NETWORK OPTIMIZATION IN INDUSTRIAL PHOTOGRAMMETRY

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Abstract:

The desiner formulates an initial network geometry, the precision of the image coordinate measurements and precision of the object coordinates. A solution is obtained for the optimal geometry and the number of camera stations. An ideal matrix of normal equations (for required precision) is used as a target function in the optimization process. The optimization is carried out by a least squares method wich minimizes the discrepancies between the real normal equations matrix of a given initial network, and the corresponding ideal matrix. The constrains for values of the exterior orientation elements for camera stations are introduced into the optimization process by means of substitution of variables.

KEY WORDS: analitic, industrial, photogrammetry, design, network, optimization, criterion, matrix.

INTRODUCTION

Actualy, photogrammetry is widely applyed, for investigation of various industrial objects. One of the main problems in this case is photogrammetry network design, which must provide required precision of object point coordinates and a minimum number of camera stations. The design is commonly solved by means of an interactive method through the process of netwokr simulation and bundle block adjustment (C.S.Fraser, 1982, 1984, 1987).

This paper deals with the algorithm of the analytical solution of the optimization problem, which permits to solve the network design automaticaly. The main idea is to provide the required precision of the object points coordinates by shifting the camera stations. A criterion (ideal) matrix is used as a target function. This matrix is formed the way an ideal covariance estimated matrix of the object point coordinates is. K.R.Koch (1982) was the first to use a criterion matrix as a target function for geodetic network design. The similar approch for photogrammetric networks was used by S. Zinndorf (1989), A. Chibunichev (1990) and D.Fritsch, F. Grosilla (1990).

Mathematical formulation of the photogrammetric network optimization

Optimization process is based on solving the following target function:

$$K_i - K_i^o = 0, \tag{1}$$

where K_i is a real covariance matrix of the estimated unknown (i) object point coordinates, K_i^o is the corresponding ideal (criterion) matrix. K_i is obteind from phototriangulation using the results of network simulation.

The function (1) can be written as (A.Chibunichev, 1990)

$$N_i - N_i^o = 0, \tag{2}$$

where N_i and N_i^o are correspondingly real and criterion matrices of normal equations.

Eq. (2) can be solved with respect to photographs orientation elements which will correspond to the required precision of the object points. The diagonal elements of the criterion matrix of function (2) may be computed in the following expressions:

$$n_{x_i}^o = \frac{\mu^2}{m_{x_i}^2}, \quad n_{y_i}^o = \frac{\mu^2}{m_{y_i}^2}, \quad n_{z_i}^o = \frac{\mu^2}{m_{z_i}^2}, \tag{3}$$

where μ is standard error of unit weight, which caracterizes the image point coordinates precision; m_x, m_y, m_z is the required precision of the object point coordinates. Nondiagonal elements of matrix N_i^o are egual to zero. In more detail this problem is described in A.Chibunichev (1990).

To solve eq. (2) it is to be expressed in a Taylor series restricted to linear terms:

$$B\Delta + L = V \tag{4}$$

with

$$B = \begin{bmatrix} b_{11} & \cdots & b_{1n} \\ \vdots & & \vdots \\ b_{m1} & \cdots & b_{mn} \end{bmatrix}; \quad \Delta = \begin{bmatrix} \Delta X_{s_j} \\ \Delta Y_{s_j} \\ \vdots \\ \Delta \varkappa_n \end{bmatrix}; \quad L = N_i - N_i^o$$

$j \in \{1, \ldots, s\}$; $i \in \{1, \ldots, k\}$; s is the number of photographs in a block; k is the number of object points; n is the number of unknown parameters Δ . $m = 6k$ is the number of equations; $b_{ij} = \frac{\partial N}{\partial x}$ are partial derivatives of eq.(2) with respect to unknown elements of photographs orientation ($X_{s_j}, Y_{s_j}, \ldots, \varkappa$);

$$N_i = \begin{bmatrix} n_{x_i} & n_{xy_i} & n_{xz_i} \\ n_{yx_i} & n_{y_i} & n_{yz_i} \\ n_{zx_i} & n_{zy_i} & n_{z_i} \end{bmatrix}$$

Since N_i is a symmetrical matrix, any object point give 6 independent equations with 6q unknown. Here q is the number of photos on which the point i appears.

Takign into account, that

$$N = A^T \cdot A, \tag{5}$$

the partial derivatives of N with respect to the elements of exterior orientation of photos can be computed as

$$\frac{\partial N}{\partial x} = \frac{\partial A^T}{\partial x} A + A^T \frac{\partial A}{\partial x} \tag{6}$$

The analitical expressions of the coefficients of the matrix A are very simple for the collinearity equations. Therefore analitical expressions of eq.(6) are simple as well.

The optimization problem is solved by means of the least-squares method ($V^T V = \min$).

The parameters of photographs to be determined may be restricted to certain intervals (because of the camera format, the inability to move the camera to a certain position and so on) can be expressed by the inequalities

$$X_{min} \leqslant X \leqslant X_{max} \qquad (7)$$

in which X_{min} and X_{max} are known vectors.

To avoid solving a quadratic programming problem we can substitute the variables according to following expresion:

$$X = X_{min} + (X_{max} - X_{min}) \sin^2 \varphi \qquad (8)$$

In this case the formulas for the derivatives of normal equations with respect to the new variables are: $\frac{\partial N}{\partial \varphi} = \frac{\partial X}{\partial \varphi} \cdot \frac{\partial N}{\partial X}$ (9)

This approach permits to solve the optimization problem without constrains and in a more simple way.

According to this approach the algorithm and the corresponding programm for optimization of camera station configuration for personal computer IBM PC was elaborated (O. Kortchagina, 1991,. Chibunichev, O.Kortchagina, 1992). This programm permits to fulfil the following tasks: 1) The desing of starting configuration of the fotogrammetric network. This process is perfomed automaticaly for simple shapes of the objects (cylinder, sphere, cube and so on) and in interactive mode for the objects of comlex shapes. 2) The photogrammetric network optimization with automatic change of photographs number in block. 3) The bundle block adjustment for checking results of optimization process.

EXAMPLES

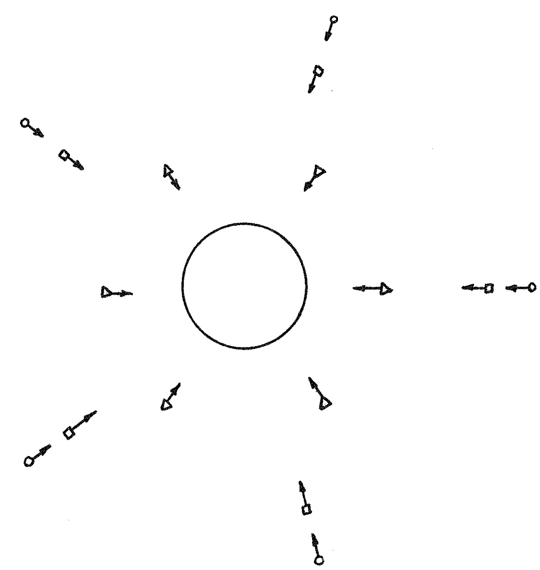
Some examples of photogrammetric network desing is illustrated in table 1 for the cylinder of 10-m diameter. Here f, μ, m_x, m_y, m_z are the initial data, and $s, D, m_x^c, m_y^c, m_z^c$ are the resultsof the design (f is the focus of the camera; s is the number of photos; D is the object-to-camera distace; m_x^c, m_y^c, m_z^c are standard errors of object points determination after bundle block adjustment using simulated photographs wich correspond to the optimal configuration of camera stations.

Table 1. Object points precision obtained after optimization process

		req. precision				simulation			
f	μ	m_x	m_y	m_z	s	D	m_x^c	m_y^c	m_z^c
(mm)	(mm)	(mm)	(mm)	(mm)		(m)	(mm)	(mm)	(mm)
200	0.01	5	3	5	5	17.2	1.2	0.9	2.1
200	0.005	5	3	5	5	17.2	0.6	0.4	0.9
200	0.001	0.1	0.1	0.1	5	17.2	0.1	0.1	0.1
100	0.01	5	3	5	5	17.2	2.3	1.7	2.9
100	0.005	5	3	5	5	17.2	1.2	0.9	1.5
100	0.001	0.1	0.1	0.1	6	6.9	0.1	0.1	0.1

IN this table we can see that in some cases the precision of the network after optimization is higher than the required precision for 5 photos. The programm reduces automaticly the number of photos to 4, becouse the required precision permits to do it. But in these cases the overlap restriction works, therefore these variants of network are considered optimal.

Let's consider steps of the designing process for one of the examples. Suppose that f = 100mm, μ = 0.001mm, $m_x = m_y = m_z$ = 0.1mm (the latter example in table 1). Figure 1 clearly demonstrates steps of the desing process of the photogrammetric network with such parameters. The first step (starting configuration of camera station) is perfomed automaticly on the basis of the approximate formula relating the value of the standard errors of XYZ coordinates, to the scale of photography and the precision of the image coordinates measurements (C.Fraser, 1984). The location of the intermediate camera stations was obtained as a result of the solution of the target function (2). In this case the optimization process was interrupted because of the overlap restriction (the precision of the object point was m_x' = 2mm, m_y' = 2mm, m_z'= 4mm at this moment). Therefore the sixth camera station was added and the optimization process was continued. This process was finished only where the precision achieves the required values.



o→ starting configuration of camera station

□→ intermediate camera station during optimization process

△→ final camera station design

Fig. 1 Steps of design process.

These examples demonstraite that this method may be used for photogrammetric network design. But it is necessary to perform its comprehensive investigation.

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