

GEOREFERENCING OF CLOSE RANGE PHOTOGRAMMETRIC DATA

Aleksandra Bujakiewicz¹, Piotr Podlasiak², Dorota Zawieska³

^{1, 2, 3} Department of Photogrammetry, Remote Sensing and Spatial Information Systems,
Faculty of Geodesy and Cartography, Warsaw University of Technology
Pl. Politechniki 1, Warsaw, Poland

¹ abujak7@wp.pl, ² ppodlasiak@wp.pl, ³ dorotaz8@wp.pl

KEY WORDS: Indirect georeferencing, Orientation, Integration of data

ABSTRACT: The paper presents some general approaches for indirect georeferencing of close range photogrammetric data being acquired for various applications by the imaging systems of different types either independently or in integration. Various digital metric or non-metric cameras and terrestrial laser scanning systems, which register the objects to determine their shape and location, can be located either on the MMS moved vehicles or on the terrestrial stable stands. Various factors, such as objects' location, dimension and shape as well as the form of data required and type of the photogrammetric imaging systems have the major effect on the approach to be used for georeferencing of photogrammetric data.

In case of dynamic collection of imaging data, direct georeferencing is required. In this case, the GPS/INS systems of adequate accuracy for direct georeferencing of registered data, have to be ensured. Such systems allow to orient all collected data (cloud of points or discrete points for the objects) in the uniform coordinate system which can be later re-transformed to the final reference system in post processing stage.

In case of imaging by the conventional metric or non-metric cameras located on the terrestrial stable stands, indirect georeferencing of data is usually executed in the post-processing stage. In many of close range applications, data collected by one or more photogrammetric acquisition systems located in various positions around the object, are integrated. This requires determination of orientation of all sets of photogrammetric data in the same reference system, which for close range applications is usually arbitrary selected. The indirect georeferencing approaches of close range imagery data require always a few control data, mostly points, either for a block of images or for each separate image/model. The methods are classified into two general groups: (1) multi-image exterior orientation, including self calibration, for orientation of images of similar or different scale and geometry taken by the metric and/or non metric cameras, in simultaneous adjustment of all photogrammetric data, and (2) the sequential. orientation of each image or model. The spatial location of control data for orientation of the block or separate model / image is determined either by the field survey or from the set of data already georeferenced, which were collected earlier by close range photogrammetric methods. In this paper, some approaches of indirect georeferencing of photogrammetric data for the selected objects, obtained only from imagery taken by metric and non-metric cameras or in integration with data from terrestrial laser scanning, are presented.

1. INTRODUCTION

Since many years close range photogrammetry methods have been used in various application areas. However, within the last years, due to rapid advances in electronics and automation, the imaging and data processing technics have been extremely diversified. To satisfy the needs of variety of close range applications, different imagery systems and large

number of processing approaches are used. Each area of application deals with the objects of various general characteristics, such as, dimension, shape, stability, location, environment, accessibility and also a very specific such as, type of material, number, size and complexity of details, and many others. Data which used to be determined by close range photogrammetric methods can be classified into shapes, deformations or displacements of the objects or their parts and also their relative spatial location. The required accuracy of these data depends on the object size and shape and complexity of features. To fulfill the accuracy requirements, not only one single approach but a few integrated methods are very often used. They are based on different types of images taken by the metric or non-metric cameras or/and on huge sets of data collected with the terrestrial scanning system. All acquired source data have to be oriented in respect to the reference coordinate system, either during the acquisition process (direct georeferencing), or in the post processing stage (indirect georeferencing). Direct georeferencing of source data requires the imaging systems to be supported with the precise GPS/INS integrated devices to provide the high accurate exterior orientation of all collected data. Indirect orientation of imagery requires some control data in the reference coordinate system to determine the exterior orientation parameters in post-processing stage. The aim of this paper is to discuss various approaches for exterior orientation of imagery data to ensure the proper accuracy for their indirect georeferencing.

2. ANALYSIS OF INDIRECT GEOREFERENCING APPROACHES IN CLOSE RANGE APPLICATIONS

For documentation of close range 3D objects (architectural archeological or industrial), data bases with different forms of photogrammetric data, such as digital vector data, orthoimages or digital 3D object models, are usually required for the entire object and/or their parts and all these data have to be referenced to the same coordinate system.

Following development of aerial photogrammetry, digital methods have been also implemented to close range photogrammetry. Conventional optical close range cameras were replaced by digital cameras, mostly non-metric and also the terrestrial scanners have become very popular data acquisition systems. Data from both type of systems are integrated and and/or complemented. However, implementation of the close range modules to digital photogrammetric workstations, for processing of close range imagery, is much slower as it would be expected. Modules for processing of aerial photography do not satisfy all specific requirements for compilation of close range photographs. They can be only used when geometry and orientation of terrestrial photography are similar to those which are applied in aerial photography. This means, that definition of interior orientation parameters and model of distortion as well as orientation of photographs due to an object, can be accepted.

The post processing georeferencing of imagery data is executed in various ways. The most general solution – multi-image exterior orientation is used for simultaneous georeferencing of a block of images. When photographs are taken with the terrestrial metric camera, oriented in similar way as in aerial photography, the conventional aerial photography modules can be used for image measurement and processing. Such case is shown in the project carried out for architectural inventory of the cathedral church in Radom, Poland [Lisowska, 2007]. For the whole object, 80 digital photographs (with

stereo-pair orientation) were taken with the metric camera Hasselblad 905SWC (equipped in Ixpress V96C) from the camera stations located on ground and the elevator. Examples of photographs are shown on figure 1.

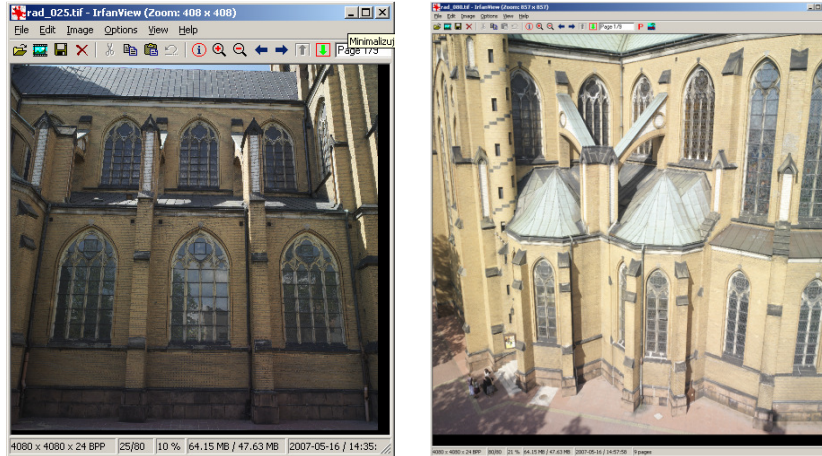


Fig. 1 Photographs taken from ground station (left) and the elevator (right).

The coordinates in the reference system of large number of control and check points around and on the object were measured with survey methods (of 0.01m accuracy). The image coordinates of all control, check and tie points were measured in stereo-mode with the Dephos workstation (fig. 2).

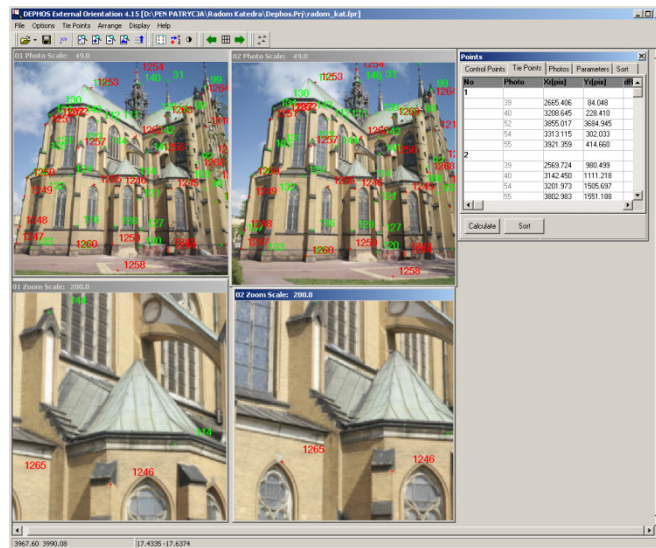


Fig. 2 Measurement of image coordinates for control, check and tie points in stereo mode with Dephos workstation [Lisowska, 2007]

The exterior orientation parameters of block of 80 photographs were determined in simultaneous adjustment process of multi-image exterior orientation executed with BINGO-F ver.4. The number of 6678 observations for 518 points (control, check, tie) was included in adjustment process. The RMS of residuals for control points and check points were 0.007m, 0.008m, 0.006m and 0.020m, 0.013m, 0.048m, for X,Y and Z, respectively. Using the exterior orientation parameters, in the next step all stereo models for the whole object were reconstructed and the final photogrammetric products in Mapper module of Dephos were compiled. The examples of vector products in CAD format are shown in figure 3.

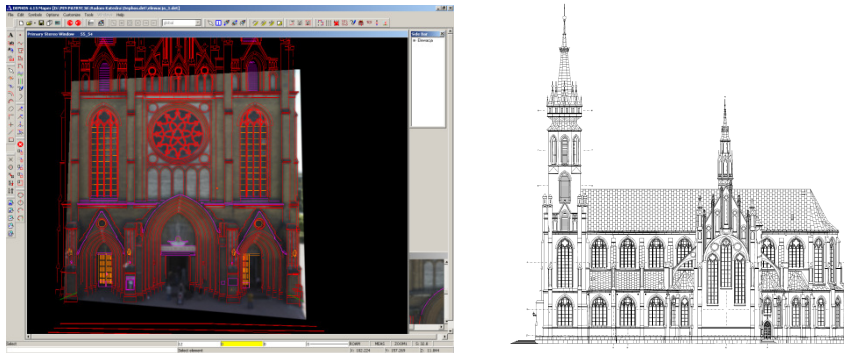


Fig. 3 Examples of vector products for parts of the object [Lisowska, 2007].

In figure 4, the visualized 3D frame model of the whole church, is shown.

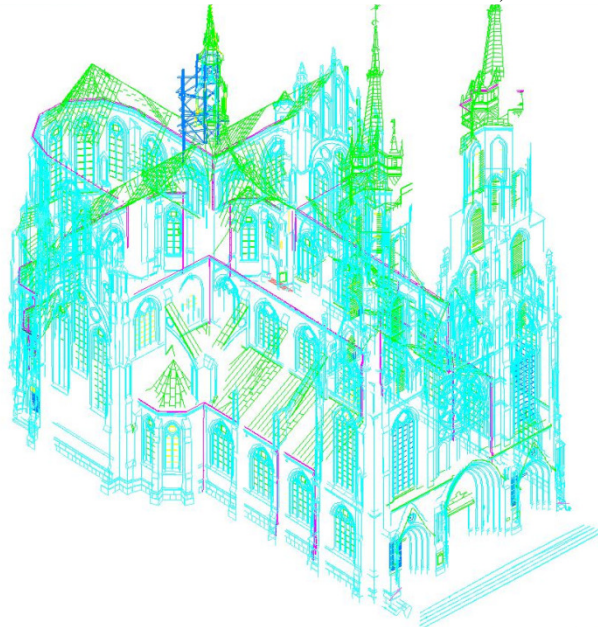


Fig. 4. 3D frame model of the whole reconstructed church

In case when photographs are taken by non-metric cameras, limitations are caused by different geometry of close range images, in respect to their image systematic errors (radial and tangential distortion) and non-stability of interior orientation parameters. The conventional modules of digital workstations do not include the approach of self-calibration process. It means, that the images have to be corrected for image systematic errors in advance. In addition, because of different type and shape of objects, close range photographs are very often taken with much different exterior orientation (angular and linear) than the conventional modules can accept. In some cases, close range photographs for the same object are taken by different type of cameras (metric and non-metric) having not the same spatial resolution and also in various scales (smaller for the entire object and larger for its parts).

In such case the best solution for determination of exterior orientation parameters of a set of photographs is simultaneous adjustment of all image observations in selfcalibration-multi-image exterior orientation process, which can also include interior orientation and image systematic errors as unknown [Habrouk, Faig, 1996; Sawicki, 2001; Xie et al, 2004]. However, the observations from images of various type (metric, non-metric), different scales and non-typical angular orientation can not be simultaneously adjusted with the conventional modules of aerial triangulation [Bujakiewicz et al, 2008]. The special multi-image exterior orientation module for close range images processing, such as for example in the Orient/Orpheus system, is very useful for multi-image bundle adjustment with self calibration of a large number of photographs with different geometry and pixel dimension and also with different scale and non-conventional overlap. However this system does not have function of stereoscopic observation and automatic matching of tie points. Therefore, there is need to use another system for image stereo observation and/or stereo matching. In case of non-metric images, determination of interior orientation parameters and correction for image systematic errors can also be executed in the separate, ealier process [Bujakiewicz et al, 2006a; Cardenal et al, 2004].

The above approach of multi-image bundle adjustment for set of photographs with different pixel dimension and scale and also with non-conventional overlap was applied to determine the exterior orientation parameters for six photographs taken for the altar in Warsaw' church [Bujakiewicz, Arcisz, Zawieska, 2008].

Two of stereo photographs, covering the entire altar, were taken by the metric optical camera UMK at scale about of 1:200 and subsequently scanned with 14 um pixel size. Four images, covering two symmetrical parts of the altar, were taken by the digital non-metric camera CANON EOS 20D, at scale about 1:40, with 10 um pixel size. All these photos are shown in fig.5.

Orientation of all photographs was carried out by multi-image exterior orientation module of Orient/Orpheus system, which allowed to adjust simultaneously the observation from images with different pixel size and various scales. Homogeneous sub-pixel accuracy of adjustment was reached using this module by weighting of deviations for various points. Some classes for points accuracy due to their type and imaging scale were distinguished. Set of commends caused the suitable deviations to be assigned to the particular groups of points. During the adjustment process, these deviations can be changed due to final acceptable value of standard deviation. Calibration of both cameras (metric and non metric) and correction for image systematic errors, were carried out in advance. The control points

for a set of images, in the local coordinate system, were established by the survey method. After simultaneous adjustment of all observations, the accuracy from 0.4 to 0.6 of the pixel size, depending on classes of identified points and imaging scale, were obtained.



Fig. 5 For the entire altar - metric photos (1) , (2); for left and right part of the altar - non-metric photos (3) – (6)

Similar approach was used for determination of exterior orientation of two metric and eight non-metric photographs taken at different scale (with pixel size of 14 and 10 μm) for the building structure. In case of building renovation, such as in the project carried out at the Warsaw University of Technology, two metric photographs (one stereo-pair) were taken for compilation of the vector product for the whole structure. In addition, for compilation of three different photogrammetric products (vector data, orthophoto and 3D digital object model) of four fragments of this object, eight non-metric images (four stereo-pairs) were used. The control points were determined by the survey method with accuracy of 0.03 m. The process of multi-image exterior orientation of a block of 10 photographs was executed with the Orient/Orpheus system. The final average accuracy of 0.6 pixel size was reached. In figure 6, data base with compiled four products is presented.

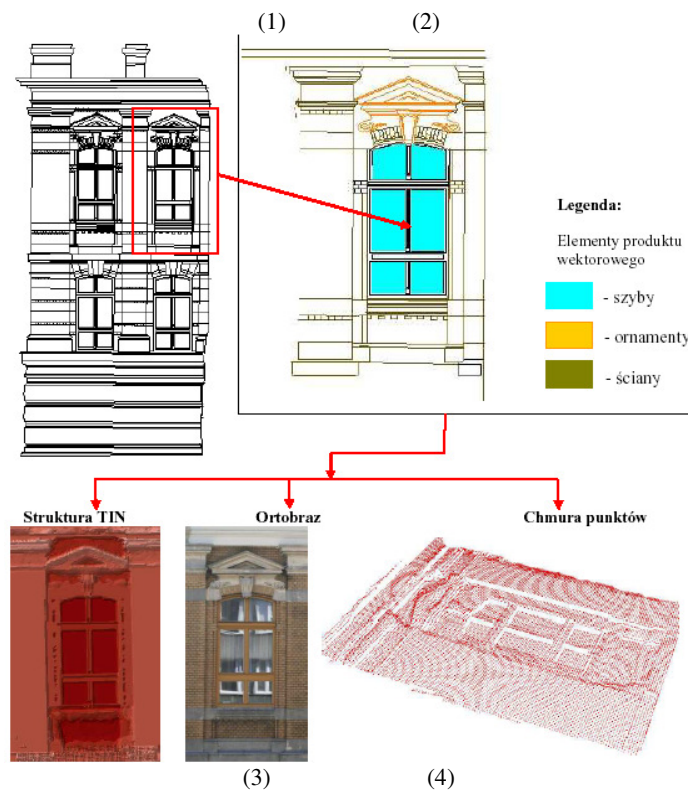


Fig. 6 Data base with: (1) vector data for the whole structure, (2)-(4) vector data, orthophoto and 3D object model for one of four compiled areas of windows [Piotrowska, WUT, 2008].

Creation of data bases for different architectural monuments and engineering structures became very popular. Developments in process of data acquisition by various close range photogrammetric systems, such as terrestrial scanning and metric or non-metric cameras, generate a wide spectrum of integration for both acquisition techniques in order to obtain better results for geometrical accuracy, visualization and reconstruction efficiency of 3D models. The high spatial resolution of photogrammetric imaging and the excellent capability of measuring the 3D space by laser scanning bear a great potential for documentation in various engineering and architectural applications [Alshawabkeh, Haala, 2004]. A lot of attention was invested to demonstrate the complementing aspect of both acquisition techniques instead of vaguely and artificially emphasized competition case [Aguilera, Lahoz, 2006; Jansa et al, 2004; Guarnieri et al, 2004, 2006].

To integrate scanning and imagery data the common geo-referencing is required. When the scan and the images are acquired for the object covered by some targeted control points, with known coordinates in the reference system, as it is shown in figure 7, the exterior orientation both of data sets can be determined in one processing step.

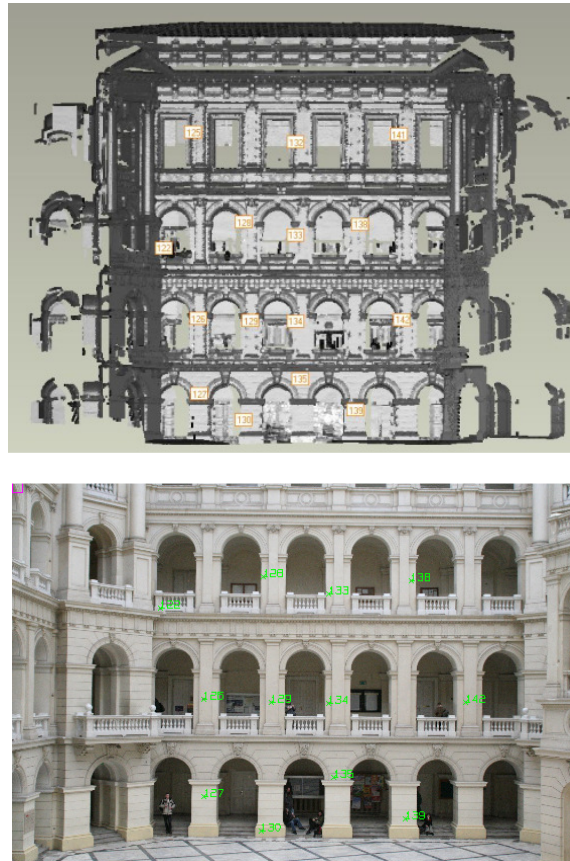


Fig. 7 Scan and one of non- metric photographs for part of the Main Aula in Warsaw University of Technology [Turkiewicz, 2006].

The scan was collected with the laser scanner 3D Leica HDS 3000 and four images were taken with the non-metric camera Canon 350D. The photo coordinates were measured in monocular mode with Orient/Orpheus and the scan points with GeoMagicStudio8. Both sets of observations were simultaneously adjusted with the multi-image exterior orientation module of Orient/Orpheus and the linear and angular exterior orientation parameters of four photographs and the scan were determined. The RMS (in object space) of 0.007m for XY and 0.015m for Z for control points, were achieved.

Another approach for georeferencing of images was applied by [Dominik, 2008] in process of reconstruction of 3D realistic model from scanning and imagery data. Four scans from the IMAGER 5006 (Z+F) and twenty non-metric images taken with the Canon EOS 350D were collected for reconstruction of 3D model of the fragment of Main Aula at WUT. To reconstruct the 3D model from scanning data, softwares GVE 3.5, Orpheus and Geomagic Studio 10, were applied. For texturing of 3D object from the oriented photographs the RiscanPro software was used. For georeferencing of the images,

coordinates of some natural control points were identified and determined within 3D scan model, and then measured on all photographs. The exterior orientation parameters (together with corrections to interior orientation data) of all photographs were determined by use of self-calibration multi-image exterior orientation module of Orient/Orpheus software. The accuracy of 2.7 mm in object space was reached. The final 3D realistic model of the object is shown in figure 8.



Fig. 8 The final 3D realistic model [Dominik, 2008]

Another example of georeferencing the photographs on base of control points selected from laser scanning data is presented in [Bakuła, 2010]. The outside façade of the main building of the Warsaw University of Technology was scanned with the IMAGER 5006 (Z+F) and images of the selected part of this façade were taken with camera Canon EOS 350D (fig. 9).

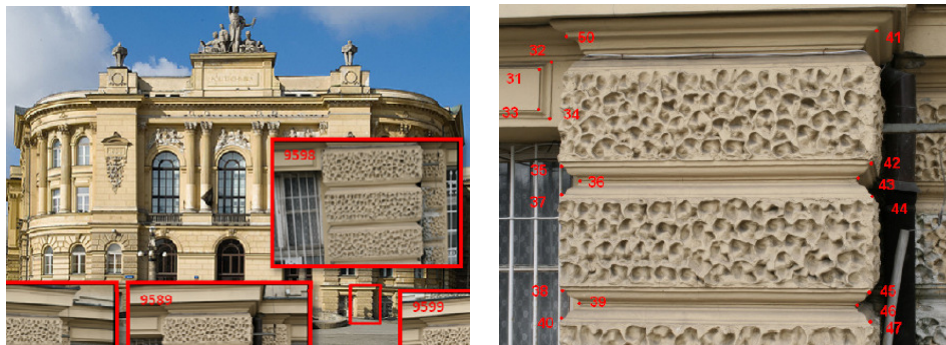


Fig. 9. The whole façade and its fragment registered by scanner and camera, respectively [Bakuła, 2010].

Two 3D models (B1, B2) of the same part of the façade were reconstructed from two stereo-pair images with ISDM module of Z/I workstation. Since non-metric images were used in the project, they had been corrected for systematic errors in advance. Relative orientation, with maximum residual y-parallax of 3.5um for both models, was obtained.

Basing on the object coordinates of the natural control points identified within 3D scan model B0 (of 10mm accuracy), the absolute orientation of image based models B1 and B2 was received with the RMS of 11.9mm, 24.3mm, 19.2mm (B1) and 13.4mm, 20.2mm, 5.4mm (B2) for X, Y, and Z, respectively. Subsequently, using the ISAE Intergraph software, DSM's were generated. Figure 10 shows three profiles along the 3D model, generated from two pairs of stereo photographs (models B1 and B2) and from laser scanning model (B0).

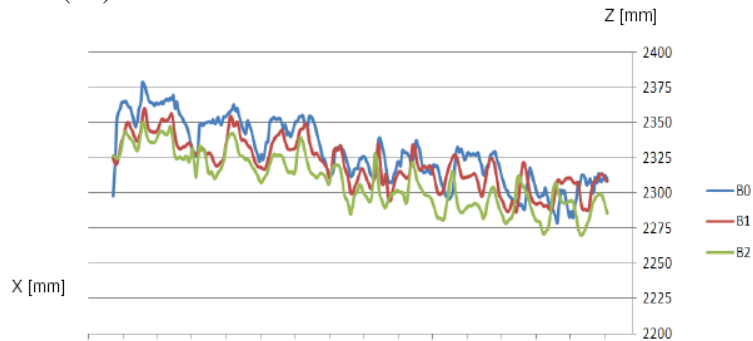


Fig. 10 the profiles along the 3D model generated from pairs of stereo images (B1- red, B2 -green) and from laser scanning (B0 – blue) [Bakuła, 2010].

The next example of georeferencing of close range images deals with the cases when they are taken for small 3D objects, architectural/archeological or mechanical details, which are located within the special frame equipped with control points of different spatial distribution. Since in such cases the high precision photogrammetric measurement is usually required, the spatial coordinates of the control points in local reference system have to be determined with sub-millimeter accuracy. The example of such frame with a set of 18 control points (built within the project undertaken at Warsaw University of Technology) is shown in figure 11.

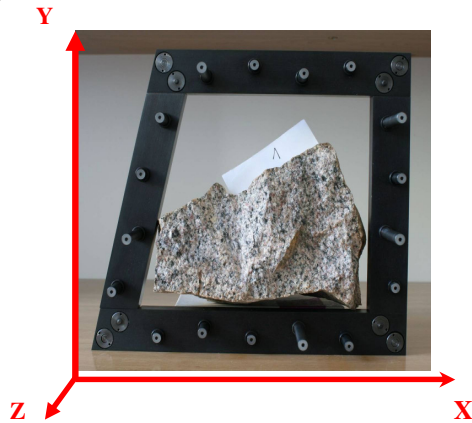


Fig. 11. Frame with a set of control points of different spatial distribution [Bujakiewicz et al, 2006 a, b].

In project executed in Digital Photogrammetric Laboratory of Warsaw University of Technology (WUT), 3D models of spatial surfaces for thirty three small archeological pieces (from the Egyptian Museum in Cairo and the National Museum in Warsaw), were reconstructed and measured. Two frames of different size, with 18 and 25 reference control points with very precise location (0.1 mm) were used. Stereo images for all 3D objects were taken with non-metric camera Canon EOS 20D and pre-corrected for image systematic errors in advance [Bujakiewicz et al, 2006 a, b]. The example of one of such object from the Egyptian Museum together with pair of stereo images taken for the pointed 3D surface is shown in figure 12.



Fig. 12. Archeological object from the Egyptian Museum with stereo images taken for the pointed 3D surface

Orientation and reconstruction of 3D models and automatic generation of their numerical 3D surfaces (DSM) were executed with ISDM and ISAE modules of Z/I Imaging workstation. Average accuracy of two steps orientation for all models were as follows, relative orientation: σ - 1.9 μ m and maximum y-parallax residual 5.7 μ m, absolute orientation - RMS_x - 0.16 mm, RMS_y - 0.12mm, RMS_z - 0.14 mm. The digital surface model (DSM) of the pointed surface (fig. 12) visualized by shading surface and color grid is shown in figure 13.

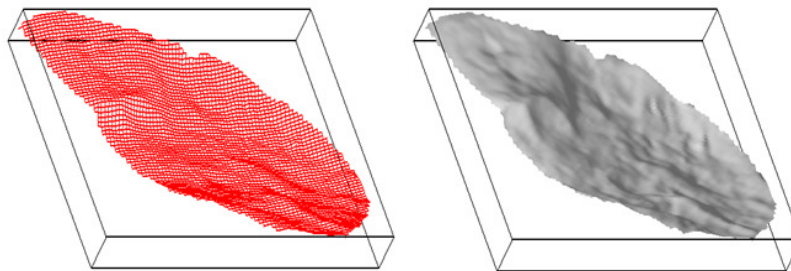


Fig. 13. Digital surface model presented by shading surface (left) and color grid (right) [Bujakiewicz et al, 2008].

The same photogrammetric approach was applied for reconstruction and modeling of deformed surfaces of 32 samples of metal plates executed in Laboratory of Digital Photogrammetry at Warsaw University of Technology (WUT). The samples were located within the reference frame with 25 control points and stereo pair images were taken with Canon EOS 20D (fig. 14).

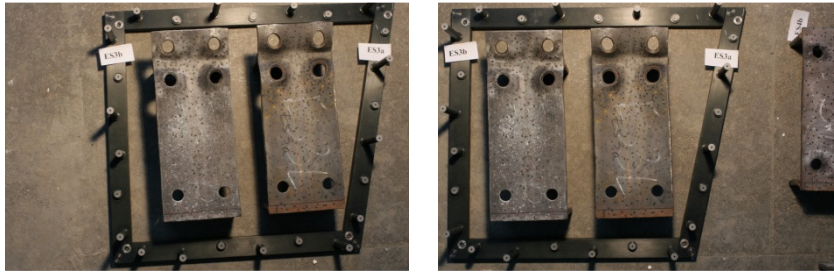


Fig. 14. Stereo images of one of the metal plate sample in control points frame.

Orientation and reconstruction of 3D models were performed with module ISDM of *Z/I*. For relative orientation - sigma of 2.3 μ m and maximal residual of y-parallax 5.4 μ m were achieved. For absolute orientation - RMS_X - 0.27 mm, RMS_Y - 0.12mm, RMS_Z - 0.42 mm were received for both control and check points. Automatic generation of their numerical 3D surfaces were executed with ISAE module. The result of one of 32 deformed surfaces, visualized in form of the perspective projections with contour lines, is presented in figure 15.

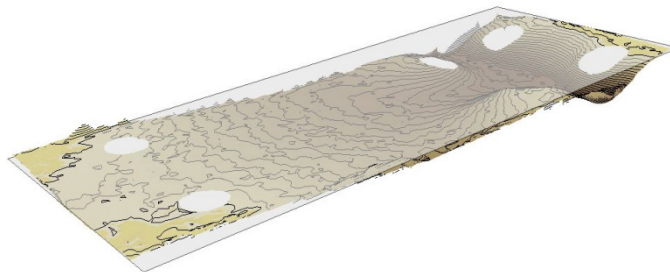


Fig. 15 Perspective projections with contour lines for one deformed samples of metal plates [project executed in Laboratory of Digital Photogrammetry at WUT]

3. CONCLUSION

Fast development of imagery and laser scanning systems for delivery of digital source data, as well as variety of approaches for their processing and visualization have opened the new possibilities for modeling and presentation of the results. A high automation in data processing is one of the major advantages. The huge amount of data obtained from imagery matching and laser scanning allows to generate the precise data for modeling of objects

because of their supernumerary observations. However, there is another less positive effect of obtaining so large clouds of points since they require very sophisticated software for their processing. Various types of photogrammetric data for the same object are usually required in the same selected reference coordinate system, therefore the process of georeferencing is the basic step which must be always involved in any photogrammetric compilation.

REFERENCES AND SELECTED BIBLIOGRAPHY:

Aguilera, D.G., Lahoz J. G., (2006). Laser scanning or Image-based Modeling? A Comparative through the Modelization of San Nicolas Church. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXVI, B5, Dresden

Alshawabkeh, Y., Haala, N., (2004). Integration of Digital Photogrammetry and Laser Scanning for Heritage Documentation. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXV, B5, Istanbul

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., (2006 a). 'Calibration of Very Close Range Digital Cameras'. *Journal of the Polish Academy of Sciences 'Geodezja i Kartografia'* (in English), pp. 95-108.

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., (2006 b). '3D Reconstruction and Modeling of the Contact Surfaces for the Archeological Small Museum Pieces'. *International Archives of Photogrammetry & Remote Sensing*. Vol. XXXVI Part 5. Dresden pp. 56-61

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., (2008). Automatic Matching of Sculpture Fragments as Modern Tool for Archaeological Verification of Hypotheses on their Origin. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXVII, B5, Beijing

Bujakiewicz A., Arcisz M., Zawieska D (2008). The Use of Multiscale Images for Data Bases of 3D Architectural Objects. *Archives of Photogrammetry, Cartography and Remote Sensing*, Vol.18a, pp. 39-48

Bakuła K., (2010) Comparison of the object shape generated from digital images and laser scanning. MSc Diploma thesis, Warsaw University of Technology.

Dominik W., (2008). Generation of Realistic 3D Model from Terrestrial Laser Scanning and Imagery Data. MSc Diploma thesis, Warsaw University of Technology.

Guarnieri A., Vettorea A., El-Hakim S., Gonzoc L., (2004). Digital Photogrammetry and Laser Scanning in Cultural Heritage Survey, *International Archives of Photogrammetry and Remote Sensing*, Volume XXXV, B5. Istanbul

Guarnieri A., Remondino F., Vettore A. (2006). Digital Photogrammetry and TLS Data Fusion Applied to Cultural Heritage 3D Modeling. *International Archives of Photogram., Remote Sensing*. Vol. XXXVI Part 5. Dresden.

Habrouk H.E., Li, X.P., Faig, W., (1996). Determination of Geometric Characteristics of a Digital Camera by Self-Calibration, *International Archives of Photogrammetry and Remote Sensing*, Volume XXXI, Part B1, Vienna, pp.60-64

Jansa J., Studnicka N., Forkert G., Haring A., Kager H., (2004). Terrestrial Laserscanning and Photogrammetry -*Aquisition techniques complementing one another*. *International Archives of Photogrammetry and Remote Sensing*, Volume XXXV, B5. Istanbul.

Lisowska P., (2007). Use of Digital Photogrammetry for Architectural Inventory. Eng. Diploma thesis, Warsaw University of Technology.

Piotrowska M., (2008). Compilation of Photogrammetric Products for 3D GIS Data Base of Architectural Object. MSc Diploma thesis, Warsaw University of Technology.

Remondino F., El-Hakim S., Baltsavias E., Picard M, Grammatikopoulos L., (2008). Image-based 3D modeling of the Erechteion, Acropolis of Athens. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXVII, B5 Beijing

Sawicki, P., (2001). Solution of Terratriangulation with Self-calibration of Digital Cameras in Precise Measurements for Engineering, *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, Vol. 11, pp. 3/25-3/32

Turkiewicz J., (2006). Terrestrial laser scanning data post-processing combined with digital imaging. MSc Diploma thesis, Warsaw University of Technology.