The Photogrammetric Journal of Finland, Vol. 12, No. 1, 1990

ON THE INFLUENCE OF THE CAMERA PARAMETERS TO THE RELATIVE ORIENTATION BASED ON THE 2-D PROJECTIVE TRANSFORMATIONS

Ilkka Niini
Helsinki University of Technology
Institute of Photogrammetry and Remote Sensing
SF-02150 Espoo, Finland

Abstract

The new method of relative orientation using 2-D projective transformations was tested in eight simulated cases. The aim was to study how the accuracy of the model coordinates change when the original inner orientation parameters were changed, or affinity and radial distortion were added to the image coordinates. The simulation results show that the method does not need any exact knowledge of the original interior orientation, or of the affinity of the image frame. Only radial lens distortion clearly affects the results. However, this shows that it should be possible to add radial lens distortion parameters to the mathematical model.

1. Relative orientation using 2-D projective transformations

A new method of relative orientation of two images has been developed at the Helsinki University of Technology. The main idea of the new method is that it uses 2-D projective transformations instead of the perspective collinearity condition. There is short mathematical presentation of the method in /Haggrén & Niini, 1990/ published elsewhere in this issue. Complete description of the method is presented in /Niini, 1990/.

The method has three main parts: 1) computation of singular correlation between the images, 2) computation of projective transformation coefficients of both images from the correlation parameters, and 3) computation of model coordinates with conventional parallax equations.

The 3-D model is linearly deformed and it is in an affine coordinate system. Therefore an absolute orientation with 15-parameter projective transformation is needed to transform the model to the cartesian ground system.

2. Simulation arrangements

A previously developed simulation program was used to produce the simulation data of this test. With the simulation program one can 'take' photographs of a self-determined object. The inner and outer orientation parameters can be changed, and noise and systematic errors can be added to the photographs. In this test the simulated photographs were put in the form of image coordinates, and the photo size was 512 x 512 pixels and camera constant was 950 pixels, like video images in the Mapvision system /Haggrén & Leikas, 1987/

Simulated cases were generated by changing the inner orientation parameters and adding systematic errors, i.e. affinity and radial lens distortion to the images. A slight amount of noise (0.05 pixels) were added to the images, too.

In the original simulation test presented in /Niini, 1990/, also different camera orientations were tested. These simulations showed that the new relative orientation method usually is usable in non-topographic purposes, where the camera station geometry is arbitrary, e.g. the convergence angle is large. The only restriction of the method is that the original object points cannot be on the same plane. Therefore, the exterior orientation of cameras can be freely chosen and can be kept constant in this simulation test, and it is possible to concentrate here only on the inner geometry of the cameras.

In all the cases studied here, the camera base was parallel with the object Y-axis, and the cameras were symmetrically around the X-axis. The object was a cube with dimensions 1 x 1 x 1 m^3. It consisted of 27 points. The convergence angle α between directions of the optical axes was 100 gons in all cases, so the base/height-ratio was 2.00. The distance from the center of the object to the cameras was 4.24 m, so the relative object depth/distance-ratio was about 0.33. The width of the image was approximately 0.80 x 512 pixels. Figure 1 shows the relations of the camera positions and the object.

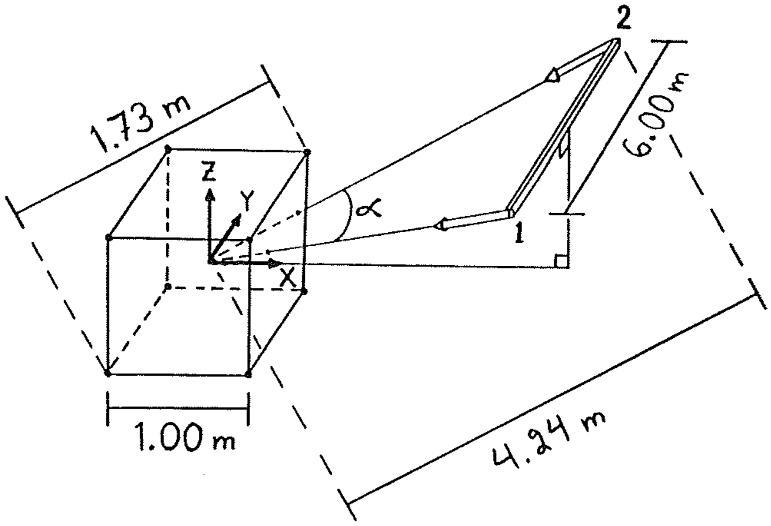

Figure 1. Camera station geometry.

The studied cases are presented in Table 1. The cases were numbered with two digits; the first number is the group number (1=inner orientation errors, 2=systematic errors), and the second number is the ordinal number in the group. The errors generated in the inner orientation values are ±20% of the correct values (x_0 = 256, y_0 = 256, c = 950). Affinity (Aff.) and radial distortion (dr) are the maximum effects in the images, and they are equal in both images. The affinity in cases 21 and 24 is relative to the scale ratio of 4/3 in the x- and y-coordinate axes, which is common using ordinary video images. The radial distortion was generated by using the equation

$$dr = K_1 r^3,$$

where $r = \sqrt{x^2+y^2}$ and K_1 is the coefficient of the radial distortion. The components of radial distortion in x- and y-directions are then $dx = xdr/r$ and $dy = ydr/r$.

Table 1. Simulated cases, where systematic errors have been added to images. The amount of error is given in pixels.

Case	c'	c"	x_0'	y_0'	x_0''	y_0''	Aff.	dr
11	0	0	0	0	0	0	0	0
12	-190	0	0	0	0	0	0	0
13	0	0	-50	50	0	0	0	0
14	-190	190	-50	50	-50	50	0	0
21	0	0	0	0	0	0	75	0
22	0	0	0	0	0	0	0	3
23	0	0	0	0	0	0	75	3
24	0	0	0	0	0	0	0	10

3. Computational results and conclusions

Singular correlation between the images was computed at first. The rectification parameters of both images were obtained from the correlation matrix. The parameters affecting only the rectified X-coordinates were also computed exactly. The model was computed with well known parallax equations. Finally, the absolute orientation with 15-parameter projective transformation /see Ghosh, 1979/ was performed using all the 27 object points as control.

The accuracy of the method can be studied in two ways: **1)** computing the mean errors (weight coefficient matrices) of the model coordinates in one adjustment using error propagation, or **2)** recomputing the adjustment many times, always generating a new random noise to the original, error free observations. Mean errors can then be achieved with statistical computations.

Both methods should lead to the same results, naturally, if the level of random noise was the same. The latter method was used, because it was also possible to check the computer program in this way.

The adjustment was recomputed 250 times and the random noise level was put on 0.05 pixels, which is the typical accuracy of the Mapvision system. The effect of the random noise was a little different in every adjustment. The influence of the random noise to the model coordinates could then be computed from the deviation. The following values were computed:

1) Sigma nought of singular correlation, s_0. It should be approximately 0.050 pixels.

2) Root mean square error of rectified Y-coordinates, $RMSE_{pY}$. When α=100 gons, this should be 0.071 [$\simeq$0.050/cos(α/2)] pixels approximately.

3) Sigma nought of 15-parameter transformation, s_{a0}, in meters.

4) Proportional accuracy σ, computed from s_{a0}. In this case it should be about 1:8200 [$\simeq$0.050/(0.80x512)] or better.

3.1 Effect of errors in inner orientation parameters

Table 2 presents the results of cases 11, 12, 13, and 14.

Table 2. Results of cases 11-14.

Case	s_0	$RMSE_{pY}$	s_{a0}	σ
11	0.051	0.087	0.00021	1:8200
12	0.051	0.074	0.00021	1:8200
13	0.051	0.086	0.00021	1:8100
14	0.051	0.074	0.00021	1:8200

Comparing cases 12, 13, and 14 with case 11 (error free case) it can be seen that errors in the inner orientation do not affect the obtained accuracy. The model itself is differently deformed, but there is only projective or linear deformation in it. This kind of deformation can be corrected via the 15-parameter transformation. For example, in the case 13, sigma nought of the 15-parameter transformation was 0.21 mm and sigma nought of the conventional 7-parameter (similarity) transformation was 12.30 mm (58 times greater!)

3.2 Effect of systematic image errors

The results of cases 11 (again), 21, 22, 23, 24 are presented in Table 3.

Table 3. Results of cases 11 and 21-24.

Case	s_0	$RMSE_{pY}$	s_{a0}	σ
11	0.051	0.087	0.00021	1:8200
21	0.051	0.085	0.00022	1:8000
22	0.421	0.730	0.00271	1:640
23	0.560	0.924	0.00330	1:520
24	1.125	1.934	0.00754	1:230

3.2.1 Affinity

Comparing cases 11 (error free case) and 21 (only affine error), it can be seen that pure affinity does not seem to weaken the accuracy of model coordinates after 15-parameter transformation. This is, in fact, expected, because the affine transformation is linear, and therefore their coefficients will coincide with the projective transformation coefficients. Affinity may have a little influence on the accuracy of the model coordinates when it is combined with radial distortion, as was in case 23.

3.2.2 Radial distortion

Comparing cases 22, 23, and 24 with case 11, it can be seen that the new relative orientation method cannot compensate radial distortion errors. As can be seen from Table 3, the systematic error is visible already in the singular correlation computation (s_0 is big). The final model cannot be corrected with the 15-parameter transformation, but it will stay unlinearly deformed.

Comparing the model residuals after 15-parameter transformations between all the 250 adjustments, it was discovered that the residuals themselves were always of the same direction, and had quite a small mean error. Mean errors computed in this way were in case 11: 0.18 mm, 0.21 mm, 0.18 mm and in case 24: 0.19 mm, 0.22 mm, 0.18 mm. In practice, they are the same. It seems that the radial distortion does not have any influence to the computational accuracy of the new relative orientation method itself, but only to the deformation of the model.

4. Summary

The simulation results show clearly that the new relative orientation method which uses 2-D projective transformations is not sensitive to the errors of the principal point or of the camera constant. Also possible affinity of image coordinates does not affect the accuracy of the method. Thus, the method can be used even, if the inner orientation is unknown or, e.g. when using video cameras which usually also have a strong affinity, and still get a correctly shaped model after 15-parameter absolute orientation using at least five ground points.

The method does not yet contain a possibility to compensate radial distortion errors, but they must be removed in advance if necessary. However, it seems to be possible to add additional parameters to compensate the possible radial distortion. This problem is to be studied in future.

References:

Ghosh S. Analytical Photogrammetry. Pergamon Press, New York, 1979.

Haggrén H. & Leikas E. Mapvision: The Photogrammetric Machine Vision System. Photogrammetric Engineering and Remote Sensing, Vol. 53, No. 8, 1987, pp. 1103-1108.

Haggrén H. & Niini I. Relative Orientation Using 2-D Projective Transformations. Presented Paper in ISPRS Commission III Inter-Congress Symposium, Wuhan , China, 1990.

Niini I. Relative Orientation of Images Using 2-D Projective Transformations (in Finnish). M. Sc. Thesis, Otaniemi, Finland, 1990.