3D RECONSTRUCTION AND MODELLING OF THE CONTACT SURFACES FOR THE ARCHAEOLOGICAL SMALL MUSEUM PIECES

A. Bujakiewicz, M. Kowalczyk, P. Podlasiak, D. Zawieska

Institute of Photogrammetry and Cartography,Warsaw University of Technology, Plac Politechniki 1, Warsaw, Poland,
abujak7@wp.pl, mikowalczyk@wp.pl, ppodlasiak@wp.pl, Dorotaz8@wp.pl

Commission V

KEY WORDS: Photogrammetry, Architecture, Archaeology, Modelling, Visualization, Close Range.

ABSTRACT:

The paper is concerned with the application of close range photogrammetry for reconstruction of the shape of the 3D surfaces of the small archaeological pieces. Such items, as statuettes, stone plates, pots, etc, are very often broken and their pieces are placed in various museums over the World. To identify their exact origin and the correspondence of the particular pieces, there is need to determine the shapes of the corresponding contact surfaces of the adjacent pieces, which belong to the same items. Creating a database for such contact surfaces, with their geometrical description and the selected thematic information, would allow to make some indications on the assignment of the pieces. In this paper, the main principles and the practical results of the proposed approach for reconstruction of the shape of the 3D contact small surfaces, are presented. In the experiment carried out in the Photogrammetric Digital Laboratory at the Warsaw University of Technology, thirty three 3D surfaces of the broken museum pieces (from Cairo and Warsaw) were determined. This project is sponsored by the Polish State Committee for Scientific Research.

1. INTRODUCTION

The problem of determination of the surface shapes of the objects by photogrammetry is not new. In the past, many different approaches have been used in medical, industrial architectural, archaeological and other applications. Such examples as, the use of photogrammetric methods for DSM of ship screw propellers (Stenberg, 1976), the building panels (Bujakiewicz, Peczek, 1974), the anatomical limbs (Duncan, 1974), the historical heritage objects (e.g. Kolbl et al, 2000; Hongo, et al, 2000; Bartolotta et al 2000; Streilen et al; 2000, Bujakiewicz et al, 2004; Garcia et al, 2004; Cardenal, 2004), are only a few of many which were published. Some applications have applied the methods based on the moire topography (for ex. Zawieska, 2000) or other principles, including the terrestrial scanning technology (e.g. Brown at al, 1995; Tsioukas et al, 2004; Obdake et al, 2004; Bohm, 2005; Alshawabkeh, 2005).

The specific close range modules of the photogrammetric digital workstations are developed much slower that it would be required. The available programmes for close range processing, such for example as, Orient/Orpheus or PhotoModeller have no possibility of the stereoscopic measurement of the images. This introduce some limitations in case of the objects where their shapes have to be described by the huge number of not targeted points, and therefore mono observation is not suitable or sufficient. The modules for processing of aerial photography are therefore very often used for generation of DSM of the close range objects, even if they would not satisfy fully the specific requirements for compilation of digital photographs taken by the digital non-metric amatour cameras, the most commonly used at present. The limitations are mainly caused by different geometry and non-stability of interior orientation of the photographs. Therefore, a very careful choice of the camera type and the proper pre-calibration and pre-correction processes are very important.

This paper discusses the application of digital photogrammetry in archaeology. The archaeological small items, such as for example, the statuettes, stone plates with relief, pots and others are very often in the pieces, which are placed in various museums over the World. In many cases, there is no record or indication to which items the museum pieces belong to. To have a confidence of matching of the two or more pieces, there is the need to determine the shapes of each of two corresponding contact surfaces. Creating a database for such contact surfaces, with some thematical information, concerned with the archaeological characteristics of the items (type, dating, material, etc), would allow to make some indication on the assignment of the corresponding pieces. The variety of digital photogrammetry methods are very usefull for reconstruction, modelling and visualization of 3D contact surfaces of the museum pieces. However, the digital surface models must be determined with a very high accuracy and also the applied method should be based on the relatively cheap and available tools. In this paper, the main principles of the method and the results of the part of the research undertaken by the authors within the project, sponsored by the Polish State Committee for Scientific Research, are presented.

2. THE AIM OF THE PROJECT AND PRINCIPLES OF THE PROPOSED METHOD

The purpose of the project was to establish the principles for the digital photogrammetric method which satisfy the requirements for the precise determination of the shapes of the 3D contact surfaces of the broken archaeological small items. The contact surfaces are of different sizes but usually not larger than 0.5 by 0.5 meter in plane and a few centimeters in height (Z). Since the archaeological items are made of various materials and also damaged by the time, the texture of the surfaces differ considerably. The required accuracy of the digital contact surface model is of range 0.3 – 05 mm in Z. The applied method should be relatively simple and cheap but at the same time must satisfy the required accuracy. The proposed method is based on the images of very large scales, taken by a semi professional

digital camera. An assumption is made that the camera is of relatively good quality, equipped with a few lenses, at least 8 millions pixels and the interior orientation, including the effect of image systematic errors, is stable in time. The camera must be calibrated in advance by the suitable accurate method. The photographic distances of the photographs taken for the object are very short (from 0.5 m to 1.5 m) and therefore the calibration of the camera must be carried out for the similar ranges of the photographic distances, since the interior parameters are significantly changing with the change of the photographic distance. This requires the specific calibration test. The contact surfaces of the archaeological items have to be surrounded by the referenced control points. The photographs must be taken from such spatial positions (base/distance ratio), that the requirements for the accurate automatic DSM measurement (automatic matching) and also for the proper geometry of the rays intersection are satisfied. Using the modules of the universal photogrammetric digital workstations, such as for example, Z/I Imaging or Inpho, for generation of digital contact surfaces of archaeological pieces, the images of the surfaces, taken by digital non-metric camera, have to be a'priori corrected for the effect of the systematic errors, determined in the calibration process, since the model of the errors is different of those for aerial photographs.
Important part of processing is the stage of visualization of the final photogrammetric product - DSM. Analysis of the shapes of the visualized contact surface models would allow to make the initial suggestion on the selection of the corresponding fragments of the broken archaeological piece.

3. DESCRIPTION OF EXPERIMENT AND PRESENTATION OF RESULTS

The entire experiment was carried out by the authors in the Digital Photogrammetric Laboratory at the Institute of Photogrammetry and Cartography, Warsaw University of Technology. For the purpose of the project twenty two museum pieces were selected. Six of them, the parts of the Egyptian statuettes, located in the Egyptian Museum in Cairo, are the fragments of the man sitting bodies, broken either in the top part of a torso (neck, shoulder), see fig. 1-a or in the middle of a torso (fig. 1-b). Four statuettes are dated from V dynasty, Niuserre or Neferirkare (coded as CG 181, CG 66, CG 198, CG 171), one from IV dynysty, Cheops (JE 40431) and one from VI dynasty, Merenre (JE 43777). Five of the statuettes are made of limestone and one of anorthite. For the selected pieces, six contact surfaces (in the part of the break) were measured.

(a) (b)

Figure 1. The broken statuettes (a) code CG 181 (break on the top of the torso) (b) code JE 40431 (break in the middle of the torso (the Egyptian Museum in Cairo)

In the National Museum in Warsaw, sixteen pieces were selected. They are the parts of nine Egyptian items of different types. The codes, types, material, date/age, the origin, no. of pieces and no. of contact surfaces (in brackets) are listed in table 1. Most of the fragments do have the common contact surfaces. For this group of pieces (16), twenty two contact surfaces were reconstructed and modelled.

Code	Type	Material	Date/age	Origin	No. of pieces (contact surf.)
149046	stone plate with convex relief	limestone	Ptolemen age	Tell Atrib	4 (6)
149282 149039	stone plate with convex relief	limestone	Ptolemen age	Tell Atrib	2 (4)
KMS74	flat pots	glass	unknown	un - known	2 (2)
139986	stone bowl	granite	Ptolemen age	Edfu	2 (2)
142216	stone plate	granite	Ptolemen age	Edfu	2 (2)
139300	Horus statuette	granite	Ptolemen age	Edfu	1 (1)
139307	part of a man torse	limestone	Average state	Edfu	1 (1)
149795	statuette BA	limestone	Meroic age	Faras	1 (3)
141275	Statuette of notable	limestone	New state	Edfu	1 (1)

Table 1. The characteristics of the museum pieces from Warsaw

The example of the stone plate with the convex relief (code 149046), broken to four pieces with six adjacent contact surfaces, is shown in figure 2.

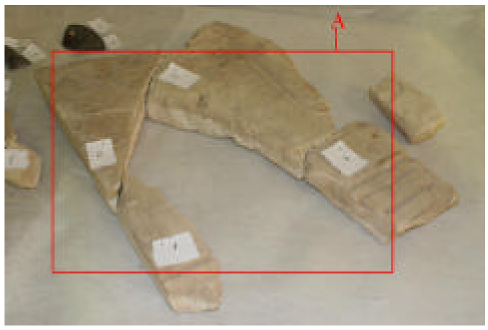


Figure 2. Four pieces of the broken stone plate (code 149046) with convex relief (The National Museum in Warsaw)

Each of the examined archaeological pieces was located in the special designed referenced structure with the control points located on the bolts (pins) of different hights, attached to the frame. The spatial coordinates of these control points have been precisely determined with the accuracy of 0.1 mm. Since the examined archaeological pieces are of different sizes, for the purpose of this project, two referenced structures of two sizes (60x50x10 cm and 10x30x5 cm for X,Y,Z, respectively) were constructed. One of the referenced structure, with the examined contact surface of the archaeological piece (presented in fig. 1- a), is shown in figure 3.
All photographs were taken with the semi professional reflex camera CANON EOS 20D, equipped with three lenses of 20, 28 and 35 mm. The photographic distances were from 0.6 to 1.5 meters. The base/distance ratio was about 1:4 and the scale of photographs ranged from 1: 20 to 1: 50. Since the texture of

some exposed surfaces has been quite poor, the illuminated targets were also projected to some of these surfaces to check whether it would improve the process of the automatic matching.

Figure 3. The reference control structure

The parameters of interior orientation, including the coefficients for systematic errors (affine, radial and tangential distortion) of the camera CANON EOS 20D with the three lenses were a'priori determined for different photographic distances (photo scales). Two different calibration methods were used. The first 'Calib', is based on the three dimensional calibration test with 52 control points distributed within the range of 0.5 x 0.5 x 0.15 metres, which has been constructed for the purpose of this project. This calibration test is presented in figure 4. The interior orientation parameters were determined (by the multi images approach) on base of six overlapped photographs of the test.

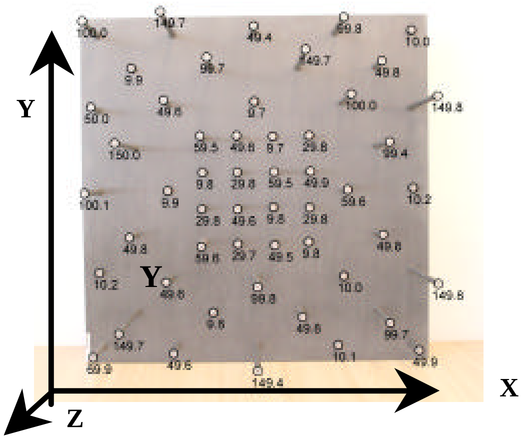


Figure 4. The three dimensional calibration test

The second calibration method - 'OpenCV' (conducted the comparison), has applied the two dimensional chess-board calibration test, which was exposed on sixteen photographs taken from different directions (fig. 5). The computing program for the images measurement and processing is based on the Intel Open Source Computer Vision Library – OpenCV.

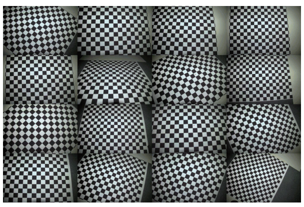


Figure 5. Photographs of the chess-board calibration test

The results of the calibration, determined by the two methods, are very similar for all the interior parameters (Bujakiewicz et al, 2006). For example, as it can be seen in figure 6, the differences in the focal length c_k for different scales of photographs (taken from different photographic distances), determined by the two methods, 'Calib' and 'OpenCv are insignificant.

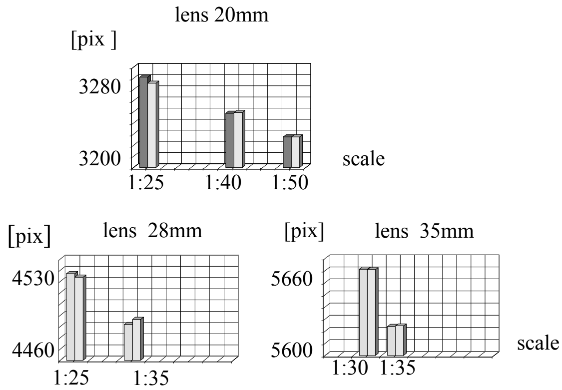


Figure 6. Comparison of the results for the focal lenghts, obtained by two methods; 'Calib' and 'OpenCV'(left and right columns)

The reconstruction of the 3D models and generation of the digital contact surfaces (DSM) of the selected archaeological pieces were carried out with the photogrammetric workstation Z/I Imaging. For orientation of the models and measurement of the surface edges and some characteristic breaklines the ISDM module and ISDC with ISSD were applied, respectively. For automatic generation of the DSM's the module ISAE was used. All acquisited photographs were a'priori corrected for the effect of systematic errors (coefficients determined by the pre'calibration process).

For the six pieces (the parts of the Egyptian statuettes) from the Egyptian Museum in Cairo, the six 3D contact surfaces were measured. For this part, the corresponding contact surfaces were not available, and therefore for each museum piece only one 3D contact surface was measured. However, for this part, some additional analysis was carried out to check how the optical targets projected to the surfaces during the exposure would affect on the results of automatic matching. The targets, projected to three selected surfaces, were in form of the colour spots of two sizes and the grid. Taking this into account, the number of eleven models for six surfaces were reconstructed.

For the sixteen archaeological pieces selected in the National Museum in Warsaw (table 1), twenty two 3D models of contact surfaces were measured of which sixteen have their adjacent contact surfaces available.

The total number of the measured models of the pieces from both Museums (Cairo and Warsaw) is equal to thirty three.

The analysis of accuracy for orientation (interior, relative and absolute) of each of thirty three reconstructed models for the contact surfaces allowed to estimate the average accuracy for the separate stages of the orientation, which is as follows:

- the interior orientation: ? = 0.8 µm and $RES_{?AX}$ = 0.5 µm
- the relative orientation: ? = 1.9 µm and dP_Y = 5.7 µm
- the absolute orientation, it means fitting of the reconstructed 3D model to the control reference points of two different size structures (fig. 3) is;
  - for smaller size control structure (with 18 control points)
    RMS_X = 0.16 mm, RMS_{maxX} = 0.29 mm
    RMS_Y = 0.12 mm, RMS_{maxY} = 0.25 mm
    RMS_Z = 0.14 mm, RMS_{maxZ} = 0.29 mm

- for larger size control structure (with 25 control points)
RMS_X = 0.18 mm, RMS_{maxX} = 0.36 mm
RMS_Y = 0.16 mm, RMS_{maxY} = 0.36 mm
RMS_Z = 0.16 mm, RMS_{maxZ} = 0.33 mm

As it can be seen from above, the accuracy of each processing step is very high and indicates that the reconstruction of 3D models has been performed very precisely. For both sizes of control structure, the absolute orientation accuracy is better than 0.2 mm for each coordinate. Most of the archaeological pieces have been smaller size, and therefore they were placed during the exposure stage within the smaller control structure.

The additional experiments have been concerned with checking how the automatic matching would be improved when the optical targets are projected to the measured surface during the exposure. In spite of the fact that most of the measured pieces are made of limestone and therefore they do have very poor texture, the pattern projected to the surface have not improved the efficiency and accuracy of automatic matching, during the process of relative orientation and the DSM generation. The average residual Y-parallaxes of the models, reconstructed on base of the photographs taken for the three surfaces targeted by the light signals, are of similar range (4.0 ÷ 10.0 μm) as for the case, when the surfaces were not targeted (4.6 ÷ 8.8 μm). This means, that there is not need for such optical targeting even if the texture of surface is quite poor.

In the process of DSM's generation, the stereoscopic manual measurement of the surface edges and breaklines has been followed by the process of the automatic matching. For all thirty three surfaces, the same parameters for the automatic matching were used. They have been estimated on base of the practical tests and finally assumed as; the grid resolution equal to 2 by 2 mm, the smoothing filter – medium and the type of terrain – hilly.

The 3D models of the surfaces can be visualized in a few different forms. This would help to analyze their shapes and initially check which surfaces belong to the adjacent broken parts of the archeological item. In the project, the 3D surfaces are shown in the perspective views with the representations as ;

- the spots of different colours, which show the efficiency of automatic matching (red – very good, yellow – good, blue – quite poor) ,
- the grids,
- the shading surfaces
- the height colour coding lines

In this paper, three of thirty three measured surfaces are presented. In figure 7, the stereo images of the contact surface of of the broken statuette no. CG 181 from Museum in Cairo (see fig. 1 a) is shown.

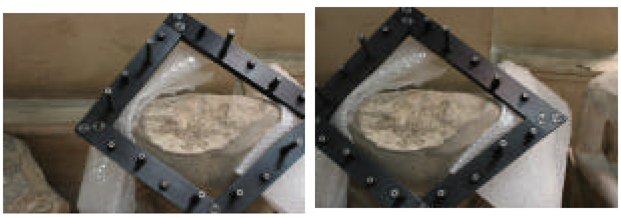


Figure 7. The stereo images of the contact surface of the statuette no. CG 181 (the Egyptian Museum in Cairo)

The four forms of the perspectiwv view for this piece is shown in figure 8 (a – d).

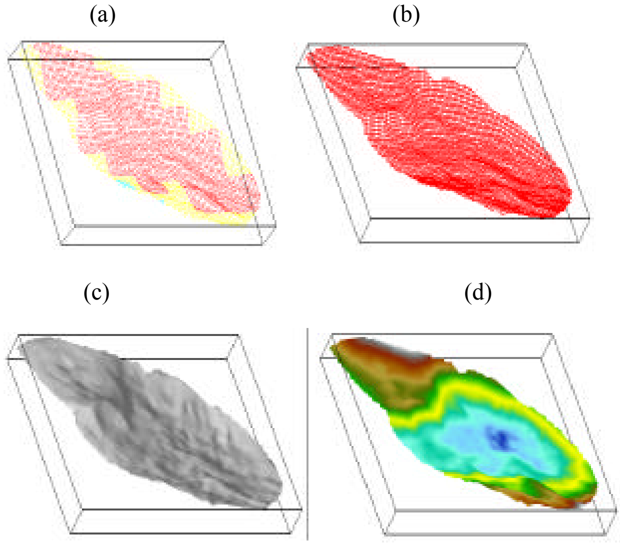
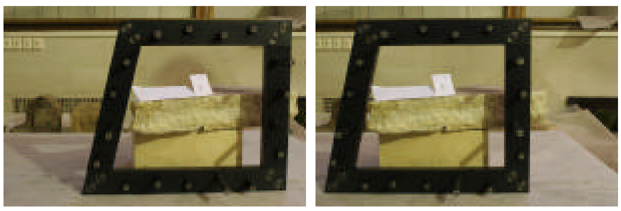


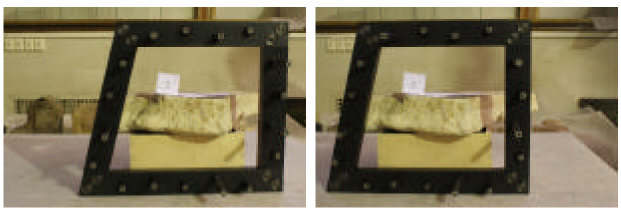
Figure 8. Four forms of the perspective view of the broken statuette no. CG 181 (a) spots of different colour (b) grid (c) shading (d) 'Z' colour coding lines

As it can be seen from figure 8 (a), for the central part of the surface, the matching process had been the most efficient (the red spots) and the poor quality of matching appears only in the small part of the edge (blue spots). The analysis of the figures (b), (c) and (d) indicates, that the breaklines on the surface are seen very clearly, specially for the shading surface (case - c).

In figure 9 (a),(b) the stereo images of the two adjacent contact surfaces A-2/A-3 and A-3/A-2 of the stone plate with the relief (code 149046 - see fig.2) from the National Museum in Warsaw are presented.



(a)

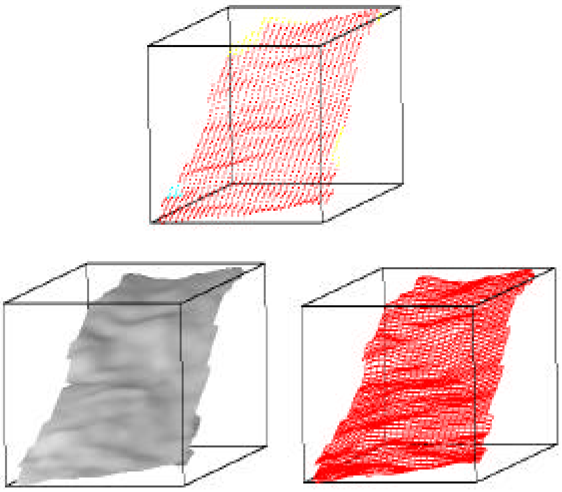


(b)

Figure 9. The stereo images of the two contact surfaces of the stone plate with the relief (code 149046): (a) surface A-2/A-3; (b) surface A-3/A-2

Three forms of the perspectiwv views for each of the two adjacent surfaces A-2/A-3 i A-3/A-2 for the broken stone plate (code 149046) are presented in figure 10 and 11.

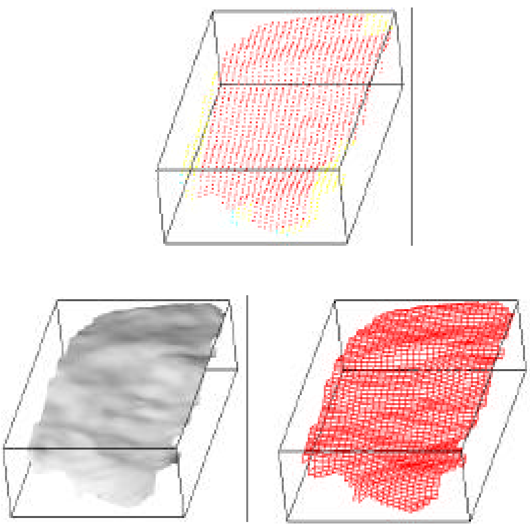
(a)



(b) (c)

Figure 10. Three representations of the perspective view of the contact surface A-2/A-3 of the broken stone plate (code 149046): (a) spots of different colour (b) shading (c) grid

(a)



(b) (c)

Figure 11 Three representations of the perspective view of the contact surface A-3/A-2 of the broken stone plate (code 149046): (a) spots of different colour (b) shading (c) grid

As it is shown in figures 10 (a) and 11 (a), similarly as in the case of the surface of the broken statuette (fig. 8-a), nearly the entire surfaces are covered by the red colour spots, it means that the matching process was very effective. Only along the edges of the surfaces, the quality of the matching process has been degraded (yellow and blue spots). This can be explained by the fact that the edges of the surface are not well exposed and difficult to measure.

As it can be seen, the surface in figure 11 is the mirror reflection of the surface presented in figure 10 and also the 3D model is pseudoscopic in respect to the 3D model in figure 10. However, as it can be observed in the figures, the edges of the two adjacent contact surfaces A–2 /A –3 and A–3/A -2 have not exactly the same shape. This might be caused by the fact, that the corresponding contact surfaces of the adjacent pieces of the same plate have been stored for many years (hundreds or thousands) in various environmental conditions, that affected differently their shapes, specially on their edges. We can definitely assume that the shapes of such surfaces are better preserved around their central parts than on the edges. The edges are not very clear, specially in case of the examined plates, which were broken to a few small pieces and therefore the edges identification and measurement is quite difficult. This indicates, that the analysis of the contact surfaces for their assignment should be based rather on the 3D shapes of their entire surfaces than on their edges. These results and observations would be taken into consideration in the next stage of this research project which is concerned with preparing some initial proposals for checking in the simple analytical way whether the two determined 3D surfaces of the two archaeological pieces belong to the adjacent fragments of the same archaeological item.

4. FINAL REMARKS.

The comprehensive research, which was carried out, have shown the possibility for the use of the photogrammetric close range approach, based on the non metric digital images, for very precise measurement of the shapes of the 3D small surfaces of the archaeological pieces. However, very strict precautions have to be taken to ensure the required accuracy of sub millimetre for the DSM generation. The most important are; the proper choice for the non metric camera and the procedure for its calibration, the assurance of the required conditions for the reconstruction of 3D surface model and DSM generation (the proper accuracy of 3D control, the possibility of the photogrammetric workstation for the manual stereoscopic measurement and automatic matching), the availability of the programme for creation of different adequate forms of 3D surface visualization which allow to analyse and choose the corresponding points or other elements on two contact surfaces of the adjacent fragments. For the purpose of this project all the above requirements have been assured and the required accuracy of 0.3 – 0.5 millimetre for the DSM generation was obtained.
All the results will be futher used for continuation of the project in respect to; (1) propose the structure of the database with geometric and thematic information for such archaeological pieces, and (2) compile some initial proposals for analytical simple procedure for checking whether the two determined 3D surfaces of the two archaeological pieces belong to the adjacent fragments of the same archaeological item.

Acknowledgements

The research was supported by the Polish State Committee for Scientific Research as the part of the project - KBN T12 E 033 26 on ‘Numerical modelling of the fragments of the archaeological pieces for the reconstruction of the original context of the relic’.

References and Selected Bibliography

Alshawabkeh Y., 2005. Using Terrestrial Laser Scanning for the 3D Reconstruction of Petra – Jordan. *Photogrammetric Week '05, Wichmann.* pp. 39-48

Asundi A., 1993. 'Moire methods using computer-generated gratings'. Opt.Eng. 32.

Bartolotta M., Di Naro S., Brutto M., Villa B., 2000. Information Systems for Preservation of Cultural Heritage. *The The International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Part B5. pp. 864-871

Bohm J., 2005. 'Terrestrial Laser Scanning – A Supplementary Approach for 3D Documentation and Animation'. *Photogrammetric Week '05, Wichmann*. pp. 263-272

Brown J. Dold A., 1995. 'V – Stars – a system for digital industrial photogrammetry'. *Optical 3-D Measurement Techniques III*, Wichman Verlag, Heilderberg.

Bujakiewicz A., Peczek L, 1974. Determination of geometrical quality of the prefabricated panels (in polish). *Geodezja i Kartografia* (Warsaw), Vol. XXIII, No.3. pp. 213-238.

Bujakiewicz A. 1984. Usefulness of Long Focus non Metric Cameras in Precise Measurements. *International Archives of ISPRS.* Vol. XXV, B5. pp.136-140.

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., 2004. 'Modelling and Vizualization of Three Dimensional Objects Using Close Range Imagery'. *The International Archives for Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXV. B5. pp. 442-446

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., Rzepka S., Andrzejewska E., 2004 – 2006. 'Numerical modelling of the fragments of the archaeological pieces for the reconstruction of the original context of the relic'. *The research project sponsored by the Polish State Committee for the Scientific Research (KBN. T12 E 033 26).*

Bujakiewicz A., Kowalczyk M., Podlasiak P., Zawieska D., (2006). 'Calibration of Very Close Range Digital Cameras'. (in english), *Journal of the Polish Academy of Sciences 'Geodesy and Cartography'* , Vol. 55, No. 2, pp. 95-108.

Cardenal J., Mata E., Castro., Delgado J., Hernandes N.A., Peres J.L., Ramos M., Torres M., 2004. Evaluation of a digital non metric camera for the photogrammetric recording of historical building'. *The International Archives for Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXV. B5. pp. 564-569

Duncan J.P. 1974. The replication of limbs and anatomical surfaces by machining from photogrammetric data. *Proceedings of Symposium of Com. V of ISPRS.* Washington.

Garcia I., Felicisimo A.M., Martinez J., 2004. 'A Methodological proposal for improvement of digital surface models generated by automatic stereo matching of convergent image networks'. *The International Archives for Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXV. B5. pp. 59-63

Hongo K. et al .2000. Development of Image Based Information System for Restoration of Cultural Heritage. *The International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Part B5. pp.372-378

Kolbl O., Cherradi F., Hostettler H., 2000. Conception of an Integrated 3D GIS for Primary Data Acquisition and data Management; Applied to an Inventory of Historic Monuments. *The International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Part B5. pp. 446-452

ObdaheT., Chikatsu H., 2004. 'Development of image based integrated measurement system and performance evaluation for close range application'. *The International Archives for Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXV. B5. pp. 684-689

Stenberg A., 1976. Photogrammetric determination of distribution and thickness of caviation on ship propellers. *The International Archives of XIII Congress of ISPRS*, Helsinki.

Streilen A., Hanke K., Grussenmeyer P., 2000. First Experiences with the Zurich City Hall Data Set for Architectural Photogrammetry.*The International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, Part B. pp. 772-779

Tsioukas V., Patias P., Jacobs P.F., 2004. 'A Nowel system for 3D reconstruction of small archeological objects'. *The International Archives for Photogrammetr, Remote Sensing and Spatial Information Sciences.* Vol. XXXV. B5. pp. 815-819

Zawieska D., 2000. Topography of surface and spinal deformity. *The International Archives of Photogrammetry and Remote Sensing*. Vol. XXXIII, Part 5. pp. 937-942