Line Feature Matching between Object Space and Image Space

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Abstract: In recent years, the linear features have seen their increasing usage in photogrammetry-related applications, such as solving for orientation or object reconstruction, etc. The correspondences of the conjugate linear features between different spaces or coordinate systems are still the key to the goal of photogrammetric automation. In this research, the authors focus on line feature matching between object space and image space in order to offer control information solving for photo orientation. The algorithms start from projecting 3-D line features into image space employing collinearity equations by approximated orientation parameters, then the candidate lines detected from the photo are chosen and filtered by imposing constraints of angles, distances from the reference point and imaging geometry in a sequential fashion. The preliminary tests reveal that the successful as well as satisfactory result of line feature matching can be achieved under the proposed working scheme.

Keywords: Matching, Line Features, Collinearity Equations.

1. Introduction

Though point features have been the essential elements or target of measurement in photogrammetry, the development of image processing technique as well as fast computational speed offered by the computer during the past decades has been making line features an alternative as the primitive processed in photogrammetric chain. Line features, often the evidence of boundaries of entities, such as building, or surface, are likely to be detected and formulated as both geometrically and radiometrically meaningful elements, thus making themselves the potential candidates for many photogrammetric applications. The utilization of linear feature for orientation purpose can be originated by Masry[1]; Habib reported the aerial triangulation solution by integrating point features and linear features[2]; Lee utilized coplanar line features solving for relative orientation and reconstructing the building roof[3]; Lin applied MIHT(Modified Iterated Hough Transform) performing matching and estimating photo orientation on linear features basis[4]; Habib and Alruzouq employed line features for automatic registration of multi-source imagery[5]; Schenk adopted the line-based collinearity in aerial triangulation[6]; A series of research about line-photogrammetry by van den Heuvel can be referred to [7].

In this research, the authors focus on line features matching between object space and image space under the central perspective imaging assumption. Geometric constraints on angles formulated by neighboring lines, topology fulfillment via reference point, and collinearity conditions are implemented for finding the most rational line matches between target lines in object space and search lines in image space. The methods and the applied strategies are discussed in more detail in following section.

2. The Proposed Method

Feature matching between different dimensions is of great challenge, if not impossible. The authors propose transforming 3-D line features in object space back to 2-D line features in image space by collinearity equations with approximated orientation parameters. Each 3-D line feature, actually line segment with two given end points, is back projected onto image space, thus a 2-D line segment presented by two 2-D end points. Matching is then undertaken by several constraints in the image space. For better interpreting how the matching is performed, the line features in object space are regarded as “target lines” while those detected in image “search lines”.

1) Initial Match via Angle Check

The formulation of angle by a set of neighboring lines can be mathematically expressed by Eq. (1).

$$\theta = arc\cos\left(\frac{(x_1 - x_2)(x_3 - x_4) + (y_1 - y_2)(y_3 - y_4)}{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \cdot \sqrt{(x_3 - x_4)^2 + (y_3 - y_4)^2}}\right) \tag{1}$$

Where (x_1, y_1) and (x_2, y_2) : coordinates of two end points of one line;

(x_3, y_3) and (x_4, y_4) : coordinates of two end points of the another line;

The angles of neighboring target lines are formulated and matched with those found in search lines. With n target lines and m search lines, the number of angles by target lines is C_2^n, while the search lines C_2^m, resulting in $C_2^n \cdot C_2^m$ total mates. It comes no surprise that matching mates would grow substantially as the number of target and search lines increases. To reduce the computational load, a pre-process that filters inappropriate matches or decreasing the number of line features is necessary. The most appropriate matches would be determined by comparing the angles between target line set and search line set. Due to the error nature that is always associated with data, even correct conjugate lines would not approve the equality of angle constraint. Thus a tolerance that takes the measuring error into account must be given for collecting the matches that are within acceptance. Given the measuring error of the features and the orientation, one is able to apply the law of error propagation for estimating the standard deviation of angle. A scaled (say 2 to 3 times of) standard deviation of angle can then be set as the threshold filtering out those matches that are against the angle agreement. The above-mentioned angle check is illustrated in Fig. 1.

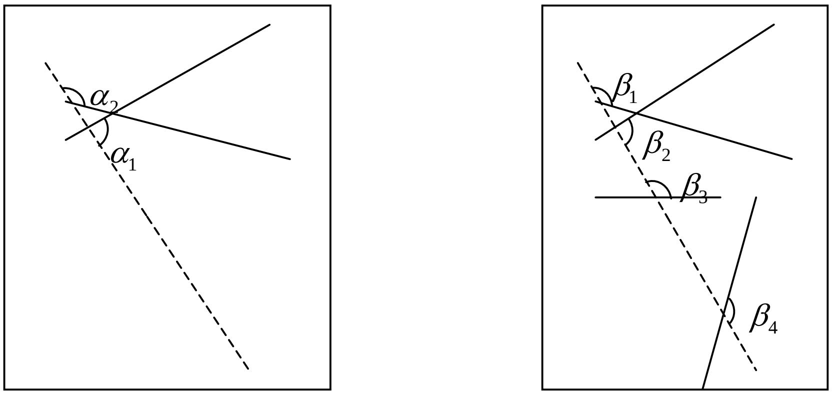


Fig. 1. Illustration of angle check, (a) target lines,(b) search lines

Referring to Fig.1, the angles are calculated both for target lines and searching features in (a) and (b), respectively. The angles associated with first target line, depicted by a dash line in (a), are compared with all mates in search lines. The same procedures are applied to all feature lines and the matches that fulfill the angle constraints would remain. An example of the matching result upon angle check is given in Table 1.

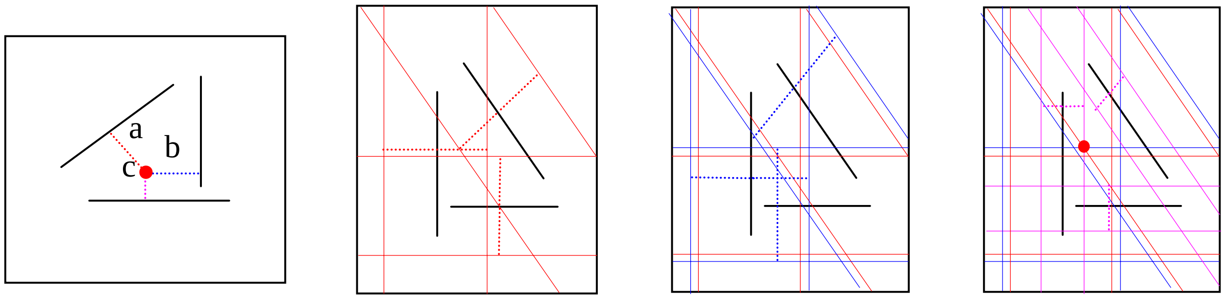
Table 1. Result of angle check

No. of target lines	**1**	**2**	**3**
No. of matched search lines	**1, 2, 3, 0**	**2, 4, 0**	**3, 5, 0**

Multiple matches for a single target line is often possible for fulfilling the angle constraint. No.1 target line finds no.1, no.2, and no.3 search lines as matches, for example. “0” in table 1 is intentionally assigned for the situation that not any match is found at all for the target line. Upon the angle check, the remaining matches are further checked and refined by reference point check, as introduced as follows.

2) Reference Point Check

The method of GHT (Generalized Hough Transform)[8] is commonly recognized for finding the conjugate feature with most similar shape attributed by distances and tangential slopes of each point along the curved feature to the reference point. The location that is clustered in accumulated array indicates the most proper matches by the search features involved. The quite same idea is applied in this study for finding conjugate line features mainly using distance attribute only. A reference point somewhere in target line space is chosen. The perpendicular distances of all target lines to this reference point are calculated and used to produce parallel lines for each search line feature. The set of correspondence that shows the largest cluster of the produced lines finds the target line to search line matches. The detailed procedure of performing line matching via reference point check can be illustrated in Fig. 2. The clustered point by the produced lines is detected, as the red dot in Fig. 2(d). Back tracing the lines that pass through this point would find the line feature correspondences between target lines and search lines.



(a) (b) (c) (d)

Fig. 2. Illustration of reference point check

Quite often, the exact scale of target lines to the search lines is not assured, by rough orientation parameter, for example, thus making the distance attribute a lot of uncertain. To accommodate this drawback, an unknown scale parameter is considered and the least-squares adjustment is implemented. Around the clustered area, the best point can be determined by minimizing the target function of Eq. (2), which constrains that the distance from the produced lines to the clustered point being zero.

$$\frac{\left| ax_0 + b + (s \times d \times \sqrt{a^2 + 1^2}) - y_0 \right|}{\sqrt{a^2 + 1^2}} = 0 \qquad (2)$$

Where (x_0, y_0) : coordinates of clustered point;

s : unknown scale parameter;

(a, b) : parameters of produced lines;

d : the associated distance that produce lines;

To reach the solution of least-squares adjustment, one needs at least three observations, thus three target lines, solving for three unknowns.

3) Imaging Geometry Check

The matching result following angle and reference point checks will not necessarily guarantee the successful or satisfactory outcome. A further verification fulfilling the imaging geometry is proposed for improving or refining the matches. A linear form of collinearity condition, DLT (Direct Linear Transformation), is employed for this purpose. The target function, as shown in Eq. (3), expresses that the projected 3-D line should be collinear to its conjugate line in the image space.

$$\frac{\left| a \times \frac{D_1X_1 + D_2Y_1 + D_3Z_1 + D_4}{D_9X_1 + D_{10}Y_1 + D_{11}Z_1 + 1} + b - \frac{D_5X_1 + D_6Y_1 + D_7Z_1 + D_8}{D_9X_1 + D_{10}Y_1 + D_{11}Z_1 + 1} \right|}{\sqrt{a^2 + 1^2}} = 0 \qquad (3)$$

Where (X_1, Y_1, Z_1) are the object coordinate of one end point in target line; $D_1, D_2 ...., D_{11}$ are the unknown parameters; (a, b) are line parameters in image space. Eq. (3) can be expressed as Eq. (4).

$$\frac{a(D_1X_1 + D_2Y_1 + D_3Z_1 + D_4) - (D_5X_1 + D_6Y_1 + D_7Z_1 + D_8) + b(D_9X_1 + D_{10}Y_1 + D_{11}Z_1 + 1)}{\sqrt{a^2 + 1}} = 0 \qquad (4)$$

Experiments show that the solution is distorted with only few line features or poor line distribution. For that situation, imaging geometry check by rigorous collinearity condition, a nonlinear system however, is strongly suggested.

4) Two- step Matching

As preciously mentioned, the matching mates grow awfully with the increased number of target lines and search lines. Besides, rougher orientation brings about a lot of ambiguity for finding appropriate matches. To alleviate the computational load, the authors propose using partial target lines in the first matching. Thus a quick matching result would be expected. Then, the result of the first matching can be used to establish better orientation parameters, thus greatly reducing the search space in the second matching for all target lines. The workflow of two-step matching can be seen in Fig. 3.

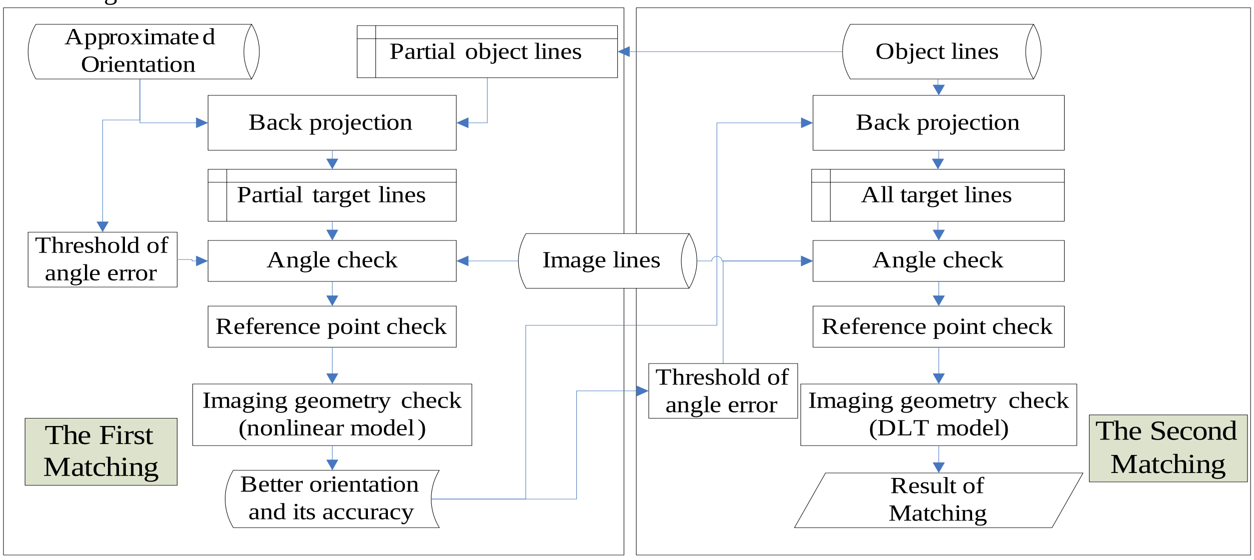


Fig. 3. Two-step matching workflow

3. Experiments and Results

The experiments are carried out by (1) simulated data sets and (2) real data set for demonstrating the feasibility of the proposed approaches.

1) Experiment 1

Imaging geometry of a single aerial photo with scale of 1/4300 and a set of 3-D line features were simulated in this experiment. The distribution of target line features is depicted in Fig. 4(a) while the image line features are shown in Fig. 4(b). The image lines are composed of noised back-projected 3-D lines and other lines that do not correspond to any target lines. Note that not all target lines can be found their conjugate counterparts in image space. Namely, the capability of in-exact matching is investigated in this test. Twelve 3-D line features and sixteen 2-D line features are tested in this experiment. The configuration of the simulated data can be referred to Table 2.

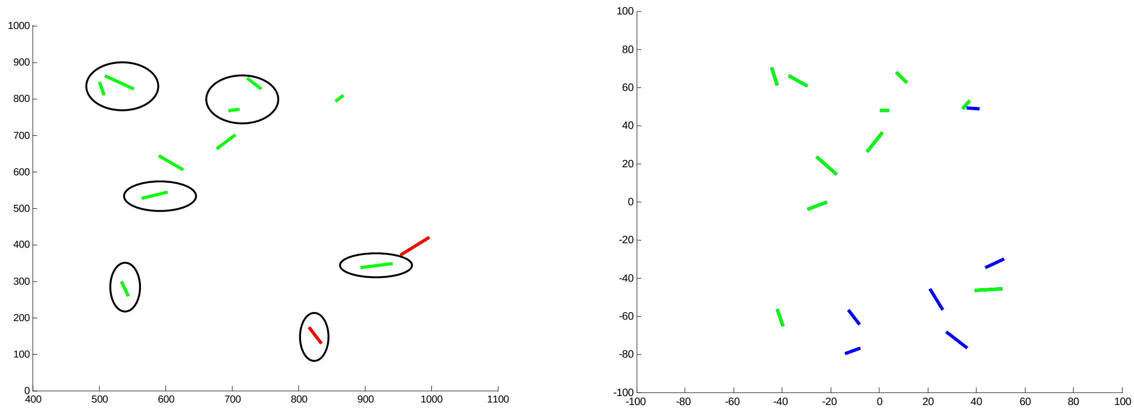


Fig. 4. 3-D line features (a) and 2-D line features (b)

Table 2. Configuration of Experiment 1

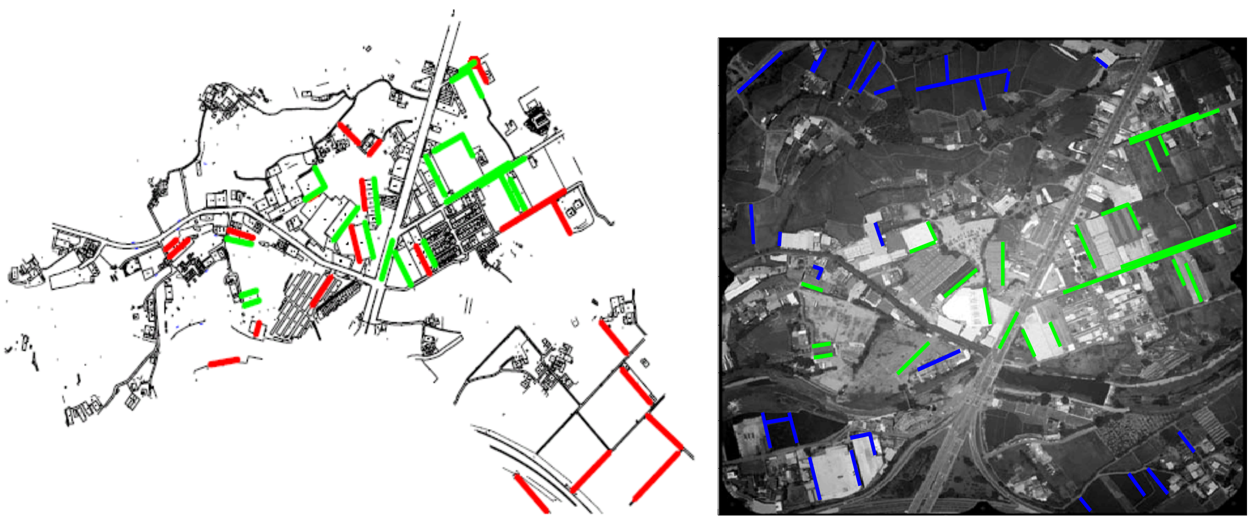
Errors in image observation(x,y)		$(50\mu m, 50\mu m)$
Errors in object observation(X,Y,Z)		(0.1m,0.1m,0.2m)
Focus		305.110mm
Orientation	X	750m
	Y	500m
	Z	1530m
	ω	2 degree
	φ	2 degree
	κ	2 degree

In Fig. 4(a) and (b), green lines indicate the conjugate line correspondences while red lines in (a) and blue lines in (b) are those lines remaining no matches. Eight target lines employed in the first matching are circled in Fig. 4(a). The matching starts from back-projecting 3-D line features to image space with given approximated orientation, 30m positioning error and 5 degree pose error.

According to accuracies of approximated orientation as well as the end points of the line segments, the threshold of angle error can be estimated. After angle check, about 7×10^6 mates are still remained (including repeated lines). Through reference point check, the most proper 200 matching mates are used for imaging geometry check. Seven lines matched between target and search lines are picked at the end of the first matching(the matching result has been confirmed correctly by visual inspection). The first matching procedure takes about 10 minutes. under current code design. Then the second matching is followed. All target lines are matched against all search lines. The remaining 9216 matching mates upon angle check, much less than that in the first matching, resulting from the refined orientation accuracy. The result of second matching is verified as a success where the in-exact matches are also realized. With the better orientation parameters, the second matching takes only 20 seconds.

2) Experiment 2

3-D line features are extracted from a topographic map with scale of 1/500 (Fig. 5(a)). An aerial photograph covering the near area is chosen and the 2-D line feature are digitalized manually (Fig. 5(b)). The notation of line color remains the same as that in simulated data.



(a) (b)

Fig. 5. 3-D line features from a topographic map (a) and 2-D line features from aerial photo (b)

There are forty three 3-D line features and fifty 2-D line features in this experiment. It takes about 80 minutes even adopting two-step matching. To further reducing the time cost, the authors group the matching mates after angle check. Ten target lines are considered as a group with well scattered distribution. The total running time in this configuration is about 20 minutes. Thus, the grouping strategy is advisable when dealing with a great amount of line features. Matching results, without and with grouping arrangement, are both visually confirmed to be correct.

4. Conclusions

The results of experiments reveal that line feature matching method proposed in this study would be satisfactory. The geometric constraints by angle and reference point checks seem effective for finding matching mates. The imaging geometric check further improves and identifies the most proper matches. The two-step matching and grouping strategies prove them reliable and efficient for speeding up the matching process. The successful matching between 3-D line features and 2-D image lines would support the task of automated orientation by line features. Furthermore, the realization of in-exact matching may also pave the potential of this study to the application of change detection. Though the matching scheme is based on the frame-form perspective projection assumption, the accommodation of current scheme into the application of different imaging geometry, such as line scanner, remains interesting for the follow-up research.

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