Application of digital photogrammetry in the process of documentation of archaeological artefacts

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The paper analyses the possibility of a convergent frame and photogrammetric scanning documents and the possible reconstruction of archaeological artefacts from the terms of accuracy and quality of the resulting model, appropriateness of use and time consuming processing of mentioned methods. Results orientation and execution as well as the advantages and disadvantages of the applied methods are presented in specific real artefacts. Photography was carried out using of digital camera Canon EOS 40D. Processing was carried out using the program PhotoModeler Scanner.

Key words: *digital photogrammetry, convergent photography, photogrammetric scanning*

Introduction

Currently, there are many archaeological artefacts that can be documented, but unfortunately in analogue form only, which informative capability is relatively insufficient considering their historical value. The storage of analogue form is relatively impractical and it is liable to atmospheric effects at the same time, leading to a reduction in its quality and durability. Therefore the field for utilization of digital technologies originates right here. The possibility of using digital close range photogrammetry appears as one of the options in the documentation of archaeological artefacts and their possible reconstruction in form of digital 3D models within the information system, as their development progresses „by leaps and bounds". A rich and varied history of our nation may be better customized to the general public in the form of digital spatial models, thanks to this innovative technology.

This contribution refers to the effectiveness of digital photogrammetry regarding the acquisition of spatial data in the process of documentation of archaeological artefacts. It analyses and evaluates methods for convergence imaging and photogrammetric scanning within the processing of measured data. Spatial data were acquired using DSLR Canon EOS 40D and processed in the software PhotoModeler Scanner.

Digital close range photogrammetry

Digital photogrammetry is a modification of analytical photogrammetry, at which we work with digital images. The new term „softcopy" photogrammetry is a synonym for digital photogrammetry and it defines rather the computer environment – digital photogrammetric workstation to solve the tasks of digital photogrammetry. Digital photogrammetric workstations are successors of analogue, resp. analytical instruments. The measuring mark of analogue instrument changes to the cursor, hand wheels to the mouse resp. „trackball", image carrier to the computer monitor and so on, in the photogrammetric softcopy system. [1].

Convergent imaging with general orientation of the image axes

Convergent imaging (Fig. 1) is a multi-image photogrammetric method requiring analytical processing using special photogrammetric software. Image axes of cameras may be generally oriented with respect to each other, but they are usually oriented so that there is the largest possible overlay between two adjacent images and the observed object is displayed on the greatest possible area of image. It is a bundle adjustment with mathematical model of perspective transformation from a methodological point of view. This photogrammetric method can be characterized as the most accurate, however, generally more laborious when compared to stereophotogrammetry. Possibilities such as automatic measurement of artificial targets, automatic identification of coded targets, automatic searching for identical points on different images and automatic creation of TIN model increases the effectiveness (time and accuracy) of digital photogrammetry. Over-determination within display of the point on three and more images is important

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feature of this method. This allows checking gross errors and it also increases the accuracy of point determination.

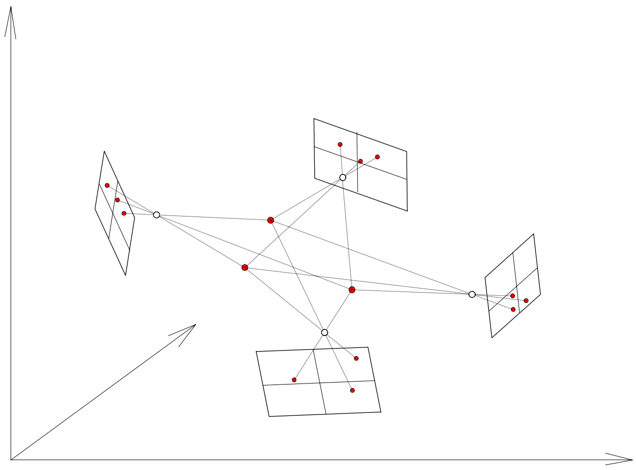

Fig. 1. Principle of the convergent imaging.

The accuracy of convergent imaging increases with increasing number of images from other stations. Configuration of imaging stations and ground control points has following effect (according to the formula (1)) on the final positional accuracy $\mathbf{m_p}$:

$$m_p = M_s \cdot m' \cdot (o + v \cdot p) \quad , \tag{1}$$

where **m'** is the accuracy of measurement image coordinates, **o** is the factor of intersection quality and it depends on the quality of the intersection angle between determining rays and their number at a given point, **v** is the deformation factor and it determines contortion and convolution of the object as a free network, and **p** is the factor of number and distribution of ground control points. Distribution of imaging stations and orientation of the image axes depends on the geometrical shape of the object and accessibility of these stations [2].

Evaluation of convergent images

The PhotoModeler Scanner solves the computation of the adjusted elements of external orientation of individual images on the basis of perspective transformation. Spatial coordinates of the conjunctive and determining points are calculated by the spatial forward intersection based on the known elements of exterior orientation. The calculation of adjusted spatial coordinates of the projection centers, ground control points and observed points in the reference coordinate system is realized by the bundle adjustment of photogrammetric rays.

The final reference accuracy of point position, determined by the convergent imaging, is a function of multiple factors:

$$m_p = f\left(M_s, Pix, m_{pix}, R, K, o, v, m_v, S\right) \tag{2}$$

where

- $\mathbf{m_p}$ is the positional accuracy of point,
- $\mathbf{M_s}$ is the scale number of the image, it depends on the camera constant f and subject distance Y,
- **Pix** is the size of the image element,
- $\mathbf{m_{pix}}$ is the accuracy of measurement of the image element, it depends on the signalisation of the displayed point and subsequently on the manual or automatic measurement,
- **R** is the method of transformation to the reference system (spatial transformation, perspective transformation, direct measurement of the elements of exterior orientation),
- **K** is the quality of the camera calibration, we can also include here quality of the camera itself in terms of stability and manufacturing preciseness,
- **o** is the quality of the intersection of determining rays, mainly the number of determining rays and magnitude of the intersection angle,
- **v** is the number and distribution of ground control, resp. identical points used for referencing,
- $\mathbf{m_v}$ is the accuracy of ground control, resp. identical points,
- **S** is the mathematical model of data processing.

The following simplified formula is sufficient for estimation of the a priori accuracy of the photogrammetric determined position of the point provided the above mentioned optimal conditions [3]:

$$m_p = \frac{Y}{f} \cdot Pix \cdot m_{pix} \tag{3}$$

Photogrammetric scanning

Photogrammetric scanner is relatively innovation in photogrammetry, although it is used in aerial photogrammetry for several years. The accuracy and method of imaging is based on the principle of stereophotogrammetry, but the method of evaluation is fundamentally different. It is based on the principle of image correlation, where the image points (pixels) are measured automatically. Therefore the photogrammetric scanner becomes extremely effective tool. Practically, malfunction in the case of objects without texture or more noise on the objects with less significant texture is disadvantage [2].

Digital image correlation

Image matching is commonly used in photogrammetric scanning. It is defined as the conformity assessment between different datasets. Groups of data are represented by image data. Image correlation is part of the image matching technology. Digital image correlation determines conformity between image parts of two or more images that capture the same territory at least in part, on the basis of statistical analyses. Image correlation is a substitute for natural stereoscopic vision. It is based on the calculation of correlation function in window with searched image and pattern image. Size of the pattern window (of the reference image) **f(x, y)** moves element by element in the larger searched window (k,l) (Fig. 2) with the target image **g(x, y)** when comparing the value of correlation function. Correlation coefficients are calculated between the pattern window and its corresponding part of the searched window in each part of its new position by the following formula:

$$K_{\hat{x}\hat{x}} = \hat{s}_0^2 . Q_{\hat{x}\hat{x}} = \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \dots & \rho_{1u}\sigma_1\sigma_u \\ \rho_{21}\sigma_2\sigma_1 & \sigma_2^2 & \dots & \rho_{2u}\sigma_2\sigma_u \\ . & . & . & . \\ . & . & . & . \\ \rho_{u1}\sigma_f\sigma_1 & \rho_{u2}\sigma_f\sigma_2 & \dots & \sigma_u^2 \end{bmatrix}, \tag{4}$$

where $\hat{s}_0^2$ is the empirical standard deviation,

$$\rho_{fg} = \frac{\sigma_{fg}}{\sigma_f \sigma_g} \tag{4.1}$$

is the correlation coefficient,

$$\sigma_{fg} = \frac{\sum\left[\left(f_i - \bar{f}\right)\left(g_i - \bar{g}\right)\right]}{n} \tag{4.2}$$

$$\sigma_f = \sqrt{\frac{\sum\left(f_i - \bar{f}\right)^2}{n}}, \quad \sigma_g = \sqrt{\frac{\sum\left(g_i - \bar{g}\right)^2}{n}} \tag{4.3}$$

are standard deviations and

$\bar{f}$, $\bar{g}$ - arithmetic means in pixels

n - number of pixels in the pattern image

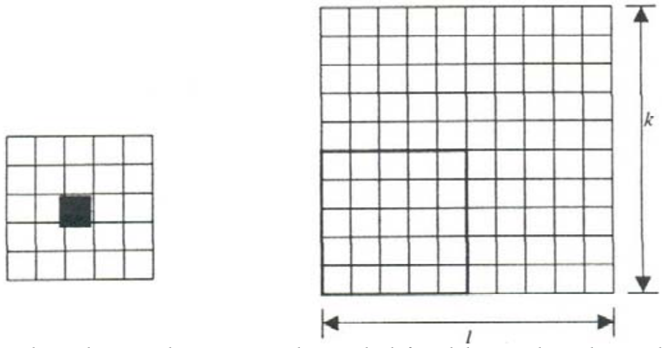

Fig. 2. The correlation between the pattern window on the left and the search window on the right.

Calculated maximum of the correlation function (in the interval $-1 \leq \rho_{fg} \leq +1$) defines position of the point (image coordinates) which expresses the result of best match between the pattern and searched window. The calculated correlation coefficient is compared to the specified critical value in order to avoid incorrect assignment of the image. If the correlation coefficient is lower than the critical value, the assignment procedure is evaluated as unsuccessful. Choice of the critical value depends on content of the searched image. An appropriate critical value is between t = 0,5 to 0,7. Measurement accuracy on the image can achieve a value of about 0,1 pixel [4, 5].

Measurement accuracy

Accuracy of photogrammetric scanning is affected by mutual orientation of images, which is conditional on accuracy of the calculation of image coordinates of the ground control points (centroid of coded targets). Calculation of centroid of the circular or elliptical target consists of the following steps (Fig. 3):

- definition of the search window with approximate location of the target,
- determination of points of an ellipse,
- calculation of ellipse parameters,
- calculation of centroid of the target.

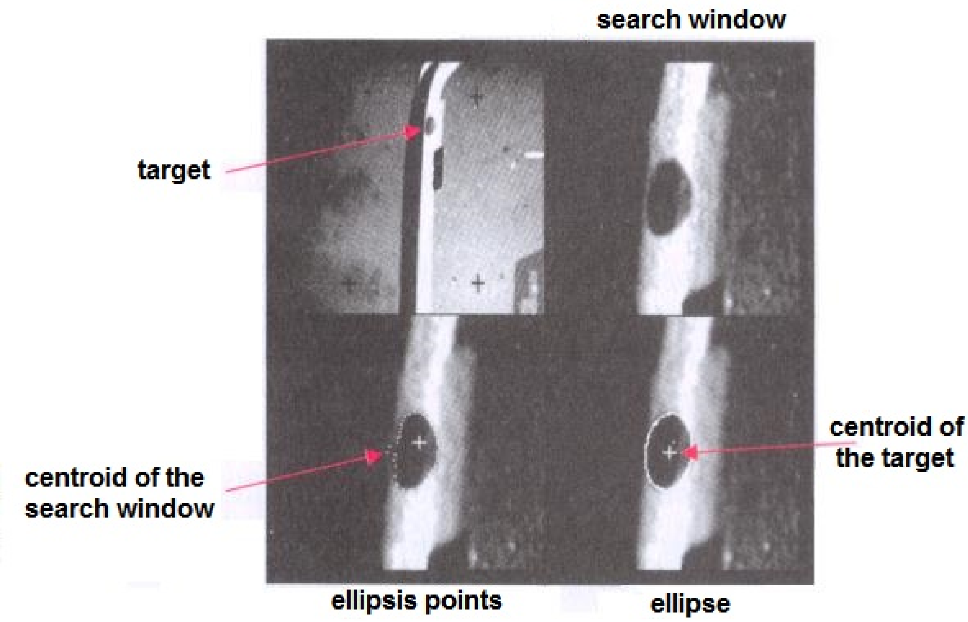

Fig. 3. Determination of the centroid of target.

Size of the target is an important accuracy factor when determining its centroid (centre). Optimal size of the target is about 5 to 15 pixels in its diameter. If the measured element consists of a symmetrical distribution of pixels, then the centroid of processing window is determined as a weighted mean of image coordinates of image elements (pixels) in the processing window by the following formula:

$$x_M = \frac{\sum_{i=1}^{n}(x_i T g_i)}{\sum_{i=1}^{n}(T g_i)}, \quad y_M = \frac{\sum_{i=1}^{n}(y_i T g_i)}{\sum_{i=1}^{n}(T g_i)}, \tag{5}$$

where,

n – is the number of pixels in the processing window,

g – is the value of image element on image coordinates (x, y),

T – is the function that decides on the use of image element in the computation. It can be defined as value of the pixel of the **t** criterion, for which applies:

$$T = \begin{cases} 0 & for \quad g < t \\ 1 & for \quad g \geq t \end{cases} \tag{6}$$

If the measured element is defined by the values of pixels at the circumference (i.e. of the circle or ellipse) they need to be included in the calculation of the target centre by the following formula:

$$x_M = \frac{\sum_{i=1}^{n} x_i grad^2(g_{x,i})}{\sum_{i=1}^{n} grad^2(g_{x,i})}, \quad y_M = \frac{\sum_{i=1}^{n} y_i grad^2(g_{y,i})}{\sum_{i=1}^{n} grad^2(g_{y,i})} \tag{7}$$

Theoretical accuracy of determining the centre of target can be estimated by:

$$\sigma_{x_M} = \frac{1}{\Sigma_{g_i}} \sqrt{\Sigma (x_i - x_M)^2} \sigma_g, \quad \sigma_{y_M} = \frac{1}{\Sigma_{g_i}} \sqrt{\Sigma (y_i - y_M)^2} \sigma_g \tag{8}$$

Standard deviation σ_{x_M} of determining the centre of target is a linear function of a noise of image elements σ_g and a function of distance of the pixel from the center, and thus depends on the size of the target. The accuracy of determining the centre of target from 0,03 to 0,05 pixel can be practically achieved in case of using circular or elliptical white targets on a dark background [5].

Photogrammetric data acquisition

Archaeological artefacts from the Celtic - Dacian hill-fort Zemplín were subject of the measurement. These are fragments of pottery vessels dating to the 11th - 12 century (Fig. 4) [6,7].

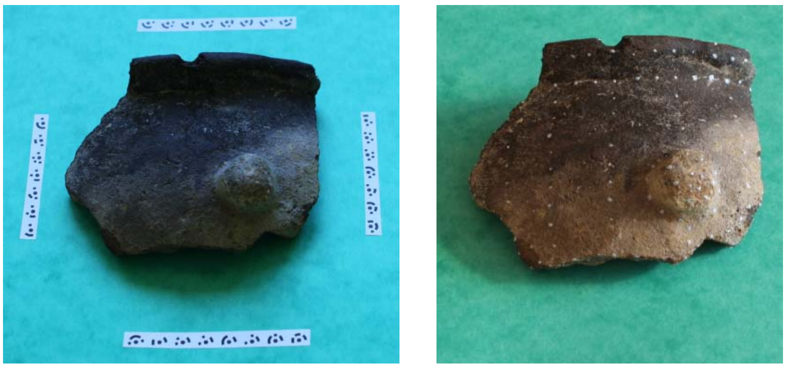

Fig. 4. left – signalling the object for photogrammetric scanning; right – signalling the object for convergent imaging.

Photogrammetric data acquisition was realized by digital SLR Canon EOS 40D (Tab. 1). Method of convergent imaging with general orientation of the image axis and method of photogrammetric scanning were used to measure objects of interest in order to assess the effectiveness of using individual methods in terms of measurement accuracy and quality of textures in the processing of measured data. Measurement was carried out according to principles of convergent imaging and photogrammetric scanning. Coded targets whose position (centroid) was determined automatically in the PhotoModeler Scanner software were used for orientation of images within the photogrammetric scanning. For convergent imaging, the spatial position of object of interest was signalised through the points with a diameter 1 – 2 mm using a removable paint on glass. The arrangement of imaging stations is shown in (Fig. 5).

Tab. 1. The parameters of digital SLR Canon EOS 40D.

Image format	JPEG, RAW
Number of pixels	10 100 000
Resolution	3888 x 2592 pixels
Focal length	170 – 250 mm
Size of the CCD	22,2 x 14,8 mm^2
ISO range	EV -0,5 to 18 (ISO

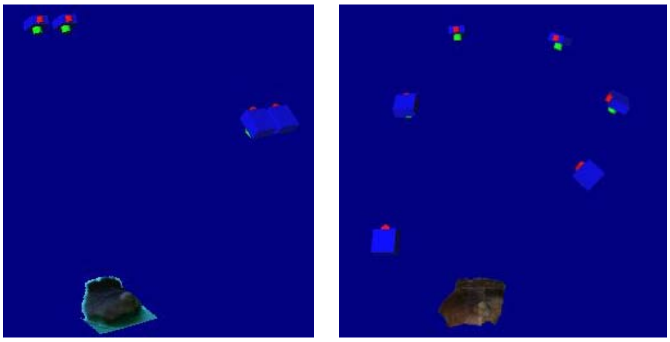

Fig. 5. Imaging stations: left - photogrammetric scanning, right - convergent imaging.

Processing of the measured data

Spatial position of the part of object surface was generated in the PhotoModeler Scanner software on the basis of data obtained by photogrammetric scanning and convergent imaging (Fig. 6).

Fig. 6. left – the final model obtained by photogrammetric scanning, right – the final model obtained by convergent imaging.

Conclusion

The aim of this paper was to assess the appropriateness of photogrammetric scanning and convergent imaging with general orientation of the image axes in documentation of archaeological artefacts in terms of time consumption of processing and accuracy of the final model considering position of measured points and quality of textures. As it turned out, photogrammetric scanning is almost useless for objects without significant texture. The surface on which the object was placed has proved to be a problem. This surface was without significant texture which resulted in imperfect scanning of object at the edges, where points of the surface were located at the same height level as the points of artefact and overlapped each other. Therefore it is necessary to place object of interest on the suitable textured surface.

Photogrammetric scanning is significantly more efficient, since it is not necessary to signalize characteristic points and edges of the measured object as in convergent photogrammetry, in terms of time consumption of measurement and processing. In both cases, the accuracy of measurement is conditional on mutual orientation of images depending on the accuracy of determining ground control points.

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