

# DIGITAL PHOTOGRAMMETRY IN OBTAINING OF 3D MODEL DATA OF IRREGULAR SMALL OBJECTS

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**KEY WORDS: 3D, Modelling, Digital Close Range Photogrammetry, Data**

## ABSTRACT:

Today, 3D models are used in a wide variety of fields. The medical industry uses detailed models of organs. The movie industry uses them as characters and objects for animated and real-life motion pictures. The architecture industry uses them to demonstrate proposed buildings and landscapes. The engineering community uses them as designs of new devices, vehicles and structures as well as a host of other uses. The use of three dimensional computer graphics and visualization techniques is becoming more and more popular, because these techniques visualize more realistic object models than graphic based object models. However, in most application of 3D modelling and visualization, large and complex 3D models data are required. The basic data source of three dimensional (3D) modeling of regular or irregular surfaced objects are known (or calculated) point coordinates. Obtaining of 3D model of the irregular surfaced objects need plenty points to represent the surface exactly. These points can be easily obtained both traditional methods and from the measurement of the photographs. In this study, the ease and ability of the close range photogrammetry have been investigated for 3D modeling. Therefore, an irregular surfaced artificial object was used to appreciate of capability of photogrammetric methods. Firstly, photographs of the object was taken. According to the photogrammetric procedures, 541 point coordinates were surveyed. Calculated root mean square error of the control points are 1.2 mm in x direction 1.1 mm in y direction and 1.0 in z direction. All procedures to obtain 3D model of the object was completed in 4 hours. Volume of the object was recalculated from the 3D model with 0.48 % error.

## 1. INTRODUCTION

The recent fast growth of the processing and memory capacity of computers has made the acquisition, recording and remote fruition of 3D digital images technically feasible, even by relatively inexpensive personal computers. Today, 3D models are used in a wide variety of fields. The medical industry uses detailed models of organs. The movie industry uses them as characters and objects for animated and real-life motion pictures. The architecture industry uses them to demonstrate proposed buildings and landscapes. The engineering community uses them as designs of new devices, vehicles and structures as well as a host of other uses. In recent decades the earth science community has started to construct 3D geological models as a standard practice.

In 3D computer graphics, a 3D model is a mathematical representation of a three-dimensional object. It can be displayed as a two-dimensional image through a process called e-3D rendering or used in a computer simulation of physical phenomena.

3D models are most often created with special software applications called 3D modelers. Being a collection of data (points and other information), 3D models can be created by hand or algorithmically (procedural modeling). Though they most often exist virtually (on a computer or a file on disc), even a description of such a model on paper can be considered a 3D model.

Close range photogrammetry offers the possibility of obtaining the three-dimensional (3D) coordinates of an object from two-dimensional (2D) digital images in a rapid, accurate, reliable, flexible and economical way. This makes it an ideal tool for precise industrial measurement [1], [10].

Digital close range photogrammetry is a technique for accurately measuring objects directly from photographs or digital images captured with a camera at close range. Multiple, overlapping images taken from different perspectives, produces measurements that can be used to create accurate 3D models of objects. Knowing the position of camera is not necessary because the geometry of the object is established directly from the images [5],[9],[15].

In this study, situation of the close range photogrammetry for the 3D data collection has been investigated. As mentioned before an artificial object was used for this purpose. A test field was prepared for the measurement of control points. These control points were used in photogrammetric adjustment procedures. Photographs of the test object were taken by the consumer grade digital camera to calculate of the camera parameters. Camera calibration steps have been accomplished. These parameters have been needed in photogrammetric orientations and adjustment calculations. A low cost digital photogrammetry software package have been used. All data (photographs, control point values and camera parameters) imported to the PhotoModeler software. PhotoModeler is a powerful 3D software product that calculates measurements and constructs 3D models from photographs simply and easily. Photogrammetric orientations parameters and adjustments have

been calculated with PhotoModeler software and 3D coordinates of 541 points on the surface of the object have been measured for the modeling its geometric surface. Volume of the object was recalculated.

**2. DIGITAL CLOSE RANGE PHOTOGRAMMETRY**

Photogrammetry is a technique to know the position, size and shape of an object obtained from some photographs instead by direct measure. The term close range photogrammetry is used to describe the technique when the size of the object to be measured is less than about 100 m and the camera is positioned close to it. Images are obtained from camera positions all

around the object [8]. The camera axes of each shot are parallel only in special cases, but usually they are highly convergent. In photogrammetry the position of a point in the space is commonly defined by a 3D cartesian co-ordinate system. The origin, scale and orientation of which can be arbitrarily defined. It is often necessary to transform between co-ordinates in systems having different origin, orientation and scale. Co-ordinate transformations may be divided into three parts: rotation, translation and scale change [4]. The rotation matrix

$R_{\kappa\phi\omega}$  can be expressed by (1),

$$R = \begin{bmatrix} \cos \phi \cos \kappa & \sin \omega \sin \phi \cos \kappa + \cos \omega \sin \kappa & -\cos \omega \sin \phi \cos \kappa + \sin \omega \sin \kappa \\ -\cos \phi \sin \kappa & -\sin \omega \sin \phi \sin \kappa + \cos \omega \cos \kappa & \cos \omega \sin \phi \cos \kappa + \sin \omega \cos \kappa \\ \sin \phi & -\sin \omega \cos \phi & \cos \omega \cos \phi \end{bmatrix} \tag{1}$$

where—  $\omega, \phi, \kappa$  —are the sequential rotations transforming the primary axes—  $x', y', z'$  —into the secondary axes—  $x, y, z$  —as shown in Figure 1 [3].

If the origin of primary axes is translated by  $T_x, T_y, T_z$ , and the scale is multiplied by  $K$ , seven parameters define the whole coordinate transformation:  $T_x, T_y, T_z, \omega, \phi, \kappa, K$ . For further information see [18]. The central perspective projection, Figure 2, is the starting point for a model in close range photogrammetry. Figure 2 shows the elements, the perspective relationship and the collinearity of  $A, O$  and  $a$ . The collinearity equations shows as a image point  $a(x_a, y_a, -f)$ , the perspective centre  $O(X_0, Y_0, Z_0)$  the object point  $A(X_A, Y_A, Z_A)$ , are onto the straight line  $Aoa$ . The collinearity Eq. (2) allow to estimate the image co-ordinates  $(x_a, y_a)$  from the object co-ordinates  $(X_A, Y_A, Z_A)$ ,

$$\begin{aligned} x_a &= -f \frac{r_{11}(X_A - X_0) + r_{12}(Y_A - Y_0) + r_{13}(Z_A - Z_0)}{r_{31}(X_A - X_0) + r_{32}(Y_A - Y_0) + r_{33}(Z_A - Z_0)} \\ y_a &= -f \frac{r_{21}(X_A - X_0) + r_{22}(Y_A - Y_0) + r_{23}(Z_A - Z_0)}{r_{31}(X_A - X_0) + r_{32}(Y_A - Y_0) + r_{33}(Z_A - Z_0)} \end{aligned} \tag{2}$$

where  $r_{ij}$  are the elements of the matrix of rotation R in which the rotation angles to be determined appear.

A multistation convergent bundle adjustment gives results of higher quality when it is used pictures of different cameras. In a bundle adjustment, all measured photo-co-ordinates are processed simultaneously using (iterative) linearized least squares methods to evaluate the exterior (and sometimes interior) orientation elements, the camera calibration parameters and the object co-ordinates. A further advantage of the multistation

bundle adjustment is that it is possible to obtain the calibration parameters of the camera and the interior orientation parameters [3], [17].

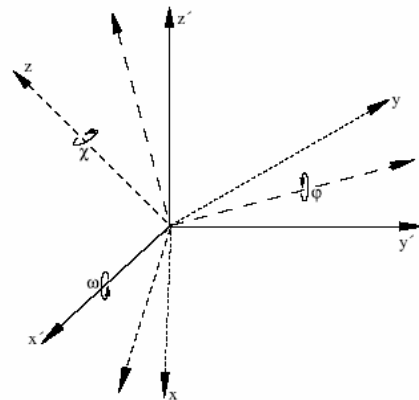


Figure 1, Rotation angles on the three axes, from the model system to the base system.

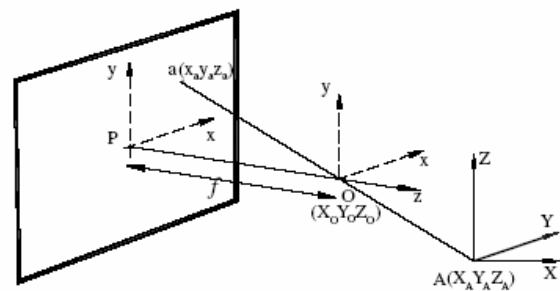


Figure 2, Central perspective of A show three-dimensional object co-ordinates and homologous point a in the projection plane. It show main point P, perspective center O, focal length f and the collinearity of A, O and a.

When several cameras placed around an object are used, it is called multistation convergent. If non-metric cameras are used, more additional parameters could be included. These equations can be written (3),

$$F(x, b, a) = 0 \quad (3)$$

where  $x$  is a vector representing the parameters to be estimated;  $b$  is a vector representing the measured elements;  $a$  is a vector representing those elements whose values are known constants. Eq. (5) is a functional model of the photogrammetry based on collinearity equations; for further information see [8], [14].

The vector  $b$  includes all photo-co-ordinates and any measurements made on or around the object. The coordinates  $(X_i, Y_i, Z_i)$  of the targets will generally be included in  $x$ . If the cameras have undergone prior calibration, and these calibrated values are accurate, then the calibrated values could be included in  $a$ , if no prior calibration values have been obtained, it is possible to include calibration elements in  $x$  only (this procedure is referred to as self-calibration) [11]. The elements of exterior orientation of the cameras may have been evaluated by a prior process so if it is reasonable to assume they have remained unchanged, the values can be included in the next process as either constants (in  $a$ ) or as measurements (in  $b$  and in  $x$ ) [3],[14].

In close range photogrammetry, where more measurements are available than the least necessary to evaluate the unknown elements, it is possible to justify the use of least squares estimation (LSE) solely on the basis of statistical probabilities. LSE provides a systematic method for computing unique values of coordinates and other elements in close range photogrammetry based on a large number of redundant measurements of different kinds and weights. It allows for covariance matrices of estimates to be readily derived from the covariance matrix of the measurements. If a covariance matrix of the measurements is assumed, a priori analysis can be used to design a camera/object configuration and measurement scheme to meet criteria relating to precision, reliability and accuracy. This attribute of LSE is particularly useful in close range photogrammetry where almost every measurement task has unique features.

LSE is also flexible, it allows elements to be treated as unknowns, or as measurements, or as constants depending on circumstances. The main disadvantage of LSE is that it does not make it easy for the user to identify blunders in measurements [14],[18].

Compared to classical surveying methods, digital close range photogrammetry is efficient and rapid, significantly reducing the time required to collect data in the field. Measurements collected in less than three days in the field would have taken 10 days in a conventional survey. Second, it was considerably safer. All surveyors were able to obtain precise measurements without physically accessing each measurement point. Third, the method was non-intrusive, creating minimal impact on traffic flow. Finally, the process produced a comprehensive visual record of existing site conditions from which any identifiable features can be measured or geometrically assessed at a later date. Digital close range photogrammetric methods have been

successfully applied to projects in archaeology, architecture, automotive and aerospace engineering, and accident reconstruction [3],[6],[8]. Digital photogrammetric systems allow the use of conventional digital cameras and consequently lower costs (about 600 €) [12].

## 2.1. PHOTOGRAMMETRIC PROCESSING

Office work is a subsequent stage to field work. Office work serves the purpose of processing previously gathered information. It is carried out in two stages: one involving the storage of data contained on the index cards and the other involving data processing. In the first stage a database must be created in order to speed up the management of information. In the second stage, 3D models reproducing the original structure on a fixed scale are obtained by means of a digital photogrammetric station. This data processing stage is divided into the following stages:

**Inner orientation.** This operation entails the reconstruction of perspective rays in conditions similar to their formation within the photographic camera, using the values obtained in the calibration process (radial and decentring lens distortion, focal length and position of the principal point). By means of inner orientation we can get rid of errors arising from the use of non-metric cameras. The camera calibration has been done using the Camera Calibrator 4.0 software included in the Photomodeler Pro 5.0 digital photogrammetric station. The method used by this software is the self-calibrating bundle adjustment, which requires taking some previous shots of a calibration grid [16] in order to obtain the inner orientation parameters of the camera. This calibration process is clearly described by [5], [7], [13].

**Exterior orientation.** In this stage the rays generated in the inner orientation process are positioned in relation to the ground in the very same position adopted at the moment of exposure of the photographs. The photogrammetric coordinates for a minimum of five points shared by another photograph already orientated or to be orientated in the same process must be measured. As ground control points are not available, the system will carry out a free network adjustment. This includes two operations arranged in sequences known as relative and absolute orientation.

**Relative orientation.** The evaluation of the exterior orientation elements of one camera with regard to the photo coordinate system of another is known as relative orientation. The simultaneous intersection of at least five pairs of homologue rays distributed through the model is enough for the remaining points to intersect as well, according to perspective geometry. The rays' equations are calculated analytically and the relative orientation parameters can be calculated applying the coplanarity conditions to the homologue rays (vectors defining the projection of every ground point on the photographs) for each pair of photos. Adopting the coordinate system based on the first Picture (origin in the centre of projection, X- and Y-axes on a plane parallel to the plate, and the Z-axis in the direction of the principal axis), the relative orientation solves the problem of calculating the relation between the photogrammetric coordinate system and the model coordinate system by means of the coplanarity condition (Figure 3):

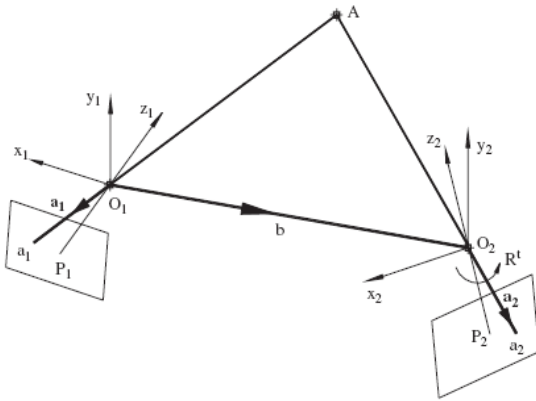


Figure 3, Reference systems of two photographs in order to carry out relative orientation

$$\begin{vmatrix} 1 & \frac{b_y}{b_x} & \frac{b_z}{b_x} \\ x_1 & y_1 & -f \\ x_2 & y_2 & z_2 \end{vmatrix} = 0 \quad (4)$$

where  $b_x$ ,  $b_y$  and  $b_z$  are the distances between the centre of projection of two photographs according to axes  $X$ ,  $Y$  and  $Z$ , respectively;  $(x_1, y_1, -f)$  image coordinates of a point in the first picture referred to the principal point ( $f$  being the camera focal length); and  $(x_2, y_2, z_2)$  the coordinates of the point in the second picture, referred to the coordinate system of the first. The latter are obtained starting from the coordinates of the point in the coordinate system of the second picture  $(x'_2, y'_2, -f')$  by means of a rotation and a translation:

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = R \cdot \begin{bmatrix} x'_2 \\ y'_2 \\ z'_2 \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} \quad (5)$$

$R$  being the rotation matrix is expressed as Eq. (1)

The collinearity condition will solve the same problem, plus it will allow calculating the ground coordinates for a point in  $n$  photographs starting from the image coordinates (and inversely). The principle of collinearity states that an image point  $a(x_a, y_a, -f)$ , the perspective centre  $O(X_0, Y_0, Z_0)$ , and object point  $A(X_A, Y_A, Z_A)$  are all on the same straight line (Figure 1). The collinearity equations can be expressed as Eq. (2).

The coordinates of the perspective centre  $O$  and of object points  $A$  will be model coordinates if relative orientation is being carried out, and ground coordinates when absolute orientation is being performed.

Once the external coordinate system for the first image has been defined, it will be the one used for each image added whose

relation will be obtained with the co-planarity condition (relative orientation).

**Absolute orientation.** Once the model has been established, we must adjust it to the ground coordinate system by means of absolute orientation. The  $z$ -axis is established from the direction defined by the plumb lines and this is how the model is leveled. The scale factor is attained via the distances measured on the plumb lines by means of a simultaneous bundle adjustment. Then we proceed to a new adjustment which ensures correct leveling, orientation and scaling of the 3D model. The homothetic relation (scale factor) between the model obtained in the relative orientation and the ground truth is calculated by measuring the real distances between the points marked in the plumb line and comparing them with the distances in the model.

Leveling is achieved applying rotations around  $X$ - and  $Z$ -axes (that means that  $\varphi = 0$  in the rotation matrix), which is the result of testing the model coordinates for the points marked in the plumb lines (the fact that these are vertical enable to establish that after the transformation they have the same  $X$  and  $Z$  coordinates). The transformation equations for the photogrammetric systems  $(x, y, z)$  to the ground coordinate system  $(X, Y, Z)$  are similar to the ones used in relative orientation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = k \cdot R \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \quad (6)$$

where  $(X_0, Y_0, Z_0)$  are the camera principal point ground coordinates,  $k$  the scale factor previously calculated and  $R$  a rotation matrix with  $\Omega$  and  $K$  rotation angles obtained in the model leveling stage.

**Restitution of the models (after scaling and orientation).** The information contained in the photographs will be materialized in a document, irrespective of whether such photographs are plans and digital files (3D and/or 2D), coordinates lists with information on the mistakes observed, etc. Several modalities of restitution are available: points, lines, polylines (or other graphic entities of interest, like cylinders, circumferences, etc.) [2].

The resulting models containing metric information and the 3D models are ready to be exported in conventional formats (dxf, dxb, vrml, etc.) into other programs in order to be visualized, edited or processed. Another feature of the system is its capability to generate 3D models of surfaces and the subsequent projection of real textures, captured from the object's photographs, onto these models.

### 3. CASE STUDY

In this study, known volume of an artificial object has been used to measure needed coordinates for the modeling. Object was evaluated according to photogrammetric principles. 541 point coordinates measured on the surface of the object.

#### 3.1. Artificial Model

Artificial object is made of gypsum with a base diameter of 9 cm, and height of 9 cm. Artificial object has a uniform surface hill-shaped (Figure 4). In order to calculate the volume of the object, a glass of 1000 ml volume was used. First of all, the glass was filled with 100 ml water, then the artificial object put into the glass. The water level is risen up to 464.2 ml. By extracting the former volume of water, volume of object is determined as 364.2 ml. For surveying the control points, a test area was set (Figure 4). After surveying the coordinates (X,Y,Z) of control points, different positions of the object were photographed by using 8 Mega Pixel DSC-F828 Sony Digital Camera (Figure 5). Calibration of the digital camera was set up. The calibration values, photos and control points were transferred to the Photomodeler 5.0 software package. Finally, the photogrammetric properties of the artificial object were obtained by surveying 541 points upon the surface of the object (Figure 6). Root mean square errors in control points are 0,12 cm, 0,11 cm and 0,10 cm in X,Y,Z respectively.

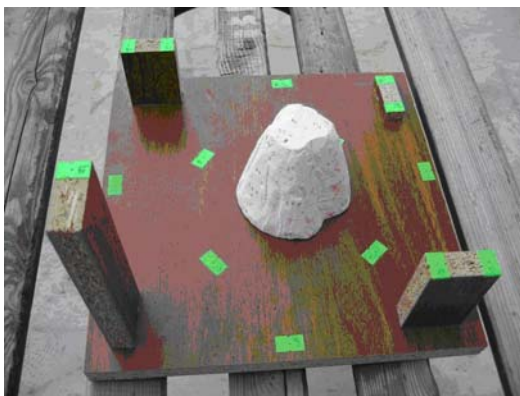


Figure 4, Artificial object and test area

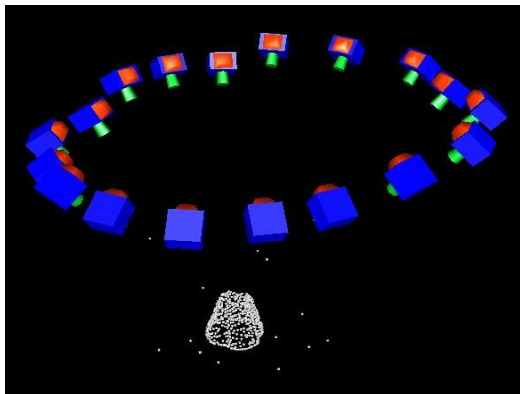


Figure 5, Object and Camera Positions

In this application, forming of the test field has been finished in 0.5 hour, camera calibration procedures have been completed in 1 hour, photogrammetric orientation and adjustment procedures have been accomplished in 0.5 hour and evaluation of the photographs to measure of the coordinates has been finished in 2 hours. Total time for the whole studies was 4 hour. Afterwards, obtained coordinate values from the object surface were imported Surfer 8 software [19]. 3D model of the artificial object and volume was calculated (Figure 7). volume of the object according to traditional measurement was 364,200 cm<sup>3</sup>. Calculated volume of the object according to measured coordinates was 362.670 cm<sup>3</sup>. The difference of volume for the

real value and calculated value was 1.529 cm<sup>3</sup>. Real object volume was obtained 99.52 % proportion.

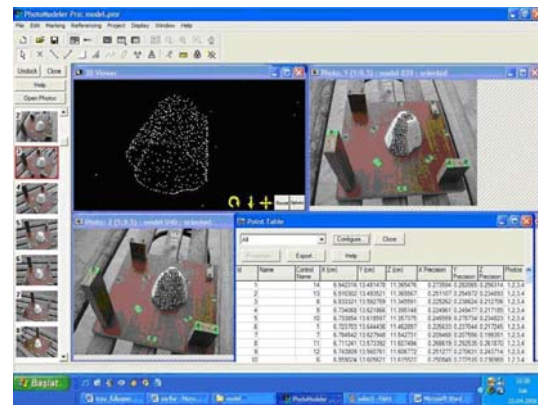


Figure 6, A view of photogrammetric evaluation in Photomodeler Software

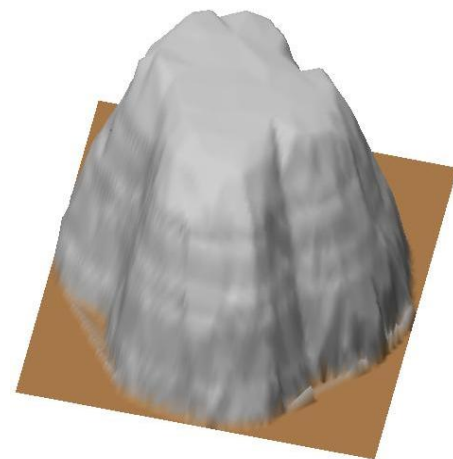


Figure 7, 3D model of Object

#### 4. CONCLUSIONS

Nowadays, both visual and scientific applications of 3D modeling are increasing day by day. 3D modeling products are using in many variety discipline. With the improving hardware and software 3D modeling studies can be done much more easily and fast. In this study, the role of digital close range photogrammetry in the obtaining of 3D model was investigated. It can be seen that, in the completed study from model, obtaining of the data with photogrammetry is quite accurate and quite fast. To produce a 3D model, needed object coordinates on the surface of the object can be obtain in a short time and much more fast. A close range photogrammetry software and a consumer degree digital camera are sufficient for this works. All studies can be completed only using photographs. That is, this is a noncontact technology. For this reason, photogrammetric method can be considered in risky places. It also can be consider to survey of directly unmeasurable objects. This is the must safe method from the point of this view. One of the main features of photogrammetric methods is the short length of time required on-site to carry out measurements. Office work during the evaluation stage is actually longer. Another beneficial factor is that the user does not require specialized knowledge of photogrammetry, and that no large-scale

investments in equipment are needed. Besides the classic wire-frame models, recent developments in close-range photogrammetry allow to obtain new 3D models with photo-realistic textures. Metric proprieties are thus combined with visual knowledge of the elements materials. Therefore, it is possible to make the most of the techniques potentialities and improve results significantly.

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