decreasing. Modern robotized UMS by its output (granted for prism less technology of length measurement) are about approaching TLS, while their price is comparing with TLS method significantly lower.

From the point of view of time requirements of data gathering and of needs for further processing of gained data, as the most efficient appears: GNSS methods and tachymetry using UMS. Data gained this way may be after their exporting from the apparatus almost without any correction used for further processing in CAD systems.

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Streszczenie

Obecnie istnieje kilka metod geodezyjnych dla obrazownia 3d obiektów. Sposoby te różnią się zasadą działania i stosowanymi urządzeniami. Wśród najczęściej stosowanych metod są tachymetria, GNSS i skaningu laserowy naziemny. Metoda GNSS jest obecnie najczęściej stosowaną metodą gromadzenia danych przestrzennych, ze względu na wystarczającą dokładność i niskie koszty. Z drugiej strony, skanowanie laserowe jest metodą nowoczesną, ale drogą, a w związku z tym jest metodą stosowaną do precyzyjnej dokumentacji przedmiotu. Wybór odpowiedniej metody zależy często od wymogów dotyczących przetwarzania danych (obłok w tls). Ocenioanano przydatność tych metod w warunkach kopalni odkrywkowej Siedlice. Wyniki modelowania powierzchni 3D na podstawie danych uzyskanych na podstawie pomiarów geodezyjnych zależą głównie od typu i ilości danych wejściowych, ale także sposobu modelowania. Celem artykułu jest przedstawienie nowoczesnych metod geodezyjnych służących do zbierania danych i analizy jakości tworzonych modeli 3D.

Keywords: tachymetria, GNSS, skanowanie laserowe, kamieniołom, model 3d