6th International Quality Conference
June 08th 2012
Center for Quality, Faculty of Engineering, University of Kragujevac

**Milan Blagojević[1)]**
**Miroslav Živković[1)]**

*1) Faculty of Engineering, University of Kragujevac, Serbia*
*{blagoje, zile}@kg.ac.rs*

# USER-GENERATED REFERENCE OBJECTS IN PHOTOGRAMMETRIC 3D MEASUREMENTS AND QUALITY CONTROL

***Abstract:*** *Photogrammetry is a technique of measuring 3D coordinates using photography as the main medium of metrology. Triangulation is method used in photogrammetry for obtaining 3D coordinates of points. The camera position in space calculation is based on the reference object. The use of factory-equiped reference objects provides the accuracy of measurements. The system gives the ability to reference objects is defined by users. This paper presents the analysis results of the possibility of using user-defined reference objects in measuring projects. Presented results of measurements show that the user-generated are accurate replacement for factory-equiped reference objects in tasks such as quality control, analysis and discovering of causes of faults.*
***Keywords:*** *Photogrammetry, Reference Objects, Measurement, Quality Control, CAD/CAM/CAE*

## 1. INTRODUCTION

Photogrammetry is the practice of determining the geometric properties of objects from photographic images [1]. In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane can be determined by measuring their distance on the image, if the scale (s) of the image is known. This is done by multiplying the measured distance by 1/s. A more sophisticated technique, called stereo-photogrammetry, involves estimating the 3D coordinates of points on an object [2], [3], [4]. These are determined by measurements made in two or more photographic images taken from different positions. Given a set of images depict a number of 3D points from different viewpoints. Common reference points, called coded reference points, are identified on each image. A line of sight (or ray) can be constructed from the camera location to the point on the object. Triangulation, the intersection of these rays, determines the 3D location of the point.

Algorithms for photogrammetry typically express the problem as that of minimizing the sum of the squares of a set of errors. This minimization is known as bundle adjustment [5] and is achieved using nonlinear least-squares algorithms. Bundle adjustment is almost always used as the last step of every reference points-based 3D reconstruction algorithm. Bundle adjustment is simultaneously refining the 3D coordinates describing the scene geometry as well as the parameters of the relative positions and the optical characteristics of the camera(s) employed to acquire the images, according to an optimality criterion involving the corresponding image projections of all points.

This paper is organized in the following way: in Section 2 the problem statement is given, in Section 3 measuring method is presented, in Section 4 a result is presented, and conclusions are presented in Section 5.

## 2. PROBLEM STATEMENT

In photogrammetry, reference objects ensure an image set can be evaluated and allow for automatic calculation of the camera spatial positions [6], [7]. When recording an image, it is the goal to see as many reference objects spread over the entire object as possible in order to achieve a high measuring accuracy.

Most of commercially available optical measuring systems as reference use the following objects: coded or uncoded reference points, orientation crosses, and reference scale bars (Figure 1).

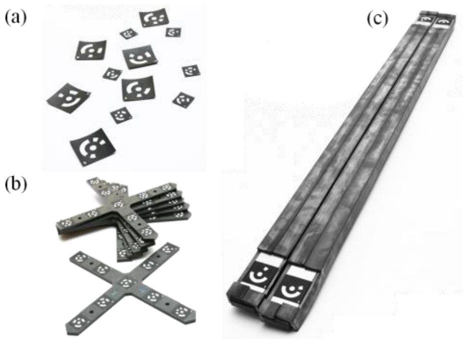


**Figure 1**. Reference objects of photogrammetric system: (a) coded reference points, (b) orientation crosses, and (c) reference scale bars

Uncoded reference points are used for indirectly determining the 3D coordinates of the measuring object’s features and are identified automatically by photogrammetric system. The measuring task determines the position of these points. The size of the reference points need to be adapted to the camera resolution (image pixels) and to the lens setting. The optimum reference point diameter is 10 image pixels.

Orientation crosses are factory-equipped with several coded points. The orientation crosses allow for easy and fast application of points to the measuring object.

In each measuring project, the scale bars are the reference for determining the dimensions. Ideally, the scale bars fit 1:1 to the measuring object. Scale bars and object would totally fill the format of at least one image. For example if the longest extension of the object is approx. 1 m and the length of the scale bars is approx. 1 m as well. Generally, 2 scale bars are used. The advantage is that the software checks the scale bars with respect to each other (discrepancy). Thus, wrong scale bar parameters are noticed better. Basically, the position of the scale bars can be arranged as you like, however it should be chosen such that the scale bars are completely or partly shown in the images and do not lie directly next to each other. For coded scale bars, the length of the scale bars refers to the distance between the upper coded and the lower coded reference points. Application software name the reference point IDs. The TRITOP software identifies the scale bars automatically by means of the reference point ID number. Due to linear extension caused by temperature, the current temperature of the scale bars would be known.

Generally, coded reference points are not used for determining the 3D coordinates of the measuring object. Around its central circle, each coded reference point has a so-called ring code. This ring code consists of regular white ring segments which contain, in coded form, the identification number of the point. TRITOP can work with 100 (10 bit), 300 (12 bit) and 420 (15 bit) reference point sets. A 100 reference point set, for example, means that the set consists of 100 reference points with the defined identification numbers 0 to 99.

The system allows the generating user's reference objects. In this paper special attention will be devoted to discussing the impact of coded reference points on the accuracy of the measuring result.

User-defined reference objects are generated in the form of images or pdf files, Figure 2. Reference objects are printed on a desktop laser printer on adhesive A4 paper.

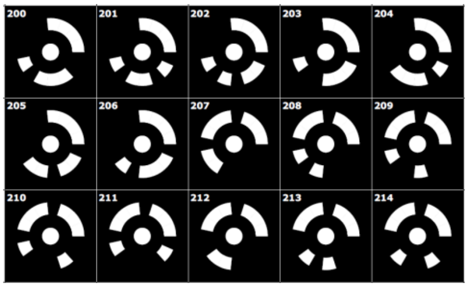


**Figure 2**. Sheet of paper sample with user-generated coded reference points

The material thickness of the reference points would be considered. It is particularly important to convert reference points to point clouds considering their material thickness when using these reference points for measuring purposes or when creating primitives based on them. The TRITOP software contains a function for the automatic correction of the material thickness of reference points. Parameter of this function is the thickness of the material. Thickness of paper at the randomly selected sampling locations is given in Table 1. Paper thickness is measured by digital caliper.

***Table 1 – Thickness of adhesive A4 paper***

| *Measure-ment* | *Thickness [mm]* | *Measure-ment* | *Thickness [mm]* |
|---|---|---|---|
| *1* | *0.09* | *2* | *0.08* |
| *3* | *0.08* | *4* | *0.09* |
| *5* | *0.08* | *6* | *0.08* |
| *7* | *0.10* | *8* | *0.10* |

As it can be seen from Table 2, adhesive paper thickness varies considerably. In contrast, thickness of the factory-equiped reference objects is calibrated. This leads us to conclude that the use of reference objects of unequal thickness may cause the inaccuracy of the measurement results.

## 3. MEASURING SETUP AND SHOOTING TECHNIQUE

Analysis of using user-defined reference objects will be evaluated by measurements performed by optical measuring system TRITOP. Configuration of Measuring System is given in Table 2.

***Table 2 - Configuration of Measuring System***

| **Item** | ***Property*** |
|---|---|
| **Optical Measuring System** | ***TRITOP*** |
| Photogrammetric Camera | NIKON D200 12Mpx |
| Scale Bars | Optical Scale Bar 1000mm SG00243, Dist.0/1: 906.351mm, CrNi Steel on $20^0$C $16.2x10^{-6}K^{-1}$ SG00244, Dist.2/3: 907.577mm, CrNi Steel on $20^0$C $16.2x10^{-6}K^{-1}$ |
| Coded Reference Points | 15bit Coded Reference Points |
| Application software | TRITOP v602 |

In order for the application software to be able to reliably and precisely evaluate reference points and image sets, some basic requirements need to be observed for the measuring setup and shooting techniques is presented.

### 3.1 Measuring Setup

In each image at least 5 coded reference points must be visible because TRITOP needs at least this number to precisely compute the camera positions. The reference point must be visible in at least three different images so that TRITOP can automatically and precisely determine the 3D coordinates of an uncoded reference point. Therefore it is useful to apply sufficient coded reference points to the measuring object at positions well visible, to ensure that this requirement is always complied with. However, cluttering the measuring setup with coded reference points will not provide higher accuracy. Also, each unnecessary point burdens the computation process.

When positioning the reference objects, the following principles are complied with:

- Stable reference point positions are ensured.
- Coded points in a 45° angle, by using angle adapters, is set-up. This results in many connecting images for measuring objects having distinct 3D structures.
- Many image connecting reference point positions are implemented.
- The reference points are well distributed and creating lines of points is avoided.

As the measurement object is considerably smaller dimensions than the reference scale bars, user-defined shortened scale bars are used.

**3.2 Shooting Technique**

During image recording, it is the goal to capture as many reference objects spread over the entire object as possible in order to achieve a high measuring accuracy. For measuring a simple object eight images is need, four calibrating images made from the top and four images recorded laterally at an angle of approx. 45°. An image group consists of many overlapping images recorded in succession. In order to avoid accumulated errors with this shooting technique, images are required that combine, for example, the right and the left side as well as the front and the rear side of the model.

TRITOP needs calibration images for computing the optical distortion of the camera lens and the position of the principle point. The calibrating images are at the beginning of an image group. Calibrating images are images recorded from a central camera position each turned by 90º (along the optical camera axis).

Using built-in function Complete Computation the 3D computation of the reference objects is carried out automatically. This computation consists of several functional and optimization processes in order to obtain precise 3D measuring data. During the complete computation, the ellipses are identified (measure image points), the reference points and the scale bars are identified, a 3D pre- and post-orientation of the images is carried out based on the coded reference points, and the bundling is optimized. Optimizing the bundling is a complex process during which the socalled reference point rays, resulting from the relation between camera position and 2D image are optimized to a minimum deviation using the calculated 3D point position.

Different measurements should lie in the same coordinate system to make it possible to compare it. TRITOP sets results in arbitrary coordinate system. In order to be able to use the 3D measuring data to carry out inspection task, project need to be transformed into a defined coordinate system. There are different transformation methods. Plane-Line-Point alignment is preferred depends on the measuring project and the data available.

With the Plane-Line-Point alignment, transformation using the primitives (plane, line and point) that were derived from the measuring data and the reference data. Equivalent primitives of the measuring data and the reference data are hierarchically assigned to each other (e.g. plane to reference plane, line to reference line and point to reference point). All elements need to be created in suitable areas according to the 3-2-1 rule. This function allows aligning objects where the reference plane is not located in the planes of the reference coordinate system.

## 4. RESULTS

Verification of the results was performed by measuring the known lengths of the gauge block [8], [9]. The paralel gages or gauge blocks are precision length measuring standard. They are used as a reference for the calibration of measuring equipment. Gauge blocks are the main means of length standardization used by industry. Gauge blocks are available in various grades, depending on their intended use. The grading criterion is tightness of tolerance on their sizes; thus higher grades are made to tighter tolerances and have higher accuracy and precision. Various grading standards include: JIS B 7506-1997 (Japan)/DIN 861-1980 (Germany), ASME (US), BS 4311: Part 1: 1993 (UK). Tolerances will vary within the same grade as the thickness of the material increases.

Grade blocks of class AA are used to calibrate inspection instruments and very high precision gauging. Their tolerance is +0.10 μm to −0.05 μm. In the presented measurements were used gage block of grade 1 with nominal length of 500mm (Figure 3). According to U.S. Federal Specification GGG-G-15C gage blocks of grade 1 are equivalent to grade AA.

**Figure 3**. Gauge block

Two measurements were made. The first measurement project was generated using a factory-equiped coded reference points, and second measurement project was generated using a user-generated coded reference points.

Measurements of 500mm gauge block are given in Figures 4 and 5.

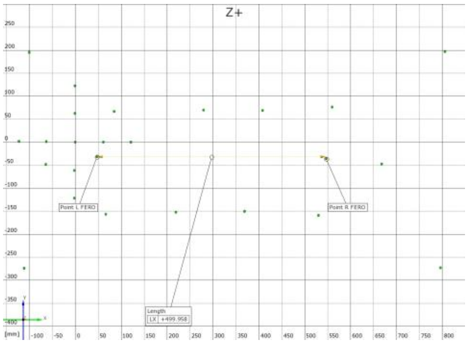


**Figure 4**. Measure of 500mm gauge block in measuring project with factory-equiped coded reference points

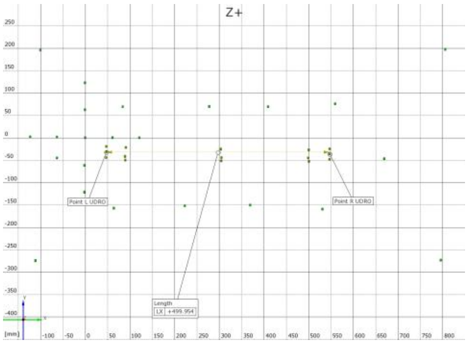


**Figure 5**. Measure of 500mm gauge block in measuring project with user-generated coded reference points

The presented results show excellent agreement between the measures in both measuring projects.

## 5. CONCLUSION

In this paper, the impact of replacing factory-equiped reference objects with user- defined is evaluated. Evaluation was performed on the proposed measurement set-up.

From the presented results can be seen that the replacement of coded reference points by user-defined does not affect the accuracy of the measurement results. This is probably a consequence of the fact that the algorithm does not compensate for the thickness of the reference objects. However, this rule is not applicable for the uncoded reference objects, so great attention should be paid to generate their replacement.

Permanent application of reference objects on the surface of the measuring object allows continuous measurement of the observed structures under the geometrically the same measuring conditions. An example of such use is monitoring of the deformation of large structures, such as dams.

If the measurements are performed under the same environmental conditions, there is no relative elongation of material. Then calibration of the distance of some reference points is possible and their use as a reference scale bars.

This contactless method is suitable, because the measuring instruments are robust and mobile, so precise measurements are possible in production conditions. It does not require any complex, heavy and maintenance-intensive hardware. However, the consumption components of the system, such as the reference objects, are very expensive. Replacing them with user-generated reference objects significantly reduces the cost of maintaining the measuring machine.

## REFERENCES:


[1] Blais, F., Review of 20 years of range sensor development, Journal of Electronic Imaging 13 (2004) 231–240

[2] Bouguet, J., Y., Visual methods for three dimensional modeling, PhD Dissertation, California Institute of Technology, Pasadena, California (1999)

[3] Blagojević M., Živković M., Quality control of contour verifier using photogrammetric measuring systems, 34th International conference on production engineering (2011)

[4] Blagojević, M., Application of optical measuring systems in modeling and simulation (in Serbian), Faculty of Mechanical Engineering in Kragujevac, University of Kragujevac (2009)

[5] Lanman, D., Taubin, G., Build Your Own 3D Scanner: 3D Photography for Beginners, SIGGRAPH 2009 Course Notes (2009)

[6] TRITOP User Information, TRITOP Adapters (2008)

[7] TRITOP User Manual - Software, TRITOP v6 (2008)

[8] Ted D., Beers J., The Gauge Block Handbook, USA: Dimensional Metrology Group, US National Institute of Standards and Technology(2009)

[9] The Gauge Block Handbook, NIST, p. 138-139


Acknowledgment: Research presented in this paper was supported by Ministry of Education and Science of Republic of Serbia, Grant TR32036.