

## Off-Line and On-Line Applications of Macro Photogrammetry

Karsten Jacobsen  
University of Hannover  
Nienburger Str. 1  
D3000 Hannover  
FR Germany

### 1. Abstract

A precise three-dimensional investigation of very small objects is possible by macro photogrammetry. The fine structure of human bones, metallic surfaces, tools and workpieces have been determined with an accuracy of few microns in the object space. Images have been made with a stereo-microscop, a Rolleiflex metric 6006 and 3003 with macro lenses and macro converter and video cameras with macro lenses. The data acquisition was made with analytical and digital stereo plotters and directly based on digital images by on-line computation in a PC.

The small view angles in macro applications are causing special geometric problems. Based on a bundle solution with a three-dimensional control pattern the exterior and the interior orientation can be determined and directly be used in analytical and digital stereo plotters. The traditional method of relative and absolute orientation will not lead to sufficient results in the case of very small view angles, so the handling of the images in the plotters and the on-line computations had to be based on a bundle solution.

### 2. Introduction

The human bone is not a solid dead material. It is a three-dimensional combination of sticks and plates which will be permanently reduced and formed again. The geometric character of this is important for the knowledge about the stability and the grown old. Research in this field has been limited to measures in cuts and stereoscopic views with stereo microscopes. By this reason a photogrammetric evaluation of the stereo pairs from stereo microscope has been made. The geometric instability of the microscopes has lead to the use of reseau cameras. By the same method the structure of metallic surfaces has been determined as preparation for a planned on-line solution based on video cameras. A similar problem is existing with the on-line check of tools and work pieces.

### 3. Stereo Microscope

The geometric conditions of stereo microscopes are quite different to usual metric cameras. No information about the geometry or a calibration certificate has been available. An investigation of the stability, check for reproduction of geometric conditions and calibration was necessary.

In close range applications the camera calibration usually is made with tilted views to a flat test field. This is not possible in the case of a stereo microscope. The



depth of focus is limiting the tilt of the object against the optical axis and the use of a three-dimensional test field with the shape of an "U" has been found as optimal (see fig. 2). On top of the "U" a reseau grid is used as 3D-control point information and instead of the object, a reseau below the "U" is used for vertical control.

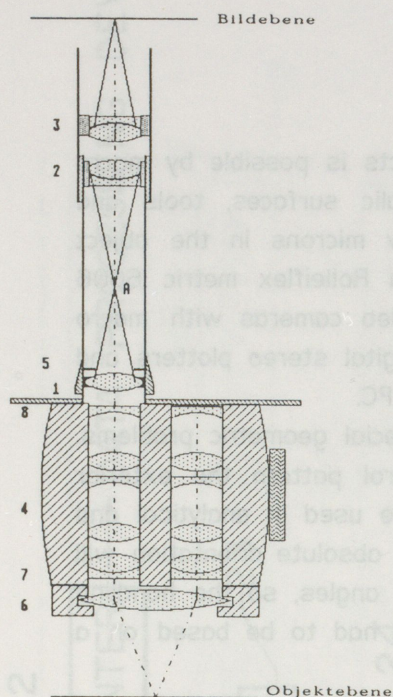


fig. 1 stereo microscope

Caused by the small view angle, the elements of interior orientation are highly correlated. But the determined object coordinates inside the three-dimensional are not influenced by this.

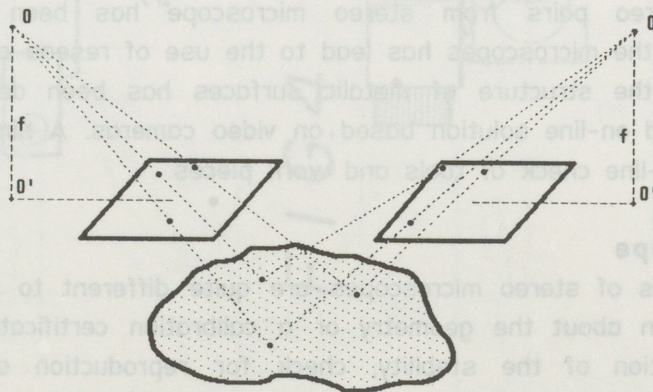
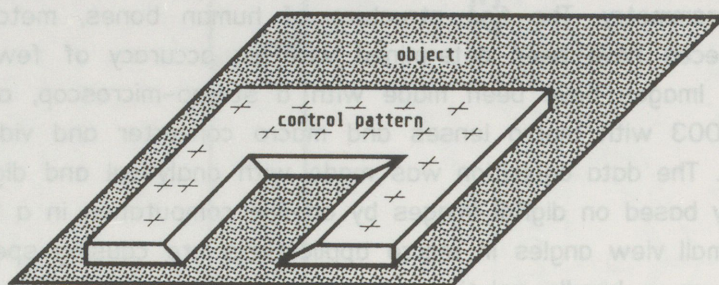


fig. 3 geometric condition of stereo microscope

fig. 2 control field for macro images





With the used enlargement, the principal point of the images with a size of 24 mm \* 36 mm is located 50 mm outside the centre of the photos. The corresponding base to height ratio  $100 : 380 = 1 : 3.8$  enables a sufficient stereoscopic impression.

The lens distortion is reaching 150  $\mu\text{m}$ . It is mainly radial symmetric, but not in relation to the principal point. The point of symmetry is located 6 mm beside the photo centre. The inner orientation and also the lens distortion cannot be reproduced, it will be influenced by any change of the focus and enlargement. In addition the photo resolution has been poor. By these reasons a switch was made to the partial-metric camera Rolleiflex metric 6006 and 3003 with macro converter and macro lenses.

#### 4. Rolleiflex metric with macro lenses

The Rolleiflex metric includes a reseau in front of the film. The 6006 has a photo size of 60 mm \* 60 mm, the 3003 24 mm \* 36 mm. The extended image size of the 6006 includes the advantage of a better angular resolution.

	Rolleiflex metric 6006			Rolleiflex metric 3003	
2-fold converter	yes	yes	yes	yes	no
adapter ring	34 mm	68 mm	102 mm	2 *	3 *
focal length	218 mm	275 mm	337 mm	258 mm	138 mm
photo scale	1 : 1.2	1.7 : 1	2.5 : 1	2.6 : 1	1.5 : 1
mean distortion	31 $\mu\text{m}$	13 $\mu\text{m}$	14 $\mu\text{m}$	18 $\mu\text{m}$	10 $\mu\text{m}$

table 1: used Rolleiflex configurations

Because of the small view angle no reseau correction for compensation of the film flattening was necessary. The inner orientation has been determined with the same three-dimensional control pattern described before.

With long focal length in the normal case only a poor base to height relation can be reached. So a tilted view to the object is necessary. The handled samples have been small but the cameras have had a very long combination of adapter rings, converters and lenses, by this reason the object was located on a tilting table and the camera has been fixed.

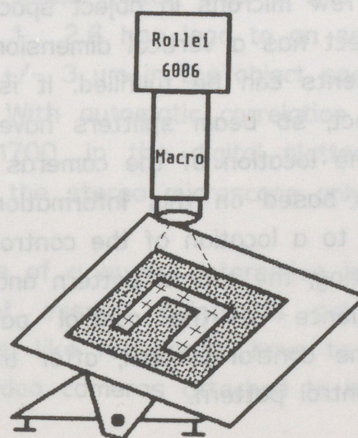


fig. 4  
configuration for  
Rolleiflex metric



The lenses, adapter rings and converters must have the correct location in relation to the optical axis. A decentering can have an influence to the geometric situation. A screw off and on again has had a small influence to the location of the principal point and also to the distortion. The distortion is not only radial symmetric. Like shown in fig. 5 there are in some combinations two centres for symmetry overlapping, which can be explained by a decentering of some optical parts.

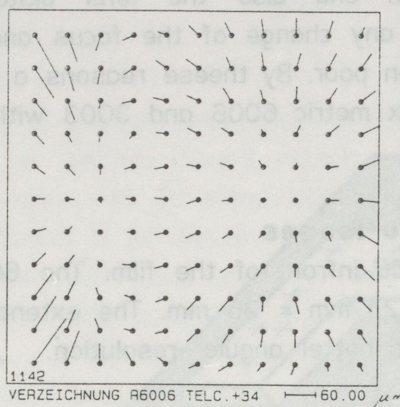


fig. 5

distortion of 6006  
with 34mm adapter  
and 2-fold converter

## 5. Video cameras

The used solid state cameras do have an array of  $768 * 512$  pixel, each approximately  $10 \mu m * 8 \mu m$ , in total  $6.1 mm * 4.1 mm$ . This is much less than the corresponding photo size. For a comparison of the geometric angular resolution, the accuracy relations have to be respected. Based on Rollei-images a standard deviation of unit weight  $\sigma_0 = \pm 6 \mu m$  has been reached. The not optimal results mainly have been influenced by the limited depth of focus. With video cameras an accuracy of  $\sigma_0 = \pm 1 \mu m$  is possible. In relation to the accuracy the array size is corresponding to a photo size of  $36 mm * 24 mm$  like present at the Rolleiflex metric 3003. That means, the information contents of the 6006 will not be reached with the used array size.

The mentioned accuracy of the video cameras has not required any precorrections. The geometric situation of the used cameras is excellent. The radial symmetric distortion of the different small angle lenses is below  $10 \mu m$ .

The aimed accuracy of few microns in object space is limiting the image scale. On the other hand the object has a vertical dimension of  $0.6 m$ . Only with a relative positioning the requirements can be fulfilled. It is not possible to place a control pattern around the object, so beam splitters have been used in front of the video cameras (see fig. 6). The location of the cameras will be determined in relation to the control pattern and based on this information the object coordinates can be calculated corresponding to a location of the control pattern around the object.

Depending upon the lighting, the control pattern and/or the object can be imaged. To avoid a negative influence of the control pattern to the automatic object identification, at first the control pattern, after this the object will be illuminated, checked again by the control pattern.



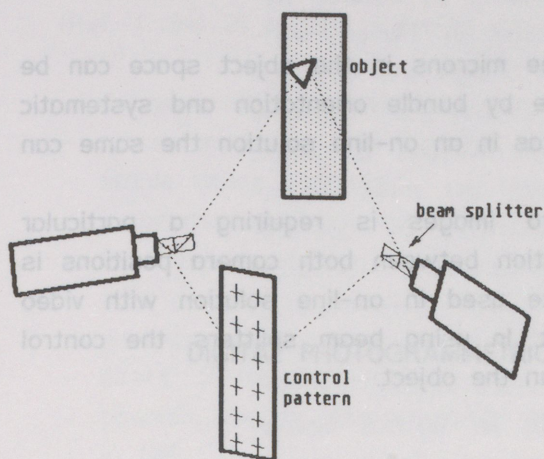


fig. 6  
configuration for  
video cameras

## 6. Data handling

The images taken by the stereo microscope, the Rolleiflex metric 6006 and 3003 and for checking purposes also displayed digital images from video cameras are handled in the Planicomp and the DSR 11. The photo orientation by bundle adjustment is computed by the Hannover program system BLUH in the case of more than 2 images or by program BUNOR. The 2-photo-bundle orientation program BUNOR is managing the whole process, including computation of approximate values, error detection by data snooping and selfcalibration by additional parameters within few seconds.

The standard programs for data aquisition can be used based on transformed photo orientations. For sufficient accuracy the systematic image errors, determined by calibration and self calibration, must be respected by a correction grid, which will give a correction to the position of the floating mark based on bilinear interpolation (Picht 1987). This flexible possibility for correction of the photo geometry allows also the handling of photos with large differences to perspective images.

The data aquisition with the digital plotter, developed by the Institute for Photogrammetry of the University of Hannover (Lohmann et al 1989), includes the advantage of optimal contrast enhancement and a more simple support by correlation.

A manual height measurement in a model taken with 6-fold enlargement by the 3003 and a base to height ratio of 1 : 2.6 has lead to an accuracy of the height determination of metallic surfaces of  $\pm 3 \mu\text{m}$  in the object space, corresponding to  $\pm 7 \mu\text{m}$  standard deviation in px. With automatic correlation based on the same photos, digitized by an Optronics P1700, in the digital plotter an accuracy  $S_z = \pm 5.8 \mu\text{m}$  was reached. Images of the stereo microscope only have enabled  $S_z = \pm 13 \mu\text{m}$ .

The digital plotter has the advantage of a human interaction in the case of failed correlation. A small percentage of missed points is not important if only characteristic parameters of surfaces, like roughness, have to be determined. This can be done close to on-line with video cameras attached to a PC. Such a system is under development.



## 7. Conclusion

Based on macro photos an accuracy of some microns in the object space can be reached if the photo orientation will be done by bundle orientation and systematic image errors are respected. With video cameras in an on-line solution the same can be done with less expensive instrumentation.

The special geometric situation of macro images is requiring a particular three-dimensional control pattern if the relation between both camera positions is not known. With a set of two cameras, like used in on-line solution with video cameras, a flat control pattern is sufficient. In using beam splitters, the control pattern can have also a different location than the object.

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