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RESEARCH ON SURVEYING TECHNOLOGY APPLIED FOR DTM MODELLING AND VOLUME COMPUTATION IN OPEN PIT MINES

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Abstract: The spatial information systems of mining company can be used for monitoring of mining activity, excavation planning, calculations of the ore volume and decision making. Nowadays, data base has to be updated by sources such as surveying positioning technologies and remote sensed photogrammetry data. The presented paper contains review of the methodology for the digital terrain model, i.e. DTM, modelling and obtaining data from surveying technologies in an open pit mine or quarry. This paper reviews the application of GPS, total station measurements, and ground photogrammetry for the volume accuracy assessment of a selected object. The testing field was situated in Belchatow lignite open pit mine. A suitable object had been selected. The testing layer of coal seam was located at 8'th pit side-wall excavation area. The data were acquired two times within one month period and it was connected with monthly DTM actualization of excavation. This paper presents the technological process and the results of the research of using digital photogrammetry for opencast mining purposes in the scope of numerical volume computation and monitoring the mines by comparison of different sources. The results shows that the presented workflow allow to build DTM manually and remote sensed and the accuracy assessment was presented by the volume computation pathway. Major advantages of the techniques are presented illustrating how a terrestrial photogrammetry techniques provide rapid spatial measurements of breaklines 3D data utilized to volume calculation.

Keywords: Digital Terrain Model, photogrammetry, volume, open cast mines

INTRODUCTION

The Digital Terrain Model, hereafter the DTM, is the most important composite of data base deposit in the open pit mine. It allows to monitor the excavation process. In

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recent years, the performance of technologies was improved by acquisition of the terrain in real time measurements with steadily increasing accuracy. The terrain of open cast mine is greatly convenient and useful for testing the sophisticated surveying technologies. The application of them is permitted and the minimum constraint requirements have to be fulfilled. Moreover, mining plant operation in the mining plans exploiting of the ore and the additional rules are significant. The limitations in the polish law regulation are governed by Polish Geological and Mining Law and interior regulations. Implementing of digital techniques for open pit mapping has increased time efficiency and is less time consuming.

STUDY AREA

The study area is located in the eastern part of Europe, the central part of Poland. The Lignite Open Cast Mine Belchatow excavation consists of two adjacent excavations. The first one is named as O/Rogowiec and signed as A at Fig.1. The geometry of open pit mine and the dumping area is clearly visible. The size of the first excavation was about 3.0 km wide by 11.0 km long and about 280.0 m deep. Opencast mining is conducted at the 12 levels of excavation. The second one is named as O/Szczercow and signed as B. Testing field was situated in the western part of A region at 8'th excavation floor in coal seat 70.0 m wide 280.0 m long and signed as C. All of the measurements were made with the aid of excavation technologists.

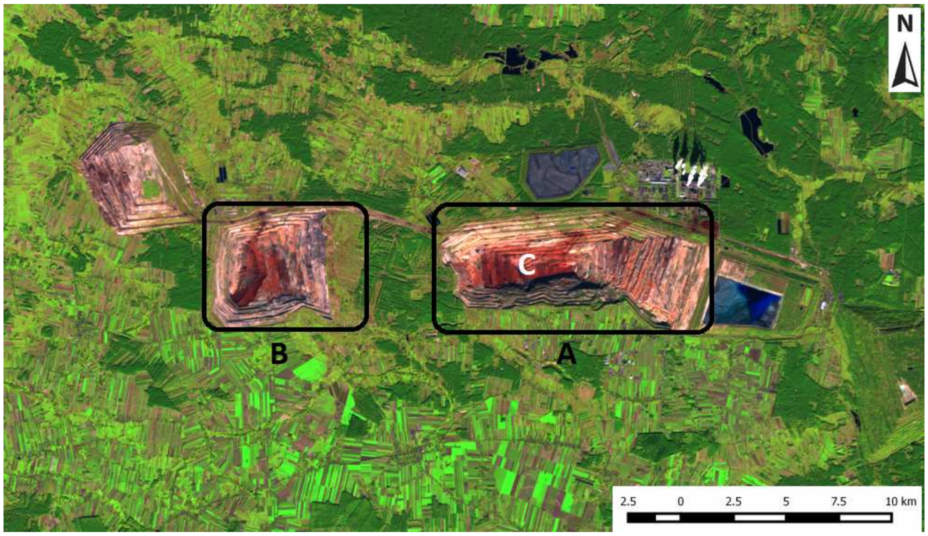

Fig. 1. Portion of the Landsat 8 composed band image of Belchatow Lignite Open Pit Mine. The combination is in false color 6-5-4 band. Acquisition time: 08.24.2014

REMOTE SENSORS AND CLASSICAL MEASUREMENTS

Cutting and filling volume calculations are important issues in mining industry. Accurate digital terrain model allows to perform it. In this study the classical method and remote sensing technique were used to provide the data for spatial database. The easiest way to update the numerical map in open cast mines is to took the classical surveying measurements. The first measurement technique based on GPS point positioning can be used in open cast mines (Karczewski et al., 2010). The GPS technique could be applied owing to wide range clear horizon and open space over the excavation area. Some problems may exist in deep excavation floor where the horizon cut of angle increases. At this moment it's not a limitation because of the large number of the satellites. The second technology which is recommended to basic surveying measurement of digital terrain model is based on obtaining 3D coordinates. The concept of the total station and volume calculation was described by (Pflipsen, 2007). High accuracy of the measurement allows to determine accurately the deposit break lines. In the case of regular excavation floors the monitoring of the digital terrain model changes are simply to by estimated.

Active remote sensed technology named as terrestrial laser scanning (TLS) was described in (Sturzenegger, Stead, 2009a) and could be applied to acquire high density point cloud for DTM modelling. The resulted point cloud is a result of mathematical calculation of distances and angle. The high frequency measurement can cause big data sets of 3D point cloud with full characteristics of it, for example the return signal intensity and RGB color bands. The wide research is presented by (Sturzenegger, Stead, 2009b) and (Kolecka, 2011). One of the numerous limitation of TLS is the fact, there exist occlusions and biases. The characteristics of Belchatow open pit mine show that the close range terrestrial laser scanning has range constraints to acquire data from the crown of the excavation. The weight of this equipment also poses disadvantage regarding the application of this technology in mining industry. Review of literature shows that TLS technology and advanced point cloud filtering methodology is used for landslides and subsidence monitoring (Hu et al., 2012). The concept of airborne laser scanning was described by (Wehr, Lohr, 1999) and the application of this technology could be used for DTM modelling and wide range actualization of the terrain. The accuracy assessment of ALS for engineering application was shown in (Wajs, 2014) and the results show that resulted model is compact and might be used in engineering applications. This technology has one significant advantage connected with strong penetration of the vegetation. And the post processing classification methods produces bare earth digital terrain model as opposed to digital surface models obtained from photogrammetry registered measurements. This shortcomings and drawbacks were outlined by (Ratcliffe and Myers, 2006) and call into question the landslides monitoring (Maciaszek, Ćwiąkała, 2010).

Classical photogrammetry i.e. passive sensing allows to reconstruct the depth from two images signed as stereopair. For the 3D measurement we have to invest ground control points and reconstruct the homologic points from collinearity, computation coplanarity and restitution photogrammetric conditions. This remote sensed technique allows to acquire data and reconstruct the model in current time. By the development of digital techniques, close range photogrammetry was used to perform geodesy works related to the construction, expansion and movement of a mine, including surveying the extracted overburden and ore. Terrestrial photogrammetry allows periodical surveying of exploited mining opencasts to be performed quickly and simultaneous implementing new surveying methods to update digital terrain model in Belchatow open pit lignite mine in 2005. The idea was outlined by (Gawin, 2004). The first tests of near thermal infrared stereo images used in geological interpretation and monitoring connected with checking of indirect stability conditions of slopes and decimations of lignite layers were investigated in (Mularz, 1993). Manual feature extraction from stereograms was presented in (Ruzgiene, Alekniene, 2007). One significant advantage of this approach is that results of measurements are in vector format which is useful to the process of planning and computer aided design CAD 3D. The procedure of aerial digital photogrammetry was presented by (Patikova, 2004). The specific demands were discussed with reference to open pit mines. The terrain of open pit mines usually does not show a variety of colors or shades of grey. Wide open air of open pit mines could be used for aerial mapping and producing the data for DTM modelling. In the last decade the structure form motion processing has developed. It's also named as close range non-metric photogrammetry based on image matching and digital computing for volume computation. This approach was presented in (Yakar, Yilmaz, 2008) and the structure form motion principles was shown in (Westoby et al., 2012) and in the future work in open pit mines could be applied. Moreover, remote passive sensing high quality satellite data might be used to open cast mine area monitoring and change detection, presented in (Mularz, 1998). Actually the land monitoring could be performed by active sensors from space, f.eg. Sentinel-1a advanced synthetic aperture radar for deformation and landslides indication presented by (Cahyono et al., 2009) and (Torres et al., 2012).

METHODOLOGY

The measurement campaign was held in September 2011 as a reference digital terrain model. The data were acquired with the use of ground stereophotogrammetry. The second stage of measurement were in October 2011 by GPS, total station and photogrammetry technique. The classical GPS measurements were executed by rover receiver Leica RX1200. All the points were acquired in real time kinematic technology connected to private reference station located between A and B excavation strip pit. The GPS measurements were made personally in accordance with the principles of generalization. In this case, it was significant to extract the ridge line of the terrain. Furthermore, additional characteristic points of elevation were measured. Nowadays, a total station is a usual measurement instrument in the mining surveying field. In this measurement, a Topcon GPT 7000i was used. The position of total station was set by GPS with reference and orientation to local geodetic datum. The spatial reference frame was located around the excavation area and marked by geodetic reference pipes. During this work the Health and Safety surveying rules have to be obeyed. The main goal was to capture the surface's variation of the area of interest with time and number of data reduction. The Belchatow open pit mine uses the terrestrial photogrammetry to survey the mining work and updates the digital terrain model. The methodology used terrestrial digital pictures and digital photogrammetric station to define three dimensional vectors. In this paper close-range photogrammetry was the main tool to compute the volume of ore in open pit mine. In the next paragraph the applied methodology will be described.

Initially, the study area has was defined. Fig. 3. indicates exactly where the area of interest has been located. The designed shortwall is presented by color lines. Subsequently, all the invested ground control points were indicated and measured by total station from mine crown by non-prism multi restitution. The second stage of measurement was to take a digital photo maintaining additionally photogrammetry requirements. The stereopair images were taken by AIC Modular camera with 7256 (H) x 5452 (V) geometric resolution. The principles of photogrammetry described in (Kurczynski, 2014) were held. Stereoscopic effects are formed when the baseline length has specific conditions. In situ data acquisition was based on object identifying and image histogram controlling. The post processing was executed in Dephos digital photogrammetry station joined with Bentley Microstation V8i software. With previous invested ground control points the geometry of external images orientation was rebuilt. The relative orientation of overlapping images describes the mutual position and altitude of two images and it based on image matching of conjugate points. Absolute orientation of the model in photogrammetry is executed by transformation model to the reference frame. This approach was outlined by (Heipke, 1997) and was presented in use by (Gawin, 2009). All the computation methodology adapted for digital model reconstruction and the breaklines in 3D which represents the ridge line of floor and roof of excavation were defined. The following Fig. 2. presents the methodology of the process. This kind of approach was described in (Gawin, 2010) in detail.

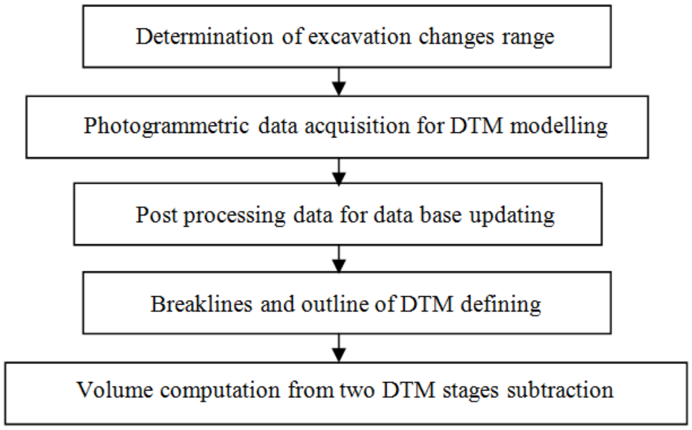

Fig. 2. Applied photogrammetric processing pathway

The most important issue was to indicate clearly homological points into lignite excavation coal seat. Furthermore, this approach allows to measure manually the points with principles of generalization. Caused by excavation digger , the predicted ridge line of slope is inaccurate and difficult to estimate e.g. machine occlusion, obscuration and irregular sidewall.

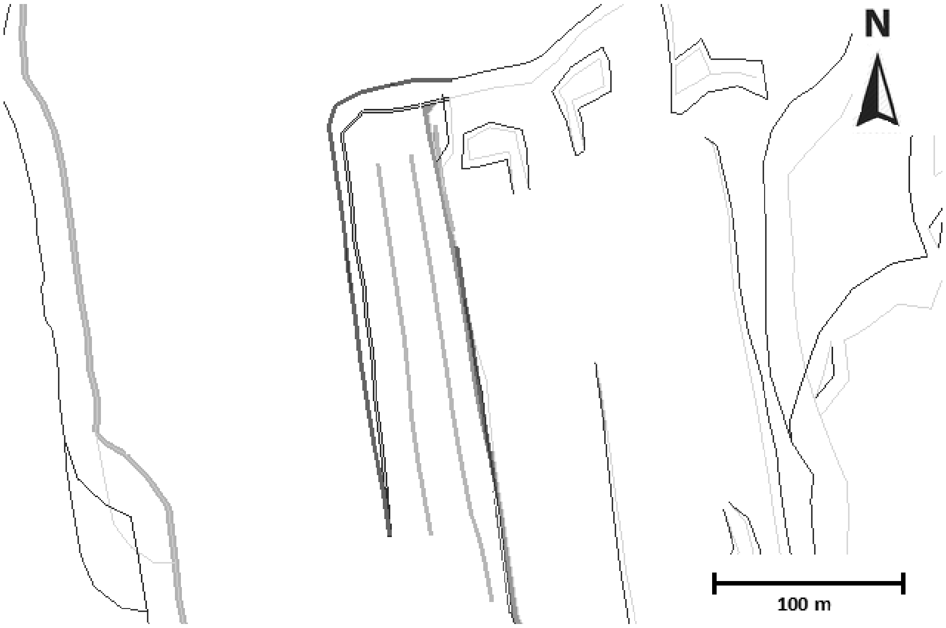

Fig. 3. Design draft of interested area

RESULTS AND FUTURE WORK

The procedure of the volume computation was called into question in (Yilmaz, 2010). The obtained volume of the object (part of ore in 8'th excavation floor) with a classical and photogrammetric methods have been given in Table 1. Three dimensional vectors were transferred to Bentley InRoads software and the volume computation have been done in several minutes. Subtracting the 'master' DTM model from the current DTM model so-called 'slave', we obtain the volume from differential DTM stages. It is apparent from Fig. 4 that processed solid is built from two DTM's. The accuracy assessment of DTM can be illustrated as discrepancies (%) in the right three columns. In most cases the triangular irregular network known as TIN has the possibility to represent ridge lines well. In this kind of DTM the defined 3D breaklines are significant joined with triangles. This approach has to force the triangles connections between previous defined breaklines in 3D. This model allows to determine DTM in an accurate way. Regarding to classical measurement technique the results show that only generalization datum has significant influence upon the results.

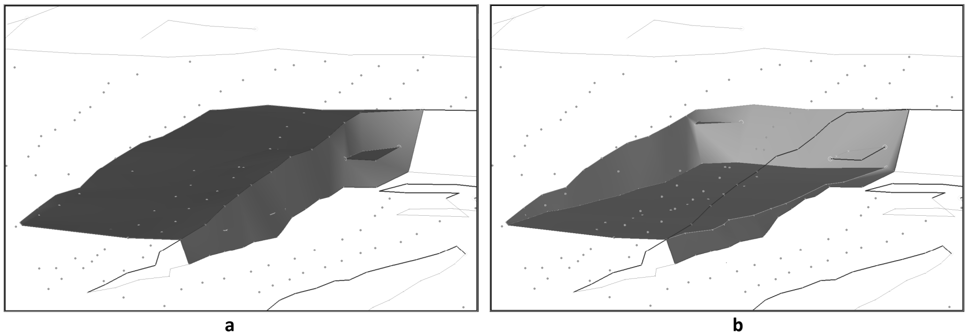

Fig. 4. Processed 3D DTM. The left image (a) represents master DTM and the right images (b) shows the slave DTM after excavation process

Tab. 1. Results of volume estimation

Applied technology		DTM model	Volume m^3 (Vi)	Mean volume (Vśr)	Max volume (Vmax)	Min volume (Vmin)	Discrepancies, %		
Reference	Slave						Vi- Vmin	Vmax - Vi	Vi- Vśr
Photogrammetry	GPS	TIN	65058.0	65193.6	65646.0	65049.0	0.0	0.9	-0.2
Photogrammetry	Total Station	TIN	65059.0				0.0	0.9	-0.2
Photogrammetry	Photogrammetry	TIN	65223.0				0.3	0.6	0.0
Photogrammetry	GPS	GRID	65049.0				0.0	0.9	-0.2
Photogrammetry	Total Station	GRID	65050.7				0.0	0.9	-0.2
Photogrammetry	Photogrammetry	GRID	65203.7				0.2	0.7	0.0

In the last decade the computer vision science has been growing up. The structure from motion presented in (Westoby et al., 2012) has been developed. Actually, the close range photogrammetry principles are strongly investigated and image matching techniques are more effective. It shows, that photogrammetry from unmanned aircraft systems, i.e. UAS, could be a good alternative for large area digital surface modeling. Increasing using non metric camera photogrammetry will be inquire and time and costs will be decreasing. The limitation of this system is payload, stability and only digital surface model registration. In open pit mine the most area represents bare earth and this fact shows that close range non-metric photogrammetry could be potential in the future.

CONCLUSIONS

Standard surveying measurements and terrestrial photogrammetry are both technologies that are solving 3D measurement problems more accurately and effectively than ever before. It can be stated that presented approach allows to produce compact and coherent 3D product to digital map updating and volume computation. Presented pathway shows that close range photogrammetry reduce temporary occlusions, dust scattering, redundant data in very safe way. This approach is appropriate to acquire data for DTM modelling and volume estimation. The a'priori DTM rebuild as master was subtracted from a'posteriori DTM stage named as slave. Estimated volume represents the excavation of the ore in one month period.

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