INFLUENCE OF LARGE TARGETS ON THE RESULTS OF PHOTOGRAMMETRIC BUNDLE ADJUSTMENT

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1 Abstract

To estimate a suitable diameter of a circular target for high precision photogrammetric measurements some requirements have to be considered. For precise photogrammetric measurements the diameter of circular targets have to be between a minimal and maximal size. Tools for estimating minimal and maximal target sizes will be given and a simulation shows how the bundle adjustment will be influenced by using targets that are too large

2 Introduction

Most photogrammetric industrial measurement systems use circular targets to define the center of points of interest.

For precise image measurements it is required that the targets have a minimum diameter. It is well known that the diameter of the target in the digital image should cover at least 3 *pixel* (picture elements) to achieve image coordinates with subpixel accuracy.

On the other hand it is mentioned in the literature /Zhou 1986, Lenz 1988, Riechmann 1992/ that oversized targets can cause measurement errors. The reason for this measurement error is briefly explained; Due to the projection of a circular target the image of the target will appear as an ellipse if the surface of the target (*target plane*) is not parallel to the image plane. The image of the center of a circular target (true target center) is not necessarily identical to the center of the ellipse in the image (measured target center). The deviation between the true and measured target center (offset) can be larger than the measurement accuracy of photogrammetric industrial measuring systems if the used target is oversized .

In general, measurement errors can be detected by the photogrammetric bundle adjustment but if they are very systematic it is possible that the parameters of a photogrammetric bundle adjustment compensate for their influence. Until now, publications mention that this measurement error exists and that this error is smeared over the results of the triangulation but a quantification of which parameters in the bundle triangulation are mainly influenced was not given.

This paper presents the results of a simulation in which the influence of large target sizes on the results of the photogrammetric bundle adjustment were investigated. It will be shown which parameters are mainly influenced by this error and how large the influence can be and also how to estimate suitable target sizes.

3 Minimal target diameter

It is known that the image of targets in the measurement picture should have a diameter of at least 3 pixel to achieve subpixel image measurement accuracy. But for practical use it is preferred to have a diameter of about 5 pixels or more. To estimate the minimal target diameter in object space the following parameters should be known: the focal distance (c), the distance between camera and target (h = *recording distance*) and the pixel size of the camera (ps), see also (Fig. 1). Using this information and taking in account that the target should have at least a diameter in the image of pn = 5 pixel (pn = number of pixel), equation (1) leads to suitable target sizes which are shown in (Fig. 2).

$$d \cdot (h/c) = (pn \cdot ps) \cdot (h/c) = D$$
$$(5 \cdot ps) \cdot (h/c) \leq D_{\min} \qquad (1)$$

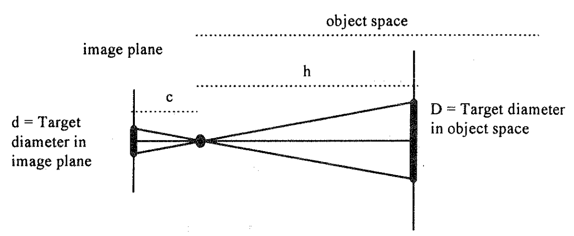


Figure 1: Relation between target diameter in image plane and object space

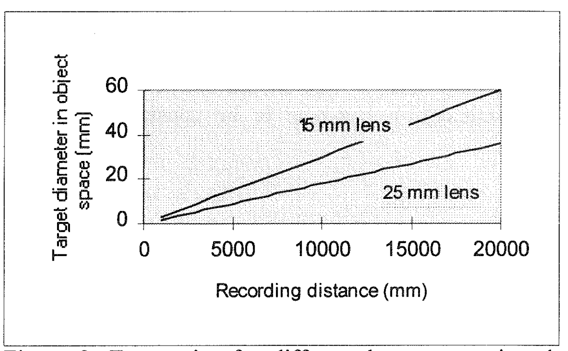


Figure 2: Target size for different lenses assuming that the diameter of the target in the image is at least 0.045 mm which is equal to pn = 5 pixel and ps = 0.009 mm.

4 Maximal target diameter

After estimating the minimal target diameters the estimation of maximal target diameters is necessary. As mentioned above and illustrated in (Fig. 3) the image of the center of a circular target (*true target center*) is not necessarily identical to the center of the eliptical target image (*measured target center*).

Under certain circumstances, especially if oversized targets are used, the distance between the true and measured target center (*offset*) can be larger than the measurement accuracy of photogrammetric industrial measuring systems. Two different cases can be differentiated.

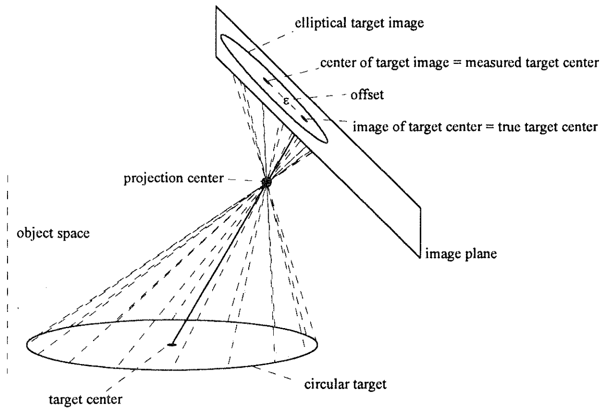


Figure 3: Measured and true target center

In those cases in which the image plane is parallel to the target plane a circular target is projected as a circle into the image. Thus, the true target center is identical with the measured target center.

In those cases in which the image plane is not parallel to the target plane, which happens in most convergent photogrammetric networks, the expected target center is not necessarily identical with the actual target center. The offset between the true and the measured target center (Fig. 3, 4) can be estimated by equation (2).

Using the parameters of a digital photogrammetric measurement system (e.g. /Brown and Dold 1996/) the offset will be estimated. In (Fig. 5, 6) the variation of the offset is shown for different lenses (15mm, 25mm; e.g. lenses for Kodak DCS camera), the maximum image radius (18mm; e.g. Kodak DCS460), typical distances between camera and target (2 m, 5 m) and different target diameters (5 mm, 10 mm, 15 mm, 20 mm). Assuming that the image measurement accuracy of digital photogrammetric systems is for real applications larger than 0.2 microns, 10 mm targets have no influence if recording distances between 2 m and 5 m are used. Target diameters of more than 10 mm should not be used for these recording distances. It has also to be considered that the recording direction using retro refelctive targets is between ±60 gon because those targets do not reflect the light for larger angles

$$\varepsilon = r_m - \frac{(r_1 - r_2)}{2}$$

$$\varepsilon = r_m - \frac{c}{2}\cdot\left(\frac{R_m + \frac{d}{2}\cdot\sin(90-\alpha)}{h - \frac{d}{2}\cdot\cos(90-\alpha)} + \frac{R_m - \frac{d}{2}\cdot\sin(90-\alpha)}{h + \frac{d}{2}\cdot\cos(90-\alpha)}\right) \qquad (2)$$

with

- ε: offset between true and measured target center
- d: diameter of target
- r_1: image radius of P'_1
- r_2: image radius of P'_2
- r_m: image radius of P'_m (true target center)
- α: recording direction
- R_m: distance between target center and optical axis.
- h: distance between camera and target
- c: focal distance.

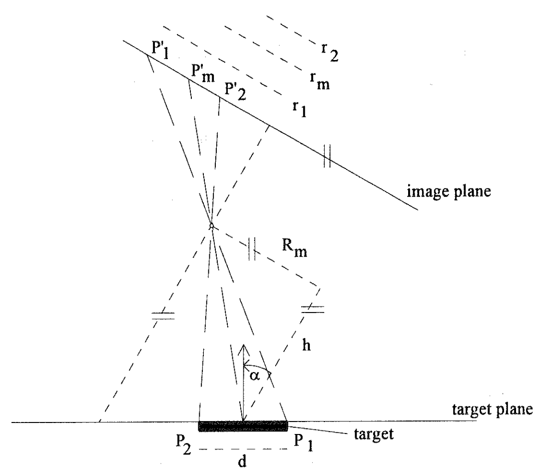


Figure 4: Relation between target and target image

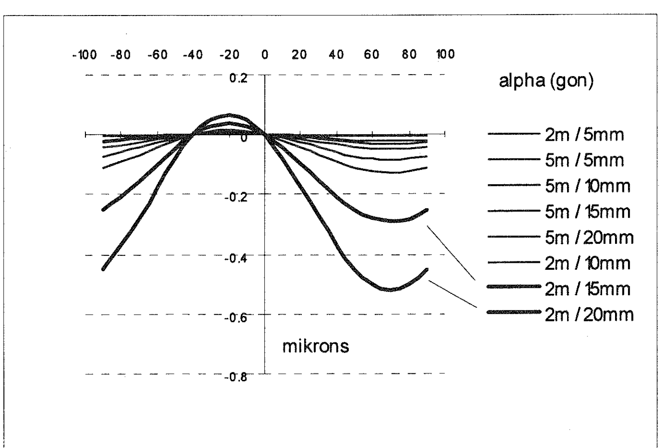


Figure 5: Estimation of offset for a 15 mm lens and a maximum image radius of 18mm.

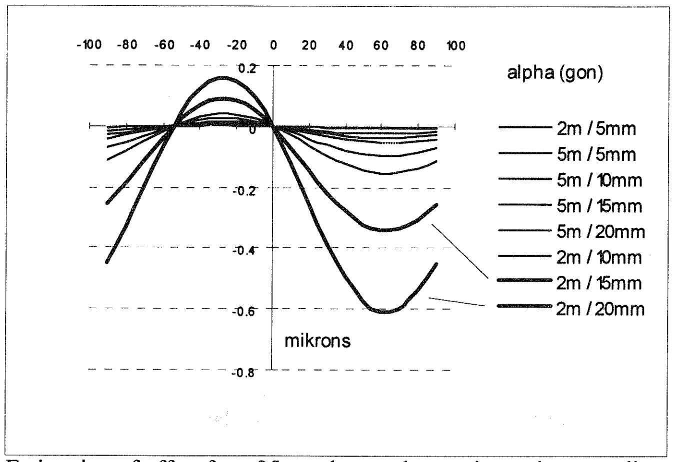


Figure 6: Estimation of offset for a 25 mm lens and a maximum image radius of 18mm.

5 Influence on photogrammetric bundle adjustment

With the help of a simulation it will be shown which parameters of the bundle adjustment are influenced if the target is oversized.

The simulated network consist out of 20 images from 5 locations (Fig. 7). The object was designed with 51 spatially distributed object points. Targets are located in three different distances (25 points app. 4.6m, 25 points 2.6m, 1 point 1.6m). For the simulation parameters of a large format film camera /Dold and Suilmann 1991/ were used. This camera has an image format of 230mm x 230mm, a focal distance of 165mm and a typical image measurement accuracy of about 1 micron. For the simulation the target diameter was chosen in this way, that the offset in the convergent images from location 1 to 4 were up to 5 microns (Fig. 8a). As explained above, no offset influences the images from location 5 because the image plane is parallel to the plane of targets (Fig 8b). With these offsets the true image coordinates were changed before they were used as an input for the bundle triangulation. Two different versions of bundle triangulation were calculated. Version 1 uses a free network adjustment without simultaneous camera calibration and version 2 uses a free network adjustment with simultaneous camera calibration.

The result of both bundle triangulations show that the simulated offset will only slightly influence the residuals of image coordinates. The residuals of image coordinates are 10 times smaller (less than 0.5 microns) than the simulated offset (Fig 9a, 10a).

In cases with no simultaneous camera calibration the offset influences not only the parameters of *exterior orientation* (location and orientation of camera) but also the object coordinates (app. 20 microns deviation to nominal values Fig. 9c and 10c). In cases with simultaneous camera calibration the offset influences also the camera parameters. Thus the influence on the object coordinates becomes smaller (app. 10 microns). Remarkable is, that the influence of the offset is mainly compensated by the exterior orientation parameters (app. 80%) (Fig. 9b, 10b). Figure 9b and 10b show the deviation between the true target centers and those target centers which are the result of the projection of the target centers in object space into the image by using the changed exterior orientation parameters which were calculated by the bundle triangulation of version 1 (Fig. 9b) respectivly version 2 (Fig. 10b).

It is dangerous is that the systematic offset is not clearly visible from the residuals of image coordinates but all other parameters of the bundle triangulation change. The influence on the exterior orientation is not critical, but the influence on the camera parameters is especially dangerous in those cases in which the camera parameters were determined in a calibration network and will be than fixed for using in a different network.

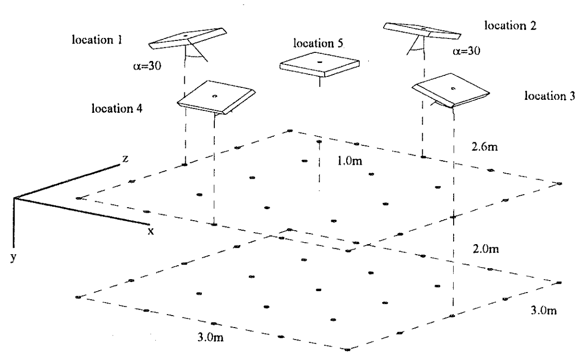


Figure 7: Photogrammetric network. On each location four images were taken (rolled by 0°, 90°, 180° and 270° around the optical axis)

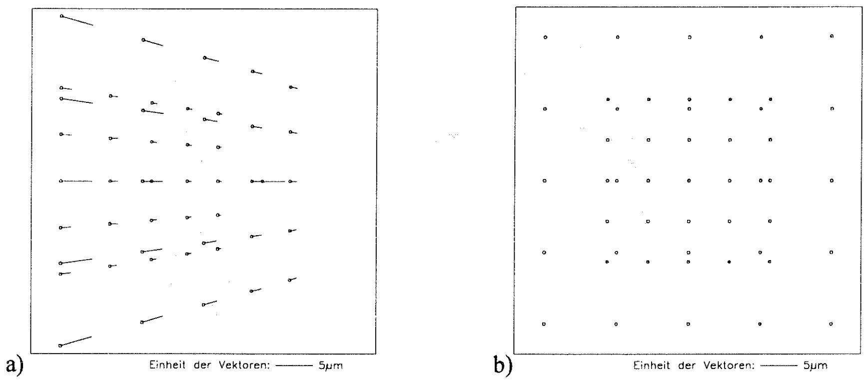
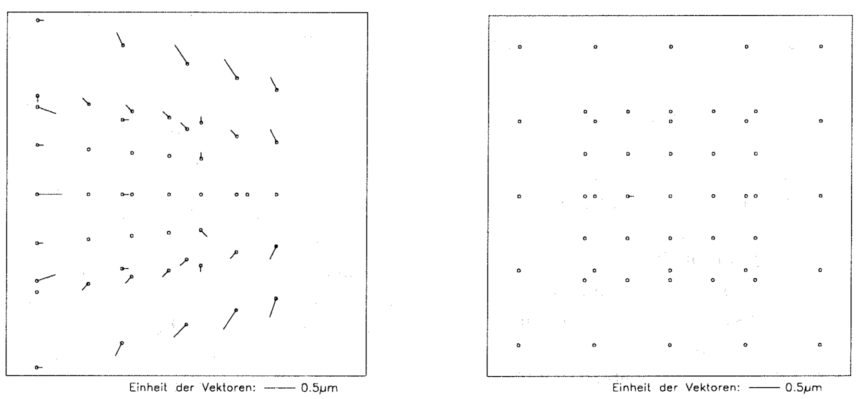
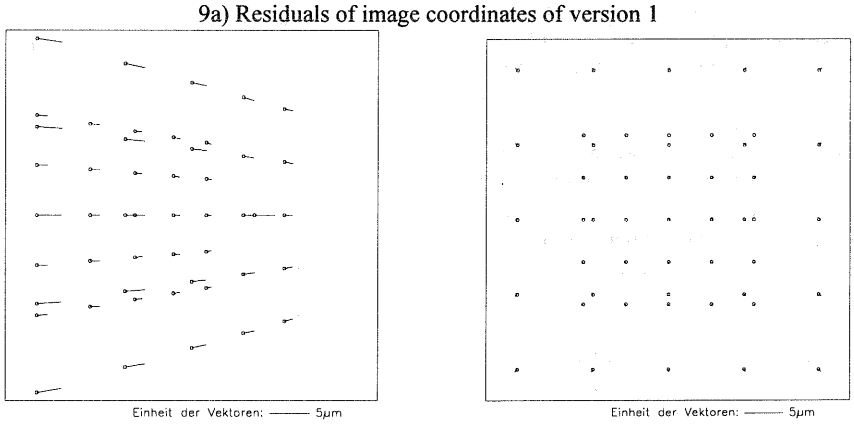


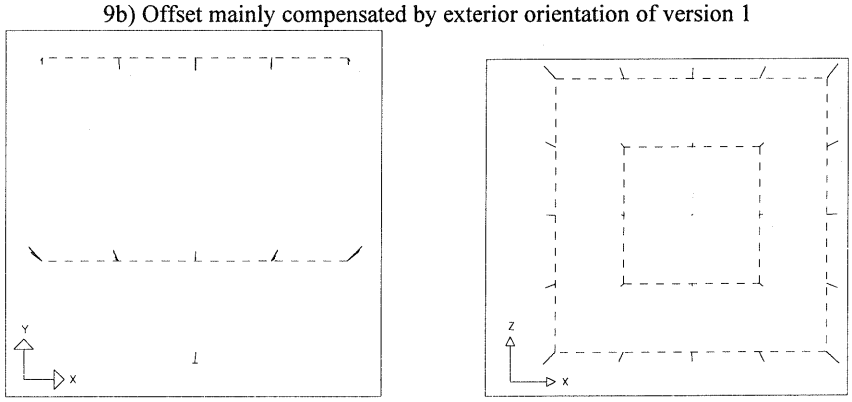
Figure 8: Simulated offsets in the images a) from location 1 to 4 and b) from location 5. With this offset the true image coordinates were changed before they were used as input for the bundle triangulation.



9a) Residuals of image coordinates of version 1

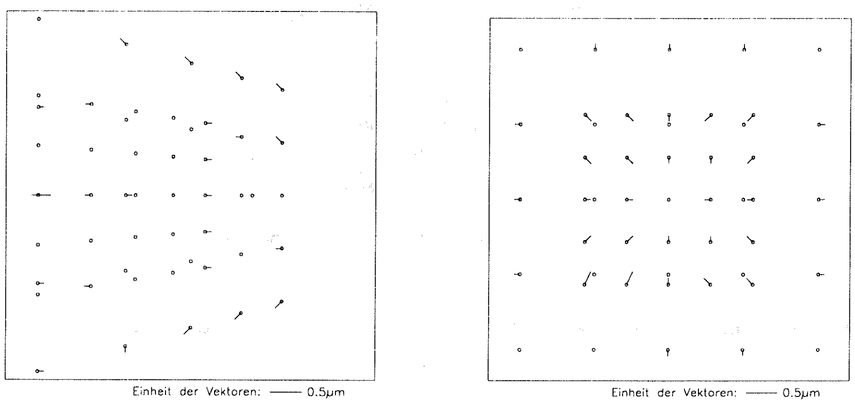


9b) Offset mainly compensated by exterior orientation of version 1

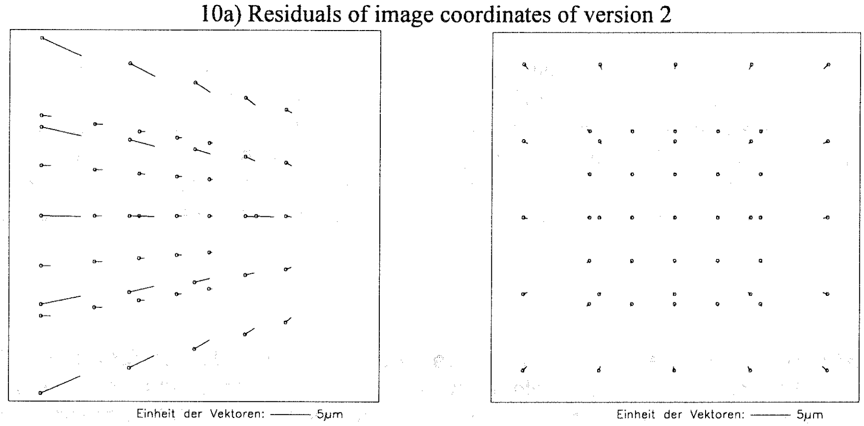


9c) Deviation of object coordinates to nominal values (version 1)

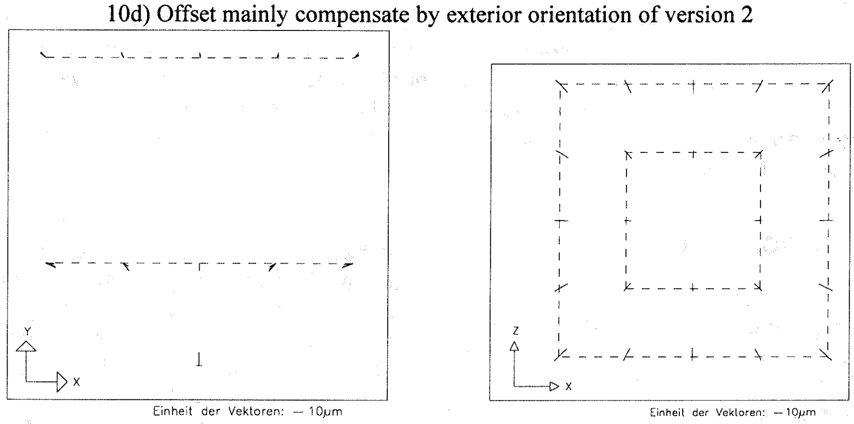
Figure 9: Results of version 1 (Free network adjustment with no simultaneous camera calibration)



10a) Residuals of image coordinates of version 2



10d) Offset mainly compensate by exterior orientation of version 2



10c) Deviation of object coordinates to nominal values (version 2)

Figure 10: Results of version 2 (Free network adjustment and simultaneous camera calibration)

6 Conclusion

To avoid offsets a suitable target size can easily be chosen by using the above described procedure (chapter 3 and 4). Thus, the influence of the offset is far below the measurement accuracy.

Even if oversized targets were chosen the photogrammetric bundle adjustment is able to compensate this influence to a large extend.

Using same networks for deformation measurements eventually existing offsets does not influence the resulting coordinate differences of measurement epochs at all, because the influence is identical for all measurements.

7 Literature

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