CLOSE RANGE PHOTOGRAMMETRY WITH CCD CAMERAS AND MATCHING METHODS - APPLIED TO THE FRACTURE SURFACE OF AN IRON BOLT

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This report describes an approach for a restitution of the surface of a broken bolt used on Turkish railway bridges. This is made possible by a joint-venture between the Istanbul Technical University and the Technical University of Berlin.
A digital 3D valuing system should give a touchless measurement of the fracture of the bolt. The images were taken with CCD cameras which were connected to a PC via a video board. Program modules to the photogrammetric restitution, e.g. for calibration, bundle adjustment and for image matching, were available.
The goal was to find the best image acquisition conditions and the best combination of the system modules. As a result one get the digital surface model of the conjugate breaks of the bolt. Afterwards the results allow statements about the material characteristic of the used bolts.

1. INTRODUCTION

For many years photogrammetric procedures have significantly contributed to the touchless measurement of objects of all kind. Especially the introduction of digital image processing techniques has opened new fields of applications for photogrammetry. Digital image processing is an efficient tool to derive geometrical information from digital imagery in a fast and economic way. In recent years versified approaches for object recognition as well as ways for extraction of geometrical information were developed for very different applications [*Suthau et al.*, 2000].

This paper describes an approach for nearly automatic restitution of the surface of a broken bolt used on Turkish railway bridges (Figure 1). This is made possible by the integration and optimisation of various algorithms for photogrammetric restitution and image processing.
A digital photogrammetric 3D measurement system was applied for image acquisition. The images were taken with CCD cameras which were connected to a PC via a video board. Program modules for the photogrammetric restitution, e.g. bundle adjustment, intersection in space, image matching and visualisation, were available, have been developed or adapted for this project.

The goal was to find the best acquisition conditions and the best combination of the system modules. As a result one get the digital surface model of the conjugate breaks of the bolt.

Afterwards the results allows statements about the material characteristics of the used bolts.
From investigations on the accuracy of the procedure it is possible to evaluate the applicability of the approach. One have distinguish between the accuracy of the calibration of the cameras, of the absolute accuracy of the overall system and the accuracy of the digital surface of the fracture.
Furthermore the applicability of this procedure to similar tasks must be considered. In general, matching objects with low gradient are available.

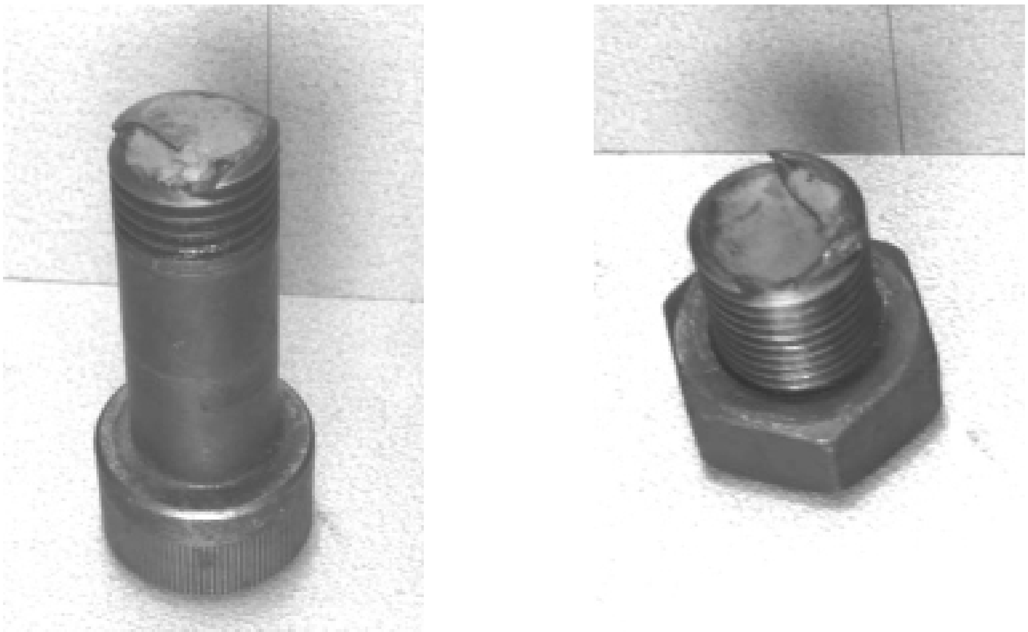

Figure 1. Two conjugate surfaces of the break of an iron bolt

2. IMAGE DATA ACQUISITION AND THE CONFIGURATION OF THE SYSTEM

2.1 Image data acquisition

In this work, a commonly available CCD camera of the type SONY XC 77CE was employed, which was connected over a frame grabber. The technical data of the camera are listed in Table 1.

Table 1. Technical data of the camera

Type of the camera	SONY XC 77CE
Number of pixels	756 columns, 581 rows
Signal transfer	Analogue composite video-signal (CCIR)
Pixel size	11,0 x 11,0 µm
Lens	focal length 16 mm

A CCD camera can be understood as a metric camera because of its solid CCD matrix. It is assumed that the lens is stably interconnected with the camera body and the focal length is fixed. The interior orientation of the cameras must either be available or has to be calculated together with the exterior orientation during the calibration of the cameras.

2.2 Configuration of the system

The configuration of the measurement corresponds to the case of aerophotogrammetry (Figure 2). The definition of the rotation that is necessary to describe the position of the cameras, is shown in Figure 2. For the determination of an appropriate configuration and the calculation of the camera parameters the following input was used:
- object size,
- principal distance and
- the size of the digital image.

The distance between object and camera was fixed to 30 cm, because the focus on the closest position (stop-position). With this configuration the photogrammetric restitution of objects with a size of approximately 12·16 cm^2 is possible. The depth of focus amounts 15 cm.

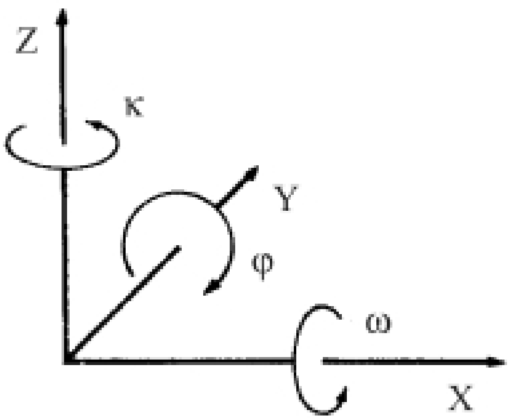

Figure 2. Definition of rotation

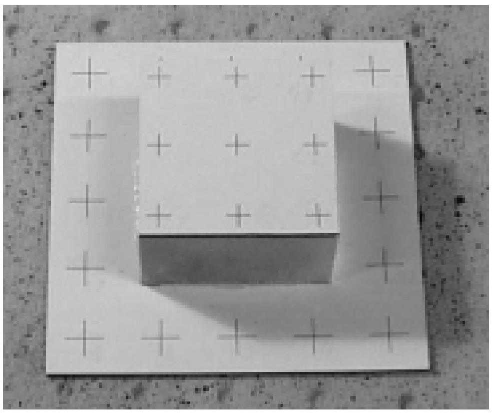

Figure 3. Calibration object

3. PHOTOGRAMMETRIC PROCESSING

3.1 Calibration

Due to the configuration of the system (Figure 2), the calibration object consists of a base-plate ($10 \cdot 10\ cm^2$) with 16 control points and an attached cube ($5 \cdot 5 \cdot 3\ cm^3$) with 9 control points (Figure 3).

A bundle adjustment was applied for calibration of the CCD camera. Thus we determine the parameters of the interior orientation of the cameras and the calibration of the whole system (including the exterior orientation) in one step. For the central perspective condition, the following equations were employed:

$$x' = x'_H - c_k \cdot \frac{d_1 \cdot (X - X_0) + d_2 \cdot (Y - Y_0) + d_3 \cdot (Z - Z_0)}{d_7 \cdot (X - X_0) + d_8 \cdot (Y - Y_0) + d_9 \cdot (Z - Z_0)} \quad (1)$$

$$y' = y'_H - c_k \cdot \frac{d_4 \cdot (X - X_0) + d_5 \cdot (Y - Y_0) + d_6 \cdot (Z - Z_0)}{d_7 \cdot (X - X_0) + d_8 \cdot (Y - Y_0) + d_9 \cdot (Z - Z_0)} \quad (2)$$

For the distortion model, the following equations were employed [*Luhmann*, 2000]:

$$x' = \Delta x' + x' \quad (3)$$

$$y' = \Delta y' + y' \quad (4)$$

$$\Delta x' = x' \cdot \frac{\Delta r'_{rad}}{r'} \quad (5)$$

$$\Delta y' = y' \cdot \frac{\Delta r'_{rad}}{r'} \quad (6)$$

$$\Delta r'_{rad} = A_1 \cdot r'(r'^2 - r_0{}^2) + A_2 \cdot r'(r'^4 - r_0^4) \quad (7)$$

with

x’, y’	- image coordinates
X, Y, Z	- coordinates of object points
d_i	- rotation matrix
c_k, x_h’, y_h’, Δx’, Δy’	- interior orientation (for each camera)
X_0, Y_0, Z_0, φ, ω, κ	- exterior orientation (for each image)
r'	- image radius
A_1, A_2	- parameters for radial lens distortion

In the experiment, the calibration object and the bolt was taken at a distance of approximately 30 cm and at the principal distance of 15,30 mm from the CCD camera from 23 different directions and positions, in such a way that the images could be overlapped 100%. In order to test the absolute accuracy of the configuration, we calculated the bundle adjustment with determination of the calibration points as new points. The achieved accuracy of the 3D measurement is 0,1 mm in X- and Y-direction and 0,2 mm in Z. In order to attain a better accuracy it would be necessary to use a calibration object around with more accurate calibration points and positions of the control points around the object. An other way is the use of cameras with a higher resolution.

3.2 Photogrammetric processing model

The photogrammetric calibration delivers the orientation parameters of the cameras and the whole system. With the application of these parameters and the measurements in the images of the represented object it is possible to derive 3D coordinates of this object. The measurement of image coordinates took place with methods of digital image processing. A system overview is illustrated in Figure 4.

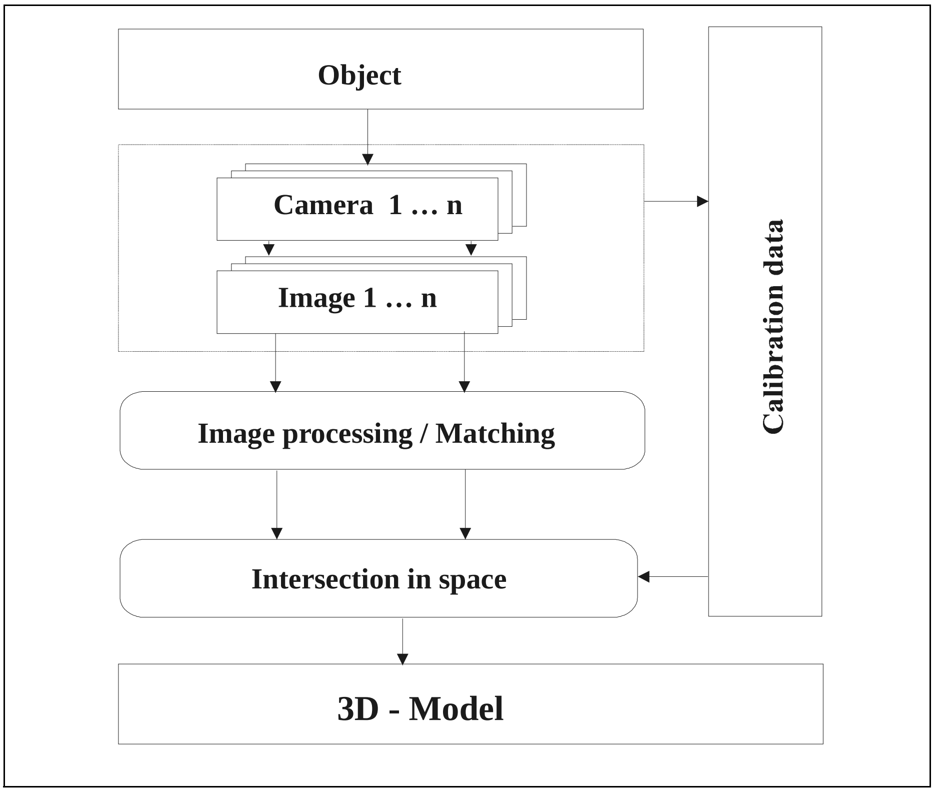

Figure 4. System overview

3.3 Evaluation of the object

The task was to survey the surface of the breaks of the bolt. So it is not possible to make a restitution of single lines and points, which characterize the object. Therefore we used the matching methods and intersection in space to determine the 3D Model of our surface.

3.3.1 Image matching

The used matching method was a combination between area based matching and least square matching. As result we get the image coordinates of all conjugate points on the surface of the fracture of the bolt. For our experiences we achieved a matching rate at 90%

(Figure 5). The good matching rate must be borne by a favourable base-to-height ratio. That means the angle between the two images was very small. Therefore the prerequisite for intersection in space is not very sufficient.

Figure 5a. Original image

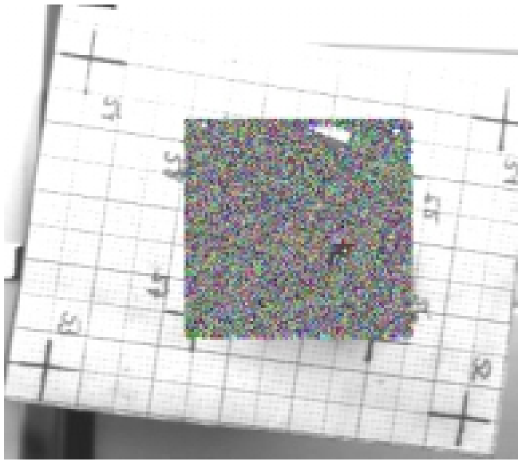

Figure 5b. Image with matching points

3.3.2 Determination of object coordinates and visualisation

After the camera was calibrated successfully and the conjugate point were matched, the object coordinates of the matched points could be calculated. The used method was intersection in space. The result is the digital surface model of the conjugate breaks of the bolt. The 3D Model was visualize with the help of the program SURFER. A perspective view is illustrated in figure 6, a contour map of the same data is illustrated in figure 7.

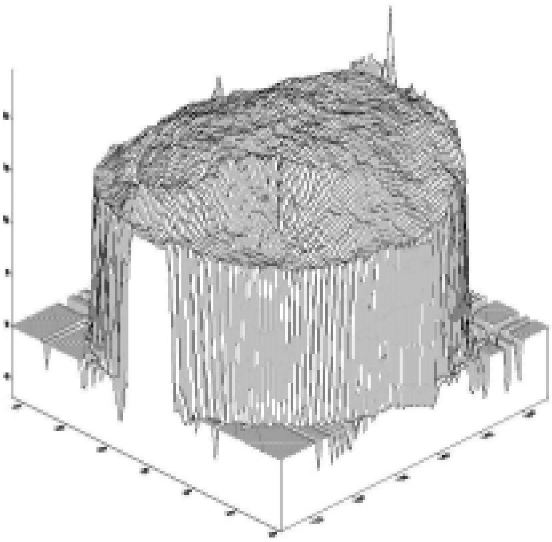

Figure 6. Perspective view

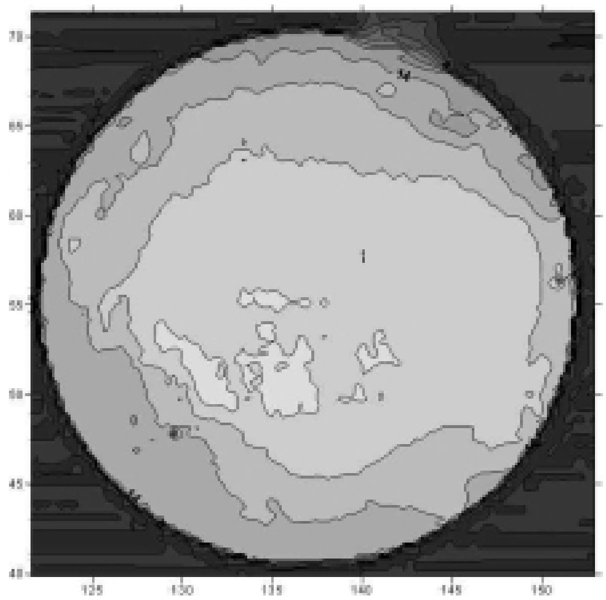

Figure 7. Contour map

4. Evaluation of results and accuracy

The achieved accuracy of the calibration is ±0,05 mm in plane and ±0,15 mm in height in the part of the image with the control points, calculated with all 23 images.
The result of the intersection in space with only 2 images and a bad base to height ratio is not so good. The achieved accuracy of the whole system is estimated ±0,3 mm in plane and ±2mm in height. But for the surface, the accuracy between points on the fracture are important. The accuracy of the spatial distance between any points around the object is 0.1 mm.

5. Conclusions

In the presented paper, an approach for nearly automatic determination of a digital surface model of breaks of the bolt has been introduced.

An improvement of the calibration (e.g. a calibration object around the object) would lead to an increasing precision. Also the using of multi-image matching and a better hight to base ratio would be the basis for better results and accuracy.
A surveying of other objects is possible, if the pre-condition (surface of the object with a low gradient) is fulfilled. The size of the object plays no role, but must be considered regarding the resolution and the accuracy however.
With the presented paper it could be shown that the utilisation of CCD cameras and suitable software enables an effective surveying of object in the field of close-range photogrammetry.

REFERENCES

Luhmann, T., "Nahbereichsphotogrammetrie - Grundlagen, Methoden und Anwend-ungen.", Wichmann Verlag, Heidelberg (2000)

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