OPTIMIZATION OF LASER SCANNING TECHNOLOGY IN MONITORING OF ROCK AND NATURAL GROUND SURFACE

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1. INTRODUCTION

The efficiency of the application of laser scanning in different kinds of surveys has been proved by both research experiments and engineering practice. Scanning technology has been adopted successfully as a method of data acquisition for topographic maps, extraction of 3D models of both single structures and whole cities, in inventory and visualization of historical structures, etc. Laser scanning also meets expectations of engineering surveying [Toś C. et. 2006], [Toś C.... 2008]. On the other hand, experiments show that the application of laser scanning techniques needs an approach that is different from the typical optimization analysis applied in traditional measurement planning. Firstly, the environmental conditions play a more significant role besides typical survey conditions referring to geometry of control, technical advancement of survey equipment and special demands of its application. Secondly, scanning technology generates problems that were unknown in traditional measurements both at the stage of field works as well as data processing. Excess data, which appears to be one of the main and difficult problems of processing stage, occurs very often in typical engineering measurements. The problem grows rapidly as the amount of data sets is constantly increasing. If the data set consists of many millions of points, the effect of analysis may not meet the demands. Commercial software does not follow the expectations of users and numerous new applications of scanning technology, it fails in many cases of processing and modeling problems.

In the case of engineering surveying all the above mentioned problems are of crucial weight, but they are different from the problems which are generated by mapping technology or architectonic inventory. Laser scanning applied as survey technology of monitoring but also natural surface and open pits needs optimization in the scope of:

- **accuracy of measurement,**
- **accuracy of model,**
- **reliability of technology.**

The problems of optimization have been analyzed in the paper basing on the case study of the Czatkowice Quarry, an open pit mine about 50 km west of Cracow. The main purpose of the experiment was to work out a method to determine the volume of both overburden and extracted limestone material. For this purpose the exploited wall has been monitored twice in the period of five months in two similar scope programs. The data acquired have been used to generate 3D geometrical models of the monitored object. The volume of material has been calculated as the difference between the volumes of the extracted models.

2. OBJECT OF STUDY

The Czatkowice Quarry is an open pit of circular shape of 1km in diameter and 100 m depth. The amphitheatrical shape consists of five stepped floors. The limestone is exploited from walls which are 20m high, as shown in Fig.1. The monitored quarry walls under exploitation are of irregular shape. The effect of irregularity is significantly increased by numerous cavities and rock overhangs. The mined material which accumulates at the bottom of the inclined section of the wall (batters) consists of different sizes of rock fragments, from small ones to stones a few meters in diameter. The slopes of batters are close to vertical, their mean value amounts to about 90^g. For security reasons very strict regulations must be followed on the pit area. The direct reconnaissance of the walls is forbidden, and staying in the vicinity of the walls under exploitation is dangerous. Survey works are also very limited due to transportation traffic and working excavating machines all over the pit area. Any measurements are strictly forbidden in the period of rock blastings which are carried out twice a day.
The present study has been concentrated on one of the exploited walls, which is 300 meters long and 20 meters high.

Fig. 1. Czatkowice Quarry at the beginning and end of five month observation.

Taking into consideration the above mentioned conditions the following monitoring requirements have been adopted:

- **observation should be carried out from a safe distance from the wall under exploitation,**
- **length of sites should be limited by interval from 200 meters to 500 meters,**
- **time of field work should be very limited, and no disturbance in the exploitation and transport of raw material,**
- **complex geometry of wall surface should be modeled as 3D with accuracy of 0,20 m,**
- **position of a single scanned point of a cloud should be measured with standard error of 2-3 cm.**

3. METHOD OF SURVEY

3.1. Scanning equipment

Measurements of cross-sections are usually carried out to calculate volumes of raw and overburden material, only in exceptional cases photogrametric methods are used. In the presented case, due to technical and environmental disadvantages, non-geodetic

methods have been used. At present what seems to be an effective alternative to all methods used in the past is laser scanning [Leica Geosystem]. To verify this opinion an experimental study of a typical open pit mine has been carried out to provide necessary evidence. The results of similar measurements have also more general significance, they can be used for standardization of measurements.

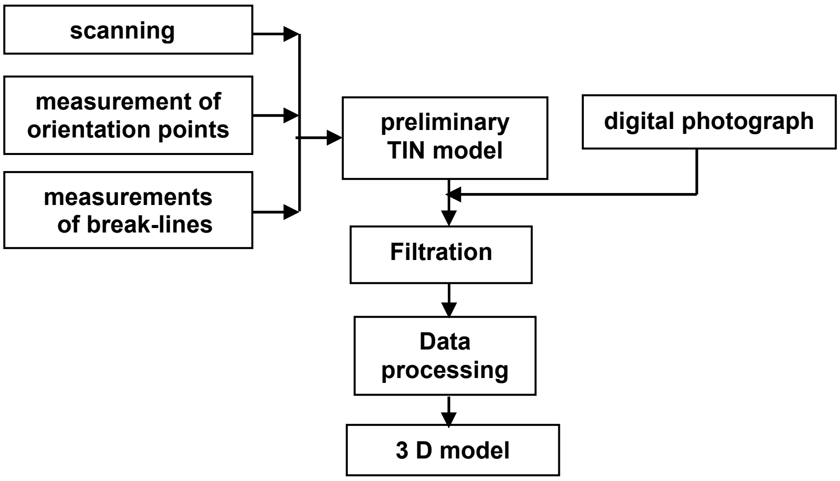

Fig. 2. Scheme of field works and data processing.

The surveys were taken by TOPCON GP 8200SCAN which is a robotic total station with a possibility of programming. The programming option allows collection of identical data as by laser scanners. Scanning tacheometers, unlike laser scanners, work slowly, the rate of data acquisition amounts to 1point/sec. However, it should be noticed that recently the market offers total stations which work at a speed of 25 observations/sec. Despite this handicap, scanning tacheometers are very useful as they are universal in application to different kinds of measurements and generally they measure long distances with better accuracy. Due to slow operation scanning tacheometers produce a cloud of points of smaller density, but as it was emphasized in section 2, a great number of points is not always advantageous. Overloading with scanning data makes processing more difficult or produces sets which store a huge number of useless data. Additionally, an important advantage is the cost of equipment and software. The lower cost can make scanning technology available to small surveying teams. The main stages of field works and processing have been shown in Fig. 2.

3.2. Control survey and points of orientation

The stations have to be located outside the impact of exploitation. They have to be stable in the long monitoring period. The aspects of safety also have to be considered as well as danger of damage of survey equipment. In the presented case the choice of station locations was extremely limited. The control survey fixed for the purpose of the study consisted of two points used as stations for scanning equipment. Processing problems which can appear at the stage of 3D model generation should be kept in mind as early as the design stage of stations location. The best results are received provided that TIN is regular and its meshes are of similar sizes. This effect is achieved if sight lines are perpendicular to monitored bench surface. The stations were located on two opposite sides of the wall, 35m above the bottom of the pit. The distance between stations was 428m and the distance from stations to scanned surface was between 200m and 500m. On the surface of the wall batters ten points of orientations have been marked. Six of

them were visible from both stations. The coordinates of the orientation points have been found by the polar system survey method.

3.3. Scanning of wall surface

The scanning parameters have been determined having in mind measurement conditions, equipment technical parameters and the geometry of the studied object. The optimization has been focused on the size and shape of net mesh, measurement accuracy, scanning field and number of scanning stations. The accuracy of surface mapping by a 3D model depends on the shape of the inclined and flat sections of the wall as well as surface irregularities. The mesh size has been determined after analyzing all these factors. Assuming that the accuracy of final 3D model should equal 0.20m, the size of the net mesh has been fixed as 1m and the same throughout the surface of the exploited wall. With such high tolerance for the 3D model the accuracy of measurement of single points of the exploited quarry wall is of minor significance. The more so that the accuracy of distance measurement by prismless total station is ±3-5mm.

Scanning has been carried out from two stations. Such a small number of stations satisfied technical demands of the survey and was advantageous from the modeling point of view. The wall surface of total ca 5000m^2 was measured by taking of 5120 points. The area of scanning has been determined by fixing boundary points. It should also be noticed that attempts at scanned area identification on control monitor failed. The photo was not readable, topographic details impossible to identify, especially in sunny weather.

3.4. Identification of break lines

What is an important element of applied technology of survey is direct measurement of break lines. In each case the break lines should be defined in the course of field works and measured by the polar coordinate system method, remembering that the TIN model is generated after integration of all acquired data. According to the authors' assumption, it is the key element of the presented technology, and it is necessary if the 3D model is generated from data acquired by a scanning tacheometer. If the sizes of meshes are greater than 0.20 m, the problem that has to be solved in situ is to decide which lines are significant for the analyzed part of the measured object, with due attention to the required accuracy of the 3D model. Let us notice that in the case of estimation of exploitation progress of quarry open pit a 3D model is generated with quite high tolerance assumed, if the problem is analyzed from the engineering surveying point of view. In the presented case only some most important break lines have been measured by direct i.e. polar coordinate system method.

3.5. Digital photographs

The efficiency of the monitoring technique described herein can be improved by integration of scanning point clouds with digital photographs. The photographs allow us to:

- **identify details which are omitted by scanning net,**
- **filter unnecessary data,**
- **identify break lines,**
- **render models with natural surface,**

- **check accuracy and scope of measurement.**

In the presented experiment the photographs have been taken only for some parts of the quarry walls, with the possibility of checking and filtrating the collected data. The shape of the surface has been described satisfactorily by the scanning method and by measurement of break lines. The rendering of the scanned surface was unnecessary because the only purpose of the survey was to find the volume of extracted raw material. The photographs have been taken from both stations with a digital camera. The camera was calibrated by means of the PiCalib Topcon program.

4. DATA PROCESSING, MODELING

The acquired data have been processed by Land Desktop 2005 program. At the first stage of processing the cloud of points and digital photograph have been transferred. The data from photographs have been used to remove points not belonging to monitored surface or data that should be qualified as errors. The latter ones are mainly signals reflected from working machines, trucks transporting the material and waste rock, etc. The filtration was carried out after primary generation of TIN model and integration of the model with photographs. The filtration has been carried out "by hand" procedure. According to the authors, such a procedure is the best way to improve the survey process reliability. According to the authors' experience, relying on automatic filtration procedures turned out to be a less reliable solution. They can lead to gross errors which must not be tolerated in engineering surveying. In the case of scanning technology based on scanning total stations the "manual filtration" procedure is possible due to a relatively low density of the cloud of points.

The preliminary 3D model can also be used to identify break lines. In respect to the number and significance of break lines the presented case study is not typical. In fact, the direct measurements of some lines have been performed only for research purposes and to illustrate the problem. The measurements have confirmed usability of digital photographs for the purpose of identification of the lines. However, as a rule, it should be generally assumed that break lines should be identified directly, i.e. by the polar system survey method. The scope of this survey can be optimized more effectively by a more experienced surveyor.

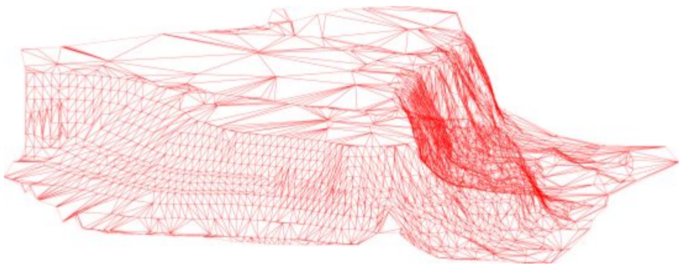

Fig. 2. TIN net after integration of all data.

The problem of TIN net generation appeared when the surfaces were observed at a relatively big angle. This resulted in the distances between points of tacimetrical measurements being bigger than the scanning mesh size. This effect can be eliminated introducing additional points by the interpolation method at the stage of postprocessing (Fig. 2).

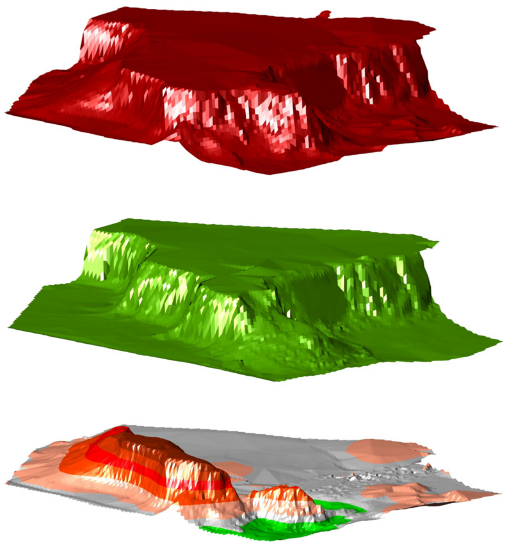

Fig. 3. 3D Models of scanned wall: (a) initial state, (b) at the end of investigation (c) model of the changes in the surface shape.

Based on the verified points 3D models have been built using the Land Desktop 2005 program. The evident and measurable results of technology applied have been found within the area where two clouds of points have been integrated (Fig. 3). The volume of extracted raw material – the purpose of measurement – has been found also by software Land Desktop 2005 program as a difference of volumes found by the models built separately for two epochs. It has been found that during the period of five months the output has amounted to 32940m^3. Generally, the accuracy of volume calculation depends on the area of walls monitored and scanning density which decides of the magnitude of the error. The accuracy of volume analysis has been estimated by a study of the differences in the alternatives of models generated separately for each of the survey epochs. The differences can be identified as the error of the model. The volumes differed, on average, 0,2 m^3 per 1 m^2 of the wall. As the surface of the wall under exploitation was 2600m^2, it can be approximately assumed that the total volume of stone output was determined with a standard error of ca. 2600 0,2 ~ 520 m^3.

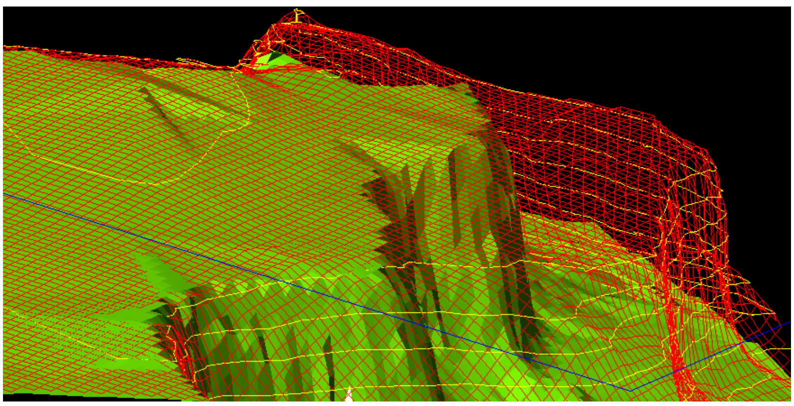

Fig. 4. Changes of the surface shape in selected cross section.

To check if the models are identical when produced by different software two program have been used, i.e. Land Desktop 2005, and PI 3000 Topcon. The results of model generation have been identical. It is also worth noticing that PI 3000 gives a possibility to build a model with natural surface provided that digital photographs are taken. The model with natural surface has been generated for the analyzed wall but from the practical point of view it was useless, as the only purpose of the survey was to find the volume of raw material.

5. DISCUSSION AND SUMMARY

To optimize the efficiency of the presented inventory technology applied to determine the output of open pit mine the stage of field works, data processing and modeling should be taken into account. The discriminants which precisely characterize the laser scanning method are:

- **Measurement accuracy of coordinates of a single point of the cloud is determined by standard error of its position,**
- **Accuracy of model estimated as standard deviation of differences between the model and the real ground surface,**
- **Reliability defined as probability of appearance of gross errors at the assumption that their magnitude is bigger than the standard error of the model [Wolski B. 2007].**

Laser scanning is particularly sensitive to signals disturbances. The harmful signals are reflected from objects which accidentally, sometimes permanently, are in the way between the monitored object and scanning tacheometer. Usually trees, shrubbery and vehicles etc., or noise, are the main source of these disturbances.

The results of the study performed may be concluded as follows:

- **Monitoring of open pit output by the laser scanning system described herein is optimal as far as accuracy, time and measurement cost are concerned. The accuracy of survey amounts to ca 0.2 cubic meters per 1 square meter of the monitored wall area. Wide application of this method results from the relatively low cost of the equipment and availability of software.**
- **Model accuracy depends on the regularity of the scanned surface and scanning density. Laser scanning by robotic total stations gives a possibility of optimization of mesh sizes in the course of field works depending on technical demands.**
- **Modeling is more effective if scanning is carried out from stations perpendicular to the scanned surfaces. An increase of the number of stations does not decrease the accuracy of the model.**
- **Digital photographs are very helpful in “hand-made” filtration but they do not solve the problem completely.**
- **Choice and scope of survey of break lines depends on object geometry. In the case of open pits and earth objects a significant part of break lines can be identified by digital photographs, but in every case the main lines should be measured directly by the polar coordinates survey method.**

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