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ACCURACY ANALYSIS OF DIFFERENT SURFACE RECONSTRUCTION MODELLING METHODS FOR HERITAGE OBJECTS DIGITIZED CONSIDERING PHOTOGRAMMETRIC DATA

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Abstract. The article explains the possibilities of reconstructing heritage objects. Measurements were made using photogrammetric data received from digital images taken by the *Canon EOS 1D Mark III* digital camera calibrated in the Institute of Photogrammetry at the University of Bonn (Germany). The images were received applying the *PhotoMod* photogrammetric software produced in Russia. *TIN* (Triangulated Irregular Network) and an orthophoto map were made in the investigated objects. The modelling analysis of *TIN* data was made using *ArcGIS* software. The purpose of the article is to reconstruct the surface of heritage objects referring to photogrammetric data, to investigate accuracy dependence of heritage object reflection on the methods of preparing the initial data and to evaluate the influence of modelling methods on to the accuracy of reconstructing heritage objects when modelling photogrammetric data and selecting the most appropriate method of modelling parameters to restore the most accurate surface of the heritage object.

Keywords: heritage object, digital camera, photo images, triangulation, orthophoto map, *TIN*, surface model.

1. Introduction

For many purposes, the available geometric information about the surface of the heritage object or the ones under construction submitted in plans or three dimensional *CAD* models is required to allow applying it to controlling, conserving or reconstructing the object itself. Data are made available by means of manual measurements using instruments for a geodetic survey, taking into account the total station, laser scanning or photogrammetric measurements. In order to make photogrammetric measurements, it is required that digital images to be made using professional calibrated digital cameras. Processing object images is carried out applying the photogrammetric method following the below presented steps to work:

- images interior orientations;
- images relative orientations;
- calculation of block adjustment (Triangulation);
- drawing the structural line of an object;
- creating the Triangulated Irregular Network (*TIN*) of object surfaces;
- creating an orthophoto map.

It is necessary to control data quality at all above mentioned work stages, particularly when obtaining the results of triangulation determining the quality results of *TIN*, the accuracy of the orthophoto map or the break lines in an object.

TIN data have been acquired employing regular, adaptive or smooth methods. In accordance with these available data, it is possible to compile the model of the surface. The article presents the results of the surface model when *ArcGIS* software is applied for *3D Analyst* expansion.

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2. Initial Data Preparation Using the Photogrammetry Method

The object of analysis is the North wall of Vilnius University yard in the old town. Two figures of humans are exhibited (Fig. 1) on the wall. The surface of the left figure will be analysed.

Fig. 1. Three overlapping images (P15-P12-P18)

The images were taken using the *Canon EOS 1D Mark III* professional digital camera. The characteristics are listed in Table 1.

Table 1. Characteristics of the *Canon EOS 1D Mark III* digital camera

Characteristics	Value
Focal length (mm)	50
Resolution (pixel)	21 mln.
Pixel size, pxl (μm)	6.4×6.4
Image size (mm)	35.9×23.9
Image size (pixel)	5616×3744

This camera is calibrated (optics distortions are determined and evaluated) using *Tcc* software at the Institute of Photogrammetry, the University of Bonn (Germany) in 2008 (Sužiedelytė-Visockienė *et al.* 2009). The parameters of the camera are presented in Table 2.

Table 2. Results of calibrating the *Canon EOS 1D Mark III* camera

Parameter	Result (pixel)
Focal length c	50.76 mm
Scale of image (constant) S_{xy}	0.99
Corrections of the principle point (pixel)	
x_0	–12.37
y_0	–63.98
Radial-symmetrical distortion	
A_1	–1.789E-09
Radial-asymmetrical distortion	
B_1	1.017E-8
B_2	–1.655E-8

The images of the object were corrected for the purpose of camera distortion using special *Tcc Distortion Correct* software made in Germany. Three overlapping images were corrected in Figure 1. These images were processed using the *PhotoMod* (Russian) photogrammetric software. At the first stage of work, image interior orientation was made. While carrying out image orientation, a fiducial – central point of the photos was measured. The coordinates of the point are equal half the size of the photo (in pixel) and make 2808×1872 (Sužiedelytė Visockienė *et al.* 2009).

The order of the process for relative orientation is considered to be as follows (CNIIGAIK 2002):

– Measuring Tie points in stereo pairs in overlapping areas and triplet zones (in case we have three images).

– Input and measurement of ground control points (*GCP*).

The quality of measuring tie and ground control points could be checked in the following ways:

– Accuracy control using the correlation coefficient the acceptable value of which could be determined by the user from image quality. For contrast and high quality images threshold is 0.9–0.95, for unclear images threshold could be 0.8 at well recognized points.

– Accuracy control using vertical parallax residual. The mean vertical parallax value should not be greater than a half of the matrix pixel size for a digital camera. For the *Canon EOS 1D Mark III* camera, the matrix pixel size is 6 microns while the mean value should be not more than 3 microns. Also, the program calculated maximum error ($E_{\max}$) and root mean squared error (*RMS*) (CNIIGAIK 2002):

$$E_{\max} = 2 \times E_{mean}, \quad (1)$$

$$RSM = \sqrt{2} \times E_{mean}, \quad (2)$$

where E_{mean} – the mean error of measurement points in the model. The results of accuracy control are presented in Table 3. We had three images and made two models P15-P12 and P12-P18.

Table 3. Measurement quality at *Tie* and *GCP*

Model	$E_{\max}$, pixel	RMS, pixel
P15-P12	0.54	0.26
P12-P18	0.51	0.29

The average maximum vertical parallax error in the models is 3.12 μm which is acceptable and considered to be a good result.

After measuring tie and ground control points in stereo pairs (models), they should be transferred to the geodetic coordinate system. One could check the accuracy of relative orientation by comparing discrepancies in point measurements obtained in adjacent models (triplets). Considering coordinates X, Y, Z, triplet errors E_x, E_y and E_z were calculated in two adjacent models. Besides, mean triplet errors in XY plane and Z coordinates had to be calculated (The recommendations... 2002):

$$E^{xy}_{mean} = \sqrt{2} \times 0.5 \times pxl, \tag{3}$$

$$E^{z}_{mean} = \frac{c}{b_x} \times E^{xy}_{mean}, \tag{4}$$

where *pxl* – the matrix pixel size of the digital camera (6 microns); *c* – is the focal length of the camera (Table 1, 2), b_x – is a base in the image scale.

The obtained triangulation adjustment scheduled error should not exceed 5, whereas heights should be 15 μm, in case b_x could be 13.2 mm in the photo. In block adjustment, we had 10 *GCP* and 9 *Tie* points. Triangulation accuracy results are presented in Table 4.

Table 4. The quality of triangulation

Point	E^{xy}_{mean}, μm	E^{z}_{mean}, μm
GPS	4	5
Tie	11	26

Triangulation results are acceptable.

After the adjustment of triangulation, we have ready-made TIN data on the object available for compiling break lines and the orthophoto map. The accuracy of all these results is determined by the received accuracy of triangulation (Table 4).

3. The Orthophoto Map of an Object

The orthophoto map was compiled following one or some images of an object. The process of generating some images into a single orthophoto map is called mosaic (Shariat *et al.* 2008). The orthophoto map of the investigated object, namely the figure, was compiled according to one P12 image where the image is taken from the front (Fig. 1. a image in the middle). It was rectified in accordance with triangulation and the points of break lines. The used smallest size of the cell of the orthophoto map was 1 mm (Fig. 2).

The orthophoto has reference to the geodetic coordinate system and looks like a picture. The orthophoto provides a possibility of carrying on the works of drawing and measurement.

Fig. 2. The orthophoto of an object

4. TIN Data Generation

By means of *PhotoMod* software facilities, *TIN* in the object could be compiled applying regular, adaptive and smooth methods.

The *TIN* of the object is made in accordance with the break lines of the object and data on triangulation (*GCP* and *Tie* points).

When applying the **regular** method of compiling *TIN*, the altitudes of the nodes of the triangle network are automatically calculated with reference to Delaunay algorithm. The least marginal coefficient of correlation (in our case, it makes 0.8) has to be set in advance. If the coefficient of correlation is unsatisfied, height is calculated in accordance with the altitudes of neighbouring apexes. It is suggested that the regular method has to be applied in cases when the investigated surface is a complicated one. The selected smallest cell of the *TIN* network in the object is 0.5 mm. The obtained cloud is made of 341 550 points. The **adaptive** method of *TIN* compiling is recommended to be applied to smoother surfaces. The calculation of the heights of points is also carried out automatically by means of correlation**.** The points not satisfying the size of the coefficient of correlation by means of the above mentioned method are eliminated. The cloud of 131 830 points was received in the object. The **smooth** method was also used for compiling *TIN*. Before works of compiling are started, it is required to select which the formation of *TIN* has to be referred in accordance with the break lines of the object or data on triangulation). It should be also considered that data on triangulation, the break lines of the object and *TIN* are formed employing some other method. In our case, data on triangulation and break lines (Fig. 3) were used. Additionally, there is preset the maximum number of points in accordance with which the calculation of the heights of the *TIN* points. It is possible to set 1000 points. Due to the adjustment of points, a possibility that the heights of surfaces contravene arises.

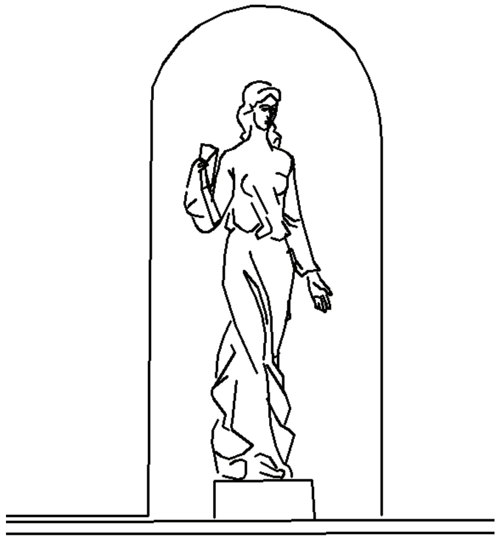

Fig. 3. Break lines of an object

In the smooth method in the object received TIN data there were 334756 points. The data obtained using various methods would be applied in compiling the model of the surface.

5. Use of *TIN* Data on Compiling the Network Model

Together with upgrading the object terrain, the possibility of modelling *TIN* data appeared. The attempts to carry out research by means of 3D Analyst applying ArcGIS software expansion and to compile *TIN* using photogrammetric methods and converting them into a network model (Fig. 4) were made. The surface models were obtained from regular, adaptive and smooth *TIN* (Ruzgienė 2010).

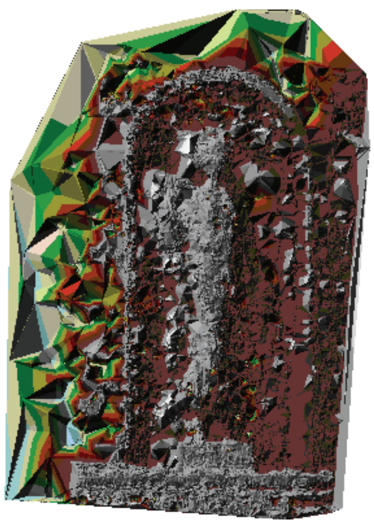

Fig. 4. *TIN* converted into the network model

Conversion was carried out by executing linear interpolation which is one of the simplest ways of interpolation where the qualities of the interpolated objects are not taken into consideration among the points of data. Thus, *TIN* triangles are interpreted as planes when to the height of the cell of the network model is attached to the height of the triangle depending on the position of the cell in the triangle in 2D space. The value of the triangle plane is attached to the value of the cell centre.

The article describes a *TIN* model in accordance with simulation parameters required for calculations: the methods of kriging, weight and splain that use weights for data analysis (Kumetaitienė 2006).

The application of different ways of surface interpolation is the main phenomenon that determines the methods of surface simulation. The article investigates the issues concerning by what means and in with what degree of accuracy a minor object of architectural heritage could be presented, namely the figure of the statue, to have it in a detailed way.

When compiling the digital model using the kriging method, circular, spherical and tetraspherical variograms were used. The variograms were selected because the accuracy of the obtained model of relief could be more precise in case a greater number of adjacent points are taken into account. During research, simulation was used including adjacent points 9, 12, 15, 18 selected for calculations.

The digital model presented in the article was also compiled using modelling methods the accuracy of which determining the weight of the heights of the used points of the surface is very significant. By applying the weight and splain methods of surface simulation, the optimal value of weight was selected according to the software program.

In modelling, relief by the chosen methods, there were selected the optimal parameters of the cell of the digital model in the research. In light of the fact that the speed of data and model processing depends on the cell parameters, it is possible to select the parameters of the cell taking into account the purpose the model has to serve. In our case, in order to get the most accurate and detailed model, the cell parameters of 1×1 m to conduct research were selected. Besides, distances between the points play a significant role in the accuracy of simulation. Research presents digital relief models compiled of the points the average distance of which is 0.06 m. The density of the points in applied research is very high. For the adaptive *TIN* simulation method, 131830 measured points were applied: for the regular *TIN* method, 341 550 points were used while for the smooth *TIN* method it made 334 756 points.

When performing measurement using the kriging method, 18 adjacent points were used. By means of a spherical variogram, the relief model from adaptive *TIN* was received (Fig. 5).

Fig. 5. A digital model taken using the adaptive *TIN* method

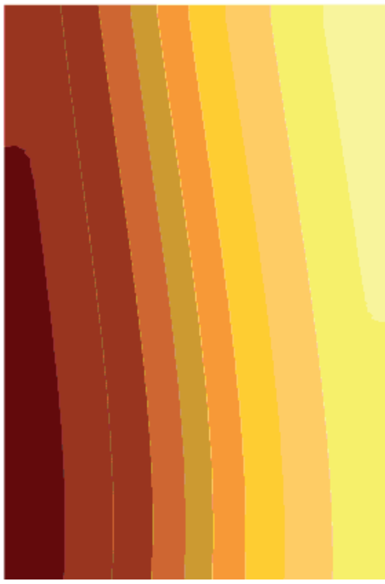

Fig. 6. A digital model was received from smooth *TIN*

When applying the kriging method, 18 adjacent points with spherical variograms were used for measurements while using the smooth *TIN* method the model of relief was obtained (Fig. 6).

By means of the kriging method, 18 adjacent points with spherical variograms were used for measurements while using regular Tin the model of relief was obtained (Fig. 7).

After analysing *TIN* compiled employing various methods, it can be stated that the most suitable method for simulation is considered to be *TIN* compiled using the adaptive method. *TIN* compiled applying the smooth method is completely inadequate for digital model compiling; however, the *TIN* model obtained using the regular method is too much washed-out. The model obtained from *TIN* using the adaptive method is reflected in the precise way. The number of points applied for the method was significantly less.

The article presents the model compiled using the splain method. Adaptive *TIN* was selected for calculations. During simulation, the surface was compiled using the regular splain method when the weight of the height of the investigated point equal to $\lambda = 0.1$ was applied selecting 18 adjacent points for calculations (Fig. 8).

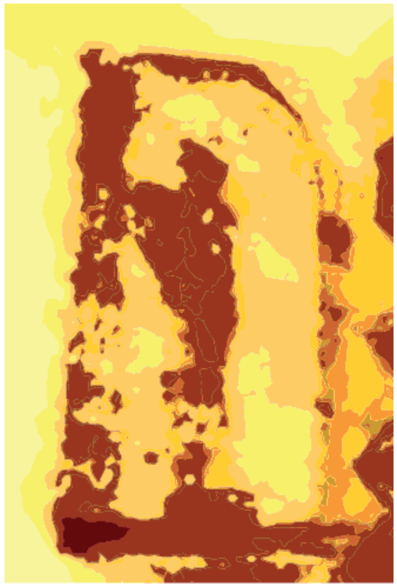

Fig. 7. A digital model was obtained from regular *TIN*

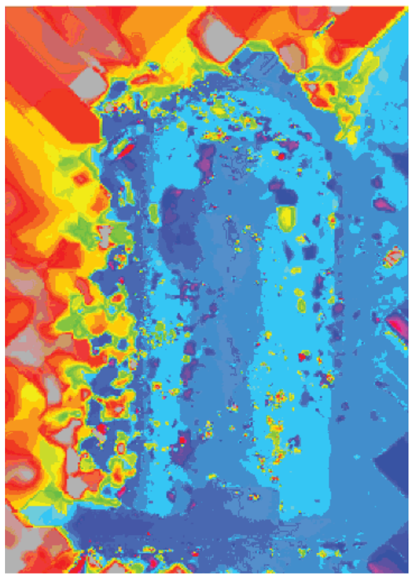

Fig 8. A digital model obtained using the splain method

Research also presents the model compiled using the weight method. Adaptive *TIN* was chosen for calculations. During simulation, 18 adjacent points and the weight value of the point $p = 4$ were used (Fig. 9).

After analysing all obtained models, the following data accuracies were presented (Table 5).

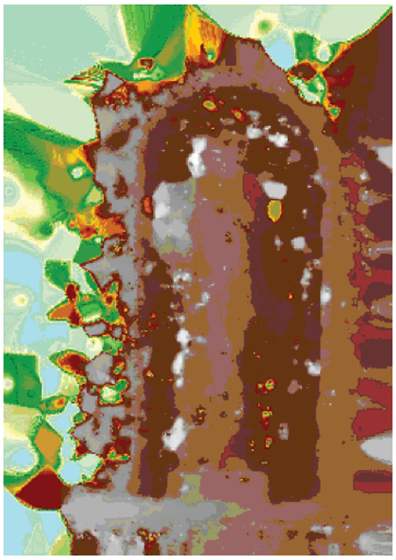

Fig. 9. A model obtained using the weight method

Table 5. The accuracy of different methods for simulation

Simulation model	Number of points used for measurements	Number of adjacent points used for calculations			
		9	12	15	18
		Standard deviation σ			
Kriging	131830	0.48	0.43	0.39	0.38
Weight		1.71	1.67	1.64	1.62
Splain		1.79	1.76	1.72	1.70

The evaluation of standard deviation is considered the value constant the result of which should not exceed 2.

When compiling different methods and comparing all digital methods of simulation with each other, we can state that the most accurate model is the one compiled using the kriging method.

It was observed that the quality of the results of the obtained model depends on the initial data, namely *TIN*, compiled applying different methods, on the number of points used for them, the interpolation model employed and the required parameters prescribed for it.

5. Conclusions

Digital images were processed using the PhotoMod photogrammetric system. Data reliability is determined by the result of triangulation adjustment characterized by plane and heights errors registered at the measured ground control and tie points. In our case, the accepted result of the mean plane error of the object is 9.5 μm, whereas the error of heights is 18 μm.

The accuracy of triangulation characterizes data accuracy of the orthophoto map, the accuracy of TIN and the accuracy of break lines (vector data) photogrammetrically obtained from the object.

The orthophoto map of the investigated object is considered to be qualitative and used for carrying out precise works of drawing and measurements; however, the received data are not three-dimensional.

Following photogrammetrically obtained *TIN* data, surface models applying ArcGIS 3D Analyst extension were compiled. The accuracy of the obtained data is characterized by the evaluation of standard deviation equal to 0.3–1.8. This coefficient should not exceed 2.

The obtained surface models compiled from *TIN* data and received by applying kriging, splain and weigh methods are not considered satisfactory. The received images are washed-out, shadowy and indistinct. The authors consider that ArcGIS software and methods chosen for simulation could not be introduced into the simulation of the architectural objects (elements) of heritage.

When carrying out drawing works of architectural elements, it is necessary to use specifically tailored software adjusted for that purpose.

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