The Change in the Altitude of an Unmanned Aerial Vehicle, Depending on the Height Difference of the Area Taken

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Abstract. Along with the development of unmanned aerial vehicles (UAVs), popularization of digital cameras and other progress in photogrammetric technologies, images obtained from different heights of flight are of great interest to scientists. One of the main advantages of UAVs when changing altitude is that they can receive images with a very high resolution of the earth. High resolution images have great potential in many situations, such as large-scale mapping, archeology, 3D modeling of cities, quarries in mining. Limiting the continuity of the terrain, which is used by most traditional matching algorithms, is unacceptable, and most traditional photogrammetric programs cannot cope with the images obtained by the UAV at different altitudes. In this paper, we propose a new approach to change the altitude of the UAV depending on the terrain, as well as determine the dependence of the accuracy of shooting from the altitude.

1. Introduction
Currently UAVs are widely used for large-scale geodetic works and mapping. Compared with manned aircraft UAVs are more economical and responsive. The altitude of the UAV is relatively low, and the terrain can lead to serious deviations. In addition, observations obtained by the positioning and orientation system (POS) are usually less accurate than observations obtained in the manned aerogram. All these factors lead to errors in photogrammetry UAVs. A three-dimensional modeling and visualization system [4-7] was developed to investigate these errors. The system is demonstrated with an assessment of the flight plan, image alignment, direct binding with POS support and orthomosaic.

In article [1-3] the approach which shows that the corresponding points between images at first are defined is offered, and then transformed to coordinates for realization of stitching of images.

In works [8-11] prospects of application of Autonomous navigation for UAVs are described. On the basis of effective, reliable and accurate comparison of plots the use of the altimeter and the method of three-dimensional position estimation is proposed.

In papers [12-14] presented a fully automated and accurate mapping solutions based on the UAV images. Several datasets are analyzed and their accuracy evaluated.

In works [15-18] the new effective algorithm for change of flight of UAVs in real time is presented.

In the works [19-20] on the basis of evolutionary calculations presented a new route planner in real time for unmanned aerial vehicles.

In works [21-22] the automated method of detection of the district and mapping at change of height of flight of UAV is offered.
2. Structure of motion (SFM) or relative orientation at different flight altitudes

Algorithms of the structure from motion (SFM) to the present moment provide a complete solution of the problem of photogrammetry from different altitude of flight according to the sequence of frames and the position of all objects of interest, camera trajectory and internal calibration parameters. The relative position is represented by the fundamental matrix F. The properties of F are as follows:

- F is a 3 × 3 matrix.
- F has seven degrees of freedom.

\[
P = K[R/t] \text{ where } K = \begin{pmatrix} F_x & s & x_0 \\ 0 & F_y & y_0 \\ 0 & 0 & 1 \end{pmatrix}.
\] (1)

R – rotation matrix, t – translation vector; \(F_x\) and \(F_y\) – focal length of the camera, expressed in the number of pixels, provided that each pixel has a different size in the x and y directions (usually the pixel has the same size in x and y); \(s = \tan(a)\).

\(\cdot\) \(F_x; x_0\) and \(y_0\) – the main point, expressed in units of pixels.

Since a photogrammetric project involves multiple camera positions, SFM is achieved by processing several images and calculating their matrix F.

The first step in determining SFM is to identify key points that could be identified in several images as conjugate or homologous points (the same point appears on different images). Algorithms that solve this problem are called SIFT algorithms.

Once the points are the same, then the matrix F must be calculated. If the number of points exceeds a given threshold, the matrix F is calculated again using a different set of matching points. Taking into account that \(x_i = (x, y)\) and \(x_0 = (x_0, y_0)\) are two homologous points corresponding to two different images, the equation will look like:

\[
(x_i')^T F x_i = 0
\] (2)

We need homologous points in which we normalize the scaling until the center of gravity at the origin of the transformation of the matrices has the following form: \(X = T_{x_i}; x_0 = T_0\)

\[
\hat{A} = Af = \begin{bmatrix} x'_1 & y'_1 & \hat{x}_1 & \hat{y}_1 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x'_8 & y'_8 & \hat{x}_8 & \hat{y}_8 & 1 \end{bmatrix}
\] (3)

where \(f\) is the matrix F in the column vector \(f = (f_{13}, f_{21}, f_{22}, f_{23}, f_{31}, f_{32}, f_{33})\).

\[
F = T^T \hat{F}'
\] (4)

After you have achieved the desired result, please do not delete. The optimization problem is solved by means of point corrections. Photogrammetric software Agisoft calculates the distortion parameters (radial and decentralized). The equations determining the distortion parameters are expressed in the following form:

\[
\Delta x = \Delta x_r + \Delta x_d \\
\Delta y = \Delta y_r + \Delta y_d
\] (5)

Where

\[
\Delta x_r = (x - x_0)(K_1 r^2 + K_2 r^4 + K_3 r^6 + \cdots) \\
\Delta y_r = (y - y_0)(K_1 r^2 + K_2 r^4 + K_3 r^6 + \cdots)
\]

\[
\Delta x_d = [P_1 r^2 + 2(x - x_0)^2] + P_2 (x - x_0)(y - y_0) \\
\Delta y_d = [2P_1 (x - x_0)(y - y_0) + P_2 r^2 + 2(y - y_0)^2]
\] (6)
are the coefficients of radial distortion, \( p_1 \) and \( p_2 \) are adhesion coefficients.

3. The technique of changes in the flight height of a UAV depending on the terrain

UAV. When comparing several functions, our method can provide a definition of the three-dimensional position:

\[
\begin{align*}
\bar{x}_i - C_x &= \frac{a_1 (X_i - X_c) + b_2 (Y_i - Y_c) + c_3 (Z_i - Z_c)}{F_x} \\
\bar{y}_i - C_y &= \frac{a_2 (X_i - X_c) + b_2 (Y_i - Y_c) + c_3 (Z_i - Z_c)}{F_y}
\end{align*}
\]

(7)

\( F_x, F_y \) - focal length of the camera; \( C_x, C_y \) - coordinates of the main point; \( (X_c, Y_c, Z_c) \) and \( (X_i, Y_i, Z_i) \) are the three-dimensional coordinates of the optical center and one of the main parameters in the global coordinate system; \( R \) is the rotation matrix between camera coordinates and global coordinates.

\[
R = \begin{bmatrix}
a_1 & b_1 & c_1 \\
a_2 & b_2 & c_2 \\
a_3 & b_3 & c_3
\end{bmatrix}
\]

(8)

In equation (6) \( F_x, F_y, C_x, C_y \) can be measured by calibration, and \( R \) can be calculated with respect to the camera. The coordinates of the image are:

\[
Z^i_H = Z_c - Z_i
\]

(9)

\( Z^i_H \) - relative height between the optical center and the point \( i \). Replacing (8) by equation (7), we obtain the following equations.

\[
\begin{align*}
s_1^i X_c + s_2^i Y_c + s_3^i Z^i_H &= s_1^i X_i + s_2^i Y_i \\
s_1^i X_c + s_2^i Y_c + s_3^i Z^i_H &= s_1^i X_i + s_2^i Y_i
\end{align*}
\]

(10)

Since the unknown quantity is \( 2 + n \), at least 2 points must be specified. The solution of linear equations with each height \( Z^i_H \) is found.

In consequence of this, the UAV can autonomously change its altitude of flight depending on the relief (Figure 1). Each new height is given by the formula:

\[
H = \frac{1}{n} \sum_{i=1}^{n} Z^i_H
\]

(11)
4. The dependence of the accuracy of shooting from the height of the flight
Low altitude of flight leads to a very high spatial resolution of aerial photographs. Depending on the focal length between the pixel centers measured on the surface (GSD), the accuracy is usually 1 to 5 cm. This high resolution is used to automatically generate homologous tie points, which are a prerequisite for image alignment.

To determine the accuracy at a height Z, a stereophotogrammetric method is used. Thus, the accuracy of the survey from the height \( \sigma_Z \) is obtained from the dispersion of the dispersion and has the form:

\[
\sigma_Z = \frac{Z^2}{c} \sigma_{px} = m_b \sigma_{px}
\]

where \( c \) - focal length; \( m_b \) - image scale; \( \sigma_{px} \) - parallax accuracy.

\( \sigma_{px} \) depends on the pixel size and the ability of the operator to recognize the same function on images with different flight heights.

5. Conclusion
Aerial photographs taken at different altitudes with unmanned aerial vehicles have several advantages, such as multiple capture angles and very high surface resolution, which increases the accuracy of the survey. A new technique was developed to change the flight height of the UAV in order to increase the efficiency of the photogrammetric process. The structure of the motion (SfM) at different flight heights determines the key points that could be identified in several images. To compare conjugate points, the SIFT algorithm is used. The problem of image optimization with the aid of point correction in Agisoft photogrammetric software is solved, where distortion parameters are calculated. An estimation of the three-dimensional position in space is given, as a result of which the UAV can autonomously change its flight altitude depending on the relief. The dependence of the shooting accuracy on the flight altitude is calculated. To determine the accuracy, a stereophotogrammetric
method is used, which is based on dispersion propagation. Experimental results show that the proposed methods are effective for processing images taken at different heights.

6. References

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