# MODELLING AND VISUALIZATION OF THREE DIMENSIONAL OBJECTS USING CLOSE RANGE IMAGERY

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**ABSTRACT:**

Databases created for various user applications require different types  of geometrical and thematic data. The physical shape, volume, and texture of spatial objects are  usually requested for objects  concerned with such  areas as, architecture, archaeology, medicine, or industry. For many years, wide range of  close range systems have been  used for acqisition of the source data.  In the last decade, the laser technology, non matric digital imagery or automatic systems based on moire projection have become popular for close range data collection. In this paper, results of  some pilot projects carried out in the Institute of Photogrammetry and Cartography at Warsaw University of Technology, will be presented. The shape and  digital surface models  of three various types of 3D objects of different size, shape and texture, concerned with architecture, archaeology and medecine applications, were determined.  The popular amatour digital cameras and moire  projection automated system were used for data acqusition. The main principles of data acqisition and processing, as well as the results and  accuracy of 3D modelling of the selected objects, will be discussed in this paper.

## 1.   INTRODUCTION

Methods of digital photogrammetry are used for modelling of objects in various areas of close range applications. The realistic or virtual models of the objects are presently required in many types of   information systems, which   are concerned with various  areas  of  industry,  medicine,  architecture  and archeology, city planning, traffic accidents, and so on. The term of  3D modelling has various meanings and interpretation, which can be assumed as;

- description of the  shape  of an object by determination of its  main frame of reference and  if required,  creation of the textural database for the selected surfaces of structure, or.

- determination of shape of  an object  by  generation of Digital Surface Model, it means description of its surface(s) with a large number of points.

The above meanings of the 3D modelling have been applied in various  applications  long  time  before  methods  of  digital photogrammetry have become popular. More than thirty years ago  various  analogous  and  analytical  approaches   of photogrammetry were used commonly around the world (also in Poland) to solve  many different  tasks concerned with 3D modeling in industry or medicine, architecture and archeology. Since 70-ties, the precise analytical close range photogrammetry methods were used  for  measurements  of surfaces of industrial objects,  such as for example, the radar antennas (Kenefick, 1972), the building panels (Bujakiewicz, Peczek, 1974), the models of complicated roofs (Linkwitz, 1971) the ship screw propellers (Stenberg, 1976), and many others. Traditional and non-conventional analogous and analytical methods were used in medicine for determination of shapes of the whole or parts of the human   bodies for medical diagnosis and control of rehabilitation, for ex. (Savara, 1971; Tokassaki, 1975; Van Wijk, 1980; Bujakiewicz, Krzesniak, Zawieska, 1984; Bujakiewicz, 1988), and for reconstruction of the anatomical limbs (Duncan, 1974). In the past years (since 50-ties),  many European countries, including Poland, have commonly used close range photogrammetry in areas of architecture and archeology. Many  of  the old buildings and monuments in the old towns and the archeological sites were measured and documented by conventional photogrammetric methods based on analogous (optical) metric single and stereoscopic cameras and graphical or analytical compilation.

Following the development of  aerial photogrammetry, close range photogrammetry has also implemented   the digital methods. The analogous photogrammetric cameras have been replaced by the digital cameras, mostly non-metric.  Non-conventional  methods of imagery, such as for examples, the optical Moire topography method,  has been developed into the fully automatic computer supported acquisition and processing system (Zawieska, 2000). The new possibility for close range acquisition  is concerned   with the implementation of the terrestrial  scanning systems. Development of the  close range modules in digital workstations is much slower as it would be expected. Modules for processing of aerial photography do not satisfy the specific requiremens for compilation of digital photographs taken by the non-metric amatour cameras. The limitations among others are caused by different geometry of close range photos,  different  models of  image systematic errors, non-stability of the interior orientation, non-availability of  the  self-calibration process. It therefore damands ealier calibration  and  pre-correction for   systematic errors.   The available programmes for close range processing, such as for example, Orient/Orpheus or PhotoModeller  have no possibility of stereoscopic  measurement of images. This would introduce some limitations in case of objects where the points can not be properly identified and  mono observation  is not  possible or sufficient.

## 2   GENERATION OF 3D REALISTIC MODELS OF ARCHITECTURAL STRUCTURES.

The 3D Architectural Information Systems contain the

integrated geometric data and semantic information on 3D realistic models of monuments and buildings. The geometrical data for such information systems are determined with the integrated data from topographical information systems based on aerial photogrammetry and data on 3D realistic models obtained by close range photogrammetry. The Visually Realistic 3D Models (VRM) of the objects, which are very usefull for comprehensive documentation and analysis of historical monuments and buildings, contain;

- the Numerical Frame of Reference (NFR) for their structure, and
- the Texture Image Database (TID) for the selected surfaces of the objects.

The NFR is the simple form of 3D presentation which describes the main parameters of a structure. Such form is sufficient for planning and monioring of objects in many applications. However, in case of the detailed analysis of the objects, for example some historical monuments, the Realistic 3D Models are needed with all the structural details and texture. For these purposes, the close range digital methods, based on images taken from the amatour digital cameras, are becoming popular, because of their economical aspects. However, they require some precautions to prevent the suitable accuracy of the determined geometrical data. The most important are listed as follows; (1) The camera has to be checked for the level of stability of the interior orientation and generation of image systematic errors. The amatour cameras have the unknown and variable at time and conditions interior orientation. The images are taken from variable close range distances and with variable focusing of the camera. Therefore the camera has to be calibrated under required photographical conditions and checked in respect to its stability. (2) To reconstruct the numerical frame of reference for the object in the required reference coordinates system some control points have to be determined in that system by the precise surveying methods. These points (premarked or natural features) have to be properly distributed around the architectural structure and well identified on images. The points which describe the frame of reference (NFR) of the object are usually natural points but they have to be carefully choosen to be well identified on photographs. (3) The set of photographs for the whole object have to be carefully planned to prevent the proper geometrical accuracy of photogrammetric reconstruction of the object and to identify all points on photographs required for determination of the frame of reference and textural data of the object. (4) The suitable package for close range processing which permits to reconstruct accurately the shapes of all bundles of rays and orient them in respect to the object reference coordinate system, and therefore to execute the reconstruction of the frame reference of the object and the collection of the textural data.

There are many examples of the real 3D modeling used for documentation of historical haritage. Some are presented in (Kolbl, Cherradi, Hostettler, 2000; Hongo, Matsuoka, 2000; Bartolotta, di Naro and others, 2000; Streilen, Hanke, Grussenmeyer, 2000).

In the experiments carried out in the Department of Photogrammetry at the Warsaw University of Technology two packages Orient/Orpheus and PhotoModeler were used for reconstruction and modeling of the of the two objects; the inside part of the construction of the Main Aula at the Warsaw University of Technology (Bujakiewicz, Kowalczyk, Zawieska, 2003) and some elements of the old building at Warsaw. For the first object the photographs were taken with the digital camera Nikon E990. During a'priori camera calibration all interior orientation parameters, including image systematic errors, were determined (Kowalczyk, 2003). It has been found that the

interior geometry of bundles was quite stable during series of photos taken with the same conditions. The efficiency of the correction of the image systematic errors was analysed on base of 15 photographs taken for the 2D test. The differences in the mean square errors evaluated on base of 56 control points were within $0.2 \div 0.3$ pixels. The stability of the interior orientation was checked by taking the series of 10 photos for the 3D test. It has been found, that the focal distance and the principal point were stable within $2 \div 4$ pixels. In fig. 2.1, two stereo photos for the West part of the Aula are shown. After pre-correction for the image systematic errors the programme Orient/Orpheus was used for the reconstruction and modelling. The absolute orientation of the model was executed with the accuracy of 0.016 m. The frame reference of the object with the selected surfaces is presented in fig. 2.2



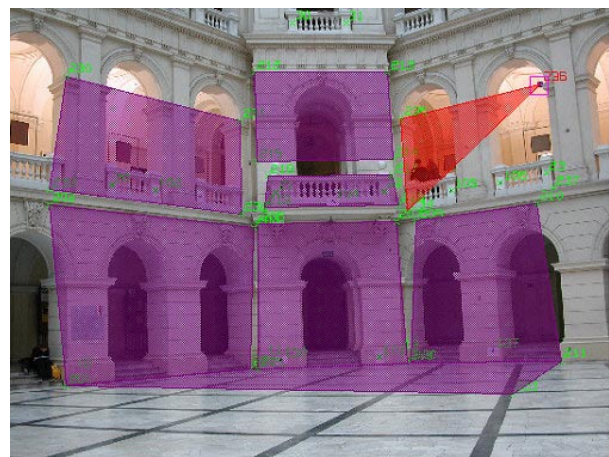Fig. 2.1 Stereo photographs of the West part of the Aula.



Fig. 2.2 . The selected surfaces for visualization surfaces of the west part of the Aula.
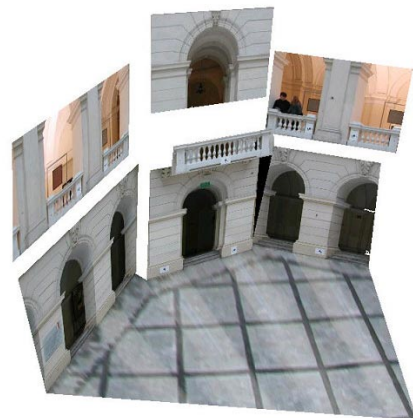


Fig. 2.3 Visualization of 3 D model with the textural data

The 3D model with the textural data is visualized in fig. 2.3. As it can be seen, the model is free of distortions since the photographs of the object were corrected for the image systematic errors, which had been determined in a'priori calibration.

The model of the second object – the elements of the old building was compiled for the purpose of the renovation. The photographs were taken with the digital camera Nikon E 990. After pre-correction for the image systematic errors the programme PhotoModeler was used for the reconstruction and modeling. In fig. 2.4 the modelling of the part of elevation and the stairs are presented. Figure 2.5 shows how the reconstruted model can be used for checking and updating of the existing architectural documentation (plans).
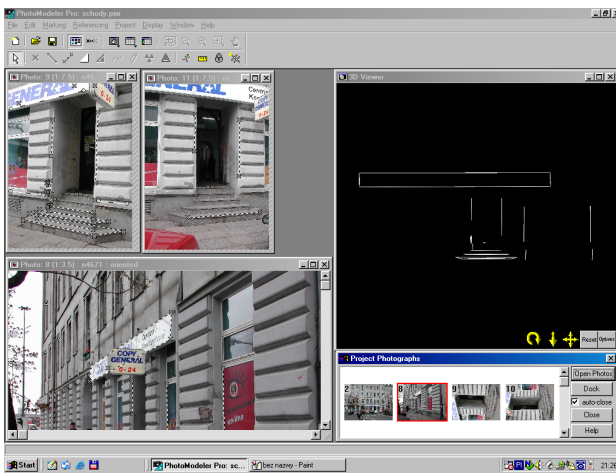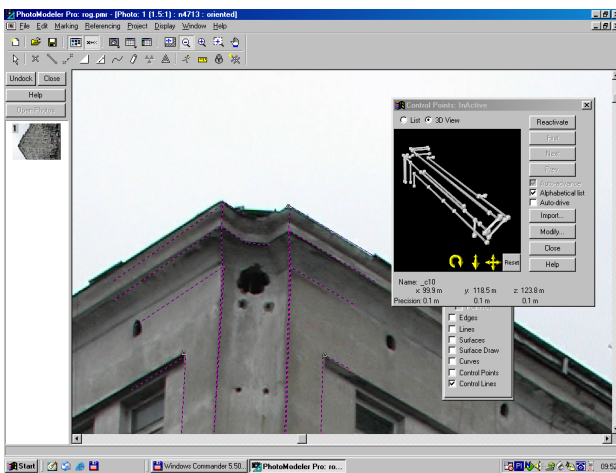


Fig. 2.4   Modeling of the stairs



Fig. 2.5  Check and update of the existing  architectural plan.

## 3. DETERMINATION OF THE SHAPE OF  AN OBJECT BY GENERATION OF THE  SURFACE MODEL.

Modeling of 3D surface  requires the determination of a large number of points which describe its shape. It means that the Digital Surface Model of the object has to be generated. As mention in the introduction, there are many applications where close range photogrammetry has been  useful for generation of DSM for various objects having different size and shape. The

digital methods based on   digital acquisition and processing systems  have increased automation and speed of the process. The accuracy depends on many factors but  mainly on the scale of the images and texture of the surface. When the object has the poor texture and therefore the stereoscopic measurement is difficult, the object should be pre-targeted. Various means of the signaling  have been used dependly on size of the object and system for image acquisition. In this paper two experiments concerning two different types of the object and two methods used for DSM generation will be presented.

The first experiment is concerned with the determination of the digital surface model of the small archeological detail which is the part of the broken statuatte. The aim of this  experiment was to check what conditions have to be satisfied to achieve the required accuracy of parts of milimeters for the measurement of the shape of such type of sample. The 3D object has size of about 0.20 meters in X and Y directions and about 0.05 meters in Z  (along the optical axis).  Since the object had very poor texture without the clear natural points and structural features and the object size was small  therefore the  optical means of points' targeting was applied. The archeological detail was located within the stable 3D frame with 16 control and check points which have been used for orientation and check of the accuracy of the photogrammetric compilation. The  coordinates for these points in the reference coordinate system   were measured  by the precise surveying method with accuracy of  $\pm$ 0.3 mm. The light grid was projected into the archeological detail to enable the measurement of the surface of the object. The stereo images  were taken  by the Olympus Camedia C-2500L digital camera from 1.6 m distance with the base/photographic distance ratio about 1:3  (fig. 3.1).
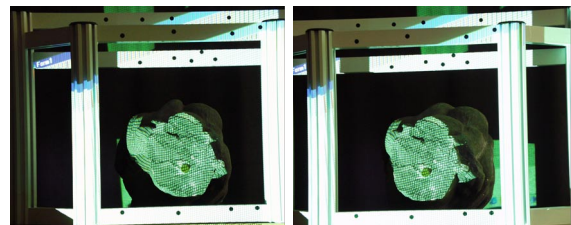


Fig. 3.1   Stereo images of  the archeological detail located within the frame  with  control points.

Before the reconstruction of the photogrammetric model the image coordinates of all points were corrected for the image systematic errors which had been determined together with the parameters of interior orientation  in  a'priori calibration.  The model reconstruction and stereo digitalization of  the surface of the detail, described by 860 points, was carried out with the use of  the   SSK package of   Z/I Digital Imaging system. The accuracy established on the base of the check points was for X and Y   $\pm$ 0.4 mm  and for Z   $\pm$ 0.5 mm. The 3D digital surface model of the archeological detail is shown in fig. 3.2.

This experiment, which was carried out as the MSc diploma (Wojtowicz, 2004), is the initial approach within the new research project   in the Department of Photogrammetry, Warsaw University for Technology. The aim of this research project is to  use digital close range photogrammetry for study of the parts of the broken archeological small findings located in various Museums to  fit the corresponding parts of the same object. The initial experiment in this area has showed the possibiility to achieve the required accuracy of  0.5 mm for the

DTM of small detail with poor texture on the surface. However the strict conditions of the photogrammetric measurement has to be preserved.
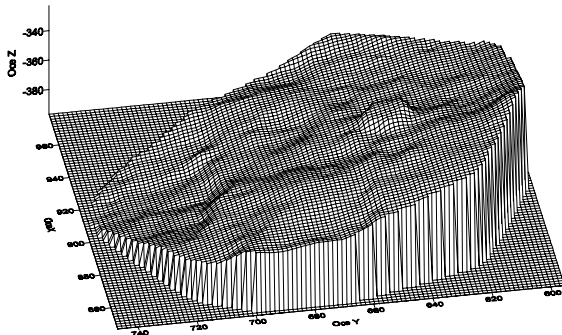


Fig. 3.2  Three dimensional surface model of the archeological detail.

The second experiment deals with applying the computer aided moire fringe analysis for measuring the 3D metric values of the spinal deformities. The system which had been developed within the few years research project in the Department of Photogrammetry, Warsaw University of Technology has been already commonly implemented for orthopedical diagnosis (Zawieska, 2000). The object shape information is encoded in moire fringe, which provides lines on the object. The temporal phase stepping approach has been used for automatic analysis of moire patterns. It has been found that the phase measuring approaches proved advantages over the intensity tracking such as the reduced sensitivity to the background and contrast variations in the moire pattern. Within the doctoral thesis (Zawieska, 2003) the accuracy analysis and examination of the elements affecting on precision of such measurement were done. For this purpose the simulated object - dummy (shape of human back) was designed with the control points located around and on the object. The 3D surface of the object was determined twice, using the conventional photogrammetric method (based on the optical metric photographs and the analytical compilation with the analytical plotter P3) and with the use of the projection moire system (fig 3.3).



Fig. 3.3  The projection moire system  [Zawieska, 2003]

To enable the measurement of the 3D surface of the object by the conventional photogrammetric method the object was premarked with the light projecting points. The photo of the object with the control points is presented in figure 3.4 and the visualized digital surface model of the measured object is shown in fig. 3.5.
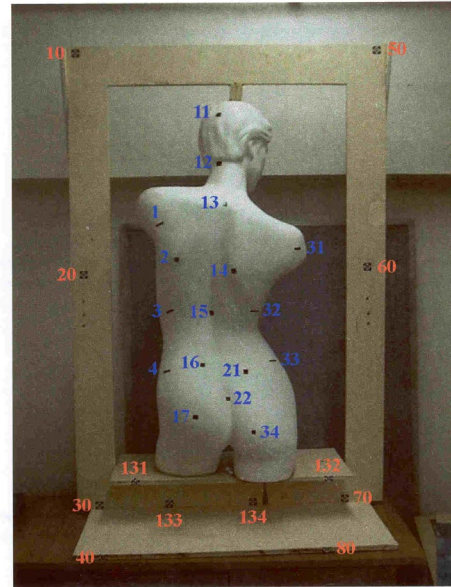


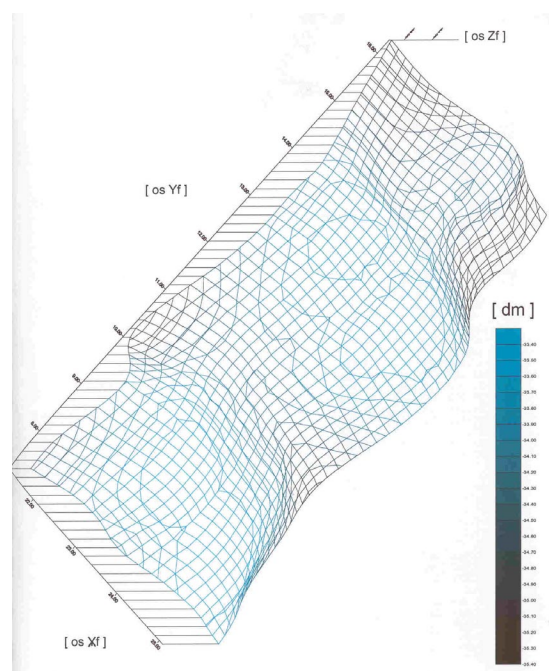Fig. 3.4  The object (dummy) with the control points.



Fig. 3.5   The DSM  of the object reconstructed by the conventional photogrammetric method.

The shape of the object which was reconstructed by the moire fringe method with the use of the projection moire system is shown in figure 3.6.  The results were corrected with the systematic errors of the system.  The distribution of the differences in the shape of the object determined by both of the

methods are shown in figure 3.7. The mean square error estimated from the differences is equal to ± 2.1 mm.
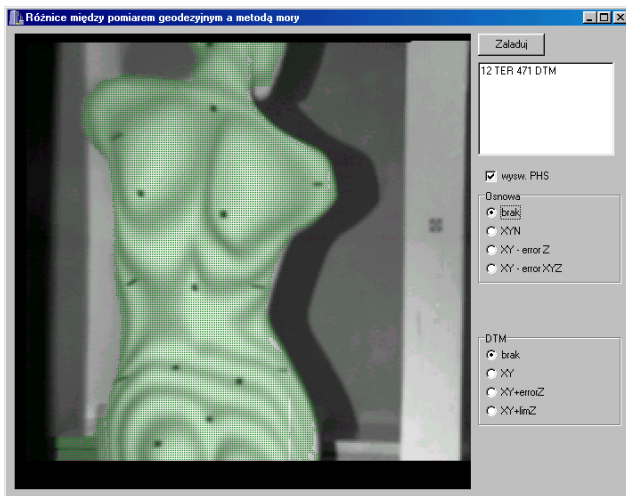


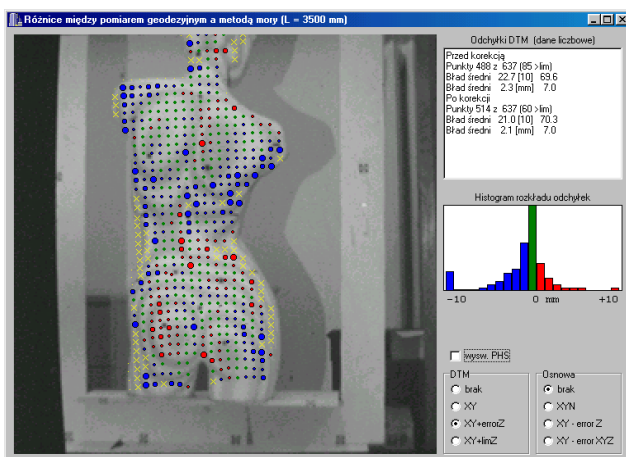Fig. 3.6 Shape of the object reconstructed by the moire fringe method.



Fig. 3.7 The distribution of the differences in the shape of the object determined by the conventional photogrammetry and the moire fringe method.

This project had reference to the medical applications but the moire fringe method can be adopted also to some other applications..

## 4. FINAL REMARKS.

The few examples, which were discussed in this paper, show the variety of the close range digital approaches. The commonly available amatour digital cameras make close range photogrammetry more universal and economical. However, some precautions have to be prevented to obtain the required accuracy of the photogrammetric measurement and modelling. The pre-calibration process of the camera should be carried out very carefully if the selfcalibration is not used within the compilation process. The control points or another control data suitable for the orientation of the photographs should be properly distributed. The points which discribe the frame or surface of the objects should be well identified on the photographs. The modules for the processing of the close range images should be developed within tha packages of the commercial photogrammetric digital workstations.

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