MULTI-WINDOW MATCHING WITH FEATURE LINE DIRECTION CONSTRAINTS FOR THE GENERATION OF DIGITAL SURFACE MODELS

Hui-Hsin Kao [a] and Liang-Chien Chen [b]

[a] Research assistant, Center for Space and Remote Sensing Research, National Central University,
[b] Professor, Center for Space and Remote Sensing Research, National Central University,

No.300, Jhongda Rd., Jhongli, Taoyuan 32001, Taiwan;
Tel: + 886-3-4227151#57623;
E-mail: [a] momokao@csrsr.ncu.edu.tw, [b] lcchen@csrsr.ncu.edu.tw

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Abstract: Digital surface model (DSM) is an important data source in building detection. The major data in the formation of DSM is 3D point clouds. The image matching may be used to generate 3D point clouds. However, the feature line direction, such as building edges, might not be taken into account in the area-based matching procedure. This could lead to unreliable matching when buildings are of the processing target. Thus, we employ multi-window matching with feature line direction constraints to cope with this weakness. The proposed method considers edge direction and puts the target point in key positions. It improves image matching when the feature is around elevation discontinuity.

The proposed method comprises four major steps: (1) feature extraction, (2) determination of feature line direction, (3) multiple image matching, and (4) generation of DSM. Extracting features by Canny operator is the first step. Then, we determine the feature line direction by Hough transform from the reference image. Third, geometrically constrained cross-correlation algorithm and central-left-right matching (CLR matching) strategy are selected in the matching procedure to generate 3D point clouds. Finally, we use triangulated irregular networks (TIN) to generate DSMs.

The test datasets include six Digital Mapping Camera II (DMC II) images with 9cm spatial resolution and the overlap and sidelap are 80% and 30%, respectively. The experimental results show that the proposed method has the high ability to generate quality DSM.

1. INTRODUCTION

Digital surface model (DSM) is an important data source in building detection. Image matching may be used to generate 3D point clouds to form the DSM. The major purpose of image matching is to find the conjugate points in the image counterparts. The commonly used methods for image matching include feature-based matching and area-based matching. Feature-based matching extracts features and uses the spatial relation to locate the conjugate points. On the other hand, area-based matching uses the change of gray values to fine the conjugate points and may obtain accurate results.

The traditional area-based image matching may generate 3D point clouds but the feature line direction, such as building edges, might not be taken into account in the matching procedure. Some features may cause ambiguous results in the area with elevation discontinuity. The ground objects or walls of the building lead matching to low correlation coefficient, which is obvious in the building areas.

This paper employs the concept of geometrically constrained cross-correlation method, as proposed by Otto and Chua (1989). If multi-strip images are available, the epipolar lines may be constructed at the different directions and the matching results may be more accurate (Huang, 2010). Besides, we use central-left-right matching, as proposed by Hsu (1990), with feature line direction constraints to improve image matching.

2. METHODOLOGY

The proposed method comprises four major steps: (1) feature extraction, (2) determination of feature line direction, (3) multiple image matching, and (4) generation of digital surface model. The details of those steps are given as follows.

Feature Extraction

The first step for image matching is extracting the features. Considering the building characteristic, we employ Canny (1986) edge detection to detect the feature lines. Canny operator comprises five major parts: Gaussian filtering, finding gradients, non-maximum suppression, double thresholding and edge tracking by hysteresis.

Determination of Feature Line Direction

We assume that most of feature lines are building lines, but there still some others lines be detected. Besides, all feature lines will not be with the same direction. Thus, we separate the unwanted feature lines and the directions of buildings. In this study, Hough transform (Hough, 1959) is selected for dividing the direction from feature lines. After the features transform to the Hough space, the feature line direction decided by two criteria: One is that the largest peak in Hough space need to larger than the feature points which are transformed, another is that the angle range between largest peak and second-largest peak.

Multiple Image Matching

The purpose of multiple image matching is to find the conjugate points in a reliable way. According to the different directions and corresponding features, we purpose the multiple image matching to find the conjugate points in different feature line direction, respectively. Geometrically constrained cross-correlation algorithm and central-left-right matching strategy are selected in the matching procedure to generate 3D point clouds. The central-left-right matching windows are shown in Figure 1, and the consent is shown in Figure 2.

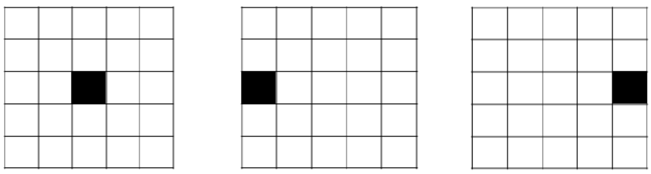


Figure 1: Central-Left-Right Matching Windows

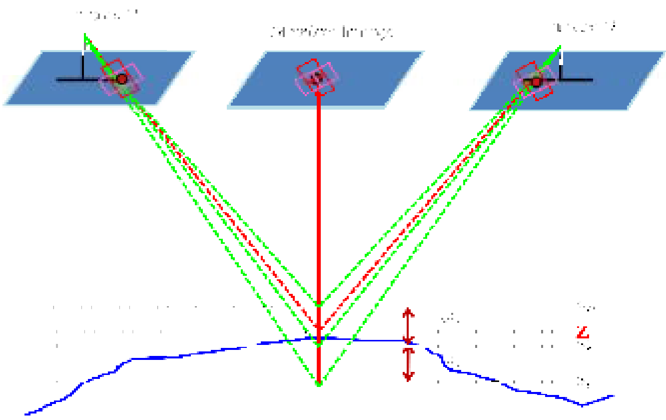


Figure 2: Multiple Image Matching

This process selects an image as the reference image and then gives an initial elevation to calculate an approximate three-dimensional position. The following step is to back-project this feature to others images and finds the correspondent conjugate points using normalized correlation coefficient (NCC) technique. We iteratively modify the elevation and compute the NCC values. Finally, we can generate the 3D point clouds when the maximum NCC is estimated.

Generation of Digital Surface Model

After multiple image matching for generation of 3D point clouds, we use bilinear interpolation to generate the DSM. This count is shown in equation (1). The concept is that use the elevation of 4 nearest points to find the elevation of the point (x, y).

$$Z = aX + bY + cXY + d \tag{1}$$

Z: Elevation
a, b, c, d: Parameters
(X, Y): Ground coordinates

3. EXPERIMENTS AND RESULTS

This test site locates in Taipei City of Taiwan. The datasets include six Digital Mapping Camera II images with 9cm spatial resolution, as shown in Figure 3. The overlap and sidelap are 80% and 30%, respectively. The image with the smallest relief displacement is chosen as the master image.

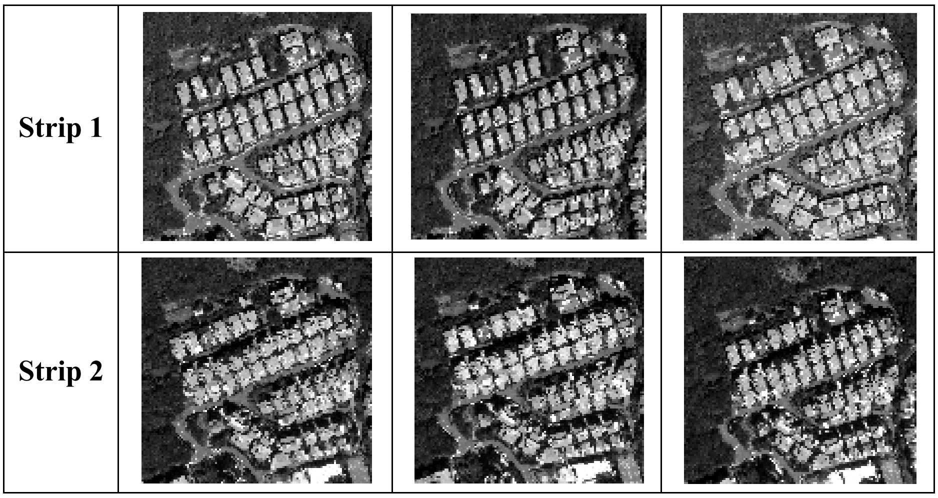


Figure 3. Overlapped Images of Test Example

Results of Feature Extraction

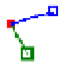
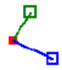
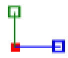
The first step for image matching is extracting the features. We extract the feature lines in the master image. There are 187200 feature points on the feature lines, as shown in Figure 4.

Figure 4. Feature distribution

Feature Line Direction

After feature extraction, feature points transform to the Hough space. We determine the feature line direction by two criterions. The results of feature line direction and number of corresponding feature points are shown in Table 1. In this test area, there are two different building bearings, and the others feature points which did not have clear direction we define their direction is 0˚-90˚

Table 1. Results of feature line direction

	Feature Line Direction 1	Feature Line Direction 2	Others
Feature Line Direction			
Angles	148°-73°	34°-116°	0°-90°
Number of Feature Points	164823	20161	2216

Results of Multiple Image Matching

According to the different feature line direction and corresponding feature points, we did the multiple image matching along different directions, respectively. The result of multiple image matching as shown in Table 2. In this case, the area with feature line direction have high successful rate, more than 79%. On the other hand, the successful rate of others points are only 47.2%.

Table 2. Results of multiple image matching

	Feature Line Direction 1	Feature Line Direction 2	Others	Total
Number of Feature Points	164823	20161	2216	187200
Number of Successful points ($R > 0.75$)	132023	16007	1046	149076
Successful Rate	80.1 %	79.4 %	47.2 %	79.6 %

Compared with traditional image matching, the multiple image matching with feature line direction constraints have higher successful rate than traditional matching. The compared results are show in Table 3. The result of multiple image matching with feature line direction have high successful rate, more than 79%. On the other hand, the successful rate of traditional matching is only 47.2%.

Table 3.Compared with traditional image matching

Matching methods	Average of R (correlation coefficient)	Successful Rate
Traditional Matching (Without Feature Line Direction)	0.75	58.69%
With Feature Line Direction	0.86	79.6%

Digital Surface Model

For this step, we select the minimum normalized correlation coefficient (NCC) threshold as 0.75 to generate DSM by using bilinear interpolation from 3D point clouds. The results are shown in Figure 3.

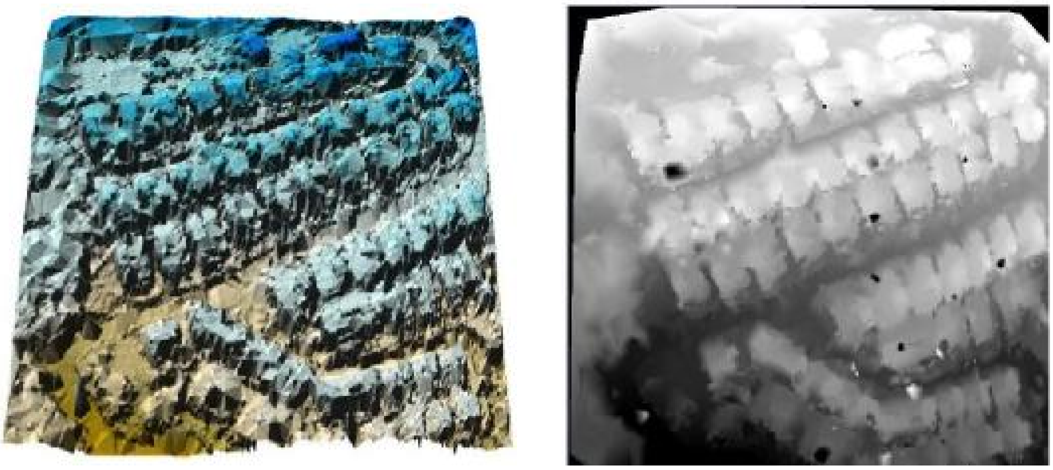


Figure 4. Digital Surface Model

4. CONCLUSIONS

This paper has proposed a scheme to improve image matching when the feature is around elevation discontinuity. The experimental results show that multi-window matching with feature line direction constraints can have higher successful rate than traditional matching. It might improve the accuracy in DSM generation.

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