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A DIGITAL CLOSE-RANGE PHOTOGRAMMETRIC TECHNIQUE FOR MONITORING SLOPE DISPLACEMENTS

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Abstract

Deformation monitoring of slope instability and its surroundings supplies important information on the behavior of the slope in that it evaluates whether potential collapse may occur. Monitoring results may also be used in verifying design geotechnical parameters of slopes such as in mines and aid in the calculation of soil mass volume. The development of digital Photogrammetry allows calculation of high accuracy three-dimensional coordinates for points on and around the slopes. A main advantage is that no physical contact with the monitoring body (i.e., to install targets) is necessary, like in conventional land surveying techniques. Given the high spatial resolution of Photogrammetry compared to discrete point monitoring of conventional surveying, it is evident that there is enormous potential for use of this technology in monitoring applications where dense data sets could provide great insight into the nature of slope displacements for risk assessment, volume computation and structural model validation. The paper describes the use of digital Photogrammetry in the slope monitoring and soil volume computation under real conditions. The proposed technique uses digital close-range photogrammetric images and non-signalized control points. The advantage in this approach is that the data processing is applied in a terrestrial photogrammetric coordinate system, i.e. xy-plane in a vertical position, but the products can be generated in a standard 3D Cartesian coordinate system (horizontal xy-plane) as well. Finally, results including 2D maps, orthomaps, 3D photorealistic views and the calculation of the moving soil mass volume are presented.

1. Introduction

Digital close-range Photogrammetry is a measurement technology which is used to acquire 3D spatial information about an object that is captured on the images. By this means, this technology derives measurements from digital images, rather than measuring the object straight. Photogrammetry offers several advantages over the conventional and well-known land surveying methods. First, it is possible to map objects that are unreachable or too dangerous to reach on foot. Second, Photogrammetry provides a flexible framework in that all data needed to perform the mapping can be achieved almost immediately, enduringly and at a permanent cost with one photographic acquisition. Mapping process can then be implemented at any time thereafter. Cost effectiveness may refer as a third advantage of Photogrammetry in contrast to conventional surveying or geodetic techniques. Finally, Photogrammetry provides several kinds of digital products such as maps, digital elevation models and orthoimages. Due to this capability, digital close-range Photogrammetry is appropriate for a variety of applications, ranging from industry to archaeology, monitoring issues (Kersten and Mass, 1995) etc.

The paper reports on how to use digital close-range photogrammetric techniques in monitoring slope displacements. The most intriguing issue in this approach is that the data processing is obtained in a terrestrial photogrammetric coordinate system, i.e. xy-plane stands in a vertical position, nevertheless the products could be generate in a standard 3D Cartesian coordinate system (horizontal xy-plane) as well.

2. Problem definition

The main question in monitoring issues (NG Tsan-wing and Leung Kin-wah, 2001) is the selection of method that best fits according to the problem definition, i.e. which is the appropriate technology to be used, like conventional surveying, GPS or Photogrammetry. In current case, the aim was the development of a technique that applies in rapid mapping conditions of an unreachable landscape with the minimum effectiveness in cost and time.

Inevitably, land surveying methods were rejected as well as the aerial photogrammetric mapping due to time restrictions. Thus, the selected technique bounded in close-range photogrammetric conditions while the accuracy of Photogrammetry is more than adequate to evaluate slope displacements, quick enough inside time limitations and not so expensive.

The goal of the project in the open lignite mine was the photogrammetric mapping of the area undergoes slope displacements and the development of a series of products (maps, orthoimages, volume calculations etc.) in order to provide the optimum and overall information for the problematic area. The total area range was about 30000 m^2.

3. The proposed technique

The preferred methodology reports this paper consist of well-known steps in the photogrammetric research. However, interesting issues are signalized all over the description of technique’s steps.

3.1 Image acquisition & manipulation

The photogrammetric accuracy is dependent on image scale so large slopes must be monitored using overlapping frames. Overlapping images acquired with the metric camera Rollei 6006 of 6 cm x 6 cm frame format and focal length of 150 mm. Special care was undertaken so as the horizontal image angles be of small values. This is a fundamental restriction imposed by the structure of the Digital Photogrammetric Stations which are used for photogrammetric mapping. Wide angles between stereo-pairs do not permit stereoscopic view and as a consequence calculations and three dimensional restitution.

Fig. 1 illustrates the mosaic of images which shows the area of the mine that suffers from displacements. The area under investigation is bounded by the heavy line. The nine images that were used in the project have been acquired from a mean distance of 500 m and as a result the mean image scale was about 1:3000.

The original images where magnified by 3 so that photogrammetric restitution be easier, and scanned in 300 dpi which refers to 900 dpi in the original acquisition. Pixel size in this resolution refers to 28 μm which is an accuracy of 8.5 cm on the ground. The resolution of 8.5 cm was sufficient for the expected accuracy of 10 cm in the scale of 1:1000 which was set as the reference production scale.

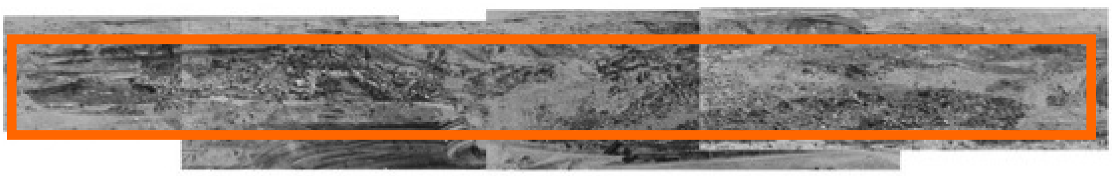


Fig. 1. A mosaic of the acquired images

3.2 The coordinate systems

A local Cartesian coordinate system was developed in the area of interest through geodetic measurements in order to establish photogrammetric control (Fig. 2) for close-range images and to provide a consistent reference system for future work studies.

Due to close range photogrammetric conditions, the original coordinate system was transformed in a new setup where the horizontal plane xy-plane appears now in vertical direction and z-axis direct through the camera axis. Fig. 2 presents the arrangement of the original Cartesian coordinate as well as the transformed coordinate system which is aligned to the needs of Photogrammetry.

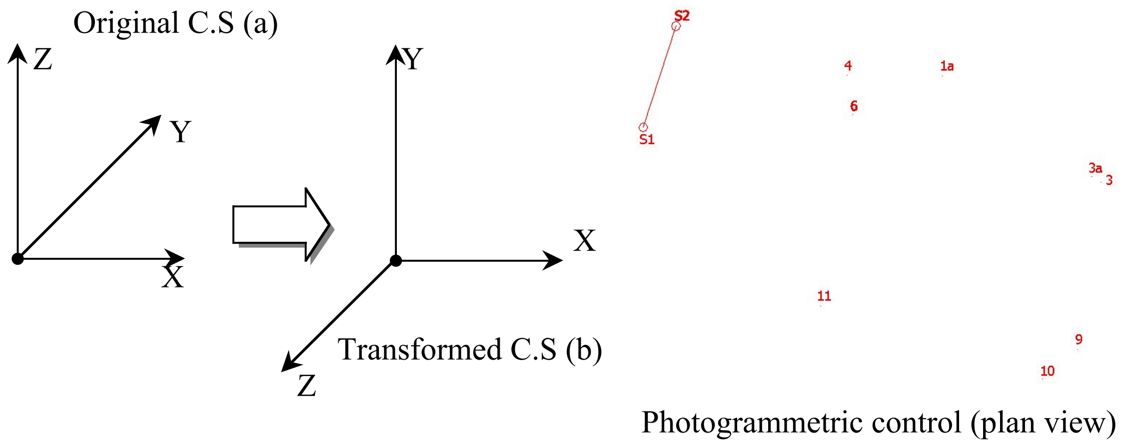


Fig. 2. The coordinate systems & the photogrammetric control points

3.3 Image orientation - Triangulation

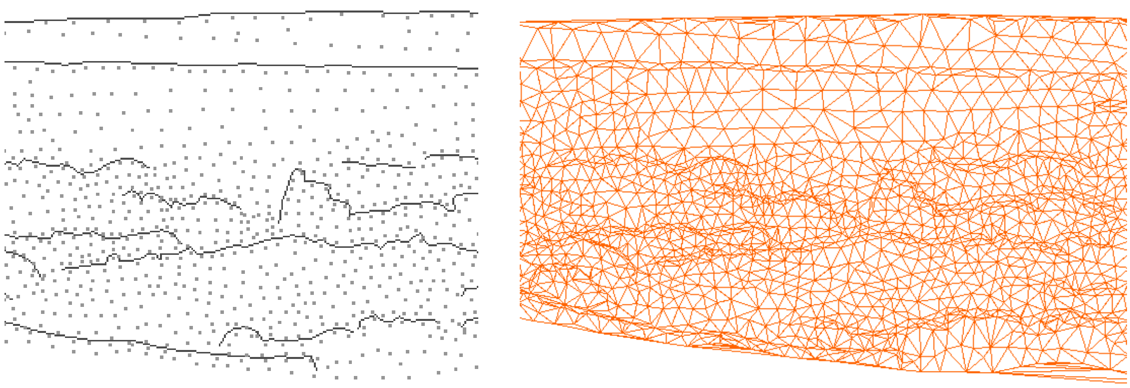
Image management follows the standard approach; starting from the interior orientation, then to relative orientation and finally through triangulation to the determination of the exterior orientation. Each stereo pair is relatively oriented and each one is tied with the previous one. This way the relative model of all the images is more stable. At last the performance of a photogrammetric block triangulation (Tsingas, 1992) leads to the definitive setup of the models.

3.4 DTM/Ortho generation

The Digital Terrain Model (DTM) of the study area extracted from side to side collection of manual mass points (Fig. 3a), while joining all the parts from stereo models the total surface model is generated. The DTM points were extracted with accuracy better than 10 cm. An automatic process for DTM generation (Krzystek, 1991) was not applied successfully.

A TIN is produced from the primary DTM mass points (Fig. 3a). An example of the TIN model from the mine area is presented in Fig.3b. The TIN that appears in the figure concerns the original coordinate system (i.e. (a) in Fig.2). Implementing the appropriate transformations the TIN model can be formed in a representation related to the transformed coordinate system which is easier to be handled in surveying or geodetic measurements. Similar results refer to the transformed coordinate system are presented in Fig.6.

The orthoimage of the study area was generated using the area surface model and the four (from nine) externally oriented images. The four generated orthoimages were mosaic to produce the final output which is shown in Fig.4. The final orthoimage was not feasible to be formed concerning the transformed coordinate system due to the lack of original images from an aerial point of view.



(a) (b)

Fig. 3. (a) Breaklines & DTM points, (b) the TIN model

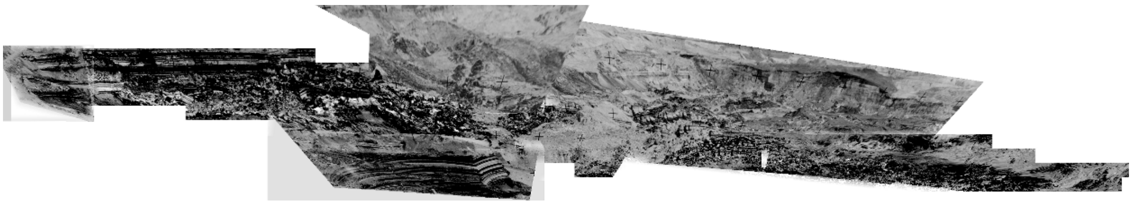


Fig. 4. The orthoimage of the study area

3.4 Three dimensional (3D) restitution

Digital Photogrammetric Stations (DPS) are integrated systems that are increasingly used in photogrammetric production (Gruen, 1991). Through a DPS is possible to map all the cartographic and terrestrial characteristics features presented at least on two images. Mainly, in cases where deformation mapping is under investigation, the restitution of descriptive elements such as inclined slopes, movable soil mass etc. is a fundamental need.

In the case study of an open lignite mine where huge masses of soil are under continuous movement the restitution of crucial boundaries and inclined slopes is of high priority. The

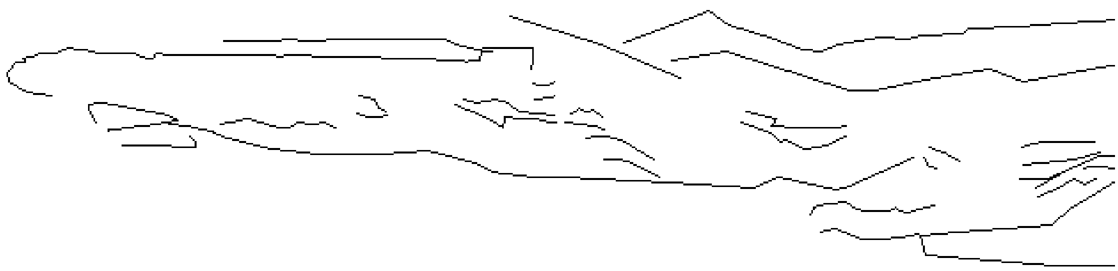


Fig. 5. 3D restitution of significant soil boundaries

conditions within the displacement phenomenon are risky enough and special care must be taken in the precise mapping of vital cartographic features. The inclined slopes within the area of interest are illustrated in Fig. 5.

The restitution products which are basically maps can be generated also in the transformed form like the one presented in Fig. 6. Like in the case of DTM collection, the 3D restitution process was implemented with accuracy better than 10 cm.

3.5 Calculations

The occurrence of a detail DTM with a grid size of 0.5 m (accuracy better than 10 cm) give the chance for an accurate valuation of the inclined soil masses within the area. Using two different methods for volume computations, i.e. Trapezoidal rule, Simpson's rule, the essential lignite soil masses above a specific elevation (the range of Z values was approximately 100 m) where calculated and the results were very close to the real situation as presented by the geologists.

3.6 Products

A series of products have been produced in order to have a sphere-shaped approach for the suffered area. All the suitable information and products were generated in order to be given in geologists and geotechnical engineers for a wide and more attentive study of the problem.

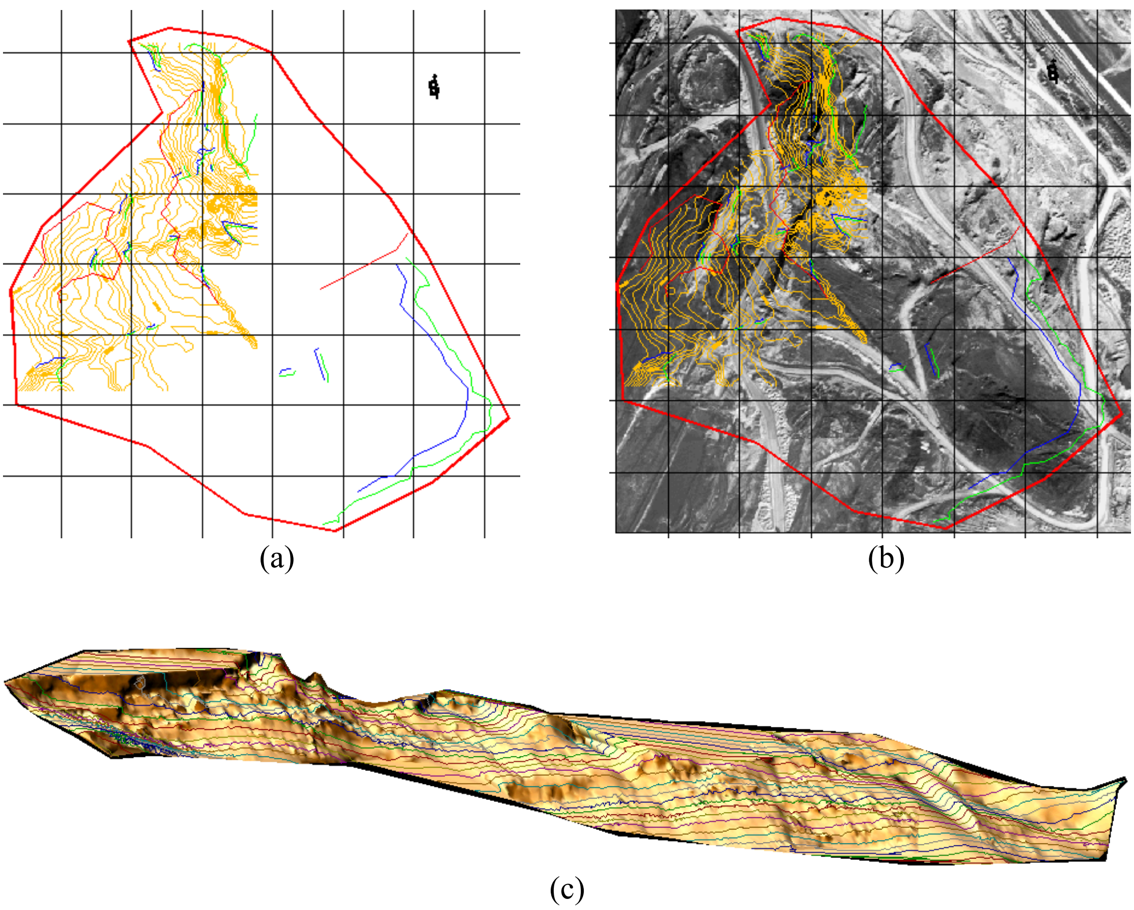


Fig. 6. (a) Boundaries of the study area including contours in plan view, (b) the situation presented in (a) superimposed to previous orthoimage and (c) photorealistic view of the study area

To give an indication of the products, three figures are presented together. In Fig. 6a the boundaries of the study area are offered in addition with the contours (contours interval is 2 m) concerning the transformed coordinate system as described in section 3.2, while in Fig. 6b the same cartographic situation is superimposed over prior orthoimage. To give an illustration of the overall view in slope displacements area, a photorealistic representation of the terrain model covered with contours is given in Fig. 6c.

4. Discussion - Conclusions

Photogrammetry is a valuable tool for monitoring dynamically moving landslides and for analyzing the whole behaviour and trend of soil masses. One may apply photogrammetric methods in the use of archival images to detect and determine displacements over long period of time. Under these circumstances the only restriction is the provision with a satisfactory number of well-defined points on a stable ground.

Normally, field surveys are more accurate than photogrammetric measurements; nevertheless they involve more personnel and need recoverable points that will not be troubled between various surveys. Additionally, one is not able to acquire extra points to fill areas that appear to have a particular interest.

The general use of Photogrammetry in this kind of research can be focus both in two and three dimensional analysis. The range of products that Photogrammetry provides is extremely useful for a complete analysis of deformations in an area that suffers from, like in the presented case study of the open lignite mine. However, the quickness and precision still remains for Photogrammetry the most powerful advantages.

The paper reports the use of digital close-range Photogrammetry in monitoring slope displacements. An integrated technique, within specific time limitations, was developed and applied under real conditions in a mine and the extracted results and products presented in the paper.

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