Investigation of the influence of elements of internal orientation of digital cameras on the accuracy of determination of coordinates of locations

M. Fys, V. Hlotov, *I. Petryshyn (Lviv Polytechnic National University)

SUMMARY

The essence of the work is to investigate the influence of the elements of internal orientation (EoIIO) of digital images obtained with the help of unmanned aerial vehicles (UAV) on the accuracy of determining the coordinates of points on the ground. It is proposed to perform this on the basis of the collinearity condition where the function is constructed, for which the optimal values of EoIIO images are determined. In this case, such a search is performed using values in the set of elements of external orientation (EoXO) and EoIIO, defined using image processing programs as an initial approximation provides further refinement of the coordinates of points on the ground. The algorithm was tested on the corresponding results of aerial photography from UAVs at control points, which made it possible to prove the effectiveness of this technique.

Keywords: elements of internal orientation, digital camera, unmanned aerial vehicle, study of the accuracy of determining the coordinates of the area
Introduction

As you know, the main photogrammetric task is to find the coordinates of points on the ground by measurements on the images. To calculate these coordinates, it is necessary to determine the EofXO and EofIO images. In the published work Hlotov, Fys & Pashchentnyk, 2020 the authors investigated the influence of EofXO on the accuracy of coordinate determination and suggested ways of their possible refinement. It is obvious that EofIO also influence the determination of the coordinates of points on the ground. Before proceeding to the consideration of the proposed algorithm, we will briefly consider current publications on this problem, which will emphasize the urgency of the problem.

In Tagoe & Mantey, 2019, the authors describe the technology of determining the elements of internal orientation by two photogrammetric software products, whose root mean square errors were Photo Modeler 0.2435 and Australis 0.2335. To determine the elements of internal orientation relied on the Brown model, in which mathematical equations consist of two components. It has been proven that the process of calibrating a non-metric camera is important especially for tasks involving measuring the size or depth of an object.

The paper Hamid & Ahmad, 2014 presents a method of calibrating a high-resolution digital camera based on two methods that were performed in in-house and field conditions. Calibration was performed on a 3D test field, for laboratory studies where a plate measuring 0.4 m x 0.4 m with a grid of intersections at different heights was used. For field tests, we chose an area that consisted of 81 points located on a horizontal surface, with a step of 9 m x 9 m. To calibrate the camera in the field used aerial photographs obtained using UAVs. It has been experimentally determined that the best method of camera calibration depends on the type of camera.

In the next publication, the author emphasizes that the process of geometric calibration (Starosotnikov, 2020) plays an indispensable role in determining EVNO, which reduces the errors of mutual installation of photodetectors on the same plane of the electronic board and the errors made by the lens. This problem is solved using the method of mathematical processing of measured data. The technique of geometric calibration of EVNO multi-matrix optoelectronic cameras provides high accuracy of measurements of 0.1 " - 0.2".

During the sequential processing of data obtained from UAV (Hastedt & Luhmann, 2015), the authors emphasize that the factors that affect the camera are of considerable interest. In most cases, digital nonmetric cameras are used in photogrammetry due to their small size for a small cost. One of the disadvantages of such cameras is the lack of stability and long-term reliability of the parameters of the image orientation elements. Most often, software products such as Agisoft, PhotoScan or Pix4D are used to speed up the process of processing the images obtained from the UAV.

Presenting main material

So mathematically, the problem can be formulated as follows: find the minimum function (target) for variables \( \alpha, \omega, \kappa, X_S, Y_S, Z_S, x_0, y_0, f \):

\[
F(\alpha, \omega, \kappa, X_S, Y_S, Z_S, x_0, y_0, f) = \sum_{i=1}^{n} (x_i - x_0 + f \bar{u}_i)^2 + (y_i - y_0 + f \bar{v}_i)^2 \rightarrow \min \tag{1}
\]

Where

\[
\bar{u}_i = \frac{a_1(X_i - X_S) + a_2(Y_i - Y_S) + a_3(Z_i - Z_S)}{c_1(X_i - X_S) + c_2(Y_i - Y_S) + c_3(Z_i - Z_S)} \quad \bar{v}_i = \frac{b_1(X_i - X_S) + b_2(Y_i - Y_S) + b_3(Z_i - Z_S)}{c_1(X_i - X_S) + c_2(Y_i - Y_S) + c_3(Z_i - Z_S)}
\]

The condition for the existence of an extremum is the equality of zero partial derivatives in EofXO.
\[
\frac{\partial F}{\partial X} \cdot \frac{\partial F}{\partial Y} \cdot \frac{\partial F}{\partial Z} \cdot \frac{\partial F}{\partial \alpha} \cdot \frac{\partial F}{\partial \omega} \cdot \frac{\partial F}{\partial \kappa}
\]

which in the expanded formula are given in (Hlotov, Fys & Pashchetnyk, 2020), and derivatives on variables EoFI0 give the following formulas:

\[
x_0 = \frac{1}{n} \left( \sum_{i=1}^{n} x_i + f \tilde{u}_0 \right), \quad y_0 = \frac{1}{n} \left( \sum_{i=1}^{n} y_i + f \tilde{v}_0 \right)
\]

\[
f = \frac{n \sum_{i=1}^{n} (x_i \tilde{u}_i + y_i \tilde{v}_i) - (\sum_{i=1}^{n} x_i) (\sum_{i=1}^{n} \tilde{u}_i) - (\sum_{i=1}^{n} y_i) (\sum_{i=1}^{n} \tilde{v}_i)}{\left(\sum_{i=1}^{n} \tilde{u}_i\right)^2 + \left(\sum_{i=1}^{n} \tilde{v}_i\right)^2 - n \left(\sum_{i=1}^{n} \tilde{u}_i\right)^2 + \left(\sum_{i=1}^{n} \tilde{v}_i\right)^2}
\]

Formulas (2) give the relationship between the elements of EoFO and EoFI0.

However, the question arises differently when using non-professional or semi-professional cameras, which are mainly used on UAVs (Hlotov, Marusazh, & Siejka, 2019). In this case, the passport data of these cameras do not provide or provide approximate values of these values. When applying this technique, it is possible not only to check the correctness of the determination of EVnO cameras after orientation, but also to improve the desired coordinates of the points of the terrain due to the above formulas (4). Undoubtedly, this gives the prospect of optimizing the processes of removal and processing of materials obtained from UAVs. Let us confirm this by the results of experimental work on the example of a landfill with the appropriate number of control points.

Research results

For the real data taken from the article (Pashchetnyk) the parameters of EZO and EVnO are specified. The results of the calculations are given in table 1.

<table>
<thead>
<tr>
<th>( \alpha^\circ )</th>
<th>( \omega^\circ )</th>
<th>( \kappa^\circ )</th>
<th>( X_0 (m) )</th>
<th>( Y_0 (m) )</th>
<th>( Z_0 (m) )</th>
<th>( x_0 (mm) )</th>
<th>( y_0 (mm) )</th>
<th>( F (mm) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>6°29′16,8″</td>
<td>1°25′6,41″</td>
<td>15°17′42,8″</td>
<td>670658.55</td>
<td>5455758.95</td>
<td>782.33</td>
<td>0.864</td>
<td>-0.230</td>
</tr>
<tr>
<td></td>
<td>6°5′21,6″</td>
<td>1°21′49,10″</td>
<td>14°39′30,86″</td>
<td>670653.27</td>
<td>545575.89</td>
<td>785.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P</td>
<td>5°01′42,44°</td>
<td>3°43′11,41″</td>
<td>14°51′43,84″</td>
<td>670681.35</td>
<td>5455765.20</td>
<td>791.94</td>
<td>0.259</td>
<td>-1.5e-7</td>
</tr>
</tbody>
</table>

According to the elements of EoFO and EoFI0 on the coordinates on the left and right pictures, you can set the values of coordinates on the ground by the following formulas:

\[
X_A = X_{S_L} + (z_A - z_{S_L}) \bar{x}_{A_l}, \quad Y_A = Y_{S_L} + (z_A - z_{S_L}) \bar{y}_{A_l}
\]

\[
X_A = X_{S_P} + (z_A - z_{S_P}) \bar{x}_{A_p}, \quad Y_A = Y_{S_P} + (z_A - z_{S_P}) \bar{y}_{A_p}
\]

(3)

where \( \bar{x}_{A_l}, \bar{x}_{A_p}, \bar{y}_{A_l}, \bar{y}_{A_p} \) - calculated coordinates of the point on the left and right images.

This raises the question of determining the coordinates of the left and right images. Because three are unknown, and four equations. As the calculations show, the values of the coordinates differ significantly for different combinations of selected systems. Therefore, it is logical to solve the system of linear equations using the least squares method. To do this, we write equation (3) in matrix form \( Ax = b \).
where

\[
A = \begin{bmatrix}
1 & 0 & -\bar{x}_{Al} \\
0 & 0 & -\bar{x}_{Ap} \\
0 & 1 & -\bar{y}_{Al} \\
0 & 1 & -\bar{y}_{Ap}
\end{bmatrix},
\quad
b = \begin{bmatrix}
X_{SL} - Z_{SL} \\
X_{Sp} - Z_{Sp} \\
Y_{SL} - Z_{SL} \\
Y_{Sp} - Z_{Sp}
\end{bmatrix},
\quad
X = \begin{bmatrix}
X_A \\
Y_A \\
Z_A
\end{bmatrix},
\]

Then the solution of the system is given as follows:

\[
X = A^{-1}A^Tb
\]

(5)

According to the given algorithm for the reference point №2, the data for which are taken from (Pash) calculations are performed and given in table 2.

<table>
<thead>
<tr>
<th>Coordinates</th>
<th>Measured by GPS</th>
<th>Matrix method</th>
<th>by X</th>
<th>by Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (m)</td>
<td>670755.53</td>
<td>670755.62</td>
<td>670755.58</td>
<td>670755.50</td>
</tr>
<tr>
<td>Y (m)</td>
<td>5455710.54</td>
<td>5455719.51</td>
<td>5455710.49</td>
<td>5455710.49</td>
</tr>
<tr>
<td>Z(m)</td>
<td>581.13</td>
<td>580.92</td>
<td>581.004</td>
<td>577.03</td>
</tr>
</tbody>
</table>

For reference points with (Hlotov, Fys & Pashchetyk, 2020) performed "reverse" and the value of the root mean square error of the difference between the calculated and specified coordinates by the formula and the results are presented in table.

\[
m_G = \sqrt{\frac{1}{3n} \sum_{i=1}^{n} \left( (X_i^o - X_i^v)^2 + (Y_i^o - Y_i^v)^2 + (Z_i^o - Z_i^v)^2 \right) ^2}
\]

Table 3 The root mean square error of the calculated coordinates on the ground

<table>
<thead>
<tr>
<th>According to input data (m)</th>
<th>Refined parameters EofZO (m)</th>
<th>Taking into account EofZO and EofIO (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mG</td>
<td>3.535</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.304</td>
</tr>
</tbody>
</table>

Joining EofIO, as can be seen from table. 3 gives a reduction of the root mean square error by 30%. Therefore, the inclusion of EofIO in the processing of photogrammetric data is simply mandatory when processing images obtained from non-metric cameras during topographic shooting from UAV. The correctness of this approach will be confirmed by a numerical experiment, based on data from the work (Such dos) EofZO and EofIO, perform their refinement in order to increase the accuracy of determining the coordinates on the ground. For compactness of record, we will display various options accordingly from I to VII. The results are presented in table 4.

<table>
<thead>
<tr>
<th>EofIO</th>
<th>Accepted (set)</th>
<th>Updated for EofZO</th>
<th>Updated for EofZO and EofIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
</tr>
<tr>
<td>x_o(mm)</td>
<td>-0.534</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>x_o(mm)</td>
<td>-0.435</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>f(mm)</td>
<td>35.236</td>
<td>35</td>
<td>35.236</td>
</tr>
</tbody>
</table>

According to the reference points and coordinates on the ground, the parameters of EZO and EVnO are defined in the Digital software package and the proposed method. for options I-VII (see table. 4).

In table. 5 presents the mean square errors of the differences between the determined and measured coordinates in the field.
Table 5 Mean square errors of the differences between the determined and measured coordinates on the ground

<table>
<thead>
<tr>
<th>Rmse (m)</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_X$</td>
<td>4.964</td>
<td>0.475</td>
<td>0.346</td>
<td>0.33</td>
<td>0.402</td>
<td>0.402</td>
<td>0.351</td>
</tr>
<tr>
<td>$m_Y$</td>
<td>4.753</td>
<td>1.89</td>
<td>1.915</td>
<td>0.244</td>
<td>0.224</td>
<td>0.24</td>
<td>0.23</td>
</tr>
<tr>
<td>$m_Z$</td>
<td>1.821</td>
<td>2.687</td>
<td>1.166</td>
<td>0.282</td>
<td>0.377</td>
<td>0.382</td>
<td>0.245</td>
</tr>
</tbody>
</table>

The reason for such a significant discrepancy in our opinion is precisely the confirmation regarding the disregard of EVnO, because these parameters, calculated by formulas (2), differ significantly from the values obtained during the orientation. An example is the values given in table. 6.

Table 5 Calculated by formulas (2) elements of EofilO

<table>
<thead>
<tr>
<th>image</th>
<th>$x_0$(mm)</th>
<th>$y_0$(mm)</th>
<th>$f$(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>left (set values)</td>
<td>-0.002</td>
<td>0.003</td>
<td>35.181</td>
</tr>
<tr>
<td>left (after specifying EofZO and EofilO)</td>
<td>0.026</td>
<td>-0.375</td>
<td>35.146</td>
</tr>
<tr>
<td>right (set values)</td>
<td>-0.015</td>
<td>-0.021</td>
<td>35.242</td>
</tr>
<tr>
<td>right (after specifying EofZO and EofilO)</td>
<td>0.129</td>
<td>0.069</td>
<td>35.241</td>
</tr>
</tbody>
</table>

Conclusions

1. EVNO for each image as it turned out as a result of processing materials are different and dramatically affect the accuracy of calculating the coordinates of points on the ground.

2. Only by taking into account EofZO and EofilO can optimal accuracy be achieved.

3. The EofZO and EofilO communication formulas (2) can be a criterion for the correct calibration of photogrammetric cameras.

References


