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Registration of Aerial Image with Lines using RANSAC Algorithm

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Abstract

Registration between image and object space is a fundamental step in photogrammetry and computer vision. Along with rapid development of sensors - multi/hyper spectral sensor, laser scanning sensor, radar sensor etc., the needs for registration between different sensors are ever increasing. There are two important considerations on different sensor registration. They are sensor invariant feature extraction and correspondence between them. Since point to point correspondence does not exist in image and laser scanning data, it is necessary to have higher entities for extraction and correspondence. This leads to modify first, existing mathematical and geometrical model which was suitable for point measurement to line measurements, second, matching scheme. In this research, linear feature is selected for sensor invariant features and matching entity. Linear features are incorporated into mathematical equation in the form of extended collinearity equation for registration problem known as photo resection which calculates exterior orientation parameters. The other emphasis is on the scheme of finding matched entities in the aide of RANSAC (RANdom SAmple Consensus) in the absence of correspondences. To relieve computational load which is a common problem in sampling theorem, deterministic sampling technique and selecting 4 line features from 4 sectors are applied.

Keywords : Registration, RANSAC, Aerial image, Lidar, Linear feature

1. Introduction

Registration between image and object space which is exterior orientation in photogrammetric terms is well established in terms of collinearity equation which describes the relationship of image coordinates and object coordinate system. Traditional approach needs 2D photo point from photos and 3D point in object space which is suitable for point measurements. Recent line/feature-based photogrammetry extends the concept of using point measurements to higher level entities, for example straight lines, curves, and free-form curves, to strengthen geometry and improve availability of features for extraction. The fullest use of line in aerial triangulation in terms of definition of lines, mathematical model and adjustment model, can be referred to Schenk (2004). Habib and Kelley (2001) modified hough-transformation to solve single photo resection with lines. The concept of higher order parametric representation was proposed by Zalmason (2000). When it comes to image data and laser scanning data, conventional point to point mathematical model does not provides correspondence between data sets and need for adapting linear feature scheme is essential for registration. Moreover, the linear feature approach can be appreciated when existing data, for example, GIS database, map and existing 3D model, are available as control information.

In this study, conventional collinearity equation is extended to adapt lines as observations in mathematical model to solve exterior orientation parameters of single photo. RANSAC (RANdom SAmple Consensus) algorithm, known as an outlier-insensitive parameter estimating technique from randomly selected samples is accommodated to relieve 1) corresponding lines in image and object space, and 2) approximation of parameters. Line extraction scheme from laser scanning data is introduced,

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when points on the wall are available, by accumulating cell and two plane intersections, provided manual approximation of line. Sample test will be presented with line incorporated model and RANSAC.

2. Photo Resection with Lines

Point-based single photo resection is a well-established straightforward process, however when it comes to identification and measurement of point in image space and object space (Ground Control Points), it is difficult to extract and match them. Many researches are intensively investigating on feature-based photogrammetry which uses feature as a measurement and observation instead of using point only and claim its geometric strength and easiness of extraction. Especially, registration between different sensors can have fullest benefit from feature-based photogrammetry, because it is much easier to extract sensor invariant feature than sensor invariant point.

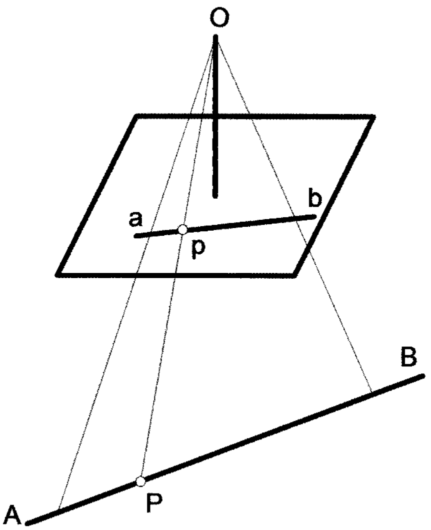


Fig. 1. Linear feature incorporated configuration

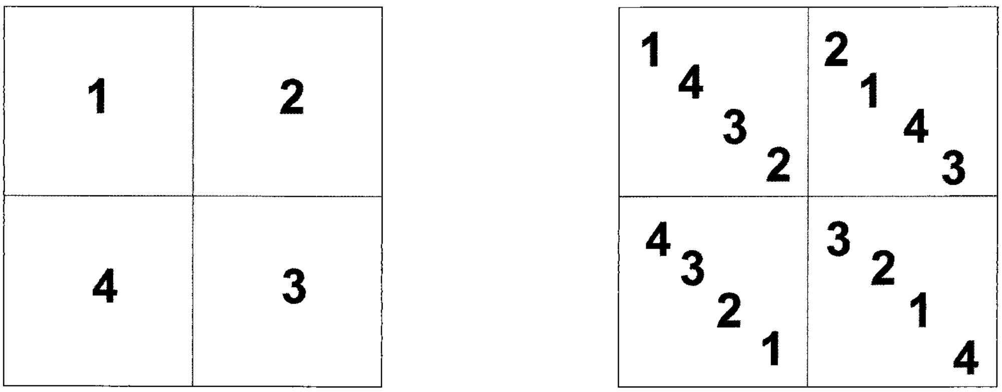
Figure 1 shows the basic concept of linear feature incorporating configuration. Let $\overline{ab}$ be linear feature in image space and $\overline{AB}$ be linear feature in object space. The conditions that we can use are 1) any point (p) in line $\overline{ab}$ is on line $\overline{AB}$ - prior information of linearity in object space. 2) any point in line $\overline{AB}$ is on line $\overline{ab}$ - prior information of linearity in image space.

In case of existing linearity condition on both image and object space, it is easy to do all calculation in image space. Let line feature in image space $\overline{ab}$ - line connecting point 'a' and 'b' in figure 2 and $n_X \cdot x + n_Y \cdot y + \rho = 0$ be 2 dimensional line in image space. Any point from ground line is back-projected to image space be x_{ao} and y_{ao}. Then the distance between line and point can be calculated and written as follow.

$$dist = nx \cdot x_{ao} + ny \cdot y_{ao} + \rho \quad (1)$$

Where nx, ny, and p are parameters of image line, and. This back-projected point (x_{ao},y_{ao}) is calculated using collinearity equation.

$$x_{ao} = x_p - f\frac{r_{11}(X_a - X_o) + r_{12}(Y_a - Y_o) + r_{13}(Z_a - Z_o)}{r_{31}(X_a - X_o) + r_{32}(Y_a - Y_o) + r_{33}(Z_a - Z_o)} \quad (2)$$



(a) (b)

Fig. 2. 4 sections selection scheme. (a) Image space section; (b) object space section.

$$y_{ao} = yp - f\frac{r_{21}(X_a - X_o) + r_{22}(Y_a - Y_o) + r_{23}(Z_a - Z_o)}{r_{31}(X_a - X_o) + r_{32}(Y_a - Y_o) + r_{33}(Z_a - Z_o)}$$

Where r_{11}~r_{33}, rotation matrix, X_o, Y_o, Z_o, perspective center, x_p, y_p, principal point position, f, focal length.

The condition that point in object space lies on line in image space is incorporated to collinearity equation and linearized with respect to exterior orientation parameters.

To solve distance minimizing non-linear function above, using chain rule for partial derivative, each partial derivative for exterior orientation parameters (X_o, Y_o, Z_o, ω, φ, k) are written as follow.

$$\frac{\partial dist}{\partial Xo} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial Xo} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial Xo}$$

$$\frac{\partial dist}{\partial Yo} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial Yo} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial Yo}$$

$$\frac{\partial dist}{\partial Zo} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial Zo} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial Zo}$$

$$\frac{\partial dist}{\partial \omega} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial \omega} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial \omega}$$

$$\frac{\partial dist}{\partial \phi} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial \phi} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial \phi}$$

$$\frac{\partial dist}{\partial \kappa} = \frac{\partial dist}{\partial nx}\cdot\frac{\partial nx}{\partial \kappa} + \frac{\partial dist}{\partial ny}\cdot\frac{\partial ny}{\partial \kappa} \qquad (3)$$

2.1 Modified RANSAC in Photo Resection

In this research, the concept of RANSAC (Fischler and Bolles, 1981) is incorporated into single photo resection. RANSAC, known as an outlier-insensitive model fitting algorithm, is based on the fact that 1) randomly selected sample can represent whole data (or majority of data), and 2) number of data which fits the model from random sample with given tolerance indicates the extent of representative of data. This idea is generalized by probability of selecting inlier and number of sampling attempts. Conventional workflow of RANSAC is as follow.

1) Random sampling with minimum number of observation for parameter estimation
2) Estimate parameters
3) Count number of data which satisfies previously estimated parameter given tolerance
4) If percentage of counted data in 3) satisfies pre-defined criteria, exit loop and accept
5) Repeat 1~4
6) After successful iterations, parameter estimation with inlier data set

There are three pre-defined parameters 1) Number of trials, 2) Error budget whether sampling is valid or not with respect to model, and 3) Percentage of data with in error budget.

Even though single photo resection can be considered as model fitting problem, to apply RANSAC algorithm to our problem, there are several important issues to be addressed. 1) random sampling from two spaces - image and object space, 2) non-linear model fitting and minimum number of sampling for parameter estimation, 3) Sampling method - random or deterministic method.

Compared to conventional RANSAC application, for example line or plain fitting, sampling takes place in two spaces - image and object space, in single photo resection. This drastically reduces the probability of being corresponding line set and increases the possible number of total combination. The second issue is that single photo resection is non-linear model. Theoretically, three lines in image and object space are needed for exact solution which means that three corresponding lines in image and object space produce correct exterior orientation parameters, however, the first order linearization with initial value doesn't produce accurate parameter estimation results. Therefore minimum number of linear feature that we applied is four instead of three. The third issue is selection method. If problem of selecting correct consensus exists, for example, probability of selecting correct combination is small, or random selection doesn't provide a good geometry that model needs, deterministic selection method is also an alternative.

Considering the limitations mentioned above, three major modifications are proposed and applied in this research.

1) 4 linear feature sampling - three minimum linear features do not produce accurate parameter and are sensitive to initial approximation of parameter.
2) Deterministic selection method - selection from four sections, To reduce the total number of combination and increase model geometry, image and object

space are divided into 4 sections and label them.

Image space is divided to four sections and a linear feature is selected from each of section, which sums up four linear features. Object space has four combination of section to cover all possible rotation. Figure 3 shows that for each one set of linear feature in image, there are four set of object linear feature in combination list. This decreases total number of combination and increases the probability of matching in spite of four linear feature selections in both spaces.

3) Validity check

Once selection is done, all object linear feature are back-projected to image and calculate the distance with the closest linear feature in image space and check if two point from object linear feature falls on the same feature in linear feature in image. Figure 4 shows validity check scheme. Bold lines are linear feature in image and dot lines are back-projected linear feature to image with exterior orientation parameters calculated from consensus set.

If the distance is within pre-defined criteria and two closest distances are associated with the same linear feature, accept and count percentage of valid (matched) set. For example, from figure, linear feature ‘A’ and ‘a’ are valid set and ‘B’ and ‘b’ does not count, because points in b have close line entities ‘B’ and ‘C’.

2.2 Line Extraction from Laser Scanning Data

Lines from laser scanning data are extracted and used for image registration. When laser points are reflected from vertical plane such as building walls, the point density is higher than other area in X-Y plane. Given approximated manual line location, 1) subset of points around approximated line is extracted (figure 5, right panel) 2) hough-transformation is applied for line detection (accumulating cell of hough transformation in figure 5, left panel). 3) least-square line fitting with neighboring points given by distance threshold. Note that this line which is a possible vertical plane in 3D space separates two neighboring planes.

Figure 5 shows subset of points and accumulating cell from hough-transformation. Based on the peak found on accumulating cell, line can be detected on X-Y plane.

Then 4) planes are found on both side of the line with RANSAC approach - three points are randomly selected with iterations and find plane parameters which satisfies majority of points. Vertical plane from detected line and two planes from points on both sides generate three planes (figure 6). 5) The intersection of two planes can produce straight line in 3D object space (cyan line in figure 6, right).

This approach utilizes priori knowledge of building wall and point density and is applicable to any building when points on the wall produce denser point distribution in X-Y plane. It can be treated as a special case of

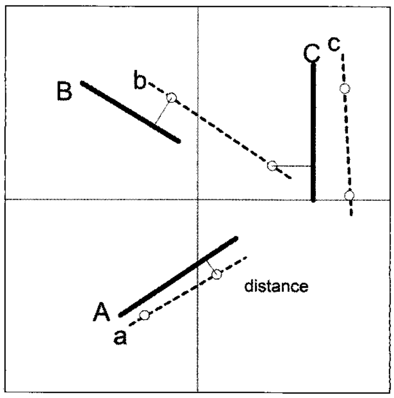


Fig. 3. Validity check scheme

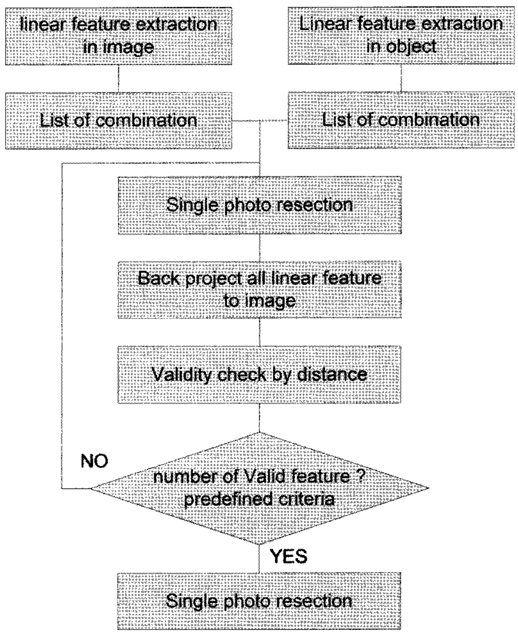


Fig. 4. Work flows

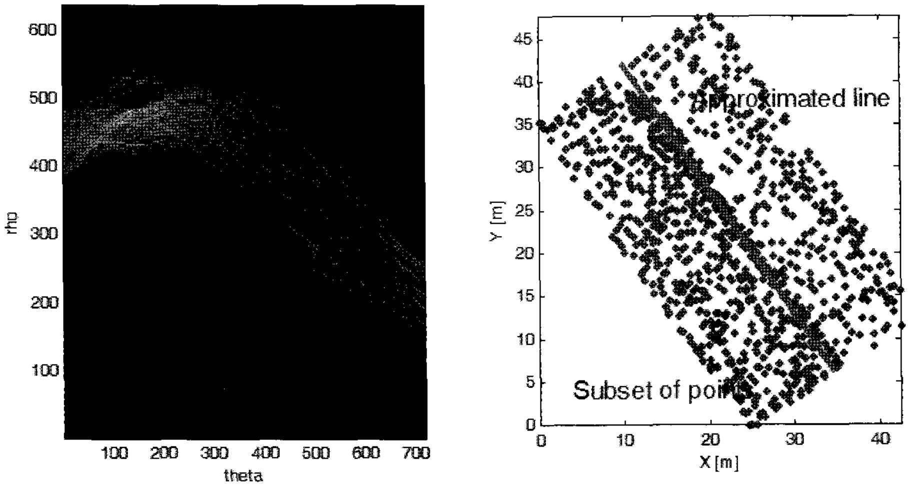


Fig. 5. Accumulating cell (peak point in pink circle) and subset of points

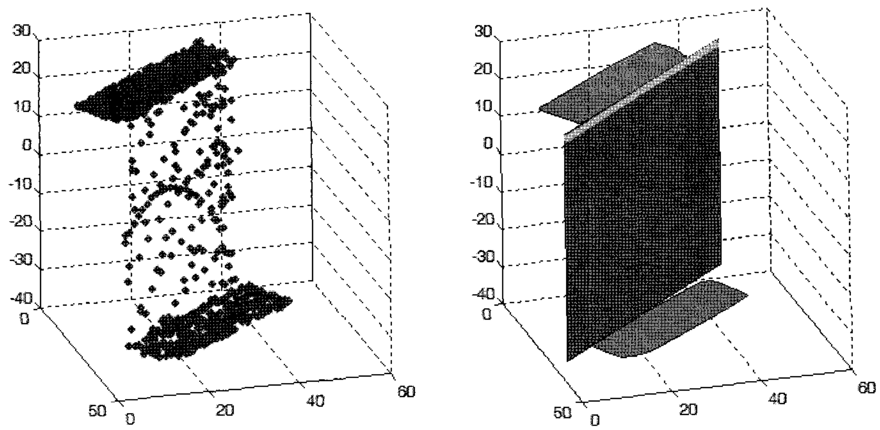


Fig. 6. 3D points clouds (left) and planes found (right), line (cyan) from upper and vertical plane intersection

conventional line extraction of laser scanning data, which shows promising results in detecting lines in roofs, however, since it occurs more in urban area with buildings, further investigation is needed.

3. Tests and Results

Total 16 linear features from stereo aerial images (6142 and 6143: 8110×8408 and 8217×8408 respectively) are extracted for test due to line distribution in object space. Linear features are calculated from stereo intersection for test.

Pre-defined parameters for RANSAC in this test are set as follow.

- Number of trials: all combinations
- Distance criteria for validity check: 25 um
- Percentage criteria: 10 lines/ total 16 lines

The same identification number of image and object feature indicates conjugate line for analysis purpose. Test was done for photo 6142 and 6143. Corresponding lines and distances for validity checks are as follow.

Four selected lines are line ID 1, 5, 7, and 12. Results show photo ID and Object ID are identical which means conjugate lines are successfully matched. Exterior orientation parameters are computer using these selected lines. All other lines in object space are projected to photo and distances are calculated for validity check. Total 14 lines satisfy distance criteria (Table 1).

Four selected lines are line ID 1, 5, 7, and 12 for photo

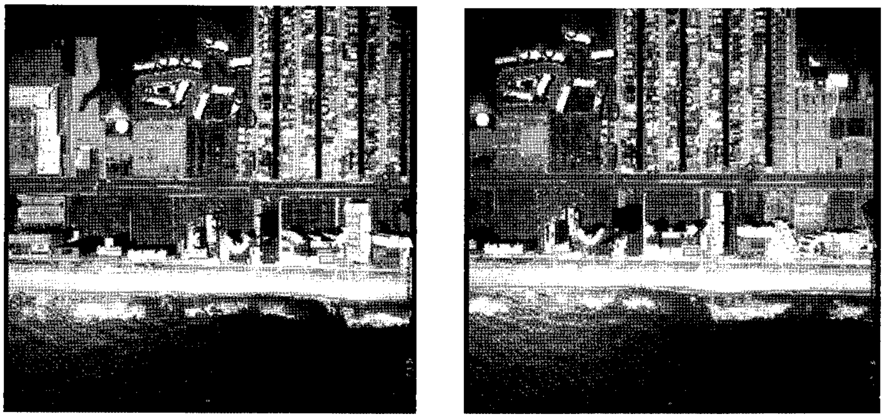


Fig. 7. Left (6143) and right (6142) aerial images with linear features

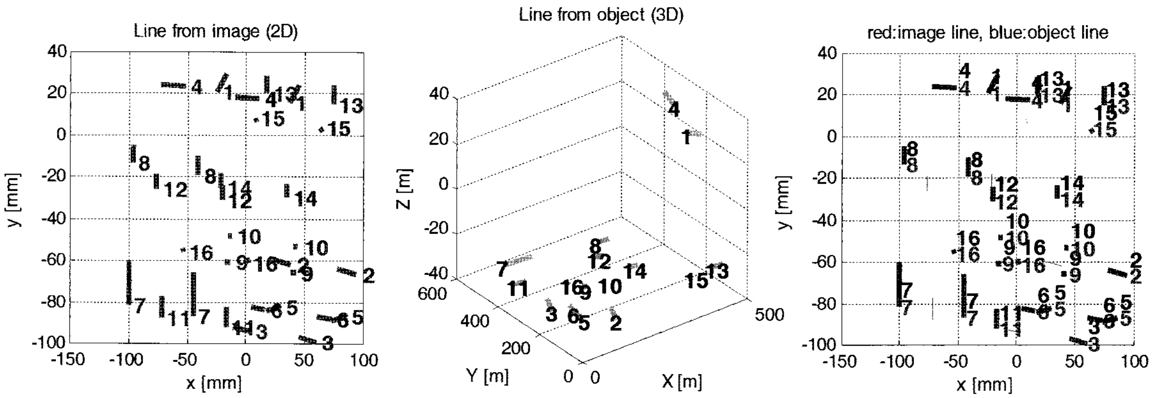


Fig. 8. 16 linear features in image & object space and matched line (photo 6142)

Table 1. Distances for Validity check of photo 6142

Photo ID	Object ID	Dist 1(um)	Dist 2(um)	Photo ID	Object ID	Dist 1(um)	Dist 2(um)
1	**1**	**8.618**	**8.288**	2	2	14.682	22.183
4	4	18.850	23.380	**5**	**5**	**3.664**	**3.922**
6	6	1.258	8.812	**7**	**7**	**0.573**	**0.062**
8	8	0.739	4.885	9	9	8.755	5.902
10	10	19.309	18.205	11	11	0.991	0.003
12	**12**	**1.764**	**2.172**	13	13	21.852	23.141
14	14	3.266	0.935	16	16	8.965	2.509

Table 2. Distances for Validity check of photo 6143

Photo ID	Object ID	Dist 1(um)	Dist 2(um)	Photo ID	Object ID	Dist 1(um)	Dist 2(um)
1	**1**	**8.877**	**8.473**	**5**	**5**	**3.706**	**4.022**
6	6	9.083	16.341	**7**	**7**	**0.142**	**1.027**
8	8	6.561	13.206	9	9	14.070	0.514
11	11	0.920	1.545	**12**	**12**	**2.606**	**3.214**
13	13	12.962	12.284	14	14	12.807	18.159

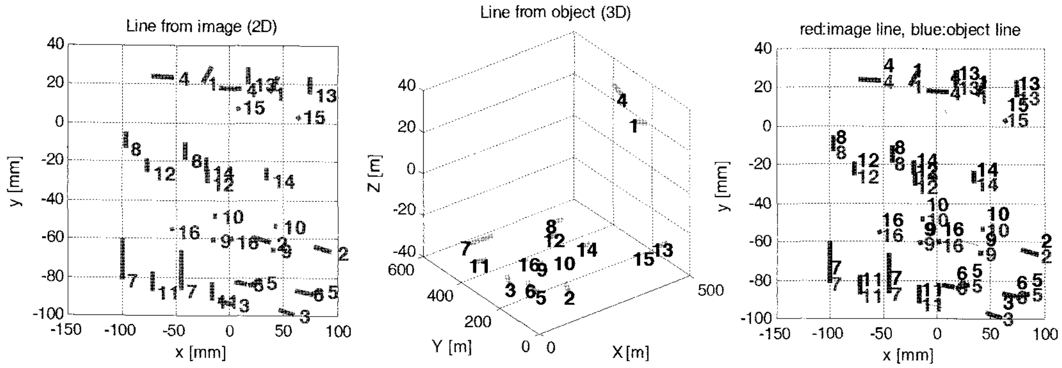


Fig. 9. 16 linear features in image & object space and matched line (photo 6143)

6143. Results also show identical point and object ID number. Total 11 lines satisfy distance criteria.

For photo 6143, total 10 lines satisfy distance criteria with selection of line 1, 4, 5 and 7.

Once correspondences of photo line and object line are found, exterior orientation are re-calculated with lines which satisfy distance validity check.

Calculated exterior orientation parameters are compared with known EOP and the differences are:

From Table 3 and Table 4, estimated parameters show small difference from known EOP and small variance components of parameters.

Conclusions and Future Work

In this study, we introduced line single photo resection using RANSAC algorithm. Test showed that image and object line correspondence can be found using this approach. Test with different number of lines and different length of lines works well producing matching results and EOP. This study also shows that approximated EOP can be relieved since only approximated height of flight is needed, which means this approach can be applied without initial EOP and correspondence between lines. Selection from four sectors reduces total number of trials and provides geometric strength however, combinations increase drastically as number of data increases. The study on reducing sampling size should be investigated for performance by candidate feature selection which selects dominant features based on surface slope of gray value, length of line, gray value distribution of line neighbor, and angle of line.

Table 3. Re-calculated exterior orientation parameters for photo 6142 and 6143

6142	Value	So	6143	Value	So
Xo	495052.998	0.177	Xo	495003.521	0.310
Yo	4252026.628	0.198	Yo	4251823.434	0.225
Zo	539.095	0.082	Zo	538.954	0.078
w	0.121437	0.019313	w	0.064855	0.018833
p	0.755788	0.019313	p	0.567563	0.028244
k	-98.151999	0.004632	k	-97.800972	0.017738

Table 4. Differences between known EOP and calculated EOP

	6142_{known}-$6142_{calculated}$	6143_{known}-$6143_{calculated}$
Xo	-0.1137 m	-0.0087 m
Yo	-0.0533 m	0.1387 m
Zo	0.0210 m	0.0446 m
w	0.0051 deg	-0.0137 deg
p	-0.0118 deg	-0.0005 deg
k	-0.0034 deg	-0.0040 deg

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References

Fischler, M., Bolles,R.,"Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and

Automated Cartography," Comm. ACM, vol. 24, (1981) 381-395.

Habib, A., Kelley, D., Single-photo resection using modified Hough transform, Photogrammetric Engineering & Remote Sensing, 67(8) 2001 909-914.

Schenk, T., Digital Photogrammetry, Vol I, Laurelvill, Ohio, TerraScan, (2000) 271, 352.

Schenk, T., From point-based to feature-based triangulation, ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 58, (2004) 315-329.

Zalanson, G. H., Hierarchical Recovery of Exterior Orientation from Parametric and Natural 3-D curves, International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B2, (2000) 610-617.

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