THE REAL CAPABILITIES OF THE PHOTOGRAMMETRIC AND THE STEREOPHOTOGRAMMETRIC METHODS FOR MEASUREMENT IN MECHANICAL AND MANUFACTURING ENGINEERING

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Abstract

The paper presents the research results of the team of authors in the application of the photogrammetric method from its initial phase to its present condition for measuring small and large dimensions in fine mechanics and technics, as well as the established theoretical bases for the application of this method for measurement of deformations in mechanical constructions and parts. Presented are the main influencing factors that have critical influence on the measurement accuracy characteristics, and determine the uncertainty budget. The typical errors of the method are outlined for certain conditions of its application and when using specific equipment. Recommendations how to decrease these errors are made. The paper devotes special attention to the initial phase of applying the stereo photogrammetric method for measurement of large dimensions and deformations in mechanical and manufacturing engineering. Presented are the main dependencies of the method by analyzing the constituent components. According to the authors, this method has a bright future for application in manufacturing and construction engineering. The goals for continual research are set out for determining the accuracy characteristics of the methods and for widening the range of their application. Recommendations are made in relation to the main characteristics, the equipment requirements and the application of these methods in real conditions.

Keywords: photogrammetric method, stereo photogrammetric method, small dimensions, large dimensions, measurement, error, uncertainty budget.

1. INTRODUCTION

The earth photogrammetry is used in various specialized scientific areas as well as a photographic method for creating plans and maps. The wide application of photogrammetry is the result of its significant advantages in comparison with all other photographic and mapping methods. The photogrammetric ways of measurement are characterized by modernity and bright perspectives, and provide wide capabilities for automation of all processes [Sotirov, B., Tonev D.,2013, pp 74-80]. The earth photogrammetry of near and distant objects is used successfully in three of its variants:

a) Photographing and creating numerical models of the object, including in mechanical and manufacturing engineering [Georgiev G. Georgieva N., 2014, pp 202-210; Sakakushev B., Grigorov V., Georgiev G., 2013, pp 77-80];

b) creating large-scale photographic plans in vertical and horizontal projection with capabilities to use in heavy manufacturing of large parts and constructions [Atanasov A., Sakakushev B., 2012, pp 21-24; Georgiev G., Sakakushev B., 2013, pp 43-49];

c) photographing and measurement of small and very small dimensions of parts which are not accessible with other measurement devices [Georgiev G., Sakakushev B., Georgieva K., 2015 pp 15-19; Sakakushev B, Georgiev G., 2016, pp 515-522; Zhelezarov, I., 2005, pp 562-565].

Significant results are achieved in determining the errors in the budget of uncertainty of the measurement method for small and very small dimensions [Georgiev G., 2016, pp 285-290; Sakakushev B. Georgiev G., Zhelezarov I., 2015, pp 54-57].

Recently, measurement installations (measurement projectors and measurement microscopes) are developed and sold on the market. They operate using the principle of image recognition but their prices are extremely high for the domestic conditions, which makes them available only for large companies.

2. DISCUSSION

The classical photogrammetric method is built on the regularities between the image, the spatial coordinates, and the properties of the central projection. The classical approach for numerical mapping consists in using the measured values of the base, the image coordinates and the horizontal parallax [Sakakushev B, Georgiev G., 2016, pp 515-522; Sakakushev B., Todorov T., Stefanov G., 2009, pp 17-20].

The scale of transformation (the scaling coefficient of the measurement - K_T) is determined by at least two artificial or natural reference points (or a dimension, which is previously measured with the highest achievable accuracy), as the distance between them is measured using a different method that is already known [Georgiev G., 2016, pp 285-290]. The measurement accuracy of the photogrammetric method can be demonstrated by the standard deviation errors at the coordinates of the points of the perspective image that are obtained according to the Gauss law of distribution of errors [Sakakushev B., Stoev S., Parvanov S., 2007, pp 74-80].

The deformations of engineering installations and constructions arise from the structural changes in the particles of the construction material, which is subjected to the action of external forces (the load). If the load does not exceed the strength limit of the given material, after stopping the loading of the installation or the construction (because of the interaction of the particles of the material) it returns to its original form. Residual deformations occur when the loads are big, and when loads are very big the bond between the particles of the material is severed and destructions occur. This may happen not only to buildings and installations, but also to machines and parts. The photogrammetric method awaits its application in this area [Sakakushev B., Todorov T., Stefanov G., 2009, pp 17-20].

Based on the approbation of the method in a plane variant and using ‘not the most suitable’ but free software [4, 5], the main sources of errors are defined – the focal distance - f (the angular range – α) of the lens and the focusing distance – „a”. The proposed term - scale of transformation „K_T” characterizes the relationship between the abovementioned two parameters of the photographic lens as a system with focusing distance – „a”, as a factor that depends on the measured object. It turns out [Georgiev G., 2016, pp 285-290] that „ K_T” depends stronger on the focusing distance of the lens.

The accuracy of measuring constructions, housing parts and other general manufacturing parts [Sakakushev B. Georgiev G., Zhelezarov I., 2015, pp 54-57] can be considered as normal. Taking into consideration the known fact that the resolution of a normal human sight at a distance of ~ 20 cm is ~ 0,1mm /100 μm/, it is established that the error varies but its maximum is 100 μm. This is the width of the hatch of the main scale of the caliper. In other words, this can be regarded as the cumulative positioning error of the start or end marker in the process of defining the measurement distance on the monitor with a randomly selected software.

It should not be overlooked that the maximum resolution of the photographical registering matrix „SONY Super CCD VHR” used in the present research is 9,2 Mpx, and the resolution of the photographs is 5 Mpx, thus the conditional dimension of a “real” (approximated) pixel is 3,1 μm. The measurement is performed on a CRT (electron beam) monitor “Samsung – SyncMaster 795DF” with a resolution – 1024x768 px /96dpi/, so that one RGB pixel has an approximate dimension of ~ 0,2 mm.

Theoretically, in an “ideal” case, a line is described in the specific case by taking a picture with a width of 1px (3,1 μm). The software allows a 200 % zoom during the measurement process. In this case, theoretically the line is described with a width of 2px (6,2 μm). These 2px of the monitor in the process of positioning the marker are described in an “ideal” case with RGB pixels with a width of ~ 0,2 mm or:

2px /6,2 μm/ matrix → 200 μm monitor

1px /3,1μm/ matrix → 100 μm monitor

Then it can be argued that the real measurement error taking into consideration the abovementioned “ideal” circumstances is ~ 6 μm. Naturally, this is not the real situation, but a much-idealized one.

In reality, a line (or a contour) almost never can be described by a width of exactly 1px /3,1 μm/. Usually, this is done by a segment of one or two adjacent pixels (the specific matrix has pixels with a shape of a regular hexagon). In this case, it would more realistic to assume that the total measurement error includes the description of the line by its width or the contour with 3 px – the actual one, and the two adjacent ones. Under these circumstances, the total measurement error is limited within ~ 6 ÷ 20 μm. For comparison, the upper limit of this error is less than the error of the measurement tool - which is 40 μm for a caliper (for measuring width, height and depth) with a range of 360-500 mm, and accuracy 0,02 mm. The fact that the total error for the abovementioned types of calipers is much larger is a sufficient proof for the perspectives and benefits of applying the method in this engineering field.

This total measurement error can be minimized when utilizing the full capacity of the registering matrix and with a high quality LSD monitor.

It is obvious that the average absolute error is a function of the discrimination capability of the matrix /or in this case of the approximated discrimination capability/, the discrimination capability and the quality of the lens /spherical and chromatic aberrations, distortion, astigmatism, etc./, the specific focal distance and the discrimination capability and the quality of the monitor, that is used for conducting the measurement, as well as the clear rendering of the contours of the measured surface, the mismatch between the geometrical axis of the system ‘lens-matrix’ and the geometrical axis of the measured part.

It is proven that this method is applicable for measurement of deformations and distances to objects. In mechanical constructions in stereo variant [Sakakushev B., Grigorov V., Georgiev G., 2013, pp 77-80; Sakakushev B., Todorov T., Stefanov G., 2009, pp 17-20] the accuracy of determining deformations by applying the stereo photogrammetric method depends exclusively on the shooting distance У and the size of the shooting base (the set) B, and research has to continue in this direction.

The main question is ‘Through which mechanisms does man perceive the volume of the reality which surrounds him?’ The answer to this question lies in anatomy, neurophysiology, and ophthalmology. They determine the main factors that provide information about the volume:

- The geometric perspective and knowing the real dimensions of objects with high enough accuracy;

- Aerial perspective;

- Shadows and reflections;

- Movement of the object and movement of the observer;

- Accommodation of the eye;

- Binocular vision – the presence of two eyes (when the brain perceives and compares the images obtained from both eyes).

The first three factors are basic in classical photography. Cinema focuses mainly on the fourth factor. The last factor is critical for obtaining a stereo image [Sakakushev B., Grigorov V., Georgiev G., 2013, pp 77-80; , Sakakushev B., Todorov T., Stefanov G., 2009, pp 17-20; Sakakushev B., Stoev S., Parvanov S., 2007, pp 74-80].

In the field of mechanical and manufacturing engineering, the following issues are specifically important:

- What is the relation between the stereo image and the real image of the part depending on the conditions for taking the photo?

- Under what condition is realized the minimal equidistance of the object (the minimal component of the measurement error)?

- How to select the base for realizing the photo (the distance between the points of taking a photo) in order to minimize the error?

The answers to these and to other important questions will be given in the future.

3. MAIN DEPENDENCIES IN STEREO PHOTOGRAPHY

L – base of the stereo photo - m;

a – angular resolution of the optical system – rad.

For a human being with normal sight, under the conditions of normal lighting, **a** = 1/5000 [Georgiev G., Sakakushev B., 2013, pp 43-49]. When using a lens with a focal distance – f = 50 mm for 35 mm film or a lens that is equivalent to its angular range combined with a digital camera, with a high quality matrix and displayed on a high quality monitor – **a** = 1/1500.

R – radius of the stereo perception –

$$R = L/a \qquad (1)$$

For normal human sight R ~ 300m.

Discrimination in depth – this is the condition at which, when taking the photo, the difference between the distances between two points that in fact are at distances S_1 and $S_2>S_1$ are clearly discernible.

$$\frac{1}{S_1} - \frac{1}{S_2} \geq \frac{1}{R} \qquad (2)$$

The radius of binocular perception is the distance to the farthest object, when it can be differentiated that this object and the infinitely remote object are not equidistant (for example clouds, the Moon and the stars are beyond the radius of stereo perception and we do cannot perceive the volume of the sky).

Dependency (2) can be presented as:

$$S_1 - S_2 \geq \frac{S_1.S_2}{R} \qquad (3)$$

Practically this means that a human who is at a distance of about 0,5 m can discern a depth of about 1mm.

The term **angular dimension of the base** is described as the proportion of the base to the distance to the object that is being photographed. Usually, for classical stereo photos, this parameter is within 0,01 – 0,1.

Thus, the discrimination capability in depth is set by the product if the normal resolution (discrimination) and the angular dimension of the base. Because of this, the discrimination capability in depth is few times smaller.

The main conclusions from this analysis can be formulated as:

- The discrimination capability decreases proportionally to the increase of the distance;
- The discrimination capability in depth decreases proportionally to the squared increase of the distance.

The selection of the base distance is accompanied by a number of limitations. The most important limitations are:

- The distance to the object that is being photographed. This distance depends on the overall dimensions of the object. This measurement approach is foreseen both for large and for very large dimensions, and for small (macro) and very small (super macro) dimensions. Naturally, for small and for very small dimensions aids (universal or tool microscopes or even stereomicroscopes) are used.

When measuring large and very large dimensions one can use the dependency, derived based on the abovementioned conditions:

$$\frac{B}{S_B} - \frac{B}{S_D} \leq \frac{H}{15.f} \qquad (4)$$

Where B is the base distance, m;

S_B – the distance to the nearest point, m;

S_D – the distance to the farthest point, m;

H – Width of the frame (the real width of the frame in the case of a photographic film or the width of the matrix in the case of a digital photo), mm;

F – Focal distance of the lens, mm.

The following dependency is obtained for the maximal base distance:

$$B_{\max} = \frac{1+\frac{S_B}{S_D}}{15\frac{f}{H}} S_B \tag{5}$$

Dependency (5) is especially necessary for large and very large dimensions.

The condition for a minimal base distance is obtained based on the dependency which results from the condition that the second photo does not lose its meaning (the base distance can become very small and practically make the second photo meaningless)

$$\frac{B}{S_B} - \frac{B}{S_D} \geq \frac{H}{1000.f} \tag{6}$$

or

$$B_{\min} = \frac{1+\frac{S_B}{S_D}}{1000\frac{f}{H}} S_B \tag{7}$$

Practical experience demonstrates that it is necessary to use dependency (7) with a large reserve (20 – 50).

For large dimensions it can be recommended to select B_{min} using an empirical ratio 1/(3f), and for very large dimensions 1/(5f), where f is the focal distance of the lens in mm which is equivalent to a 35 mm film.

When implementing this method for small and very small dimensions, it is necessary to include one additional limitation– to take into consideration the proportion of the base length and the working diameter of the lens (the working diameter of the lens is obtained by dividing its focal distance to its diaphragm number).

The condition that the base has to be several times greater than the working diameter of the lens is a mathematical sequence of the fact that the frontal and the back limit of the depth of the sharpness has to be several times greater than the distance which the stereo photo presents in depth [Sakakushev B., Stoev S., Parvanov S., 2007, pp 74-80]. Practically, the proportion of the base and the working diameter of the lens for example is the number of planes that are parallel to the focal plane and positioned at either side of the focal plane (in front of it and behind it) and which can be discerned by the optical system (this relates to the quality of the optical system of the lens). If this proportion is greater than 30, then it is of no practical importance and the number of base planes is determined by the discrimination capability of the optical system (the lens). If the depth of the sharpness and the base are sufficient for the specific part, then this proportion is not an obstacle to take the specific photo. Under normal conditions, if the proportion of the base and the working diameter of the lens is small, then either the depth of the sharpness for the given part is not sufficient, or the base is not sufficient to express this depth (also possible is a variant for which the base is so large that it is impossible to express the depth of the sharpness of the specific part; this case is current when taking macro photos).

When photographing a specific mechanical part of a construction it is necessary to consider several common cases:

- the far plan is rather remote from the near plan (constructions, casings, hub parts or bushings, bearing bodies, etc.). When taking a photo with a normal lens (50 mm – compared to 35 mm film with the aid of a relevant crop factor) a base plane is selected at 1/30 of the distance to the near plan (the nearest surface of the part which is subjected to measurement);
- if the lens is **„k”** times long focus (**„k”** times smaller viewing angle), then the base is also decreased **„k”** times;
- for wide angle lenses (with a focal distance less than 35 mm equivalent, related to a 35 mm film) this

recommendation may be wrong. It can be assumed that because of the existence of distortion and higher values of spherical aberrations, this type of lenses are not appropriate for the purpose of this type of measurement.

All these cases and combinations of factors need to be considered and analyzed in detail. But firstly, one has to consider and analyze the applicability of the method for large scale constructions and parts, and to research the accuracy and the uncertainty in this engineering domain.

4. CONCLUSION

In conclusion, it can be outlined that the method has been developed to be applied in the domain of small and medium sizes. Its accuracy and uncertainty have been researched with adequate detail. It is established that they meet the requirements in these two areas if application in engineering.

It can be assumed that the method is applicable for measuring dimensions and deformations of large parts and constructions, by this has to be researched using scientific methods in order to confirm or reject this hypothesis.

The next step is to research the method in its stereo variant /3D/ that has proven advantages in comparison with the plane /2D/ variant.

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