# AUTOMATIC IMAGE ORIENTATION BY USING GIS DATA

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**KEY WORDS:** Sensor, Orientation, Database, GIS

## ABSTRACT

This article addresses a methodology and the experience gained on automatic exterior image orientation by using current information existing in GIS database. The proposed approach automatically extracts and matches feature points in evenly distributed patches on aerial and ortho images. The elevation of successfully matched points on the aerial image will then be obtained through interpolation calculation on the DTM data in the database. Robust bundle adjustment with great redundancy is therefore conducted to estimate the exterior orientation parameters. An innovative algorithm is proposed for mono-image intersection by using thus obtained exterior orientation parameters and current DTM data. The proposed approach is evaluated based on manually measured a great number of check points. Tests and analyses showed that for the ground points obtained through mono-image intersection, the planimetric accuracy is better than 1pixel, which fulfills the requirement of orthoimage production for database updating purpose. The elevation accuracy is solely dependent on the current DTM and its interpolation applied on it, which reaches 0.003% flying height in this relative flat test area.

## 1 INTRODUCTION

Research from national and private organization shows that orthoimage is becoming an indispensable component in GIS (Geographic Information System) and its updating cycle is shortening to 5- 4 years or less [3,5]. Therefore, efficient method is expected, which can best utilize existing database information, such as orthoimage and DTM (Digital Terrain Model) to update current database. Exterior image orientation is the first step in this process.

One of the main concerns in an automatic process is its accuracy [2]. In order to reach high accuracy, an automatic approach is proposed in this article, which extracts and matches feature points from evenly distributed patches on the aerial and ortho images. In this way, thousands of image points are obtained for the subsequent bundle adjustment, where robust estimation is therefore introduced to further detect and eliminate mismatched points to ensure the quality of space resection for the determination of image exterior orientation. Evaluation on the proposed approach is performed on coordinates of ground points determined by using a novel mono-image intersection algorithm. In this way it provides a direct accuracy estimation for the updated orthoimage.

The remainder of this article consists of three sections. Section 2 describes the methodology of the proposed approach for automatic orientation calculation. In order to evaluate the accuracy of image orientation and its influence on ortho-rectification for orthoimage production in GIS database updating, an innovative and accurate algorithm for conducting mono-image intersection by using DTM is proposed in this section as well. By using the test data provided by OEEPE, Section 3 presents the test results for feature extraction, correspondence, and matching; orientation parameters and their precision estimation. Evaluation on the efficiency and quality of the proposed approach is conducted in Section 4, where coordinates of ground points determined from mono-image intersection based on manual and automatic measurements are compared and analyzed. The article is summarized in Section 5 with concluding remarks.

## 2 METHODOLOGY

The proposed approach is based on image matching between aerial image and its corresponding orthoimage in GIS database. Successful matching with orthoimage will provide the image points on the aerial image with their planimetric ground location. Their elevations can then be obtained by subsequent DTM interpolation operations. Space resection is therefore conducted by including all successfully matched image points and their three-dimensional coordinates in a

robust bundle adjustment. The approach intends to reach an optimal solution for automatic exterior image orientation regarding to precision, reliability and efficiency.

The proposed approach starts with selecting a number of image patches in several standard locations of the aerial image. In order to ensure high reliability in the automatic process, each patch contains at least 512*512 pixels; and minimum 3*3 evenly distributed patches are selected (Fig.1). Corresponding patches in the orthoimage are obtained based on *a priori* initial exterior orientation parameters or by manual selection. In this way, the search space and amount of computation are greatly reduced in subsequent processing. Corresponding patches on aerial and orthoimage will be conducted with feature points extraction, feature correspondence, feature matching and precision matching.
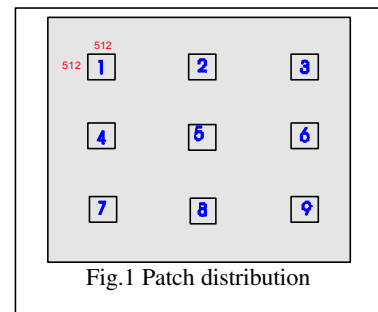


Fig.1 Patch distribution

Fig.2 illustrates the workflow of the proposed approach. As is shown, feature extraction is respectively conducted on theses selected aerial image patches and on the corresponding orthoimage patches. Moravec operator and Förstner operator [4] are used to extract point features. The number of extracted feature points in each patch can reach upto a few thousands. Such a great amount of observations will substantially ensure the quality of subsequent image matching and orientation computation.

Next, feature correspondence is performed among the extracted feature points by cross correlation within a bounded search window in the corresponding aerial image and orthoimage patches. In order to avoid false matching, local topologic and geometric constraints are introduced in the feature correspondence step. Experience shows that these constraints are necessary for obtaining reliable correspondence results. Once the feature correspondence is established, cross correlation and least squares matching [1] are applied to further refine the result. Usually, a large amount of feature points (1000-2000) can be selected for the final bundle adjustment (see Tab.1 in next section.).



Fig.2 Flowchart of image orientation with orthoimage and DTM
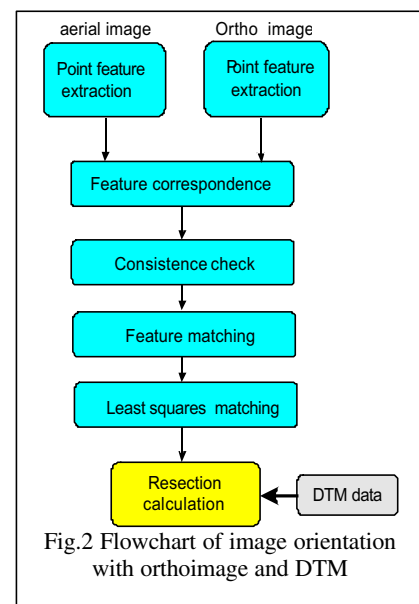
Exterior orientation parameters are calculated by bundle adjustment with successfully matched feature points in preceding steps. Since large amount of matched points are involved in the calculation, robust estimation is therefore introduced in this step to detect and eliminate remaining false matches so that the quality of this automatic orientation procedure can be further ensured. The covariance matrix of exterior orientation parameters indicates the ideal accuracy of space resection. Comparing the result of automatic orientation with the one obtained from sufficient manual measurements does a further evaluation of the proposed approach.

Upon obtaining the exterior orientation parameters, the 3-D location of an image point can be determined by using the existing DTM data. This is one of the fundamental issues in ortho rectification and database base revision based on image features. For this purpose, an integrated algorithm for point determination by using mono-image as well as DTM data is developed and evaluated. A brief derivation of this algorithm is shown below.

The well known collinear equation is written as

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = l\mathbf{R}\begin{pmatrix} x \\ y \\ -f \end{pmatrix} + \begin{pmatrix} Xc \\ Yc \\ Zc \end{pmatrix} \tag{1}$$

where (X,Y,Z) and (Xc,Yc,Zc) are coordinates of a ground point and the camera center respectively, (*x,y*) are image coordinates of the corresponding ground point, *f* is the principal length of the camera, **R** is the 3x3 orthogonal rotational matrix whose elements are determined by orientation angles of the aerial image, l is the scale factor related to that image point.

On the other hand, the given DTM can be expressed in general as

$$Z = F(X, Y) \tag{2}$$

where $F$ denotes the elevation interpolation function, which is chosen as bilinear form through out the computation in this article.

Linearizing above two equations will yield following observation equations

$$
\begin{aligned}
\bar{z}dX + \quad & \quad - \bar{x}dZ & = \bar{z}(Xc - X) - \bar{x}(Zc - Z) \\
\bar{z}dY \quad & - \bar{y}dZ & = \bar{z}(Yc - Y) - \bar{y}(Zc - Z) \\
\frac{\P F}{\P X}dX + \quad \frac{\P F}{\P Y}dY \quad & - dZ & = Z - F(X, Y)
\end{aligned}
\tag{3}
$$

where

$$
\begin{pmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{pmatrix} = \mathbf{R} \begin{pmatrix} x \\ y \\ -f \end{pmatrix}
\tag{4}
$$

Given the DTM as expressed in general in Eq.(2), for each image point, its 3-D ground coordinates can be calculated with Eq.(3). The calculation is iterative. Initially, the $Z$ coordinate of that image point is given as the average elevation of the area, while in the subsequent iterations it is determined with Eq.(2) with approximate $(X,Y)$ coordinates. The iteration stops when the coordinate corrections $dX$, $dY$ and $dZ$ are smaller than the given tolerances. Comparing thus obtained ground coordinates with their known coordinates provides an independent evaluation on the exterior image orientation.

The entire approach is implemented with Java as a stand-alone program, therefore software developed for this article is platform independent and can be easily implemented in the Internet environment.

## 3   TEST RESULTS AND ANALYSES

### 3.1   Feature extraction and matching

Tab.1 lists the number of image points obtained in automatic feature extraction and image matching steps. As is shown, each patch has average more than one thousand point features extracted. In total, more than ten thousands of feature points are extracted in the nine patches from aerial image and orthoimage respectively (denoted as a-image and o-image in the table, respectively). Through feature correspondence step, about one tenth of the feature points are left for the final orientation calculation.

Tab.1 Amount of feature points,correspondence points and matched points

| Patch No. | Feature extraction | | Correspondence & matching | |
|:---:|:---:|:---:|:---:|:---:|
| | a-image | o-image | correspondence | LSM matching |
| 1 | 957 | 1037 | 340 | 206 |
| 2 | 1039 | 1237 | 285 | 195 |
| 3 | 1072 | 2287 | 360 | 240 |
| 4 | 1992 | 1542 | 506 | 320 |
| 5 | 1335 | 1468 | 502 | 312 |
| 6 | 3749 | 4022 | 218 | 156 |
| 7 | 1252 | 1460 | 260 | 160 |
| 8 | 966 | 2043 | 157 | 95 |
| 9 | 924 | 1093 | 223 | 155 |
| Total | 13286 | 16189 | 2851 | 1840 |

## 3.2 Orientation parameters

Exterior orientation parameters are determined by bundle adjustment with robust estimation. Different thresholds are tested to eliminate blunders remained from the previous automatic feature extraction and image matching step. As is shown in Tab.2, different thresholds have only minor affection on the final orientation parameters, however, the orientation angles show small instability relative to various thresholds.

Tab.2 Exterior orientation elements

| Blunder threshold | Orientation (in deg.) | | | Position (in m) | | |
|---|---|---|---|---|---|---|
| | $\varphi$ | $\omega$ | $\kappa$ | $Xc$ | $Yc$ | $Zc$ |
| 1.8 $\sigma 0$ | -1.29535 | -0.10104 | -88.39527 | 46.482 | 605.524 | 4202.176 |
| 1.9 $\sigma 0$ | -1.29975 | -0.09158 | -88.39479 | 46.787 | 604.746 | 4202.268 |
| 2.0 $\sigma 0$ | -1.29859 | -0.08755 | -88.39251 | 46.691 | 604.342 | 4202.119 |

Tab.3 gives the estimated standard deviation for orientation parameters obtained from the covariance matrix in bundle adjustment. Comparing to the image scale of 1:27,000, the planimetric precision of the camera center is within 10 μm or 1/3 pixel, while the precision of $Zc$ is approximately 0.002% flying height (4100m). Multiplying the standard deviations for $\varphi$ and $\omega$ with flying height indicates that they are compatible with the precision of camera positions. Such a high precision is only made possible by the high redundancy in space resection and its good geometry of wide-angle photography. The standard deviation $s_0$ for image coordinates reflects the precision of feature extraction, image matching and other errors caused by image scanning, camera calibration and DTM interpolation etc. This value varies slightly with different blunder thresholds in bundle adjustment.

Tab.3 Precision of orientation parameters estimated by covariance matrix

| $s_0$=31.9μm | $\varphi$ | $\omega$ | $\kappa$ | $Xc$ | $Yc$ | $Zc$ |
|---|---|---|---|---|---|---|
| s(deg., m) | 0.00325 | 0.00253 | 0.00110 | 0.264 | 0.230 | 0.091 |

## 3.3 Ground points

Ground coordinates for 25 check points, which are chosen by the test organizer, are obtained with the mono-image intersection method described in last section. The test organizer will use them as an external check.

## 4 EVALUATION

In order to evaluate the accuracy of the proposed approach, 97 evenly distributed conjugate points are manually measured on the aerial image and orthoimage. The image coordinates on the orthoimage are scaled and translated to get the planimetric coordinates on the ground. Elevations for those ground points are then obtained through DTM interpolation. The derived 3-D ground coordinates will be used as either control points or check points to evaluate the proposed approach.

The evaluation is first done on the designated 25 image points, whose coordinates on the aerial image are provided by the test organizer. In this case, the manual measurements are used as control points to estimate exterior orientation parameters. Mono-image intersection described in Section 2 is thereafter conducted to calculate the ground coordinates of those chosen points. Comparing thus obtained ground coordinates with the ones obtained from automatic image matching does the evaluation. Tab.4 shows their root mean square errors (RMSE), which reflect the influence of different exterior orientation parameters on ground coordinates.

A first analysis on Tab.4 reveals that the proposed automatic approach virtually obtains the same elevation as the manual measurements do. This shows that the elevation accuracy for ground point is mainly dependent on DTM interpolation rather than space resection. The difference on planimetric coordinates is at the order of 1 pixel, even when large percentage of matched points is screened out in space resection. Since the manual measurement is performed on the screen in mono mode, space resection done with those measurements will be no better than the one from automatic matching. Thus, as a conservative estimation, when the two resection methods have the same affection on the RMSE in Tab.4, the variance of planimetric coordinates of ground points in automatic matching is 0.57m (0.7 pixel).

Tab.4 RMSE at the given 25 points

| Blunder threshold | No. of points | Root mean square errors (RMSE, m) | | |
|---|---|---|---|---|
| in resection | For resection | X | Y | Z |
| 1.8 $\sigma_0$ | 85 | 0.878 | 0.938 | 0.0667 |
| 1.9$\sigma_0$ | 262 | 0.732 | 0.833 | 0.0381 |
| 2.0$\sigma_0$ | 454 | 0.735 | 0.7035 | 0.0594 |

Tab.5 RMSE at manually measured points

| Blunder threshold | No. of points | Root mean square errors (RMSE,m) | | | No. points for |
|---|---|---|---|---|---|
| in resection | For resection | X | Y | Z | Statistics |
| 1.8 $\sigma$0 | 85 | 1.138 | 1.177 | 0.170 | 61 |
| 1.9 $\sigma$0 | 262 | 1.071 | 1.158 | 0.231 | 60 |
| 2.0$\sigma$0 | 454 | 1.028 | 1.076 | 0.196 | 58 |

Another evaluation is done by using the manual measurements as check points. After exterior orientation parameters are obtained through automatic image matching, mono-image intersection is performed for all check points to calculate their ground coordinates, which are then compared with the ones derived from measurements on the orthoimage. The RMSE is listed in Tab.5. Since the measurement is done manually on the screen in mono mode, its precision is expected no better than 1 pixel and several blunders have been detected and deleted. Considering this fact, the RMSE for planimetric coordinates listed in Tab.5 actually has two components, errors caused by space resection and by measurement errors on check points, namely

$$(RMSE)^2{}_{X,Y} \quad = \quad s^2{}_{re\sec tion} + s^2{}_{check\,po\mathrm{int}s} \tag{5}$$

Taking the average of all $(RMSE)^2{}_{X,Y}$ for X and Y in Tab.5 and counting $s_{check\ points}$ as 0.8m (1 pixel), the actual affection of space resection on planimetric coordinates on the ground is then estimated as $\sigma$resection = (1.23 – 0.82) = 0.77m (< 1 pixel). It should be noted that this value is also an accuracy estimation for the new updated orthoimage. As the elevation of ground points is virtually determined via DTM interpolation, its accuracy (RMSE)$_Z$ is solely dependent on terrain slope and the planimetric accuracy, namely

$$(RMSE)_Z \quad = \quad \sqrt{(F_X{}^2 + F_Y{}^2)} \; (RMSE)_{X,Y} \tag{6}$$

where $F_X$ and $F_Y$ are terrain slopes at $X$ and $Y$ directions respectively. For flat area as covered by this test image, the slope angle is less than 5 degree, therefore the elevation accuracy is estimated better than $1.414*tan5 *\sqrt{1.23} =$ 0.14m or 0.003% flying height.

## 5    CONCLUDING REMARKS

An approach for automatic exterior image orientation is proposed based on DTM and orthoimage in current GIS database. The approach uses automatic feature extraction and matching within image patches in aerial image and orthoimage. Large amount of feature points (ca.2000) is included in the bundle adjustment, which may reach a precision of 1/3 pixel for orientation parameters due to the large redundancy. To evaluate the quality of this approach, a novel mono-image intersection algorithm is developed. Analyses and comparison based on results from manual measurements indicate that the accuracy of planimetric coordinates of ground points, determined by mono-image intersection, is better than 1 pixel. This is also the accuracy estimation for the new updated orthoimage. The accuracy of elevation is solely dependent on DTM interpolation. Further research will be focused on linear features detection and using them along with point features in GIS to automate the exterior orientation and orthoimage update procedure.

## ACKNOWLEDGEMENTS

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