CLOSE-RANGE PHOTOGRAMMETRY WITH AMATEUR CAMERA

Dimitar Jechev

GIS Sofia Ltd., Bulgaria, BG-1000 Sofia, 5 Serdika Str., e-mail: jechev@gis-sofia.bg

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ABSTRACT:

A frontage of a building has been experimentally surveyed and processed in two basically different methods – photogrammetric and geodetic. The photogrammetric survey has been made by means of an amateur digital camera, and the geodetic survey - by a total station. The shortcomings of the amateur hardware, that have been used for the experiment, were compensated by application of a specific mathematical model. The results from the two surveys performed have been compared. The RMS in the plane of the picture (the building frontage) has been calculated to be ±1.9 cm and for the depth ±6.1 cm. Photogrammetric software PHOTOMOD Lite of Racurs Co. has been used for this experiment.

1. THEORY

1.1. Problems

The work with non-metric cameras for photogrammetric purposes is accompanied by the following problems:
- Defining the image co-ordinate system (non-metric cameras do not have fiducial marks).
- Defining the unknown elements of internal orientation (focal length and image co-ordinates of the principle point of the photograph).
- Maintaining the elements of internal orientation unchanged in time - usually when working with non-metric cameras, the elements of internal orientation get slightly changed after every single exposure.
- Defining the distortion of lens - the distortion with amateur cameras often amounts to considerable values and have substantial effect.

1.2. Solving the problems

There are three basically different methods for solving the above mentioned problems known:
- **Calibration in advance.** Before surveying, in a laboratory (calibration centre) the unknown elements of internal orientation and distortion of lens shall be defined. The advantage of this method is that the calibration takes place at a laboratory and hence better accuracy at defining of unknown quantities is achieved. The problem with their fluctuation in time remains.
- **Calibration during the processing.** The unknown elements are defined by means of a special mathematical instrument. A larger number of control points is needed for their defining - at least 5 points, and it is recommendable 8-10 points per model, compared to 3 points per model when using metric camera.
- **Self-calibration.** It is based on the mathematical means of the geometry of overlapped areas for defining the unknown elements. The principles involved are similar to the ones, used for relative orientation of stereo-pair with analogue instrument. It is specific for this method that it does not require larger number of control points.

1.3. Mathematical processing

In accordance with the co-linearity condition, every object point, its image and the projection centre, should belong to one and same line, called ray. Mathematically this can be represented by means of the following 3 equations:

$$\begin{bmatrix} x_i \\ y_i \\ 0 \end{bmatrix} - \begin{bmatrix} x_0 \\ y_0 \\ f \end{bmatrix} = \lambda_i R \left\{ \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} - \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} \right\} \qquad (1)$$

where: $i = 1, 2, ... n$

$\qquad n$ is the number of measured image points,

$\qquad (x_i, y_i, 0)^T$ are image co-ordinates of point i,

$\qquad (x_0, y_0, f)^T$ are the elements of internal orientation,

$\qquad \lambda_i$ is the scale factor,

$\qquad R$ is the rotation matrix, defining the spatial rotation of the geodetic co-ordinate system in relation to the image co-ordinate system. R is function of the three angles ω, φ, κ,

$\qquad (X_i, Y_i, Z_i)^T$ are the geodetic co-ordinates of point i,

$\qquad (X_0, Y_0, Z_0)^T$ are the geodetic co-ordinates of projection centre O.

It is not justifiable to render different scale factor for each i point. The scale factor could be eliminated by dividing the first and second equations from the system by the third one:

$$F_x = x_i - x_0 + f \frac{m_{11}(X_i - X_0) + m_{12}(Y_i - Y)_0 + m_{13}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)} = 0$$

$$F_y = y_i - y_0 + f \frac{m_{21}(X_i - X_0) + m_{22}(Y_i - Y)_0 + m_{23}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)} = 0$$

$$(2)$$

where: m are the elements of R matrix

$$R = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \quad\quad (3)$$

A system of kind (2) could be composed for each measured image point i. This means that if the object is photographed by one stereo-pair, each point from the object would originate two systems of kind (2) or in total 4 equations, since each point is appeared on two photographs.

1.4. Unknown quantities

In case that the survey is performed by a metric camera, each bundle (photograph) contains 6 unknowns: the tree rotation angles ω, ϕ and κ, defining the matrix R, and co-ordinates (X_0, Y_0, Z_0) of the projection centre O. Since each measured image point originates 2 equations, in order to define synonymously one bundle, 3 control points are sufficient. Also 3 points are sufficient for calculation of one stereo-pair, as long as the points are located in the overlapping area of the photographs.

In case that a non-metric camera is used, the elements of internal orientation x_0, y_0 and f are not defined, which means that the unknowns for each bundle get increased with 3. In order to secure a synonymous solution for the 9 equations, 5 control points are needed. Since the number of equations usually is larger than the minimum required and the measured image co-ordinates contain casual errors, the least squares adjustment is applied.

1.5. Additional parameters

Lens distortion, as well as some other possible defects of the camera, are origin for systematic errors in image co-ordinates, because the images get drawn away from correct central projection. One of the conditions of the least squares adjustment is that the adjusted quantities should not contain systematic errors. With amateur cameras, as distinct to professional cameras, these defects may have significant values and hence may considerably disturb the processing.

If the lens distortion is known, the image co-ordinates may be adjusted before the bundle adjustment. This process is know as image *refining*. Even in case of some distortion, the refining is ineffective, because with non-metric cameras it gets changed in time. It is more effective for the image defects to be reduced by introduction of additional parameters into the mathematical instrument:

$$x - x_0 + \Delta x_p = -f \frac{m_{11}(X_i - X_0) + m_{12}(Y_i - Y)_0 + m_{13}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)}$$
$$\quad (4)$$
$$y - y_0 + \Delta y_p = -f \frac{m_{21}(X_i - X_0) + m_{22}(Y_i - Y)_0 + m_{23}(Z_i - Z_0)}{m_{31}(X_i - X_0) + m_{32}(Y_i - Y_0) + m_{33}(Z_i - Z_0)}$$

where the additional parameters Δx_p and Δy_p are function of some unknowns and take part in adjustment together with the rest of unknowns.

The selection of additional parameters is based on two contradictory principles:
- The number of parameters should be as less as possible, in order to reduce the number of control points, and respectively to reduce the volume of calculations.

- The number of parameters should be as large as necessary to ensure minimum co-relation with the other unknowns. Otherwise it is possible for the normal matrix to get degenerated.

In contrast to the traditional photogrammetry, where the additional parameters may be considered as constants for all photographs within a block or at least for a group of photographs, the use of non-metric cameras may require a full set of additional parameters for each single photograph. This leads to an increase of the amount of calculations, which however is not a serious problem, because the blocks made by non-metric cameras usually are smal.

2. EXPERIMENT

An experiment has been conducted, aiming to determine what accuracy may be reached at close-range photogrammetry when non-metric digital camera with unknown elements of internal orientation and distortion of lens is in use.

2.1. Surveying

The frontage of a residential building, located in City of Sofia, has been surveyed by a total station Leica TC 1610 geodetically. By means of intersections 55 not marked survey points have been defined. The error of their location is within the range of ±0.5 cm.

The same frontage have been surveyed photogrammetrically with one stereo-pair. The distance beteen the camera and the object is about 20 m, while the distance between the two projection centres is about 4 m. The main camera optical rays
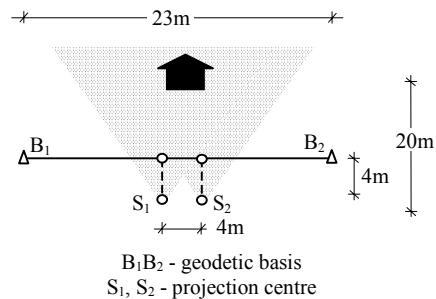

Figure 1. Survey performance

are approximately parallel and inclining towards the vertical plane. The pictures has been taken by means of an amateur digital non-metric camera Canon S230 with a focal lenght, corresponding approximately to 35 mm and size of 3 mega pixels of the photographs.

2.2. Processing

The images have been processed by PHOTOMOD Lite – a photogrammetric software of Racurs Co., allowing operations with non-metric cameras. The calibration with this software is done during the processing. The lens distortion can be taken into consideration only in case that it has been defined before hand.

For the purposes of this experiment, the orientation of the stereo-model has been conducted by means of 8 control points and 30 tie points. The lens distorsion is unknown. For the sake of reduction of distortion influence, the edge zones of the

photographs have not been used, as it is expected, that these are the areas of grossest distortion.
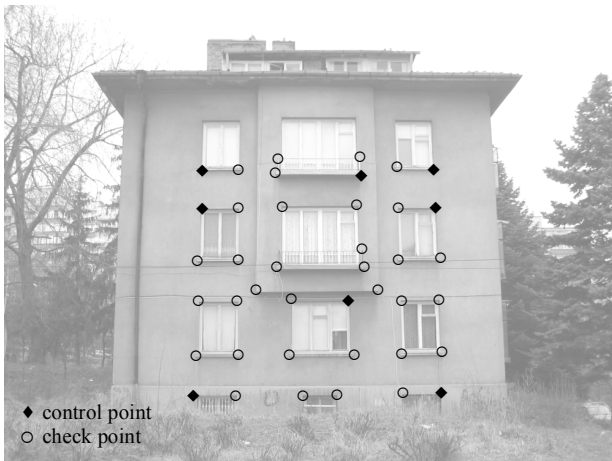

♦ control point
○ check point

Figure 2. Point location

2.3. Results

The co-ordinates of 33 geodetically determined points have been measured from the stereo model. The differences between geodetical co-ordinates and the ones, defined by photogrammteric method, have been calculated, as well as the RMS of photogrammetrically defined co-ordinates (see Ttable 1).

Axes	RMS [cm]
along axis X	±1.2
along axis Z	±1.4
in picture plane XZ	±1.9
in debt (along axis Y)	±6.1

Table 1. Accuracy assessment

The co-ordinates, established by photogrammertric method have been examined for systematic errors, whereas the theoretical and empirical values of the mean absolte errors and median errors:

$$r_{theoretical} = 0.80 \text{ m} \qquad (4)$$

$$v_{theoretical} = 0.67 \text{ m}$$

where: r   is the mean absolte error,
         m   is the RMS,
         v   is the median error.

The comparison shows standard distribution of errors of photogrammetrically defined co-ordinates (see Table 2 and Ttable 3).

Mean absolte	X [cm]	Z [cm]	Y [cm]
Empirical	±1.0	±1.1	±5.1
Theoretical	±1.0	±1.1	±4.9

Table 2. Mean absolte error

Median	X [cm]	Z [cm]	Y [cm]
Empirical	±0.8	±0.9	±4.7
Theoretical	±0.8	±1.0	±4.1

Table 3. Median error

The frontage of the building has been vectorised in stereo mode, the three dimensional model (DTM) of its surface and ortho-image have been created. The co-ordinates of 30 points have been recognised from the ortho-image and have been compared to the ones, obtained from the geodetic measurements. The RMS for the location of points from ortho-image has been calculated to be ± 2.2 cm.

3.   CONCLUSIONS

- The shortcomings of non-metric camera can be eliminated by usage of special software.
- In order to make adjustment by means of self-calibrating at least 5 control points or 9 control distances must be measured. Having known camera parameters, the number of control data is reduced.
- The accuracy of the ortho-image directly depends on the quality of the digital three dimensional model (DTM) of the object and does not exceed the one of the stereo model.
- The unknown lens distortion and the inconsistency of the parameters of internal orientation did not render systematic influence on the results of the experiment.
- The results from the experiment show, that this method completely meets the requirements of the assigned task and could successfully be applied, being an inexpensive and efficient technology for application in various fields, such as preservation of building frontages of cultural monuments.

REFERENCE:

1. Non-topographic photogrammetry, 2nd edition. 1989, American Society for Photogrammetry and Remote Sensing, Falls Church, Virginia.