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PHOTOGRAMMETRIC ANALYSIS OF OBJECTS IN UNDERMINED TERRITORIES

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Abstract. The Institute of Geodesy and Mine Surveying of the Technical University of Ostrava performs long-term monitoring works and evaluates the effects of undermining in the Ostrava-Karviná coal-field, a major industrial conurbation in the north-east of the Czech Republic. Local extraction of bituminous coal has had significant effects on the surface relief. Actual undermining effects are monitored on selected built objects on a regular basis. Some of them are public buildings, roads, listed historic monuments, and buildings of cultural or historic value. Damage to the buildings, etc. can be eliminated to some extent by prudent planning of extraction works in space and time and by applying appropriate protective measures.

Keywords: terrestrial photogrammetry, calibration, 3D modelling, measuring, scanning.

1. Introduction

Selected locations of the Ostrava-Karviná coal-field are equipped with monitoring stations, like triangle chains, polygonal networks and monitoring lines. One can therefore record the depressions and displacement at each point as well as determine the direction and size of principal tilts and deformation as they occur. Points for regular vertical measurements are located on the built objects (brass spikes). Historic monuments deserve special attention. Many have suffered significant damage from extraction works and minequakes. Some are only known thanks to photographic archives. But a majority of them have been reconstructed or are on waiting lists for renovation.

Photogrammetric documentation provides important input as to the current condition of the buildings being examined or when restoration or rehabilitation works are planned. Photogrammetric images have a significant documentary value for studies into the process dynamics and provide better value than standard maps. Photogrammetric output includes, inter alia, 3D models that can be enhanced by adding real textures. A built object can be analysed from every angle or depicted as a stereo image. Photogrammetric projects can be exported in a number of formats for further processing and their potential can be used to the full, including that for visualizations and animations.

Outstanding monuments in the Ostrava-Karviná coal-field have been subject to geodesic and photogrammetric surveying. Some of them are the Church of St. Peter from Alcantara in Karviná-Doly; the Augsburg Protestant Church in Orlová; the Mary Magdalene's Church in Stonava; St. Ann's Church in Polanka nad Odrou; St. Barbara's Church in Louky nad Olší (Fig. 1); the road in the area of Doubrava; public buildings in Žolnov, etc.

Fig. 1. Surveyed churches of the Ostrava-Karviná coal-field

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2. Methods of measurement

2.1. Geodesic surveying

Surveying works rely on geodetic points located near the limits of undermined areas. We used trigonometric points No. 2, 4, 12, 15, 39 and 34.2 that form the vertices of a hexagon and are located outside the coal extraction impact area. The stability of the hexagon is under constant monitoring using a static GPS method. Monitoring points were set up in the road axes and in perpendicular lines to them to monitor the effects on roads in the Doubrava area. The elevations of the monitoring points were determined by trigonometric levelling and geometric levelling using the TOPCON GTS-6A electronic station and the TOPCON DL 101 digital level. The data includes displacements at points, road section axial and cross tilts, curve radii and terrain horizontal displacements.

Geodesic and photogrammetric methods were applied to evaluate the undermining effects at Žolnov. The basis for evaluation consisted of aerial photographs taken before the start of coal extraction and as the works progressed. Geodesic surveying included horizontal and vertical measurements of the monitoring station, i.e. the triangular network, the deformations of power line posts and the displacements of built objects. Aerial photography helped locate the control points, surface break lines, road edges, building feet, lakes, forest lines and surface points forming a 20 by 20 m grid (Fig. 2).

Monument buildings are localized by means of a polygonal network and by brass spikes. Exact elevation measurements have been made since 1995 on a regular basis to evaluate the depression and deformation parameters that describe undermining intensity in technical and legal terms as per ČSN 730039. Another parameter under survey is the vertical deviation of the church's outer walls. The measurements were made in two more or less perpendicular lines of sight: along the portal wall and along the side walls.

Naturally visible ground control points were identified in the polygonal network to define the model scale and rotation. Part of the marking system are the coded marks that serve automatic point identification and measurement. 3D models were related to the coordinate systems either using groups of three points or by determining the starting point, the axes and the scale of a coordinate system (derived from a known length). The polygon network points and the ground control points were surveyed with the Leica TPS 1200+ Total Station with an integrated GPS receiver. The station's scanning module was tested on a set of selected terrain and building samples.

Elevation data gained by exact geometric levelling were related to the OKR coal-field levelling network that must be checked against the reference points of the national levelling network located outside the subsidence area every three years as a rule.

2.2. Photogrammetric surveying

Images of the monument buildings were taken by a pair of digital cameras: the professional-class reflex camera Fuji FinePix S2 Pro with a Super CCD chip and up to 12.1 megapixel resolution (4.256×2.848); and the Canon EOS 30D with EF-S 17-85 mm lens and a resolution of 8.2 Mpix (3.504×2.336). The cameras had been calibrated by means of the PhotoModeller and MATLAB software. The PhotoModeller Scanner software by EOS System Inc., Canada, was used to create the 3D model. The Scanner version of the software is good for evaluating rather complex surfaces on which identical reference points are difficult to find, such as terrain, slopes, rocks and stone walls. The software is also suitable for surveying built objects without reflective surfaces or monotone fresh paint. The photogrammetric surveying of the churches was made in 2009 and 2010.

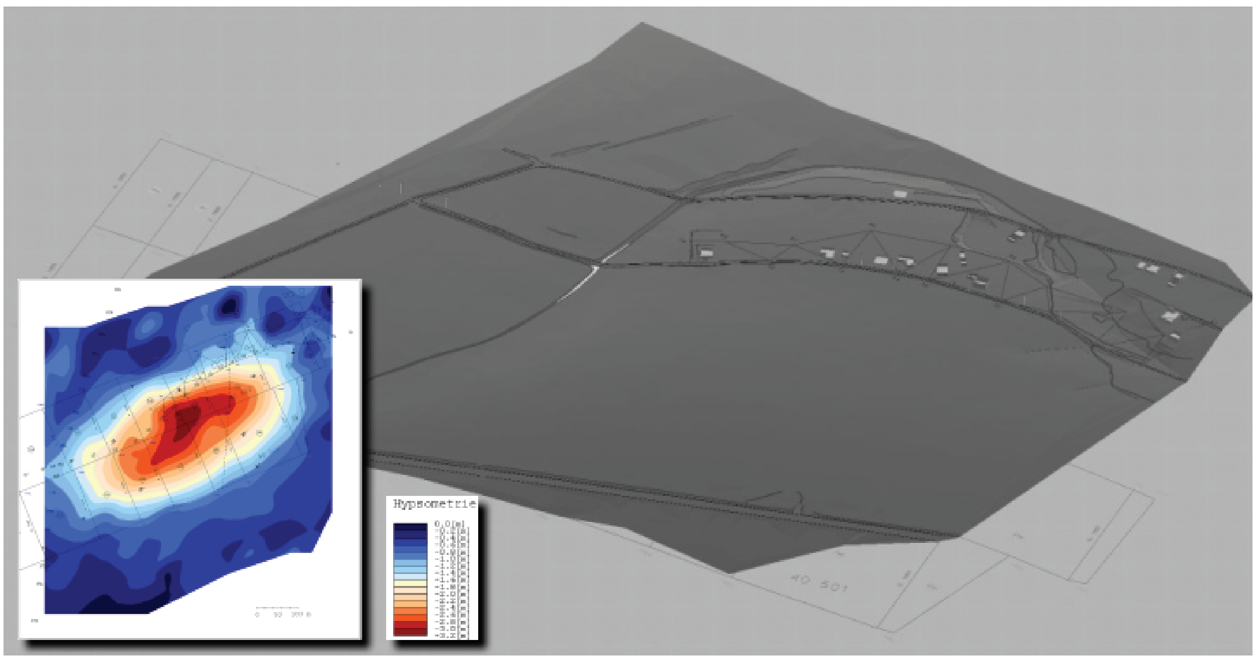

Fig. 2. Surface digital model derived from aerial photography, hypsometric depressions

The terrain digital model was developed from aerial images by means of the ATLAS DMT software. Selected details of the buildings were processed in the form of aerial photographic plans using the TOPOL xT 9.5 DMT software. Due to the complex vertical topography of the buildings, the method is constrained by deformations in aerial maps.

3. Descriptions of selected monument buildings

St. Peter's Church (Loc: 49°50'3"N, 18°29'20.999"E) is a unique witness to the history of the effects of coal extraction from their very beginning. Situated in the cadastral area Karviná II-Doly alongside the Ostrava-Karviná road (Fig. 3), it finds itself inside the area affected by the activities of two collieries: Československá armáda and Darkov. The baroque church was built in 1736. Coal extraction started in 1854 and 27 seams with a combined thickness of 46 m have been extracted from underneath the church making it sink 32 m and tilt 6.8° toward the north. While coal extraction began in 1854, early mining effects had not become visible until 1891, the date of the earliest written records of mining below the church. The original spire was pulled down during the church reconstruction in 1935. The next round of repairs followed in 1969 including the levelling out of the floor tilt that had reached up to 70 mm per meter. The latest renovations date back to 1994–1995 when a static stabilisation and general repair of the building were made. Minor landscaping and remediation works were done around the church in 1999–2000 (Gavlovský *et al.* 2005). Geodesic surveying from 1995–2009 determined that uneven sinking of the building continued in lengthways and transverse directions. The church survived coal extraction from rather shallow depths of 300–400 m below the surface. This gives us hope that the current fading aftereffects of coal extraction at app. 800 m below the surface may not pose an existential threat to the building.

The foundation stone of the Protestant Church in Orlová (Loc: 49°50'45.74"N, 18°26'23.63"E) was laid in 1861 and the church was consecrated one year later (Fig. 4). The brick building was designed in the late Classical style with a single ship and a spire that was altered later. The frontage is rather articulated with many cornices and rosettes. Showing visible undermining effects, the church has been rehabilitated several times. Significant damage was caused by minequakes. The latest large-scale rehabilitation was carried out only in 2005, stabilising the structure by applying modern technologies and renovating the frontage.

Fig. 4. The Protestant Church in Orlová before and after renovation. Photos courtesy <www.sceav.cz>

4. Creating 3D models and point clouds

The actual imaging process was preceded by the camera calibration using 2D and 3D test fields. The A3-A0 sized 2D fields were based on PhotoModeller v. 6. The results were summed up in the calibration protocol listing the internal parameters of both photo chambers (stadia constant, principal point, lens distortion, etc.). Focal distance, shutter and focus were set at fixed values during the calibration process. A tripod was used and the lens was manually focused to a specific distance. Digital device practical testing and calibration was made by means of the 3D model of the surveying observatory at the Institute of Geodesy and Mine Surveying (Fig. 5) that consists of 24∅50 mm round marks. Geodesic surveying of the point marks was made and the points were related to an autonomous grid to calculate their respective X, Y, and Z coordinates (Linder 2006). A suitable test field was identified on the basis of the process total error and residual error.

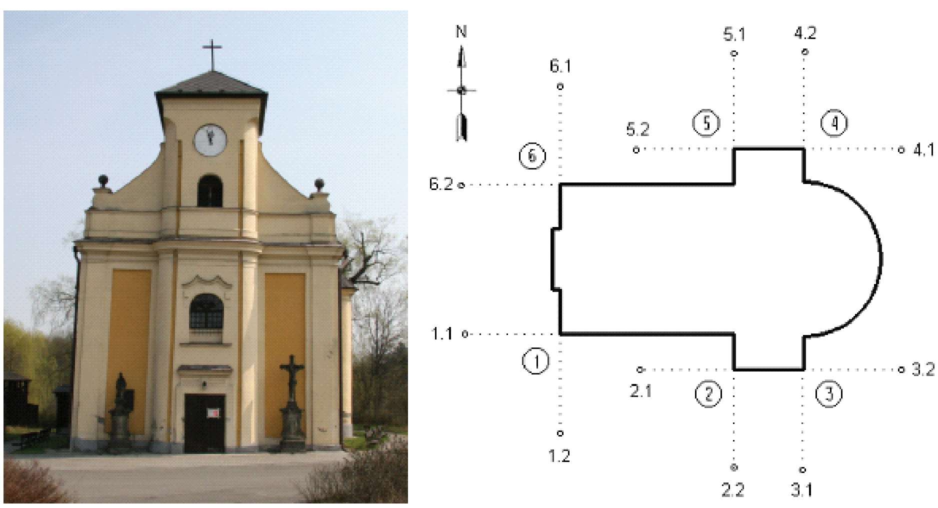

Fig. 3. St. Peter's Church in Karviná, vertical tilt measuring system

The audit dialog provided a prediction of the calculation success. A second check calibration was made by means of a series of photographs of a chessboard-like field consisting of 10 by 10 white and black 5 cm squares. The data were fed in the MatLab software.

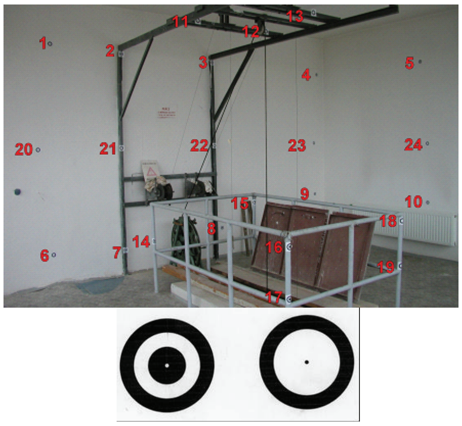

Fig. 5. A 3D field and ∅50 mm round marks

Code marks from the PhotoModeller Scanner software were attached to, or close to, the objects surveyed where possible. They are quite helpful in the process of the automatic orientation of images and for high-accuracy point-by-point surveying. Different sizes and versions of the code marks can be printed out to suit a wide variety of project scopes. The diameter of the bull's eye in the middle of the mark is crucial. A variety of mark sets and sizes must be at hand depending on the distance of the camera from the object surveyed.

In our case, 12-bit RAD coded marks were used. A white bull's eye on a black background proved to be the better choice where total stations were to be used (Fig. 6).

Fig. 6. 12-bit RAD coded marks

A convergent imaging method and a parallel imaging method were used to survey the objects in this case. The two axes used in convergent photogrammetry should be more or less perpendicular. Where this is not possible, the angle between the imaging axes could be less (no less than 30°). But sharp angles are detrimental to the accuracy of the resulting model. The camera should sit on a tripod, be set to maximum resolution and be activated by a self-timer. Having set the scale and orientation of the model, 65 control points were measured on the church objects by means of the total station and the points were related to a local coordinate system. We shot 37 images of St. Peter's Church and 45 images of the Protestant Church in Orlová, each with a resolution of 3,504×2,336 pixels. The imaging was made in winter to suppress distortion by vegetation.

4.1. Convergent imaging

The next step was to replace real images by idealized ones. Thus pictures were drawn up on the basis of the camera calibration data in which distortions were eliminated (Fig. 7). The re-drawn images are suitable for adding textures and to create dense fields of points. Further steps are:

- Automatic identification of marks and signal points;
- Orientation of images;
- Relating to a coordinate system;
- Detailed evaluation of convergent images using vectors;
- Adding textures;
- Data export, e.g., animation, VRML Google Earth, or numerous other formats.

A combination of a 3D model enhanced with real textures and geometric data maximizes the information yield. A 3D view can include camera positions with lines of sight to the control points or mean error ellipses. Setting the image planes will visualize the lines of sight and each image will be put in the corresponding camera position. The method provides a perfect visual check of the entire surveying process. Where parts of the object are

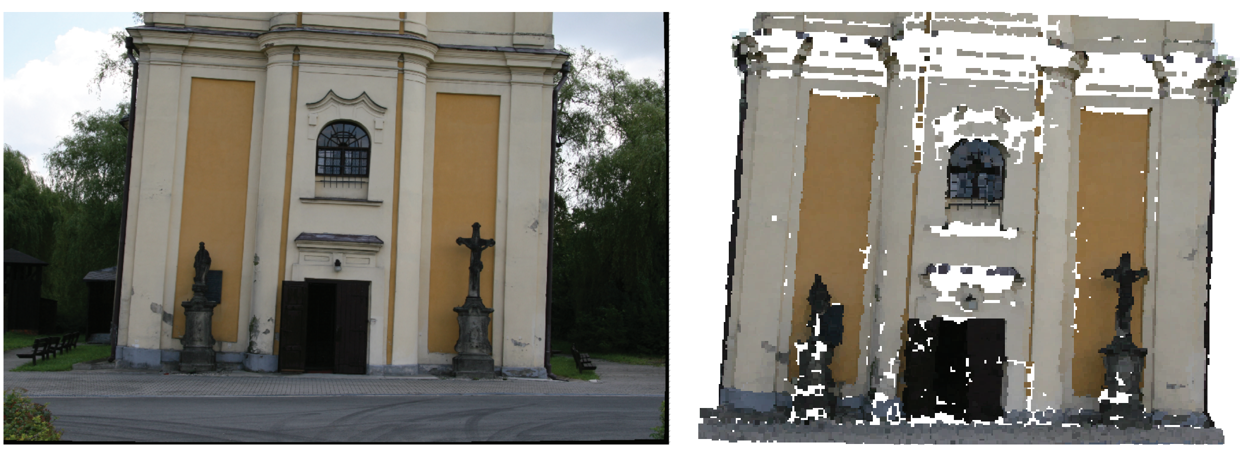

Fig. 7. Idealized image, a point cloud

obscured by greenery or other objects, a different imaging station can be used or a freely invented texture can be applied. The 3D model accuracy m_{XYZ} is up to 2 cm.

Fig. 8 shows a photogrammetric image of the Protestant Church in Orlová combined with a vector drawing and with a model indicating the camera positions and lines of sight. Fig. 9 shows the vector model of the baroque church in Karviná.

Export to Google Earth in the KML or KMZ format is certainly an attractive option. Export to Google Earth requires GNSS coordinates of three points in each image. The model will then be shown at relative height or it can be "pegged to the ground" or the position can be manually adjusted to correspond with the real world (Fig. 10).

An animation can be created by exporting a model and by adding a sequence of key images to the 3D view. A well-done and smooth sequence can be achieved by further optimizing the avi-format export file.

Fig. 8. A 3D model of the Protestant Church in Orlová

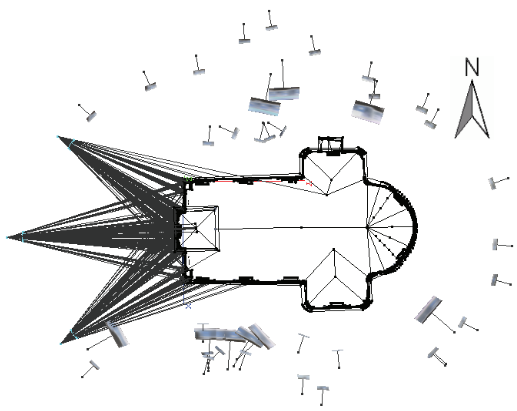

Fig. 9. A 3D model of the baroque St. Peter's Church in Karviná

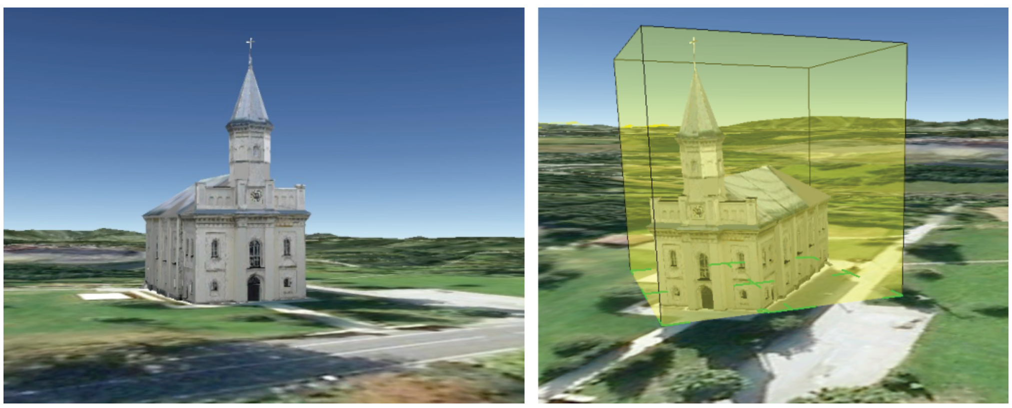

Fig. 10. Export of a 3D model in Google Earth, position adjustment

4.2. Parallel imaging

Parallel imaging with 60% overlap was used to generate automatic digital surface models (DSM) consisting of a point cloud (Fig. 11). This is a way of replacing a complex manual generation of models from points and lines. An area for a point field is defined in the image and a calculation is made on the basis of pairs of images. The object is then placed in a coordinate system and DSM planes are generated. Parameters to set, include the point field density, the definition of an area and the matrix radius in pixels. The result is a dense point field that needs optimization. The point field is converted to a triangular network with a texture. The next step of optimization aims at reducing the number of triangles by app. 70% and then the model is smoothed out.

Where terrain is the object, contour lines can be created. Where the surface lacks features, the points can wander away from the area of scrutiny. The effect is called "signal noise".

4.3. Single-image analysis

Single-image analysis was used to depict selected details of the churches and of the tombs of the Staněk and Forner families at St. Peter's Church in Karviná. Where possible, images were made using horizontal lines of sight that were perpendicular to the object face. Single-image photogrammetry is limited by the deformation of the photographic plan due to surface complexity of the object. The photogrammetric images were transformed to obvious control points like window corners, window-ledges and other facade details. The photographic plan was made by digital rewriting using the TOPOL xT 9.5 DMT software (Fig. 12).

Fig. 11. A point cloud in PhotoModeller Scanner.
A sequence of point cloud, triangle net and texture

Fig. 12. A photographic plan of the facade, the tomb
of the Staněk and Forner families

5. Conclusions

Monument buildings in undermined territories are exposed to extreme stress from coal extraction works. Many have been refurbished or are on the waiting list for renovation. Such objects require regular attention and a painstaking documentation effort to preserve the heritage for the generations to come. Geodesic surveying made on a regular basis enables us to keep track of and evaluate displacements and deformations of the terrain and buildings. The damage can be mitigated by applying suitable protection measures. Photogrammetric methods can provide data for analysis and restoration planning, refurbishment, dynamics studies, historic and technical research. New developments in the areas of geodesy and digital photogrammetry hold a great potential if used for the visualisation and documentation of historic monuments.

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