Seed Point Selection Method for Triangle Constrained Image Matching Propagation

Qing Zhu, Bo Wu, and Zhi-Xiang Xu

***Abstract*—In order to select proper seed points for triangle constrained image-matching propagation, this letter analyzes the affects of different numbers and different distributions of seed points on the image-matching results. The concept of distribution quality is introduced to quantify the distribution of seed points. An intensive experimental analysis is illustrated using two different stereo aerial images and, based on the experimental results, a seed point selection strategy for triangle constrained image-matching propagation is proposed. An automatic selection method is then introduced that gives good distribution quality for a defined number of seed points.**

***Index Terms*—Distribution quality, seed points, stereo image matching, triangle constraint.**

I. Introduction

SOME stereo image-matching methods require a user-selected set of corresponding points (seed points) in the left and right images to initiate automated stereo matching routines [1]. For example, Tang *et al.* [6] presented a dense matching method by making use of a Voronoi diagram constructed by N reliably matched seed points, with the whole image being divided into N cells, each cell containing a seed point taken for propagation inside its region, and the eight corresponding neighboring points of each seed are found using the disparity of this centered point under the continuity constraint. Chen *et al.* [2] utilized pyramidal stereo matching for urban three-dimensional building modeling; they divided the original image into several areas, and selected the most reliably matched points in each area as the seed points of the up-layer image matching. Zhu *et al.* [8] presented a robust image-matching propagation method based on the self-adaptive triangle constraint, which relies on the initial corresponding triangulations formed by a few seed points in the stereo pairs.

The image-matching methods mentioned above start the matching process from seed points; therefore, the selection of seed points will consequently affect the final matching results. Chen *et al.* [2] indicated that the selection of seed points directly determines the validity and practicability of pyramidal matching, and it is important to ensure a good spread of points across the images. Jonathan [3] used the Otto and Chau method [5] to process SPOT images, and attempted to produce digital elevation models (DEMs) using 5, 10, 15, 20, and 100 seed points. High-contrast difference was the criteria used for seed point selection, as found at field corners and road junctions, or at features easily identified in both images. The initial seed points were selected by users or extracted from the ground control points automatically. The matched DEMs were compared to a reference DEM produced by University College London from aerial photography. Comparisons show that the number of seed points is not critical, but the accuracy is related to the distribution of seed points.

The image-matching propagation under the self-adaptive triangle constraint [8] needs initial corresponding triangulations on the overlap area of the stereo pairs from a few seed points (at least four points for two triangles covering the whole image overlap area). For practical applications of this matching propagation algorithm, it is very important to study the effects of seed point selection on the final results. There are two key factors for the selection of seed points, i.e., the number and their distribution. Based only on this analysis, more elaborate seed point selection methods could be designed.

This letter is divided into five sections. Following this introduction, Section II discusses the two factors that affect the network geometry of the initial triangulation: the number and distribution of seed points. Section III compares the matching results of different numbers and distributions of seed points through intensive experimental analysis by using of different stereo images. Based on the experimental results, a seed point selection strategy for image-matching propagation under the self-adaptive triangle constraint is proposed in Section IV, and an automatic selection method that gives good distribution quality for definite number of seed points is then introduced. Finally, some concluding remarks are given in Section V.

II. Network Geometry of Initial Triangulation

The network geometry of initial triangulation for image-matching propagation is determined by two factors: the number and the distribution of seed points.

To construct the initial corresponding triangulations in order to start the image matching, the overlap area of the stereo pair first needs to be determined. The overlap area can be described by a boundary polygon defined by four corner points. The seed points mentioned here are the initial well-matched points, which have the most distinctive texture in the overlapping area. The minimum number of seed points is therefore four.

The distribution of seed points can be described by the area and shape of the triangles formed by them. The general area

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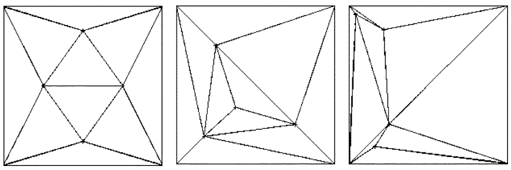


(a) (b) (c)

Fig. 1. Triangulations with different distribution qualities (eight seed points). (a) Distribution quality: 0.291. (b) Distribution quality: 1.408. (c) Distribution quality: 2.392.

descriptor and shape descriptor for seed points distribution can be defined respectively as

$$D_A = \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{A_i}{\overline{A}}-1\right)^2}{n-1}} \quad \overline{A} = \frac{\sum_{i=1}^{n} A_i}{n}$$

$$D_S = \sqrt{\frac{\sum_{i=1}^{n}(S_i-1)^2}{n-1}} \quad S_i = \frac{3 \times \mathrm{Max}(J_i)}{\pi}.$$

where n is the number of triangles, A_i is the area of the triangle i, and $\mathrm{Max}(J_i)$ is the radian value of the largest internal angle of the triangle i.

The area descriptor is a measure of the dispersion or variation in a distribution of seed points' triangle area. Smaller the area descriptor, more better the distribution of seed points. The shape descriptor indicates the dispersion or variation in a distribution of seed points' triangle shape, lower the shape descriptor, more better the distribution of seed points. Taking into account both the area and shape descriptors, the distribution of seed points can be described by "distribution quality" defined as below

$$D = D_A \times D_S = \frac{\sqrt{\sum_{i=1}^{n}\left(\frac{A_i}{\overline{A}}-1\right)^2 \times \sum_{i=1}^{n}(S_i-1)^2}}{n-1}. \quad (1)$$

Distribution quality is invariable with respect to the scale change and rotation; it describes the distribution of seed points over the image in a quantified manner. Fig. 1 illustrates the triangulations of eight seed points with different distribution qualities.

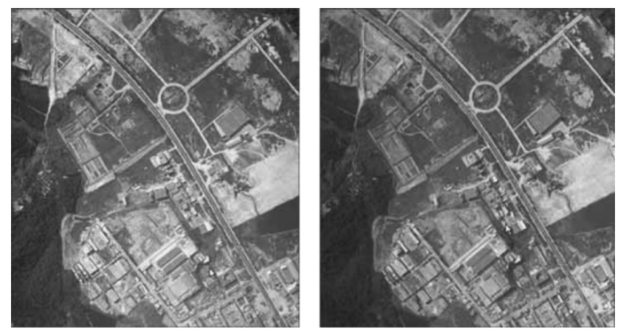
III. Experimental Analysis of the Seed Point Selection

Two actual stereo pairs are employed to compare the triangle constrained matching results using different numbers and different distribution qualities of seed points (Figs. 2 and 3). The stereo pair 1 was downloaded from the ISPRS official website (http://www.isprs.org/data/avenches), the size is 1800×1800 pixels, the scale is $1:5000$, and the image overlap is 60%. The stereo pair 2 was collected from Gaungdong Province, China, with the size of 1504×1607 pixels, the scale at $1:10000$, and 65% image overlap.

In order to get insight into the seed points selection, 18 schemes were designed from 4, 5, 7, ... to 141 seed points,

(a) (b)

Fig. 2. Stereo pair 1. (a) Left image. (b) Right image.



(a) (b)

Fig. 3. Stereo pair 2. (a) Left image. (b) Right image.

and the initial triangulations were generated based on two distinct distribution qualities, then the triangle constrained image-matching propagations were carried out and the corresponding triangulated digital surface models (DSMs) were obtained. The matched DSM was compared to a reference DSM (the reference DSM of stereo pair 1 was downloaded from the dataset on the ISPRS official website, and the reference DSM of stereo pair 2 was collected interactively from a digital photogrammetric workstation). After interpolating the elevation values of all the matched points from the reference DSM, the root mean square error (RMSE) and the maximum error (Max) were computed. The experimental results of stereo pair 1 are shown in Fig. 4, and the stereo pair 2 in Fig. 5.

The experimental results show that generally the RMSE and the Max of stereo pair 1 decrease significantly with an increase in the number of seed points, and the lower the distribution quality, the better the result. While it is not the same case to the stereo pair 2, the RMSE and the Max do not change significantly even using different seed points schemes. However, a lower distribution quality with the same number of seed points will result in lower RMSE and Max values in most of the seed points schemes. Comparing the two stereo pairs, stereo pair 1 (Fig. 2) is of large scale and poor image quality. More experiments give similar results by making use of other stereo images. The following conclusions is therefore summarized as below.

1) When the image-matching conditions of stereo pair are favorable (short photographic base line, small convergent angle, small photographic scale, and similar radiometric property), the number of seed points does not obviously

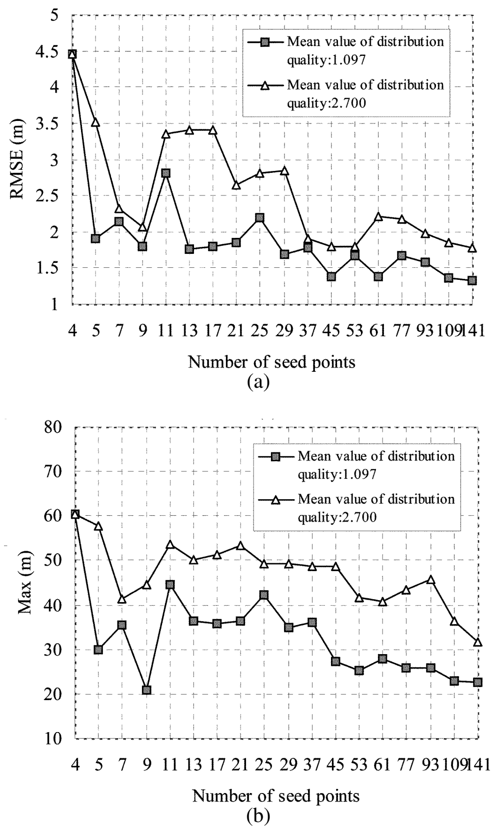


Fig. 4. Comparison results of stereo pair 1. (a) RMSE (m). (b) Max (m).

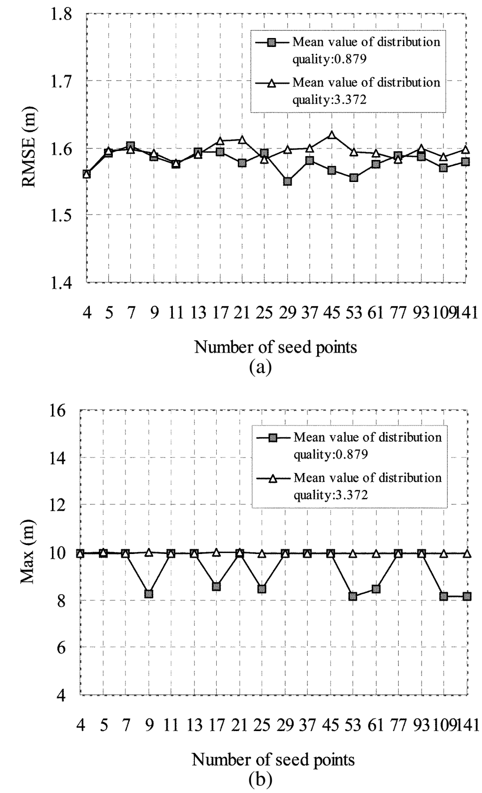


Fig. 5. Comparison results of stereo pair 2. (a) RMSE (m). (b) Max (m).

affect the matching results, and this agrees with the conclusion of Jonathan [3].

2) When the image-matching conditions are poor (long photographic base line, large photographic scale, and dissimilar radiometric property), more seed points give better matching results.
3) For all image-matching conditions, a lower distribution quality gives better matching results. However, the distribution quality affects the matching results more significantly in the case of poor image-matching conditions.

IV. Seed Point Selection Method

Based on the experimental analysis mentioned above, the seed point selection strategy for triangle constrained image-matching propagation is as follows.

1) If there are some reliable corresponding points, such as those resulted from relative orientation, aerial triangulation or ground control points, they can be selected as seed points directly.
2) If there are no predefined interest points available, then we have the following.
   a) When the image-matching condition is favorable, the four corner points of the boundary polygon should be taken as seed points. The boundary of the overlap area of the stereo pairs can be obtained manually or by automatic template matching [7].
   b) When the image-matching condition is not good, the four corner points of the boundary polygon must be selected as seed points, and at least another seed point has to be selected in the overlap area. The poorer the image-matching condition, the more seed points need to be selected. Considering the difficulty of selecting dozens of seed points, it is appropriate to select between 5 and 40 seed points.
   c) When selecting seed points in the worst image-matching conditions, the distribution quality of seed points needs to be less than 2.0.

Because the photographic conditions and the texture features in different images exhibit great differences, so the image-matching conditions of most stereo pairs are not perfect, especially with aerial photographic images of built urban areas. Therefore, image matching usually needs to select a definite number of seed points with proper distribution quality. An automatic seed points selection method is introduced as below.

If k seed points need to be selected, and the threshold of the distribution quality of these seed points is set to d, then the following should be performed.

1) Search for the four corner points of the boundary polygon in the overlap area of the stereo pair, and set $k = k - 4$.
2) Partition the overlap area: divide the overlap area of the stereo pair into k grid cells, whose areas are roughly equivalent, with shapes similar to the boundary polygon (Fig. 7). Let the size of grid cell numbered i be $a_i \times b_i$.
3) Initialize the matching windows in each grid cell: set the center of each grid cell as the center of its matching window, and set the size of the matching window in grid cell numbered i as $t_i \times (a_i \times b_i)$, where t_i is the scale coefficient of the matching window numbered i, and t_i ranges

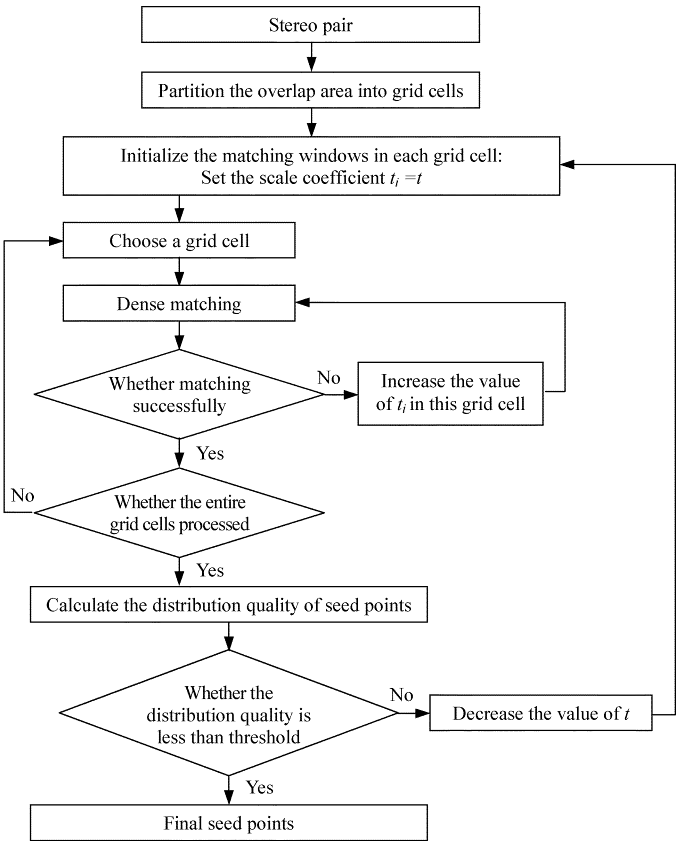
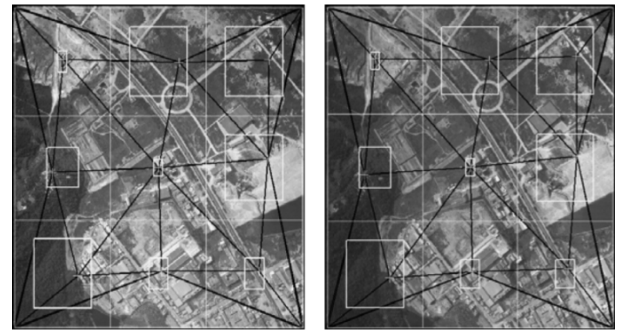


Fig. 6. Flowchart of the automatic selection of seed points.



(a) (b)

Fig. 7. Automatic selection of seed points. (a) Left image. (b) Right image.

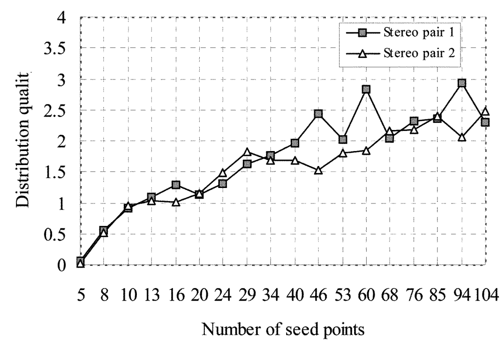


Fig. 8. Experimental results of automatic seed point selection.

from 0.1 to 2. Set the scale coefficient in all matching windows $t_i = t$ (the initialized value of t is set to 0.5).

4) In the matching widow whose size is $t_i \times (a_i \times b_i)$, carry out dense matching [4] pixel after pixel from the center of this window.
5) If a pair of corresponding points is successfully matched, then select them as the seed points, otherwise, increase the value of t_i, and go back to step 4).
6) Process all the matching widows in the grid cells, construct the initial triangulation from the matched seed points, and calculate the distribution quality of these seed points using (1). If the distribution quality is larger than d, then decrease the value of t, and go to step 3). Else if the distribution quality is less than d, then the seed point selection terminates.

The flowchart of this method is shown in Fig. 6.

The seed points selected automatically according to this method are always points with distinct texture features. Fig. 7 shows the process of selecting 13 seed points in stereo pair 2. First, the overlap area of the stereo pair is located and divided into 9 grid cells (3 × 3). Then matching windows are selected in all the grid cells. Different grid cells have different matching windows; if the texture of the central area is distinctive, then it is easy to match seed points successfully in this grid cell, and the size of the corresponding matching window is also smaller. However, if the texture of the central area is poor, it is difficult to match seed points successfully and the size of the corresponding matching window would extend.

However, based only on gray value correlation, it may be impossible to automatically match the necessary seed points successfully in grid cells with poor texture, or even to automatically match seed points successfully in these grid cells after extending the matching window. If the matching window is extended too much, points may be found in adjacent grid cells and then the distribution quality would not satisfy the threshold value, and it becomes necessary in these cases to select a few seed points manually. Stereo pairs 1 and 2 were tested to select different seed points using this method, the threshold of distribution quality set to 3.0. The results are shown in Fig. 8.

From the experimental results, when the image-matching conditions are favorable (in the case of stereo pair 2), the distribution quality of seed points selected by this method is less than 2.0 and there is no need for any manual interaction when the number of seed points is less than 60; when the image-matching condition is worse (in the case of stereo pair 1), the automatic selection of seed points is still satisfactory when the number of seed points is less than 40.

V. Conclusion

This letter conveys the following conclusions.

1) When the image-matching conditions are favorable (with short photographic base line, small convergent angle, small photographic scale, and similar radiometric property), it is unnecessary to select additional seed points besides the boundary corners. Otherwise, if the image-matching conditions are poor, it is appropriate to select 5 to 40 seed points.

2) Seed points with proper distribution gives better matching results, and the distribution quality is a useful descriptor to the distribution of seed points.
3) This letter proposed an automatic seed points selection method to obtain certain number of seed points with good distribution quality.

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