545. The Analysis of Possibility of Creating of Terrestrial Orthophoto

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Abstract. Photogrammetry is the science of creating 2D or 3D models of object basing on several photo images. With the modern digital technologies it can be widely implemented for different tasks such as constructions and structures measurement, reverse engineering of curved surfaces etc. Photogrammetric measurements with the high speed cameras can be also implemented for measurements of vibrations. One of the intermediate stages of photogrammetric data evaluation used for 2D measurements and storing the obtained information is an orthophoto image. Here in this paper a short review of the principles and possibilities of the photogrammetric data acquisition are presented. Also the creation of orthophoto and basic 3D surface model of the manor-house ceiling performed by means of *Canon EOS 1D Mark III* camera and *PhotoMod* photogrammetric software is described.

Keywords: photo camera, photo images, triangulation, orthophoto image.

1. Introduction

Photogrammetry is the science of creating 2D and 3D models of the objects by means of photographic images implementing the principle of triangulation. Objects on the images are captured at the certain moment in time (the moment of taking the image), at a certain condition, therefore data from the images are valuable in retaining the maps, performing the preservation and restoration of objects, researches of deformations etc. After processing of several images by means of special computer software (bulky mechanical devices were used in the past) the spatial (3D) point cloud of the object can be obtained, which can be used for creating the 3D models of objects (buildings, machines etc.), determination of the object deformations, accumulating the heritage information, modelling the complicated 3D surfaces, reverse engineering and other similar tasks. Same technology with the high speed cameras can be implemented for vibrations analysis.

For storing the images and 2D measurements the orthophoto image of the object is usually being created. Orthophoto is the strictly scaled image composed of set of images so that they reflect the maximum available information on the object from certain point of view (top usually). Orthophoto of terrestrial objects can be created using 1, 2 or more photographic images of the same object taken from different directions by means of:

- triangulation points (special points picked by the operator or software);
- Structural lines of the object;
- Triangular Irregular model (TIN, the set of automatically picked points at a certain grid);
- Combining all mentioned methods.

Further in this article the creation of orthophoto of the terrestrial object using different sources of photogrammetric data is described, with brief analysis of the accuracy and general quality of obtained results.

2. The orthophoto rectification

During the process of image taking objects on the photo image are projected through a perspective centre onto the image plane (Fig 1). As the result of this, the image depics the perspective view of the world. Objects that are placed at a same point but at different heights will therefore be projected to different positions in the images.

In case of relief displacement objects are placed at a higher position and look relatively bigger in the images, while orthophoto is the image free of mentioned flaws. The result of orthophoto rectification is an image where the perspective aspect of the image has been removed. It has consistent scale and can be used as a planimetric map and precise measurement of object geometry (in 2D). The orthophoto has a reference to a coordinate system and look like picture [1, 2, 3].

In classical airborne photogrammetry orthophoto rectification is done by reprojection, where rays from the image are reprojected onto a model of the terrain in two ways: forward and backward projection (Fig 2).

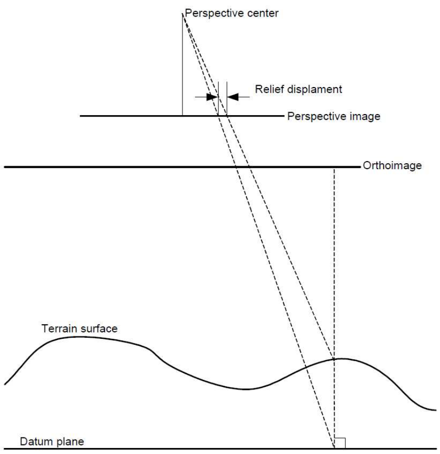

Fig 1. Perspective and orthographic image geometry

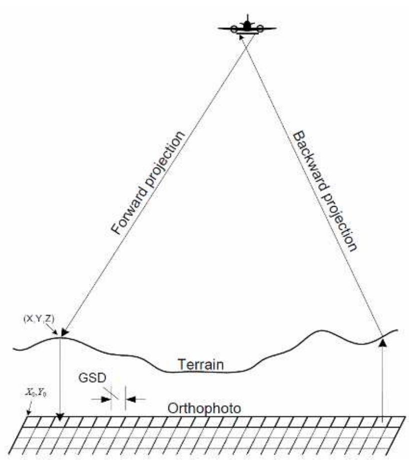

Fig 2. Forward and backward projection

The forward projection projects the source image back on the terrain (fig 2). The point where the projected point intersect the terrain (X, Y, Z) is then stored in the orthophoto. If the corner of the orthoimage is placed at X_0, Y_0 the pixel coordinate in orthoimage is found by [1]:

$$\begin{bmatrix} colum \\ row \end{bmatrix} = \frac{1}{GSD} \begin{bmatrix} X - X_0 \\ Y_0 - Y \end{bmatrix}, \tag{1}$$

where GSD – ground sample distance, which is distance between each pixel. In the pixel coordinate system has the Y axis is downward and the geodetic coordinate system has the Y coordinate upwards/north.

In the backward projection a coordinate of a pixel in the orthophoto is converted to the general coordinate system, and the Z coordinate is found at this point in the terrain. The pixel transform is given by [1]:

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} X_0 \\ Y_0 \end{bmatrix} + GSD \begin{bmatrix} column \\ -row \end{bmatrix}, \tag{2}$$

The position in the source image that corresponds to the found X, Y, Z coordinate can be found by modelling the camera [4].

Ortophoto can be generated using single image of the object or several images. The generation of several images into ortophoto is called the mosaicking [5].

Mosaicking images involves additional features (which are unneeded in case of a single image):

- Seamline generation;
- Colour matching;
- Feathering and dodging.

The seamlines in a mosaic defines where the images are stitched together. This process can be done automatically or manually by computer software. The images mosaicked should have same color characteristics near the seamlines. If the colour or brightness of the images are very different, the result of mosaic will be very poor and the placement of seamline visible. Colour matching and dodging techniques are applied to remove the radiometric differences in the images, by analyzing and comparing the overlapping sections.

While creating the orthophoto using the TIN points (point cloud) maximal amount of the information must be extracted from the images, therefore every pixel of the image should be evaluated. To project every orthophoto pixel on to the original images with the collinearity equations, the third coordinate (elevation Z) of every ortho-photo pixel is needed. Thus every ground pixel, with coordinates X, Y of the orthophoto matrix, is interpolated in the digital surface model in order to calculate its elevation Z. The interpolation method used is nearest neighbouring sampling [6].

3. Object under research

To evaluate the possibilities of methods of creation of orthophoto, the fragment of the Uzutrakis manor-house ceiling was chosen as an object under research. To create the orthophoto the following geodetic and photogrammetric tasks were accomplished:

- Marking and measuring of the geodetic reference points (needed for scaling and general orientation in space);
- Taking the images of the object;
- Corrections of the images optical (camera) errors (mentioned in section 2);
- Triangulation, performed by the photogrammetric software;
- Stereo-digitalisation – the creation of structure lines;
- Creation of the TIN.

There should be no less then 5 reference points on the surface of the object (software requirement), which are needed for the calculations of the triangulation and general positioning of the created model. Additionally according to these points the accuracy of the obtained orthophoto can be controlled.

The images were taken by the professional *Canon EOS 1D Mark III* digital photo-camera. The characteristics of the *Canon EOS 1D Mark III* digital photo-camera are listed in Table 1. This particular camera was calibrated (its optics distortions determined and evaluated) using *Tcc* software at the Institute of Photogrammetry of University of Bohn (Germany) in 2008, A special calibration stand-template with the marked points (at certain coordinates) was used for that task [7]. The determined camera parameters are given in Table 2.

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

	Characteristics	Value
	Focal lens (mm)	14
	Resolution (pixel)	21 mln.
	Pixel pitch (μm)	6,4×6,4
	Image size (mm)	35,9×23,9
	Image size (pixel)	5616×3744

Table 2. Result of camera *Canon EOS 1D Mark III* calibration

Parameter	Result (pixel)
Principal distance	
c	2145.98041
Scale of image (constant)	
S_{xy}	0.999512
The base point corrections of the photo-camera	
x_0	2.41205783
y_0	-4.09312175
Radial-symmetrical distortion of the photo-camera	
A_1	–9.51815216E-09
A_2	8.29203383E-16

Using the described photo-camera two overlapping images of the ceiling were taken at manual mode (which is essential for high accuracy obtaining) with the objective focused to infinity (Fig. 3).

Fig 3. Overlapping mages of the ceiling

The images were corrected using *Tcc DistortionCorrect* (Germany) software according to the camera calibration results to eliminate the distortions of the objective-lenses (Table 2). The processing of the images was performed using the *PhotoMod* (Russia) software, which consists of several modules:

- *PhotoMod Montage Desktop*, base module, used for creation of project and loading other modules;
- *PhotoMod AT* – measurement of triangulation points, composition of geometrical models of images;
- *PhotoMod Solve* – calculation of triangulation;
- *PhotoMod Stereo Draw* – stereo-vectorisation;

- *PhotoMod DTM* – creation of digital terrain model;
- *PhotoMod Mosaic* – creation of orthophoto.

Measurements and calculations of triangulation using 5 geodetic reference points (mentioned above, used for interior and exterior images orientation) and 7 additional tie points (interior images orientation – inside the software) were performed by *PhotoMod AT* module. The results of points triangulation measurements are given in Table 3, it should be mentioned that listed results correspond to the software internal calculation errors (obtained by comparison of reference and tie points) and may differ significantly from the "real-life" results.

Table 3. Accuracy of triangulation (internal results of the software)

Points Nr. Nr.	Accuracy results, mm		
	E_X	E_Y	E_{XY}
Reference points of triangulation			
942	–0.4	0.4	0.6
943	–0.4	2.4	2.5
945	1.3	0.7	1.5
947	–0.8	–1.6	1.8
948	–0.3	–2	2.1
Tie points of triangulation			
1	1	–0.3	1.1
2	0	0.4	0.4
3	–0.3	–0.5	0.6
4	0	1.2	1.2
5	–1	–0.9	1
6	0	1	1
7	0.2	–1.2	1.2
RMS*	0.6	1.2	1.4
Max**	1.3	2.4	2.5

*RSM – Root mean square error;
**Max – Maximal deviation

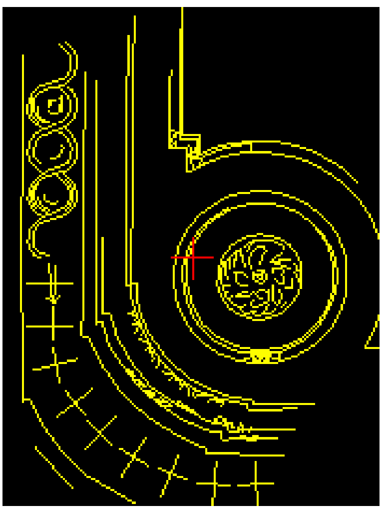

Fig 4. Structural lines of an object

By means of *PhotoMod Stereo Draw* software module the object was stereo-vectorised and structural lines of the object were obtained. (Fig. 4).

The TIN of the object was created in automated mode using *PhotoMod DTM* software module. The smallest TIN cell size in the project described was 3x3 mm. The discrepancy of TIN points regarding the Z coordinate was in range of 0.4 – 3 mm, root mean square error RSM – 1.8 mm (mentioned data were determined form the software inner calculations and can differ from the real deviations). The results of the TIN (point cloud) are shown in Fig. 5, a, with the surface created through the point cloud shown in Fig. 5, b.

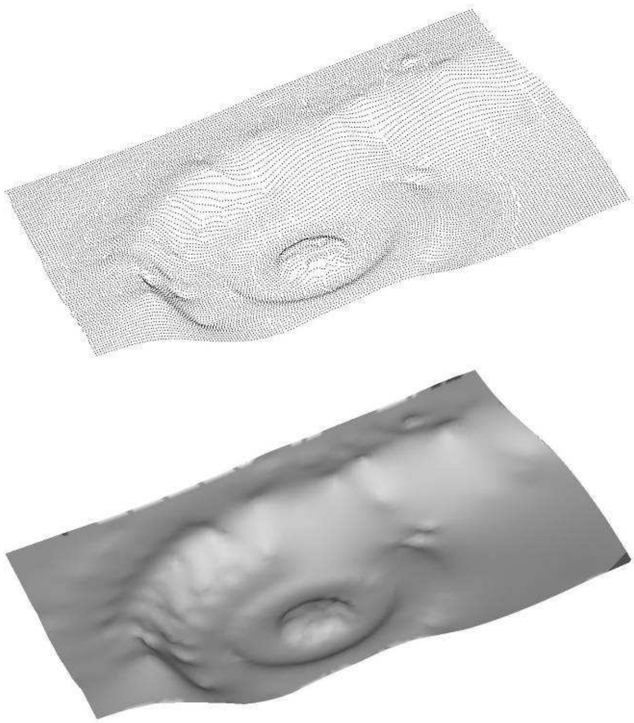

Fig 5. TIN of the object, a – point cloud, b – surface attached

As can be seen from Fig. 5 the surface of the object (ceiling) has some deviations from the original (actual ceiling) this was probably caused by the significant distance form the camera position (on the floor) to the object itself (ceiling). Nonetheless the 3D point cloud of the object and the surface created using those points is the most informative part of the model giving the biggest amount of information regarding the actual object [8, 9].

4. Creation of orthophoto

As was mentioned before (in introduction) the orthophoto is an intermediate stage of photogrammetric images processing mostly used for 2D measurements, nonetheless accuracy of orthophoto may significantly influence further measurements. Since the photogrammetric software (*PhotoMod*) allows creating the orthophoto by means of three principles all of them were tested and resulting data evaluated.

Creation of model by means of points of triangulation

Using the points of triangulation the orthophoto of the Uzutrakis manor-house ceiling was composed with the resolution of 0.3 mm per pixel (Fig. 6).

Fig 6. Orthophoto of the ceiling composed using poionts of triangulation

Table 4. Quality of orthophoto

Accuracy, mm	E_X	E_Y	E_{XY}
RSM	0.6	1.2	1.4
Max	1.3	2.4	2.5

For the calculation of orthophoto all 5 reference and 7 triangulation tie points were implemented. According to the coordinates of these points obtained during calculation (recombining the points) the accuracy of orthophoto can be evaluated (Table 4).

According to the calculation results evaluation the quality of the model is sufficient [8].

Creation of orthophoto by means of points of triangulation and structural lines

An orthophoto of the ceiling was composed by means points of triangulation and structural lines data with the resolution as previous – 0.3 mm per pixel (Fig 7).

Fig 7. Orthophoto of the ceiling composed using points of triangulation and structural lines data

Table 5. Quality of orthophoto

Accuracy, μm	E_X	E_Y	E_{XY}
RSM	0.7	1.1	1.3
Max	2	2.9	3

The accuracy of this orthophoto is also influenced by points coordinates differences obtained after the reduction. The summarised results are given in Table 5.

The results of the accuracy are quite sufficient but the orthophoto view quality is obviously lower – some black points and flaw lines have emerged.

Creation of orthophoto by means of object TIN data

While composing the orthophoto by means of object TIN points the reference and tie points were not used during the processing (Fig 8).

Fig 8. Orthophoto of the ceiling composed using object TIN data

Table 6. Quality of orthophoto

Accuracy, mm	E_X	E_Y	E_{XY}
RSM	3	3.7	4.8
Max	8.1	11.1	11.3

The accuracy of model was influenced by the differences in TIN points coordinates after the reduction of orthophoto. The summarised results are given in Table 6.

As can be seen from the Table 6 accuracy of orthophoto is considerably lower then in previous cases. The variance of TIN points of the model according to Z axis has significant influence on the accuracy of calculation of orthophoto.

Such orthophoto contain all the scaled 2D information available from the images which were used for model creation therefore they can be used for further 2D measurements.

5. Conclusions

The following conclusions of the research could be given:
1. By means of photogrammetry both 2D and 3D coordinates of the object can be obtained (single points of interest or point cloud of the surface).
2. Orthophoto of the object is an intermediate stage used for reduction of unneeded data and composing all the critical photogrammetric data into a single file which is easier process.
3. The fragment of ceiling of was used as the object for researches. Processing the images the RMS (root mean square) error of points of triangulation (comparing to the same points coordinates obtained by geodetic measures) was in range of 0.2–2.5 mm;
4. The accuracy of the orthophoto constructed by means of points of triangulation is influenced by the X and Y coordinates of the points obtained after the reduction. The RMS error of the coordinates differences is in range of 0.6–1.4 mm, which is quite sufficient.
5. The accuracy of orthophoto constructed by means of points of triangulation and structural lines is very similar to the one described above, but the orthophoto view is distorted in some areas and some black (errorous) points have emerged.
6. Reducing orthophoto by means of TIN points of an object RMS errors reaches 3–11.3 mm, which is unacceptable in most of the cases.

7. According to results obtained it might be stated that the most accurate orthophoto of terrestrial object can be obtained by implementing only points of triangulation in the calculations (RMS 0.6–1.4 mm). Implementing Structural lines and TIN points of the object distorts orthophoto view due to the gross errors in heights (Z coordinates) of points.

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