THE BRAZILIAN EXPERIENCE ON CAMERA CALIBRATION

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Abstract
By 1978 a large program of research was started, tied with the Graduate Program in Geodetic Science in the Geosciences Departament of the Paraná Federal University. The aim was to improve the methods and to create the facilities to calibrate both aerial and terrestrial cameras according to the modern concept of calibration of instruments. It was shown that a 3-D test field where only distances between targets are measured is sufficient to calibrate aerial cameras. Such a test field was established close to Curitiba by 1980.

Introduction

By 1978 a large research program was started at the Department os Geosciences of the Paraná Federal University, tied to the Program of Graduation in Geodetic Science, aiming at the development of methods as well as the creation of facilities to calibrate aerial and terrestrial cameras according to the most modern concept of instrument calibration as established by EISENHART (1963).

The development of such task was crucial to Brazil. This Country, because of its large territorial extension uses extensively photogrammetric solution for mapping. Under this circunstances naturally exists a great quantity of measuring systems - i.e. the instruments used to make the measurements - in totally different technical conditions. However, the necessary control of metric quality of the photogrammetric equipment which forms the measuring system could not be done though the pertinent legislation requires it. The nonexistence of facilities to calibrate cameras leaves only one alternative: to send the cameras overseas to be calibrated there. The high costs and burocratic barriers in addition to the retention of the equipment made this solution impraticable. So we looked for a method to calibrate the entire system avoiding retention of the equipment and according to the modern concept of calibration.

This job was developed in 4 phases:

Phase 1.

In the first phase the existing methods were studied through simulation in computer, The Mixed Ranges Method (MMR) (MERCHANT (1971)) shows to be the most convenient one(OLIVAS (1980)).

Phase 2

Secondly, when all the computational background was tested, we looked for the ways to imporve the MMR. First was verifyed that the number of targets could be minimized by taking more photographs from different positions and attitudes. With this scheme a strong improvement of determination occurs.

Later other experiments confirmed the hypothesis that only levelling among the targets is sufficient. And Lastly was verified the hypothesis that a simultaneous adjustment of the photogrammetric observations (photo-coordinates)with distances measured among the targets and an arbitrary reference system is enough to solve the problem. The mathematical background used were the projective equations extended according to BROWN (1966) to express the position of the principal point; and lens distortions:

$$x-x_0-(k_1r^2+k_2r^4+k_3r^6)(x-x_0)-P_1(r^2+2(x-x_0)^2)2P_2(x-x_0)(y-y_0)-$$
$$-c\frac{(X-X_0)m_{11}+(Y-Y_0)m_{12}+(Z-Z_0)m_{13}}{(X-X_0)m_{31}+(Y-Y_0)m_{32}+(Z-Z_0)m_{33}}=0$$

$$y-y_0-(k_1r^2+k_2r^4+k_3r^6)(y-y_0)-2P_1(x-x_0)(y-y_0)-P_2(r^2+2(y-y_0)^2)-$$
$$-c\frac{(X-X_0)m_{21}+(Y-Y_0)m_{22}+(Z-Z_0)m_{23}}{(X-X_0)m_{31}+(Y-Y_0)m_{32}+(Z-Z_0)m_{33}}=0$$

where,
x,y are the fiducial coordinates of the image points.
x_0,y_0 are the fiducial coordinates of the principal point of photogrammetry.
k_1,k_2,k_3 are the coefficients for symmetric radial distortion

P_1,P_2 are the coefficients for decentering distortion

m_{ij} are the elements of the orthogonal orientation matrix M,

functions of the Euler angles
and

$$r^2=(x-x_0)^2+(y-y_0)^2$$

Phase three

The third phase was to choose the test field place and to establish it. The elected place fullfilled all the requirements with additional advantages. The main requirement was to present 200m of height difference inside the area covered by one photograph at the scale 1:8000 and easy access to the target points. The main additional advantages the place shows are: the possibility to effect the signalization of the the targets on rocks and the flatness of terrain divided into two plateaus separated by a rip of about 200m The test field is located about 50km from Curitiba at the road Curitiba-Ponta Grossa. Thirty targets were painted on the rocks and only 6 had to be constructed with concrete. In the center of the targets were implanted metal marks with the point number. The shape of the targets was a circumference with 48cm diameter inside a 2.0m side square. (CAMPOS(1979)).

All the distances were measured among intervisible targets, and a first-order levelling was performed connecting all the target points. The standard deviation of the distances was 1cm

The measurements were made by the Institut for Land and Cartography.

Phase 4
To study the effect of refraction photographs were taken at the scales 1:8000 and 1:12000. The camera was a Zeiss RMK A 15/23, property of AERODATA S.A.

A simultaneous adjustment of the distances and photo - coordinates of 168 images of the 36 targeted points was done by the Least Square Method. The "apriori" variance of unit weight was 1 and its "aposteriori" value was 1.0259.

Table 1 shows the results.(ANDRADE (1981))

The levelling was not used on calibration, but to realize the system of reference the heights of three points were used to permit a later verification of the elevations as computed by photogrammetry with the calibrated camera. Table 2 whows the results of this comparison.

parameters	value	standard deviation	unity (parameter)
x_0	-0.004	0.008	mm
y_0	0.003	0.008	mm
k_1	2.257×10^{-8}	1.278×10^{-8}	mm^{-2}
k_2	-1.343×10^{-12}	1.140×10^{-12}	mm^{-4}
k_3	2.568×10^{-17}	3.343×10^{-17}	mm^{-6}
P_1	-2.633×10^{-7}	9.646×10^{-8}	
P_2	5.433×10^{-8}	1.290×10^{-7}	
c	153.294	0.073	mm

Table 1. Results of the Calibration.

Max.Difference..................................	0.127 meters
Ave.Difference..................................	0.026 meters
Standard Deviation..............................	0.049 meters
Flying height: 1200 m.	

Table 2. Verification of the Calibration.

The Use of the Test Field
AERODATA S.A. took the incumbency of preservation and maintenance of the test field. They are also entrusted with the task of take the photographs in the proper way to calibrate the photogrammetric system.

The photo-coordinates are observed on the PLANICOMP ZEISS C-100 at the Department of Geoscience (Geodetic Science Program) and processed on the main computer of the Paraná Federal University.

Phase four.
Calibration of Terrestrial Cameras.
The use of "non-metric" camera type may offer great flexibility but affords careful calibration and continuous control. Considering the measurement of hydraulic models (SILVA (1983)) and monitoring deformations on estrutural elements of concrete (MENDONÇA (1984)) camera calibration has been done using convergent photographs according to the analytical self-calibration method (KENEFICK (1972)). The image quality was also tested by bar targets including microdensitometer measurement analysis for MTF determination under different conditions. (BAHR, ANDRADE & OLIVAS (1983)). The camera used in the experiments was a ROLLEI-SLX - a commercial camera manufactured by ROLLEI-Braunschwig.

Main components are:
* 6 cm by 6 cm format, using commercial non-perforated roll film.
*Interchangeable lenses available from 40mm to 350mm.
* Mirror reflex viewing system.
* Fully automatic exposure control (Shutter speed preset)
* Acessories: Remote release and unit for multiple exposure.

The ROLLEI-SLX was first used for photogrammetric applications by WESTER-EBBIGHAUS (Bonn University), who suggested incorporation of a reseau plate, which is produced by HEIDENHAIN/FRG and mounted by ROLLEI. The "reseau" consists of 121 crosses of 5mm distance. In Curitiba the ROLLEI - SLX Reseau Camera is available with the lenses 80mm; 50mm and 40mm.

The mathematical model was the same as described in phase 2.

This was the first of a series of experiments that are still running at the Paraná Federal University (Graduate Program in Geodetic Science).

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