

Error Detection Methods in Photogrammetry

Tamas Jancso

*Institute of Geoinformatics, Alba Regia Technical Faculty, Óbuda University
Pirosalma u. 1-3, Székesfehérvár, H-8000, Hungary
jancso.tamas@amk.uni-obuda.hu*

Abstract— The error detection plays an important role in the photogrammetric evaluation process. Digital Photogrammetric Workstations (DPWs) are offering to cover the whole process starting from the camera calibration until gaining the ground coordinates of points for mapping, for 3D models and for producing orthophotos. To achieve the final products in the image evaluation with high accuracy, the error detection is an essential part in each step. The paper summarizes the error detection methods and solutions for correcting the final products in photogrammetry.

Keywords— photogrammetry, error detection, camera calibration, aerial triangulation

I. INTRODUCTION

In the process of image evaluation gross errors could appear in photogrammetry. We can divide these errors into three groups, although a sharp limit between these groups doesn't exist [2]:

1. Large gross errors. Usually, we call them mistakes. The possible origin of these errors could appear in image or geodetic coordinates of points.

The origins of large gross errors in measuring the points:

- faulty replacement of point numbers,
- faulty replacement of coordinates,
- faulty identification of some common (tie) points in the common model,
- poor identification of points,
- the sign errors and confusion because of wrong direction of coordinate axes of geodetic and model coordinate systems,
- mistakes when typing the control data into file.

2. Gross errors of middle range. The origin of this error-type relates to the image and geodetic coordinates, too. Only the dimension of the error is smaller. here a new source of error can be a personal measurement error due to wrong interpretation or some errors in calculation of geodetic coordinates of control points.

3. Small gross errors. The origin of errors can be:

- a small mistake in observation and measurement of image point coordinates,
- a poor identification of tie and control points in image.

In this paper we deal with small gross errors only and to be more specific, we specify small gross errors by the formula (1).

$$4\sigma_0 \leq |\varepsilon_i| \leq 20\sigma_0 \quad (1)$$

Notation in (1): ε_i : gross error, σ_0 : unit weight error.

Gross errors can occur in every step of an evaluation process bound to DPWs, but most of all we can collect gross errors during the orientation process, see Fig. 1.

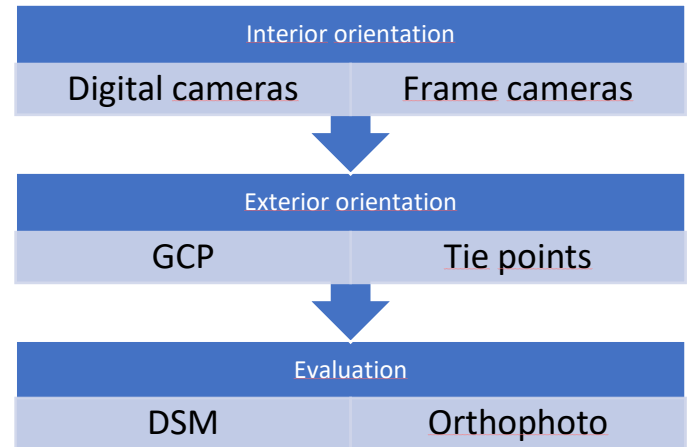


Figure 1. Evaluation process for a DPW [1]

During the interior orientation - for frame cameras – the photo coordinate system should be determined by the measurement of fiducial marks. This measurement can be automated based on an area-based image matching technique, but in rare cases the algorithm makes mistakes and misidentifies the fiducial marks, which leads to gross error.

The goal of the exterior orientation is to determine the ground coordinates of the exposure centre and the rotation angles of the camera for each photo. This procedure is also called as aerial triangulation. The whole algorithm is based on the bundle of rays built from the exposure centre, the image point and the associated ground point. During the calculations, we use ground control points (GCPs) and tie points. The GCPs can hold errors coming from the surveying calculations, and on the other hand, we can make mistakes (gross errors) during the measurement of these point in images.

The image matching algorithm is very fast and collects the tie points automatically, but among the collected points, we encounter gross errors, and it is not feasible to find them with manual inspection. If we detect these errors, then the sophisticated DSM (Digital Surface Model) and orthophoto production can be fully automatic and free from gross errors.

In this paper, we will have a closer look at the orientation process with attention to error detection.

II. INTERIOR ORIENTATION

The task of the interior orientation is to find the camera constant, the coordinates of the principal point, the pixel size, the resolution, and the distortion parameters of the camera. Normally, these data are known for metric cameras summarized in the camera calibration report. In case of using scanned photos taken with frame cameras, the part of the interior orientation is to calculate the transformation parameters between the image and photo coordinate system. Usually, we use affine transformation for solving this task. The fiducial marks will play the role of common points between these coordinate systems. The photo coordinates of fiducial marks are known from the camera calibration report. Our task is to measure the pixel coordinates of these points. The measurement can be done manually or automatically by an area-based image matching algorithm with cross-correlation technique (see eq. (3)) [3]. In both cases, we can have faulty measurements and the large residuals will indicate gross error after the adjustment. The system of equations based on equations (2) is linear for the unknowns and can be solved directly [3], [4].

$$\begin{aligned} X &= a_0 + a_1x + a_2y \\ Y &= b_0 + b_1x + b_2y \end{aligned} \quad (2)$$

Notation in (1):

X, Y : photo coordinates

x, y : image (pixel) coordinates

$a_0, a_1, a_2, b_0, b_1, b_2$: transformation parameters

The area-based image matching is frequently used also for the measurement of tie points necessary for the exterior orientation or DSM points for orthophoto production.

$$\rho = \frac{\sum_{r=1}^R \sum_{c=1}^C (g_1(r,c) - \mu_1)(g_2(r,c) - \mu_2)}{\sqrt{\sum_{r=1}^R \sum_{c=1}^C (g_1(r,c) - \mu_1)^2 \sum_{r=1}^R \sum_{c=1}^C (g_2(r,c) - \mu_2)^2}} \quad (3)$$

Where:

g_1 - the greyscale value of the pixel in the target area

g_2 - The greyscale value of the pixel in the search area

r, c - row, column index

μ_1, μ_2 - Average grey values in the target and search areas

R, C - number of rows and columns in the sample area

Let's see an example of an interior orientation based on fiducial marks. The image consisted of 8 fiducial marks and the measurement was done manually. The pixels size was 0.085 mm. The expected residual should be around one pixel or less after the adjustment. As we can see in Fig 2, at least one gross error should exist in the measurement, but among the residuals every fiducial mark indicates a large residual (0.144 mm). The overall standard deviation $\sigma_0 = 0.208$ mm, which means approximately 2.5 pixel error.

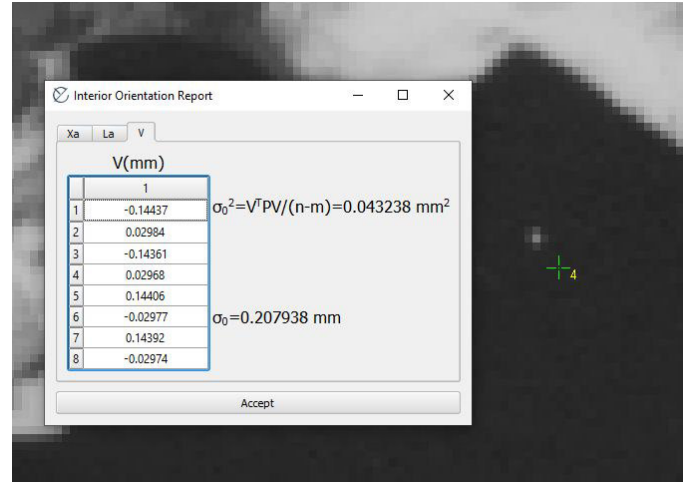


Figure 2. Residuals and standard deviation with gross error in fiducial mark no. 4

In general, it is easier to repeat the measurement and find the fiducial mark responsible for this error. By visual inspection, we can notice that the fiducial mark number 4 was measured incorrectly. After repeating the measurement, we significantly improved the standard deviation ($\sigma_0 = 0.137$ mm) as it is visible in Fig 3.

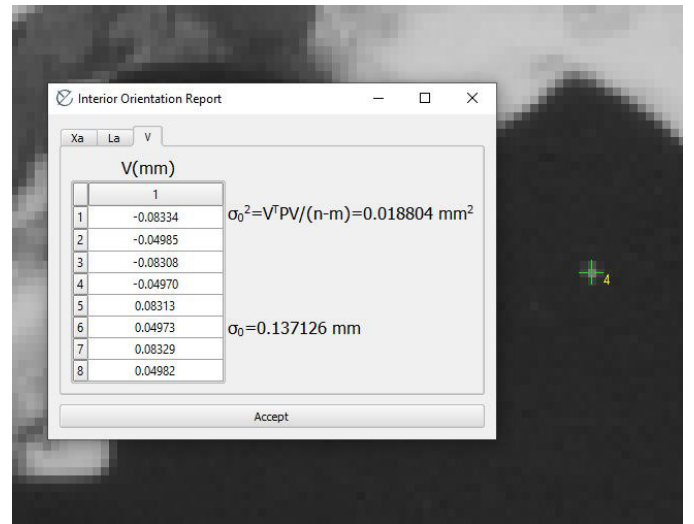


Figure 3. Residuals and standard deviation without a gross error

III. EXTERIOR ORIENTATION

During the exterior orientation, the photo coordinates of tie points and control points can hold small gross errors. In addition, the geodetic coordinates of control points can have gross errors as well.

Methods for detecting small errors can be divided into two major groups:

- mathematical and statistical analysis of the results of the adjustment made by the method of least squares,

- robust estimation designed for processing of measurement results. These estimation methods are significantly less sensitive to gross errors than the least squares method.

In the following, some error filtering methods are briefly described [4].

The Data snooping method starts from the concept of reliability. The reliability reflects the degree of consistency in the measurements, and it expresses the extent of control in the adjustment. This depends on the number of redundant measurements and the geometric arrangement of the measured points. So, reliability puts in our hands a metric value by which we can determine the effectiveness in detection of gross errors.

Reliability can be derived from the $\mathbf{Q}_{vv}$ equal to the covariance matrix of the residuals (4):

$$\mathbf{Q}_{vv} = \mathbf{Q}_{ll} - \mathbf{A} \cdot \mathbf{Q} \cdot \mathbf{A}^T \quad (4)$$

In formula (4), $\mathbf{Q}_{ll}$ denotes the covariance matrix of the measurements, which is equal to the inverse of the weight matrix $\mathbf{P}$. The matrix $\mathbf{Q}$ is $\mathbf{N}^{-1} = (\mathbf{A}^T \cdot \mathbf{P} \cdot \mathbf{A})^{-1}$.

Total redundancy of the equalization (number of redundant measurements) is written in (5) as:

$$r = n - u = \text{trace}(\mathbf{Q}_{vv} \cdot \mathbf{P}) = \sum r_i \quad (5)$$

In formula (5), the r_i values denote the diagonal elements of the $\mathbf{R} = \mathbf{Q}_{vv} \cdot \mathbf{P}$ redundancy matrix as the redundancy of the given l_i measurement relative to the total r redundancy. The value of r_i can vary from 0 to 1. The value of redundancy is a relative number that expresses the extent to which a given measurement contributed $(1 - r_i)$ or did not contribute (r_i) to the determination of the unknowns. A low value of redundancy indicates a weak configuration, making it more difficult to have control, but it is easier to have control at higher values. The $\mathbf{R}$ redundancy matrix can be used to write a relationship between residuals $\mathbf{v}$ and measurements $\mathbf{l}$ (6):

$$\mathbf{v} = -\mathbf{R} \cdot \mathbf{l} \quad (6)$$

Thus, the equation (6) can also be written for the measurement of Δl wearing a gross error (7):

$$\Delta \mathbf{v} = -\mathbf{R} \cdot \Delta \mathbf{l} \quad (7)$$

Equation (7) allows the detection of gross errors because gross errors do not have large residuals when the redundancy value is low. According to Baarda's suggestion, the normalized residual can be used instead of the residual itself (8):

$$w_i = \frac{v_i}{\sigma_{v_i}} \quad (8)$$

The standard deviation of the residuals σ_{v_i} in formula (8) can also be calculated from the covariance matrix of the residuals or the redundancy value (9):

$$\sigma_{v_i} = \sigma_0 \sqrt{(\mathbf{Q}_{ll})_{ii}} = \sigma_{l_i} \sqrt{(\mathbf{Q}_{vv} \cdot \mathbf{P})_{ii}} = \sigma_{l_i} \sqrt{r_i} \quad (9)$$

Based on Equation (9), it can be seen that w_i cannot be interpreted at $r_i = 0$, so error filtering is not possible in that case. Otherwise, gross errors can be detected as follows (10):

$$|w_i| \begin{cases} > k: \text{gross error} \\ \leq k: \text{no gross error} \end{cases} \quad (10)$$

The value of k in condition (10) can vary between 1.96 and 3.29 according to the corresponding statistical tests.

With the Data snooping method, we can only detect one gross error at a time, so the adjustment should be continued iteratively until all gross errors have been filtered out.

Robust estimators can be divided into two major groups:

- L_p -norm estimators, where p denotes the power, and it can be between $1 \leq p \leq \infty$. If $p = 2$, then this corresponds to the least squares method. In the cases $p = 1$ and $p = \infty$, the solution leads to linear programming. In photogrammetric practice, the L_1 and L_2 norms are most relevant.
- The adjustment method of least squares using weight functions that reduce the weights associated with gross errors.

The essence of this weighting-dependent iterative method is as follows:

The adjustment begins with the least squares method in the traditional way. However, in subsequent iterations, the observations receive a new weight (p'_i) according to a specific weight function that includes residuals and other defined parameters. If the weight function is chosen correctly, the weights for gross errors will become smaller and smaller until they reach zero. When the iteration process is complete, the remaining errors will clearly indicate the points having a gross error.

Kruck suggests the following weight function (11), [4]:

$$p'_i = p_i \frac{tg\left(\frac{1-r_m}{c}\right)}{tg\left(\frac{1-r_i}{c}\right)} \quad (11)$$

The c in formula (11) is given empirically, for the redundancy values r_m is the average redundancy, which can be calculated by the following formula (12):

$$r_m = \frac{n-u}{n} \quad (12)$$

The weights become constant as the iterations progress, and a stability is reached, namely when $r_i = r_m$ becomes true.

IV. CONCLUSIONS

As a summary we can say that a fully automatic gross error detection is not possible in every case. The error filtering process is working well only in those cases if the following conditions are fulfilled:

- the number of gross errors is not very high,
- large and medium size gross errors should be eliminated before the adjustment procedure,
- the sample (the number of measurements) is large enough to detect gross errors with statistical methods,
- the allowable random errors follow the normal (Gaussian) random error distribution,
- the geometric configuration of points participating in the adjustment should be favourable.

We can meet some conditions in the above list but not all ones. Therefore, the fully automatic error detection still remains

a task. On the other hand, we can see a very progressive development in this area thanks to the development of more sophisticated solutions for cloud services designed for processing of UAV images. Here the whole process is fully automatized, the user receives only the final products as orthophoto, DSM or DTM model.

REFERENCES

- [1] Jancso T., "Design of Software Modules for Serving DPWs", In: Orosz, Gábor (Ed.) AIS 2018 - 13th International Symposium on Applied Informatics and Related Areas, Székesfehérvár, Hungary, Óbuda University, Alba Regia Technical faculty, pp. 5-10., 2018.
- [2] Wang Z., "Principles of Photogrammetry", Beijing, Press of Wuhan Techn. Univ. of Surveying and Mapping, 1990.
- [3] Kraus K.: Photogrammetry, Geometry from Images and Laser Scans, Walter de Gruyter GmbH & Co. KG, Berlin, 2nd edition, ISBN 978-3-11-019007-6, 2007
- [4] T. Luhmann, S. Robson, S. Kyle and I. Harley: Close Range Photogrammetry, Whittles Publishing, ISBN 978-3-11-030269-1, pp. 97-103., 2014