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Automated Volume Analysis of Open Pit Mining Productions Based on Time Series Aerial Survey

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***Abstract* - Photogrammetry based 3D model creation provides a new opportunty to survey and to evaluate natural and arificial surface formations. The photos needed for 3D model building can be taken using fixed wing aircraft or multicopters. These machines are more economical and are capable of more precise route tracking than big machines operated by human personnel. Depending on the size of the area (0.5 to 10km^2), the survey can be finished within an hour. The volume calculation method is introduced in the paper through the example of an actual, operating mine. Previous, mainly manual but competent analytical tasks, which demand engineering work, can be partly replaced agorithmically. The method may provide more accurate volume results than a conventional geodetic survey, as it builds a model with 10 cm resolution of any examined area or object. Another advantage is that the results are ready within a few hours after beginning the survey, it is not necessary to wait days for accurate volume data.**

Keywords – UAV, 3D surface model, photogrammetry, volume computing, matlab, point cloud

I. Introduction

Using a small-sized aircraft piloted by a robot, surface formations can be surveyed fast and at low cost. For the survey, it only needs to carry a small-sized camera, which is capable of taking high-resolution photos (minimum 10Mpixel). The camera firmware is prepared for special, uninterrupted photo shoots at specificied intervals. From the data provided by this combination of the aircraft and the camera, a 3D model can be built on which further tests can be conducted regarding the real object.

Apart from high resolution, another requirement of 3D model construction is to take pictures with at least 60% overlap. This image set makes it possible to place certain points in space which are visible in the 2D picture, and by doing so, to make a point cloud, which is equivalent to the real object. Based on experience, apart from the resolution mentioned above, a real-virtual correspondence of 3.5cm/pixel can be achieved from 150m of flight altitude at the flight speed of 50 km/h. In case we choose a lower flight altitude and speed when using a multicopter, this accuracy can be improved easily up to 0.1cm/pixel.

The device detailed above can also be used at open pit mines. In this way, for the use of tracking mine production, it can be a cheap and fast alternative to conventional aerial photography requiring several people. It can also replace the conventional geodetic survey of mines, for such a level of resolution of the surveyed landmarks can not be achieved using manual methods, or only within a considerably bigger time frame and at high costs.

The method to be introduced was tested by analysing the volume of an easily measurable, artificial structure, which was a swimming pool. The pool is easily surveyable using a tape measure and it is an accurate reference for the test which uses the method to be introduced shortly. The reference test shows that the deviation is between 1 and 2%, in other words, a bigger deviation is not to be expected at the mine survey either. If we accept this, it can be declared that the result of the technological and technical set detailed in the paper can be better than a volume analysis based on geodetic surveying. The main topic of the paper is how to rotate and fit the point cloud of the models made in different years using an algorithm.

II. Rules of Photogrammetry

The basis of the photogrammetry method is to take a sufficiently great number of pictures of a given object from different angles, which overlap each other. In case of the aerial photos taken of the mine, we conduct the photo shoot in a way that one pixel can be found in more than two pictures. The spatial position and the direction vector of the optical axis of the employed camera give the real and spatial position of the pixel. It is possible to calculate the spatial location because, in reality, the given pixel does not move, but the photo shoot location alters [1].

The information referring to the spatial location of the photo shoot location can originate from the device systems made of the union of GPS (Global Positioning System) or GPS and IMU (Inertial Measurement Unit). Pictures can be taken having significant overlap. In this case, it is not strictly neccessary to utilise the data of the above-mentioned device system, but rather by analysing the pictures, the spatial location of the photo shoot location can be determined. We can assume that the middle pixel of the pictures is distortion-free and we can consider this as the reference point between the pictures. We can search for further reference points, which deviate from these points,

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which appear in several pictures and whose calculated distance does not change in reality, however, the calculated distance in the pictures changes. This value is perspectivical distortion, which is used as a basis for the accurate calculation of the exact spatial location of the device taking the photo.

Finding common pixels in the pictures and calculating their spatial positions can be easily automatized. Using several successive algorithms, a spatial point cloud can be created, which represents the photographed real object. After fitting the point cloud on each other adequetly, placing them in a common coordinate system, fitting them together, they can be suitable for the algorithmical calculation of volume data [2]. As such, the method presented subsequently can be a real alternative to classical geodetic surveying.

III. Geodetic surveying

The discipline of science employing classical methods of surveying artificial objects or natural formations is called geodesy. Geodesy can be divided into two bigger areas.

Theoretical geodesy deals with the determination of the Earth's size and its form factors. Furthermore, it lays down the theoretical foundation for solving continental and international problems. Its task is also to determine geodetic trig points for surveying, preferably with high accuracy, and also to maintain the data of these points.

However, practical geodesy (surveying) handles local surveys. Typically, it handles setting parcel boundaries and surveying buildings. Its two types are horizontal and altitudinal surveying.

First of all, a geodetic survey is to determine the corner points, points indicating shape, which determine the shape of the object to be surveyed. They use reference points to survey the points and compared to this they determine the spatial location of the point to be surveyed by the following methods: angle measurement, distance measurement. In the latter case, the diagonally calculated distances can be calculated horizontally. In case of area calculation tasks, they use the result derived from the horizontal calculation result; its accuracy depends on the accuracy of subpoints. To calculate altitude they use the altitude difference between the calculated points, or they use the altitude above sea level. To conduct calculations, they use constant or temporary benchmarks to which the location of the point being surveyed can be calculated.

A. *Problems with surveying*

Geodetic surveying raises many problems during the surveying of a mine.

A fundamental problem is that surveying is extremely time-consuming. The surveying tool (theodolite) always has to be moved along the walls of the mine or even within the active extraction area as well. Surveying and calculating particular points using constant or temporary reference points individually takes much time, but for a real, objective survey of a mine there is a need for tens or hundreds of survey points.

Figure 1. Ortophoto of the quarry in 2017 made from UAV pictures

On the basis of these, determining reference points can take minimum half a day, a day or even several days. In the knowledge of reference points, another task is to create data from them, which are important for the customer (volume, depth, etc.).

It is a problem that however precisely they wish to survey a mine, with the method mentioned it is only possible to approximate, which includes big errors. The reason is that the surfaces between the reference points are created wih interpollation, in other words, using approximative curves and lines. This in itself can produce great inaccuracy.

The presence of the surveyor can be a problem in the function of the mine, as a surveyor who is not an expert in mine operations works in an industrial area which operates along rules unbeknown to him. In this way, his presence must be secured; for him to work in safety this can result in the partial restriction of the mine.

B. *An alternative surveying method*

The method introduced in this paper might provide a solution to the problems of geodetic surveying. Although the method requires special devices (a small-sized drone and a special camera), the need for special devices is also a characteristic of geodetic surveying (fig. 1.).

Surveying is not time-consuming, namely because, depending on the size of the area, 15-60 minutes of time is needed for the creation of a sufficent number of input data. Field work in itself requires this much time, all the other tasks can be finished in an office environment within a few hours.

In contrast to geodetic surveying, creating a point cloud using the photogrammetry method can be considered the set of the surveyed reference points in itself. In case of the classical method, in contrast to the few hundred points used for surveying, the models contain 10 to 20 million, which individually and on the whole are accurate representations of the actual values. There is no need for interpollation in case of such a big data set, as all the parts of the mine are accurately represented with 30 mm of accuracy. It can be realized that surveying an operating mine of such scale is almost impossible using the manual method.

In this paper, surveys from several years are available of the introduced mine [3]. The model from 2015 contains 20 million reference points while the survey from 2017 contains 15 million reference points (fig. 2.).

For calculation, we reduced the point cloud representing the mine, as working with such a big amount of reference points requires large compution capacity. The algorithm developed for the determination of the volume data is capable of determining the volume in 4 minutes in the data set reduced to 1%. We must also take it into consideration that the reference point set reduced to 1% results in 150 to 200.000 reference points.

Based on our calculations, the algorithm finishes volume determination within the following run times, while using average hardware by today's standards.

TABLE I. CORROLATION BETWEEN THE NUMBER OF REFERENCE POINTS AND RUN TIME

Number of reference points	Run time
20 million	infinite
2 million	~60 min
1 million	~15 min
200 thousand	~ 4 min

During the survey and volume calculation, we had to determine the active edge of the mine. Without this step, we could get distorted volume data. For the determination, we would typically use data from the extraction plan, namely, coordinate sets of the surveyors, however, we had none of them at our disposal. Based on the data surveyed for this present research material, we determined the active area of the mine.

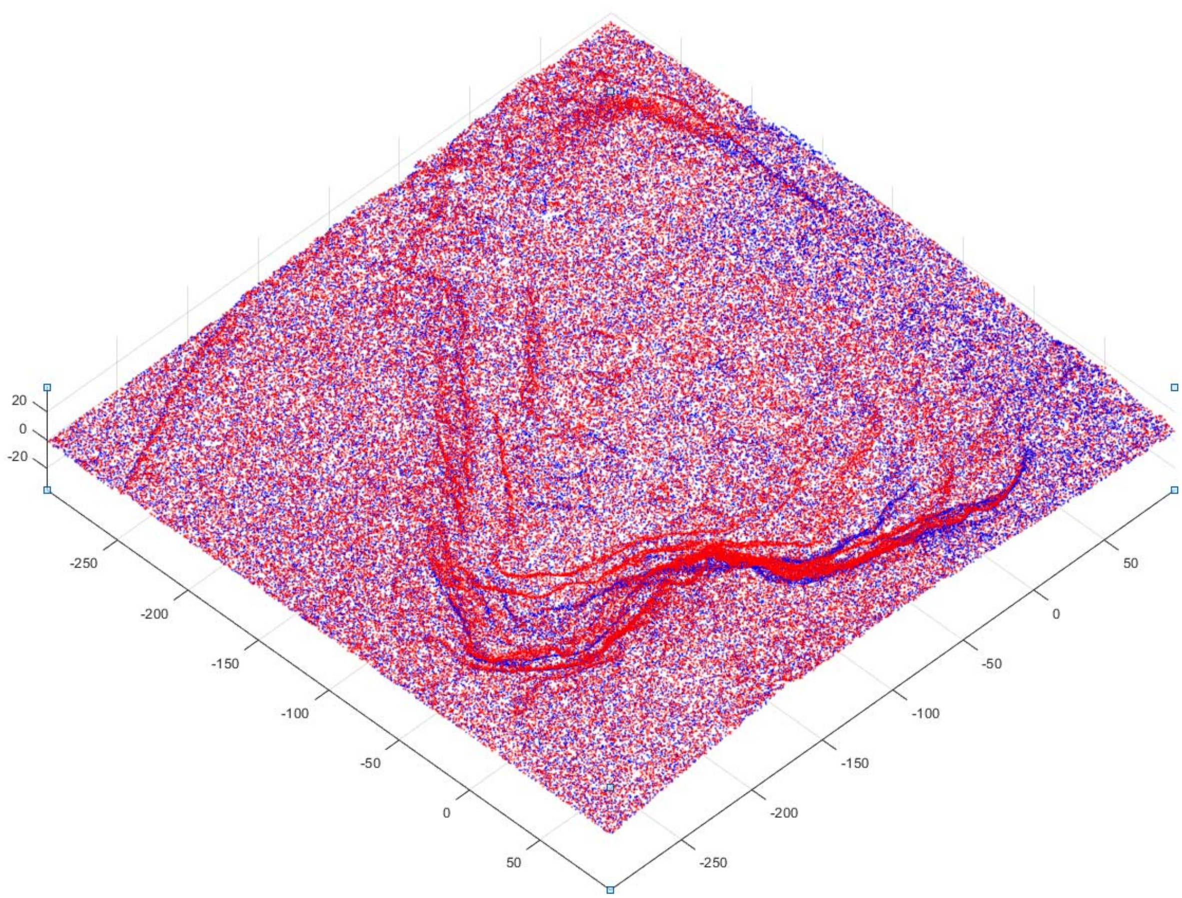

Figure 2. Point Cloud difference between 2015 (red) and 2017 (blue)

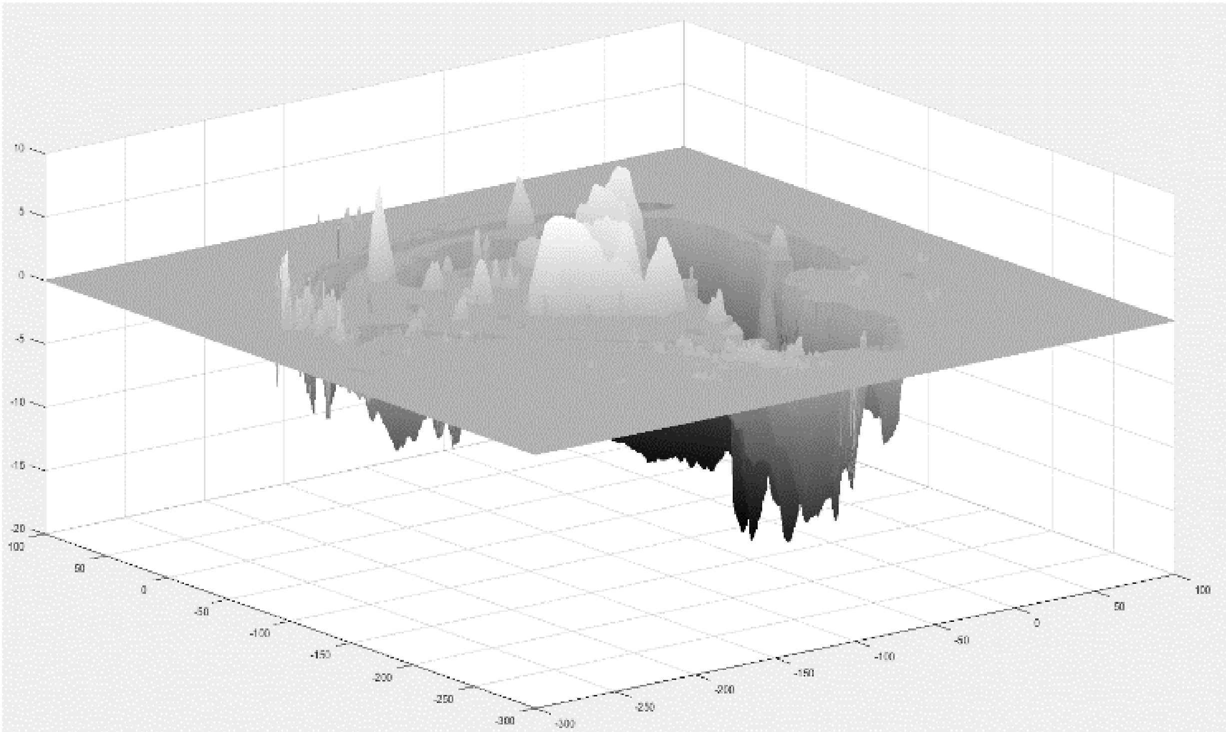

Figure 3. 3D visualization of mining process

IV. Building the 3D point cloud based on photogrammetry

The examined quarry has been surveyed every year for the last three years (2015 to 2017). In every case, the test was conducted using a drone piloted by a Pixhawk, which was built on the foundation of a Skywalker X8. The mounted camera was a Canon S100 with 12.1 megapixel native resolution. The UAV flew to the mine following a predetermined route at an altitude of 150m AGL (above ground level). The trail contains parallel routes 50 m from each other which results in the creation of pictures with 60% of lateral and longitudinal overlap. An advantage of the camera is that it uses CHDK firmware, which makes its optional and programmed control possible [4]. Reaching target height, the machine flies the area making 1.2 pictures per second. After the flight, the number of taken pictures is of the order of 1 to 2000. Using photogrammetry, the pictures are fit together with the SfM (Structure from Motion) method [5]. The basis of this method is the detection of the feature points between the different pictures, and on the basis of these, the calculation of camera locations, most often the SIFT [6] or the SURF [7]. These, and similar methods can be used on 3D point clouds also as presented in [8] for mobile robots using RGBD camera and can be effective on GPU [9]. At the end of the procedure a 3D point cloud is created, which is suitable for further processing.

V. Point Cloud alignments

The point cloud contains the detected features, whose distribution is not even. Typically they cluster at visually characteristic points and they are rare at homogeneous areas. Next, filtering procedures must be employed on the point cloud; the points created because of defective fitting must be removed. This can be done automatically, using denoising algorithms or manually, by removing the points which emerge from the plane. Subsequently, with the further extraction of image data, a dense point cloud is created from the sparse point cloud. This dense point cloud is the input of the 3D area creation, from which a Digital Elevation Model (DEM) can be exported, after which we determined the ground control points in the input pictures and in the point cloud. Thus, depending on the accuracy of the survey, with an average GPS device 5 to 10m, with DGPS device an accuracy of <1m can be achieved. In fact, the exported DEM is only a 2D data set, which contains fewer feature points compared to the point cloud, thus its post-processing encounters difficulties [10].

The operation of the algorithm developed by us is derived from the sparse point cloud. The input data are from the surveys conducted on the mine in 2015, 2016 and 2017. These are point clouds with an accuracy of ~10m, containing points in the range of 1 million. The task is the determination of the translation and the rotation between the point clouds, which makes it possible to rotate them into one identical position and to compare them.

Without this, at volume calculation, a cummulative error appears in the order of ~1000m^3 resulting from the error of georeferencing. The surveyed points of the GPS are always local, in other words, the points surveyed at the same time contain errors of the same direction and degree. This results in that georeferencing does not bring a geometrical error into the 3D data set, only an 'offset' error, which can be expressed using a tranformational matrix.

As its first step, our algorithm determines this transformation matrix using Rigid Iterative Closest Point – ICP [11].

The algorithm interprets the difference between the mines, in other words the difference between the point clouds, as errors. Working within the given error margin, it omits these points from the calculation and it only calculates with the unchanged "rigid" part. In our case, non-rigid ICP can not be employed, because we want to precisely determine the degree of difference between the point clouds.

As a first step, we examined the correctness of our procedure. In this way, we reduced our data set to 1% for faster processing. Calculating with a data set of 100%, optimizing its processing speed and the acceleration of parallel processing by GPU, which has major benefits over CPU computing [12][13], can be topic of further research

As a first step, the ICP rigid registration matches the points between the original, so-called fixed and the later, so-called moving point clouds. Subsequently, it removes incorrect matches by an outliner filter using incliner ratio (~10%). After filtering, rotation and translation are determined, which provides a 3D affine matrix (1).

$$\mathrm{T} = \begin{pmatrix} 1.0000 & -0.0022 & -0.0065 & 0 \\ 0.0022 & 1.0000 & -0.0017 & 0 \\ 0.0065 & 0.0016 & 1.0000 & 0 \\ -26.0160 & 69.9159 & -1.2566 & 1.0000 \end{pmatrix} \quad (1)$$

Completing the transformation, the point clouds become overlapped, so their Z axis-based values can be compared.

VI. Results

Performing the procedures discussed so far, time series survey produce a series of overlapped data sets, so it's possible to carry out a volume analyzing.

The only problem is that though point clouds largely display the same area, but because the data are scattered, their coordinates are not uniform.

For this, after fitting, a linear interpolation raster dataset had to be created from the scattered data area containing the mines, in which the points are located as gridded data; in this way the difference between them becomes computable.

By omitting the data outside of the contour of the mine, the difference can be clearly calculated. Based on axis Z, by integrating the differences, the production between 2015 and 2017 becomes 167 530 m^3, which is in accordance with previous measurements (fig. 3).

VII. Conclusion

Based on aerial photos, we created 3D models using the introduced method. The models were made of the same mine in three different years. The produced formations showed great similarity in the areas outside of the mine area, but the active mine area showed significant changes. To illustrate the changes graphically, we marked the models made in specific years with different colours.

The models made in different years could be rotated and fit together based on previouly chosen reference points. The choice of reference points was important, as during the years, unchanged parts of the environment had to be chosen in the vicinity of the mine. This task is extremely meticulous, it requires a professional, as aligning reference points (thus aligning models), compared to the solution detailed in the paper, was time-consuming.

The solution presented just now approximated the problem with rotation. There is no need to chose reference points manually, as the ICP algorithm searches for point pairs automatically and it rotates and fits the models into alignment based on them. The models created and rotated this way show much better fitting than in case of the previous, manual method. More accurate fitting makes mine models suitable for the graphical display of even little changes; in this way a few m^3 of change become visible in the mine area (fig. 4).

Another result is that we also reached the determination of the mine volume using the algorithmic method. Using previous methods, results could be presented with an error margin of ~10%, whereas the present algorithm calculating with 10 cm of resolution works with less than 1% error.

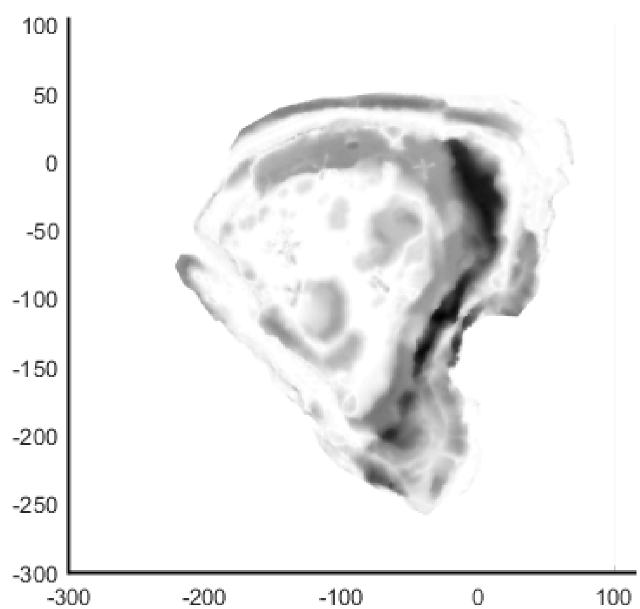

Figure 4. Top view representation of the mining process – darker the higher difference

The present solution is very much CPU extensive. The data set representing the mine is great, thus logically the combined processing of three years' data, finishing operations, calculating rotation matrices mean further load. This is one reason why we chose the 1% downsampled data set version representing the models. A later task is to conduct calculation on the real data set, in this way, further increasing accuracy. Expectedly, this can be possible using a kind of GPU- or cloud-based computing method.

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