

DIGITAL PHOTOGRAMMETRY IN THE PRACTICE OF OPEN PIT MINING

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ABSTRACT:

Mining activity monitoring, volume calculations, data for information systems of mining companies, decision making and planning, reclamation proposals are some of the most important fields, where photogrammetry can be used in open pit mining. Nowadays mostly digital methods find their utility in providing stereoscopic digitisation of a current situation of mining, precise orthophotos and digital terrain models. There are requirements for high precision especially in heights due to volume calculations and therefore high-resolution aerial images with low flight altitude are taken for the open pit mining purposes. The image scale is usually between 1:4,000 and 1:10,000. The huge amount of photos scanned with high geometric resolution and therefore gigabytes of data have to be processed fast and accurately. Fast computers and necessary photogrammetric software together with other ancillary programs (e.g. programs for digital terrain modelling (DTM), for computer aided design (CAD), and converters) are a basis of the work. However, above all this technical background the human factor is important. Well educated in photogrammetry, specialised in the field of open pit mining, experienced people with sufficient software knowledge are needed to achieve good results.

Despite images with high resolution, the biggest problems are caused by the image interpretation. The terrain of open pit mines usually does not show a variety of colours or shades of grey. Therefore shadows can be advantageous but also disadvantageous. A very good 3D visual perception without systematic errors is essential in stereoscopic digitisation. The setting of the smallest height difference at break lines and slopes is important for their digitisation in order not to lose time with too detailed designs, or on the other hand, to avoid a too benevolent work without the necessary details. If a final user of the data has not any photogrammetric equipment and uses a variety of software, different result formats are required in both vector and raster data. Specific demands have to be discussed very carefully and clearly defined. The paper illustrates also typical actual problems which can be met during the workflow.

1. INTRODUCTION

Mining companies monitor their mining activity regularly. There are several possibilities to do so. However, very precise terrestrial measurement is a too time consuming technology. Absolute precision of single points is high (in units of cm) but it is not economic to measure too many details. With photogrammetry large areas can be measured even with details. Accuracy at a single point is a bit lower (tens of cm) but still sufficient in the case of open pit mining. Relative accuracy of DTM is even better than at terrestrial measurement because of a higher number of points which can express terrain well. Usually, two persons are needed for the terrestrial measurement. Photogrammetric processing itself can be done by one person. Only ground control points (GCP) have to be signalised and measured in terrain by the geodetic methods. However, it means just a few points in a comparison to an evaluation of all points or lines in a quarry or a mine. Therefore, photogrammetric methods are used more and more often in this case. Nowadays, mostly digital photogrammetry is applied due to many advantages compared to the analytical one. Nevertheless, there are many specific aspects in the use of digital photogrammetry in the field of open pit mining which have to be taken into account for getting proper results.

2. PHASE OF PREPARATION

2.1 Project Preparation

The first step before any start of a job is the preparation of the existing data and the collection of information about the mine

or quarry. It depends on requirements from the side of the open pit mining company and their data archive, especially maps, databases, 3D vector data, digital terrain models, co-ordinates of geodetic points. Very important are metadata, what can be simply explained as data about data. They include used co-ordinate and height systems, the date of the data acquisition, scales, in the case of aerial images also calibration protocols of the cameras, scanning resolution, information about formats, versions of software and so on. Nowadays, bigger mining companies usually have digital vector data describing the status of the quarry.

If a previous vector data set exists, the position of the locality is more or less defined. Then only some differences have to be discussed, e.g. an expansion of the mine or quarry in some direction in the next years, and then a larger area has to be covered by aerial photos and afterwards processed in a vector and also raster (orthophoto) form. If there is no previous data set on hand, the position and the size of the locality has to be defined exactly on the existing map with a suitable scale (1 : 10,000 and bigger scale).

In the case of vector data, the lines, points and areas have special style, thickness and colour. All these attributes are defined in a legend or a catalogue of objects provided by the open pit mining company.

According to the position of the locality and additional requirements of the open pit mining company, the flight planning has to be done. The co-ordinates of the area corners and position of the projection centres drawn on the map or directly in the last vector data are prepared for the specific camera with specific focus length and specific photo scale. The

scale and co-ordinate system have to be known to the company providing the aerial survey to eliminate misunderstanding. There are different software tools available especially for the flight planning. They facilitate to define the area, the type of camera (focus length), overlaps between photos in the strip and between strips, photo scale and scanning resolution.

Ideal weather for taking aerial photos in open pit mining is not a blue sky with sharp sunshine and sharp shadows. There are very deep areas with nearly vertical walls in a mine or quarry. The sharp and dark shadows make the processing (especially the evaluation of heights) in such places more difficult. Therefore soft light going through high clouds is preferable. Sometimes waiting for the flight mission is quite long because of the wrong weather conditions. Therefore, a well co-ordinated communication between the aerial surveyor, processing company and open pit mining company is crucial. It has to provide a fast checking of stabilisation of ground control points in terrain combined with a good weather forecast. Otherwise, GCP are covered with snow or leaves or are destroyed.

2.2 Input Data

The most important input data are photos and co-ordinates of GCP. Depending on the company, accuracy requirements in the open pit mining are around 15 cm in position and 20 cm in height. Therefore the scale of photos is between 1 : 4,000 and 1 : 10,000, scanning resolution usually is 1,200 dpi (21 microns). Then the ground resolution is between 8,5 and 21 cm. The scanning resolution can be higher but the data volume increases rapidly. The photos can be panchromatic but colours make the interpretation much more easy. Nowadays, also digital photos are available. However, the quality of conventional photos is still higher according to the author's experience. Especially the colours of neighbouring photos are better balanced at conventional photos.

The co-ordinates of projection centres and control points are very critical aspects in the whole workflow. Nearly every open pit mining site works in a different co-ordinate system. The aerial surveyors navigate in WGS-84. This has to be taken into account already during the planning stage of the flight mission. The transformation between systems has to be done very carefully with the knowledge of the co-ordinate system definition.

For interior orientation of conventional photos the camera calibration protocol is needed from the aerial surveyor. In the case of digital photos, only information of the number of columns and rows and the resolution in microns is required to create the calibration file in the software. Some software tools have already integrated parameters of digital cameras and then interior orientation is done automatically. Together with the photos, the aerial surveyors deliver also data of external orientation (positions of projection centres and roll, pitch and heading angles) from their GPS/INS systems. It helps to reduce a number of control points during aerotriangulation. The aerial surveyor usually provides also the scanning of the conventional photos. It has to be done with special calibrated photogrammetric scanners with not too sharp contrast without compression which could cause the loss of information.

The position of GCP themselves has to be discussed before the flight planning. Usually they are located around the mine or quarry. It would be useful to have also some GCP inside the area but there is a danger of their destruction by the mining activity. If the data processing company does not signalise GCP itself, it is necessary to explain all rules of the point location and signalisation to the responsible geodetic company. Some of the rules are known but also have to be mentioned. They

include for example that GCP should not be covered by high buildings or trees, should be located on a contrast background. Especially the size is very important. They must not be either too small or too big. The size depends on the scale of the photos. For example, at 1 : 6,000 scale a quadratic signal has the size 20 x 20 cm, an arm of a cross signal is 60 – 80 cm long. The colour is usually white because white subjects on a dark background seem to be bigger than they are in reality. This effect is called irradiation.

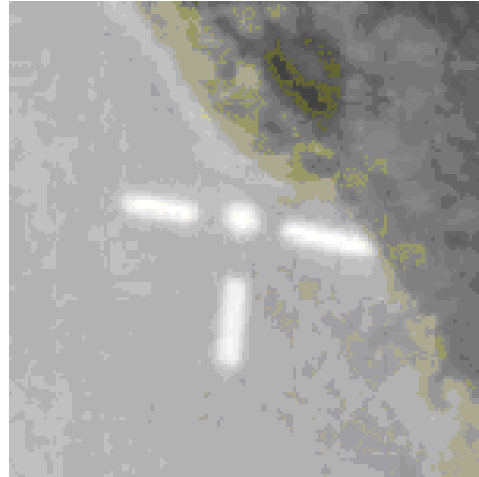


Figure 1. Example of signalisation of a ground control point

2.3 Software and hardware equipment

There are many software tools on the market and usually the open pit mining company uses a different tool than the data processing company. Therefore a detailed discussion about required formats and accuracy is necessary. In the case of different tools, conversions of data have to be done. Sometimes conversion programs are made to order and have to be tested before use. Nearly every software company withholds their format structure, and then testing the converters is crucial to eliminate systematic errors originating from conversion.

Variances in software use do not only occur between open pit mining company and data processing company. Also within the processing company different programs are used for the flight planning, aerotriangulation, stereophotogrammetric processing, digital terrain modelling, finalisation of vector data. To simplify conversions known formats as TIFF for raster data and DXF for vector data are used in the cases where it is possible. Otherwise converters are made to order.

As a huge amount of data has to be processed in photogrammetry nowadays, faster and more powerful computers are required. Normal standard computers can have 1.5 GHz processor and 1 GB RAM. Computers are usually equipped by CD/DVD burners, big hard disks and by special back-up systems. A standard for the stereophotogrammetric processing is Crystal Eyeware with emitter.

2.4 Human factor

The human factor still plays a very important role in photogrammetric processing, although many procedures are automatic. Well trained, reliable and precise people are fundamental for every successful work. On the one hand, people specialising in photogrammetry should have a good mathematical background of software tools, what they can expect from a program, which kind of adjustment is used and

what the mean square error and deviation are. On the other hand, people educated in the field of open pit mining have an advantage in the interpretation of objects on photos and can consider the importance of objects in the specific job much better than the closely focused photogrammetrist. The third aspect refers to people who know and are well trained in different software tools, are flexible to respond to appearing situations and are able to solve problems.

Another important issue is a good estimation of the time schedule during the project management. Otherwise, time pressure and stress cause other problems.

2.5 Tasks

There are different requirements from the open pit mining company concerning the data and deliverables. Some of the companies are working with an own information system into which the data delivered have to be integrated. Therefore they have special requirements for the format of vector and raster data. In other cases, the company uses only hardcopy plans with vector drawing and an orthophoto in background. They are more focused on the figures from volume calculation and the hardcopy is only a guideline for their decision making in a development of the mining activity.

2.5.1 Updating the situation

As mentioned above, the open pit mining company either has or has not information about the first or original status quo of their quarry in some form. This may be available in paper-, but not digital-form. However, bigger companies do plan their activities in digital form already. Then vector data are delivered in some specified format. The task is to update the data according to the new situation on taken photos. Sometimes legends or object catalogues are so complex that it is very difficult to be well oriented in it. In some cases, the catalogue is created to the structure of the project during the project preparation and can be changed also later on. Various lines identify for example crest and toe of the slope in active mining, dump, overburden, or nature surface, the water level of ponds, access roads for machines, railways, tunnels, pipelines, open pit mining plants, other buildings, belt conveyors, crushers, fences, forest, cadastral borders and so on.

Mining companies have different needs what to digitise and what is not so important for them. The size of the smallest detail to be digitised is different from quarry to quarry, from purpose to purpose, from object kind to object kind. Sometimes it is sufficient to digitise slopes which are higher than 1.5 m, sometimes also smaller ones. Sometimes dumps are important and sometimes not etc.

Vector data with points, lines and areas in digital form or as hardcopy are a result from stereoprocessing aerial photos.

2.5.2 DTM and Volume Calculations

In many cases also volume calculations are required. Therefore updated data from aerial photos are used for digital terrain modelling.

Volumes can be calculated as a difference between old and new model or new model and a defined plane. The result contains information of cut and fill volume and also cut and fill area.

The delivered form can be a digital terrain model, a string file, a file with 3D triangles, 3D DXF, or just a text file with point co-ordinates and information about edges.

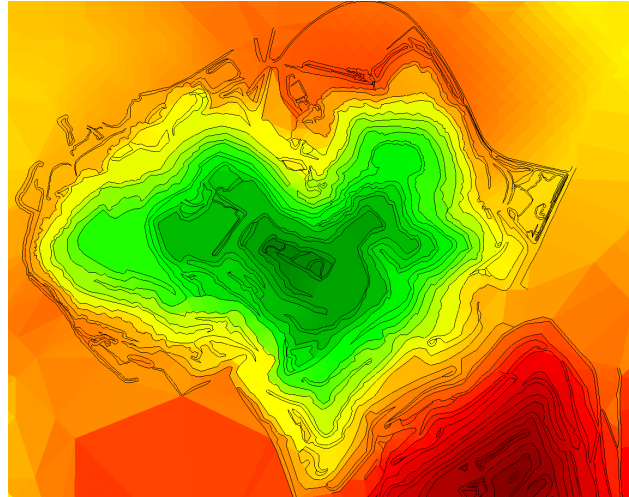


Figure 2. DTM represented by hypsometry

2.5.3 Information systems of mining companies

Nowadays, many companies recognised the advantages of information systems for the monitoring and planning of their mining activity. However, the market of information systems is very wide and still not well standardised. Special systems tailored to the companies' needs can bring problems during a data integration.

Updated vector data from aerial photos, DTM and orthophotos in mosaics can be used in the information system for analyses of the open pit mining development, animations, simulations and archiving.

2.5.4 Planning

In the case of planning the mining activities, digital terrain models are crucial. 3D modelling can show real views of the quarry or mine, how it looks from different places, what the influence of mining to the nature and mine surrounding is. Also 3D flight over planned situation and other various visualisations can be done.



Figure 3. 3D view at the open pit

3. WORKFLOW

After the project preparation mentioned above including the discussion about formats, accuracy, and necessities of deliverables, flight planning and taking the photos, the work itself starts with the checking of the received data, especially

CDs or DVDs with photos. These media are not so reliable and often files are not readable. If the amount of data is huge, replaceable and more reliable hard disks are used.

The first step in the photogrammetric software is setting up the new project. The calibration protocol file has to be created in a form according to the software needs. Then other input data have to be set, e.g. an attachment of the photos, scanning resolution and scan position of photos, the average flight altitude or the average terrain height, the file with co-ordinates of GCP with accuracy, the file with co-ordinates of projection centres and roll, pitch and heading from GPS/INS system with accuracy as well, definition of strips and blocks, corrections like atmospheric refraction, earth's curvature and lens distortion and information about used units.

Usually many photos are taken in a project even in several strips. Therefore the method of aerotriangulation is used to save a number of ground control points. Neighbouring photos are connected by so-called tie points which are searched for in the triple overlap of the photos. Therefore the overlap between two photos should be 60% at a minimum to get a suitable triple overlap (20%) between every three following photos. The tie points can be searched for also automatically. The information about co-ordinates of projection centres and rotations is a very big help in the automation of tie points searching. The GCP have to be picked up exactly on their position on the photos. All co-ordinates of measured GCP and tie points with external orientation parameters from GPS/INS, whether automatically found or manually measured, are used in adjustment – usually the bundle block adjustment method. A result from aerotriangulation includes adjusted values of external orientation parameters, adjusted co-ordinates of GCP and tie points with mean square errors to consider an accuracy.

Afterwards, the epipolar pairs are created to reduce the effect of vertical parallax and enable better stereoviewing. The work in stereomode includes drawing new lines and points, deleting old ones, moving, splitting lines, trimming and other operations. A correct interpretation can be worsened by shadows and a low contrast between crest and toe and plane areas. Therefore, software tools include usually a function of gamma corrections and a change of brightness and contrast at photos “on the fly”.

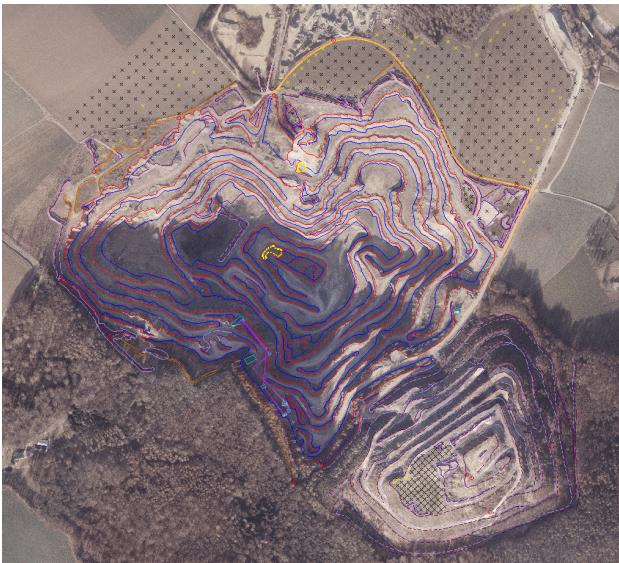


Figure 4. Example of shadows on orthophoto combined with vector data

For the creation of orthophotos, the raster points from automatic correlation are needed to form the digital terrain model. This correlation facilitates to search for corresponding pixels in the overlap of neighbouring photos and to get their third co-ordinate = altitude from their horizontal position on the photos. The digital terrain model is made from correlated points and points, lines and areas evaluated in stereomode. Sometimes buildings and plants are drawn in the height of their roof even though they should be on the ground. Belt conveyors are also not on the ground. Therefore, for the purposes of the digital terrain model the objects which are not on the ground are deleted. Only for the purposes of a real orthophoto, the buildings should be made as cubes or blocks to remove also distortion of them. However, buildings and plants are not so important in the case of the open pit mining.

The colours and contrast can differ from one photo to another. Therefore, a colour balancing is necessary. The last step includes masking and mosaicing the colour balanced orthophotos.

After delivering all outputs to the open pit mining company a very important step follows. This is the sorting of all data and saving all important information on CDs, DVDs, hard disks and/or servers.

4. CONCLUSIONS

Even though a suitability of the use of photogrammetry in the open pit mining compared to the conventional measurement is still discussed, many examples and projects speak about its advantages, e.g. the economic view especially in saving time for processing, and sufficient accuracy aspects as well. Also the purchase costs have a more favourable rate with the geodetic equipment. Compared to past times when big analogous and analytic photogrammetric instruments were very expensive, nowadays only fast and powerful computers with software are needed, that could often be obtained at decreasing prices in the last years. Taking photos is still quite expensive, though. But costs can be reduced by an economic flight planning which combines near located open pits in one flight mission. The costs for human power are in photogrammetry lower as well. In the terrestrial measurement usually two people are needed, and during photogrammetric processing only one person.

Therefore photogrammetry is a suitable method even in the case of large scale photos and high accuracy requirements. All these cost reducing aspects suggest the use of photogrammetry in the open pit mining evaluation not only for bigger organisations but also for smaller open pit mining companies.

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