COLOUR IMAGE MATCHING FOR DTM GENERATION AND HOUSE EXTRACTION

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ABSTRACT

Image matching plays a key role in automatic DTM generation and house extraction. For the house extraction from large scale imagery, point matching and line matching complement one another: Line matching gives the 3 dimensional line information which supports house reconstruction at ridge lines or roof boundaries; dense well distributed point matching results contribute to the surface model generation of the remaining non-breakline regions. We propose a new epipolar line equation, which is determined by orientation parameters and supports both epipolar line search and epipolar imagery generation. The proposed matching process is divided into point matching and line matching. To derive highly reliable results in point matching we include blunder suppression based on the positional relationship between possible corresponding point pairs. Line matching is supported by the results of point matching to reduce the number of possible corresponding line pairs. Regarding similarity comparison for line matching we use the line shape, the flanking regions colour, information on positional relationship and connectivity between candidates for corresponding lines and neighbouring points and lines. We tested the proposed method with a sample dataset and show the results .

1 INTRODUCTION

Image matching plays a key role in automatic DTM generation and house extraction. Applications on DTM generation can be found in many current commercial digital photogrammetry workstations, and methods and applications of house extraction can be found in [Gruen et al, 1997; Henricsson, 1996]. For the extraction of houses from large scale imagery, both point matching and line matching are necessary: Line matching gives the 3 dimensional line information which is useful for both for breakline detection and house reconstruction; whereas dense well distributed point matching contributes to the surface model generation of the remaining non-breakline regions. Many studies have been made related to this issue, but still there is a general robust method missing.
The aim of this study is to find a matching method focussing on this particular problem. In this paper firstly we will describe the new epipolar equation with geometrical proof. Secondly we will describe our study on a new matching method. Finally the results of our matching methodwill be described and discussed.

2 PROPOSED EPIPOLAR LINE EQUATION

Epipolar line geometry is one fundamental principle in image matching domain [Paul R. Wolf, 1984]. Within an overlapping imagery pair, the corresponding point of one point lies on the epipolar line which is corresponding to that point. Here we suggest a new epipolar line finding method. The basic principle of the epipolar line derivation is the condition of coplanarity, the details are as follows:
Let there be a couple of cameras which capture an object at the same time. We call one as left camera with indices 1, another as right camera with indices 2. Let O_1, O_2 be the left and the right camera centre. And Let P be a point on the object. By definition O_1, O_2, P are on the same plane called epipolar plane. Epipolar lines corresponding to P are defined by the intersections of the epipolar plane and the image planes of the left and right camera. As the intersection of two planes is always a straight line, the resulting epipolar lines are straight lines and there exist a couple

of epipolar line corresponding to P. Let p_1 be a point of the left image corresponding to P. Let k_1 be a point on the epipolar line of the left camera image, k_2 a point on the epipolar line of the right camera. Then O_1, O_2,P, k_1, k_2 lie on the same plane, which is called "coplanar condition". Therefore the vectors $\overrightarrow{O_1O_2}$, $\overrightarrow{O_1p_1}$, $\overrightarrow{O_1k_1}$ and $\overrightarrow{O_2k_2}$ lie on the same plane. Let $\vec{B}$ be vector of baseline, f be the camera's focal length. Let R_1 and R_2 be the rotation matrices of the left camera and right camera.

Let the terrestrial coordinates of O_1, O_2, be (X_1, Y_1, Z_1), (X_2, Y_2, Z_2). Let the photo coordinates of p_1, k_1, k_2 be (x_{p1}, y_{p1}), (x, y), (x', y').

$$R_1 = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}, \quad R_2 = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}$$

Then,

$$\vec{B} = (Bx, By, Bz) = (X_2 - X_1, Y_2 - Y_1, Z_2 - Z_1) \tag{1}$$

$$\overrightarrow{O_1p_1} = (X_{p1}, Y_{p1}, Z_{p1}) = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} (x_{p1}, y_{p1}, f) \tag{2}$$

$$\overrightarrow{O_1k_1} = (X, Y, Z) = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} (x, y, f) \tag{3}$$

$$\overrightarrow{O_2k_2} = (X', Y', Z') = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix} (x', y', f) \tag{4}$$

Because the vectors $\vec{B}$, $\overrightarrow{O_1p_1}$, $\overrightarrow{O_1k_1}$ satisfy the coplanar condition,

$$\vec{B} \bullet (\overrightarrow{O_1P_1} \times \overrightarrow{O_1k_1}) = 0 \tag{5}$$

Therefore,

$$\begin{vmatrix} Bx & By & Bz \\ X_{p1} & Y_{p1} & Z_{p1} \\ X & Y & Z \end{vmatrix} = Bx(Y_{p1}Z - Z_{p1}Y) + By(Z_{p1}X - X_{p1}Z) + Bz(X_{p1}Y - Y_{p1}X) = 0 \tag{6}$$

From (2),(3),(6)

$$\begin{aligned} &\{a_{11}(ByZ_{p1} - BzY_{p1}) + a_{21}(BzY_{p1} - BxZ_{p}) + a_{31}(BxY_{p1} - ByX_{p1})\}x \\ &+ \{a_{12}(ByZ_{p1} - BzY_{p1}) + a_{22}(BzX_{p1} - BxZ_{p1}) + a_{32}(BxY_{p1} - ByX_{p1})\}y \\ &+ \{a_{13}(ByZ_{p1} - BzY_{p1})) + a_{23}(BzX_{p1} - BxZ_{p1}) + a_{33}(BxY_{p1} - ByX_{p1})\}f = 0 \end{aligned} \tag{7}$$

(7) is the epipolar line equation on the left image which is corresponding to the point p(xp1,yp1) of the left image. This can be represented as follows.

$$Ax + By + Cf = 0 \tag{8}$$

$$\begin{pmatrix} A \\ B \\ C \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}^T \begin{pmatrix} 0 & -Bz & By \\ Bz & 0 & -Bx \\ -By & Bx & 0 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} x_p \\ y_p \\ f \end{pmatrix} \tag{9}$$

The epipolar line equation for the right image which is corresponding to the point p_1 on left image is obtained as follows:
Because the vectors $\vec{B}$, $\overrightarrow{O_1 p_1}$ and $\overrightarrow{O_2 k_2}$ satisfy the coplanar condition,

$$\vec{B} \bullet (\overrightarrow{O_1 P}_1 \times \overrightarrow{O_2 k_2}) = 0 \tag{10}$$

Therefore,

$$\begin{vmatrix} Bx & By & Bz \\ X_{p1} & Y_{p1} & Z_{p1} \\ X' & Y' & Z' \end{vmatrix} = Bx(Y_{p1}Z' - Z_{p1}Y') + By(Z_{p1}X' - X_{p1}Z') + Bz(X_{p1}Y' - Y_{p1}X') = 0 \tag{11}$$

So we can get the following epipolar line equation for the right image which corresponds s to p_1 of the left image.

$$A'x' + B'y' + C'f = 0 \tag{12}$$

$$\begin{pmatrix} A' \\ B' \\ C' \end{pmatrix} = \begin{pmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{pmatrix}^T \begin{pmatrix} 0 & -Bz & By \\ Bz & 0 & -Bx \\ -By & Bx & 0 \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} x_p \\ y_p \\ f \end{pmatrix} \tag{13}$$

When we use pixel coordinates, we have to know the transformation between pixel coordinates and photo coordinates. If we have a pixel coordinate (u_{p1}, u_{p1}) of the left image, we can get (x_{p1}, y_{p1}) by transformation between pixel coordinates and photo coordinates. The epipolar line equation (8) always passes two points $(0, -\frac{Cf}{B})$, $(-\frac{Cf}{A}, 0)$, and also the epipolar line equation (12) always passes two points $(0, -\frac{C'f}{B'})$, $(-\frac{C'f}{A'}, 0)$. We can get the pixel coordinates of these points by transformation between photo coordinates and pixel coordinates. Then we can get the epipolar line equation represented in pixel coordinates.

3 PROPOSED MATCHING METHOD

The basic proceeding of the proposed method is composed of two separate steps: in the first stage we apply point matching, and in the next stage we perform line matching. The positions of matched points are used as a constraint to reduce the number of possible line matches.
Additionally we can get the approximate differences for each colour channel between corresponding regions in overlapping images for the matched point set. This serves as another supporting constraint for line matching. Concerning point matching the similarity between corresponding areas near the point is used as local consistency check, and the positional relation between possible neighbouring matched points is used as global consistency check. Concerning line matching the similarity in shape, the angle of the lines, the flanking regions' colour serve as local consistency check, and the relation between possible corresponding lines and neighbouring matched points serve as global consistency check. A scheme of the basic flow of the proposed matching method is shown in Figure 1.

3.1 Point Matching

First we generate points for matching by the Foerstner Interest Operator [Foerstner et al, 1987] for each image. As

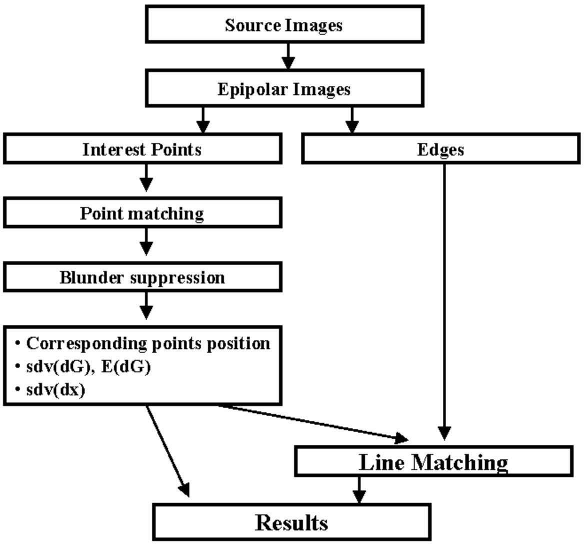

Figure 1. Basic flow of proposed matching method

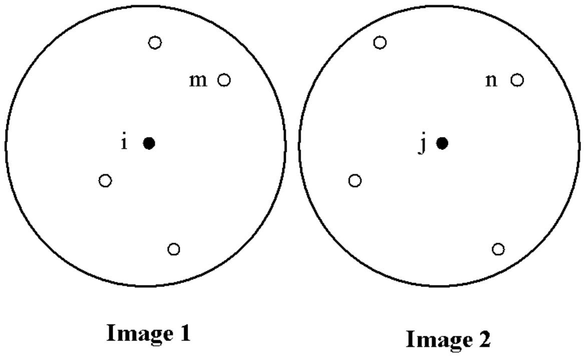

Figure 2. Neighbouring points in point matching

threshold of Interest Value w which is related with the contrast, we use a positive value of $w_{\lim}$, for example $w_{\lim}$ =1.0. We don't consider the value q which is related with shape. The reason of this is the line matching of the next step. In literature many methods for matching between Interest Points can be found [Foerstner et al, 1987;Zhang, 1994]. One simple method is the correlation coefficients method. To increase the reliability of matched points, we perform an additional check for the case when the template window and search window is reversed. If the result for each point pair matched is the same for both - normal case and reversed case-, it is accepted. This method is called back-matching [Hannah, 1989]. To improve the reliability we accept the case when both of the matched points are Interest Points. Till this stage the matching is performed with the images' gray values because of better performance. Through the above process we get possible matched points sets. Then we check the correlation coefficients between each matched point pair for each RGB colour channel. If any of correlation coefficients for each colour channel is less than 0.5, that point pair is rejected. Till this process we check the local similarity of areas near the points.

3.2 Blunder suppression to possible matched point set

Based only on the local similarity comparison, avoiding blunders is difficult. To solve this problem we check the global similarity between a possible corresponding point pair and its neighbouring possible corresponding point pairs.
Let two points of a possible corresponding pair be point i, and point j. We assume that there is a number M of neighbouring points near the point i, and point j. Suppose a point m, and its possible corresponding point n are near the point i, and point j as shown in Figure 2. The coordinates of point i, point j, point m, point n are (i_x, i_y), (j_x, j_y), (m_x, m_y), (n_x, n_y). We define a measure of Strength of Matching SM_{ij} for the pair of point i, point j as follows :

$$SM_{ij} = \frac{C_{ij} + \sum_{(m,n)} C_{mn} \dfrac{\exp(-abs(dx)/2sdv(dx))}{1+[(d(i,m)+d(j,n)]/2}}{1+\sum_{(m,n)} \dfrac{1}{1+[(d(i,m)+d(j,n)]/2}} \tag{14}$$

C_{ij} : correlation coefficient between point j and point j

C_{mn} : correlation coefficient between point m and point n

$d(i,m)$: distance between point i and it's a neighbouring point m

$d(j,n)$: distance between point j and it's a neighbouring point n

$dx = (i_x - m_x) - (j_x - n_x)$

This definition has empirical character. If the point pair relation between other point pairs is similar, SM_{ij} will be relatively high. If the relation is weak then SM_{ij} will be small compared to other point pairs.

Point pairs whose SM is lower than a threshold are eliminated, for example the pairs with lowest 5% in SM value.

3.3 Line matching

If we can reduce the number of candidate lines to be compared, we reduce the processing time and increase the possibility of finding corresponding line pairs. In line matching, firstly we reduce the number of possible candidate lines as described in the following: If the relation between any matched point and a pair of lines on both image is reversed like Figure 5, this case of line can be discarded. One line has two flanking regions see Figure 3. If a pair of lines is corresponding, then at least one flanking region of them is similar in each colour channel. So line pairs without any similar flanking regions can be rejected .

Because we can know the positions of many overlapping windows by matched point sets in previous stage, we know the approximate difference in each RGB colour channel value for whole corresponding regions using the matched points. We represent the differences as mean and standard deviation for each colour channel. We assume that the following case rarely happens for each colour channel.

$$|dGij - E(dG)| > 4*sdv(dG) \tag{15}$$

$dGij$: flank region difference between line i and line j

$E(dG)$, $sdv(dG)$: mean & standard deviation of corresponding region difference

If both flanking regions of a line pair fulfill the above case, then we can discard such a line pair in the comparison. We consider the line pairs which pass the test as two check points.

In the next step we calculate the similarity coefficient for the overlapping part between the lines for the local similarity comparison. There are many possible definitions for this similarity coefficient.

One simple definition is as follows. Suppose the coordinates of a point on the line of image i as (x_i, y_i), and its corresponding point as (x_j, y_j). Then $y_i = y_j$ without any rotation except through relief displacement in stereo epipolar imagery. The line similarity coefficient C_{sij} can be defined as

$$C_{sij} = \frac{\mathrm{cov}(x_i, x_j)}{\sigma_{x_i} \bullet \sigma_{x_j}} W_{cij} W_{nij} \tag{16}$$

W_{cij}: weight for the number of overlapping flanks. (e.g. $W_{cij} = 1$ when one of the line flanks is similar. And $W_{cij} = 1.5$ when both flanking regions are similar for every colour channel.)

W_{nij}: weight for the number of overlapping points between line i & j, i.e. the number which has same y coordinate each other between line i & j.

This above definition doesn't consider the effect due to slope in object space. This slope may be straight or curve. To simplify comparison, we suppose average slope in height. Suppose there is angle θ due to average slope like Figure 6. The bigger average slope in height is, the bigger the angle θ is.

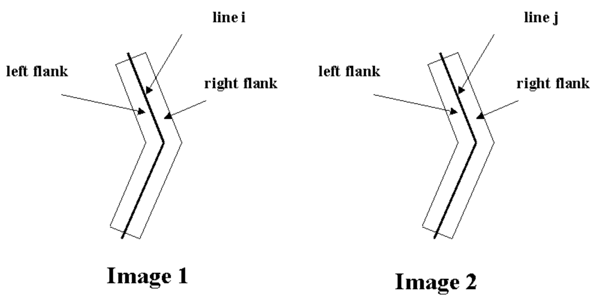

Figure 3. Flanking region of a line

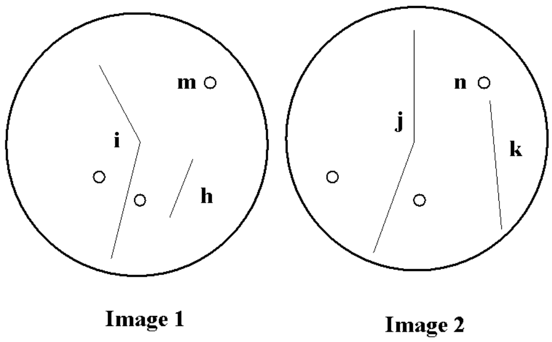

Figure 4. Neighbouring points and lines in line matching

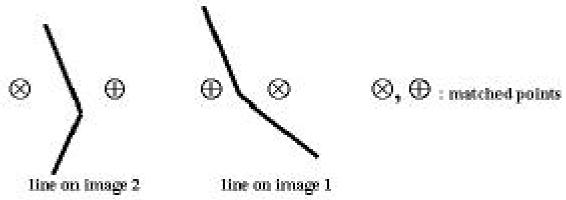

image 1 image 2

Figure 5. Suspicious corresponding point and line relation

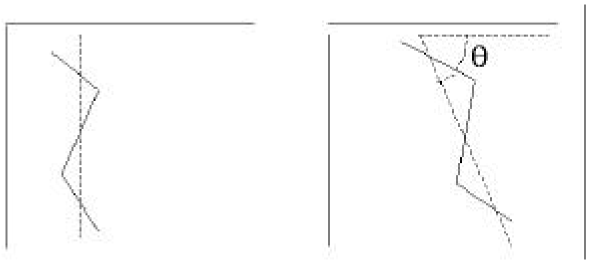

Figure 6. Angle due to average slope in height

Instead of x_j we can use x'_j which is modified by angle θ. The Angle θ may be related with relief displacement, and also may not be related with relief displacement. So we define C_{sij} as follow

$$C_{sij} = \frac{\mathrm{cov}(x_i, x_j)}{\sigma_{x_i} \bullet \sigma_{x'_j} \bullet \exp(\theta)} W_{cij} W_{nij} \tag{17}$$

And we reject the line in which the expression $\frac{\mathrm{cov}(x_i, x_j)}{\sigma_{x_i} \bullet \sigma_{x'_j} \bullet \exp(\theta)}$ is less than a certain threshold, for example <0.6.

Furthermore we reject the pairs which have less overlapping points than a threshold, for example <10.
Then we define the parameter Strength of matching SM_{ij} for line pairs as follows.

$$SM_{ij} = \frac{Wp \sum_{(m,n)} \frac{\exp(-abs(dx)/2sdv(dx))}{1+[(d(i,m)+d(j,n)]/2}}{\sum_{(m,n)} \frac{1}{1+[(d(i,m)+d(j,n)]/2}} + \frac{(1+W_{nij})(C_{sij} + \sum_h \sum_k \frac{C_{shk} \bullet w(i,j;(h,k))}{1+[(d(i,h)+d(j,k)]/2})}{1+\sum_h \sum_k \frac{1}{1+[(d(i,h)+d(j,k)]/2}} \tag{18}$$

(m,n): a pair of matched points
h, k: neighbouring possible candidates for corresponding lines near line i, j
Wp: weight for neighbouring matched point. For example Wp=7
C_{sij} : line shape similarity coefficient between line i and line j
C_{shk} : line shape similarity coefficient between line h and line k

$w(i,j;(h,k))$ is like a co-operative coefficient in [Gruen et al, 1998], which is related with the probability when a possible corresponding pair (i, j) and its neighbouring pair (h, k) exist at the same time. In this context we define it as follows.
If the relation between i, h and j, k is reversed, $w(i,j;(h,k))$ = -1.
And if i, h is connected and j is overlapping with both i and h, then $w(i,j;(h,k))$=1
And if j, k is connected and i is overlapping with both j, k then $w(i,j;(h,k))$=1.
And if i, h is connected and j, k is connected then $w(i,j;(h,k))$=1.
Other case $w(i,j;(h,k)) = \frac{\exp(-abs(dx))}{1+[d(i,h)+d(j,k)]/2}$

If we have a set of strength of matching parameters {$SM1_{ij}$} for lines in the left image, then we can easily get another set of strength of matching parameters {$SM2_{ij}$} for lines in the right image. {$SM1_{ij}$} and {$SM2_{ij}$} are symmetric. When we calculate $SM2_{ij}$, we only need to find a symmetric value corresponding to each $SM2_{ij}$ in the list of {$SM1_{ij}$}, and then assign it.
The next step is to find the matching pair using {$SM1_{ij}$} and {$SM2_{ij}$}. For each i in $SM1_{ij}$ we determine the pair which has the highest Strength of Matching value. One line can have two or more corresponding lines. So we choose all possible pairs with highest SMs which are not overlapping each other. We apply the same process with {$SM2_{ij}$}. If a

line pair is corresponding to another, then it will have a high probability concerning{ $SM1_{ij}$ } and { $SM2_{ij}$ }. So both results are consistent, and we select the pairs and continue with another set of pairs. We call this { P_j }. Then we discard P_j less than a threshold, for example the lowest 5%.We receive a final set of matched line pairs.

4 RESULTS OF TEST AND DISCUSSION

We tested the proposed matching strategy with the Avenches dataset described in [Mason et al, 1994]. We checked the results by human visual inspection with stereoscope. Figure 7 shows one example of our tests. We used the SE operator [Heitger, 1995] as edge detection operator. Our epipolar imagery generation using the proposed epipolar line equation was successful in all cases. Concerning point matching there was no blunder among 1050 matched point pairs when we set the mask size for the Foerstner Interest Operator W=5. Concerning line matching 323 line pairs were matched and no blunder was found. At least 2 pairs of lines are matched for each house. Generally the ridge line was matched. The use of previous matched point sets supported line matching useful. Available matched points reduced the number of candidate line pair in comparison to the case without previous matched points. So far the changing topology problem was not solved though our method although there is no blunders in matched line pairs. For example sometimes the roof line and the bottom line are seen as one line on one image, but has two separated corresponding lines in an other view. In this case it can happen that the roof line is matched to the bottom line or to the roof line. We need more studies to solve this remaining problem successfully.

5 CONCLUSIONS

In this paper we propose a new method which is useful for image matching, for DTM generation and house extraction. The proposed new epipolar line equation which is determined by orientation parameters is easy to implement and useful for epipolar line search and epipolar imagery generation. Concerning image matching two new ideas were proposed. One is blunder suppression to matched point pairs based on positional relationship between possible matched point pairs in point matching. The other one is the use of matched point sets as constraints for line matching in two ways - one to define position constraints and the other to define a colour similarity constraint for overlapping flanking regions. The matching strategy of combining line shape, flanking region similarity, positional and connectivity relationship between corresponding lines and corresponding points, corresponding lines and its neighbouring corresponding lines works fairly well with our test dataset. But there is still problem in solving the changing topology case. More thorough evaluation for various imagery and and search for a solution for the changing topology case will be continued in future studies.

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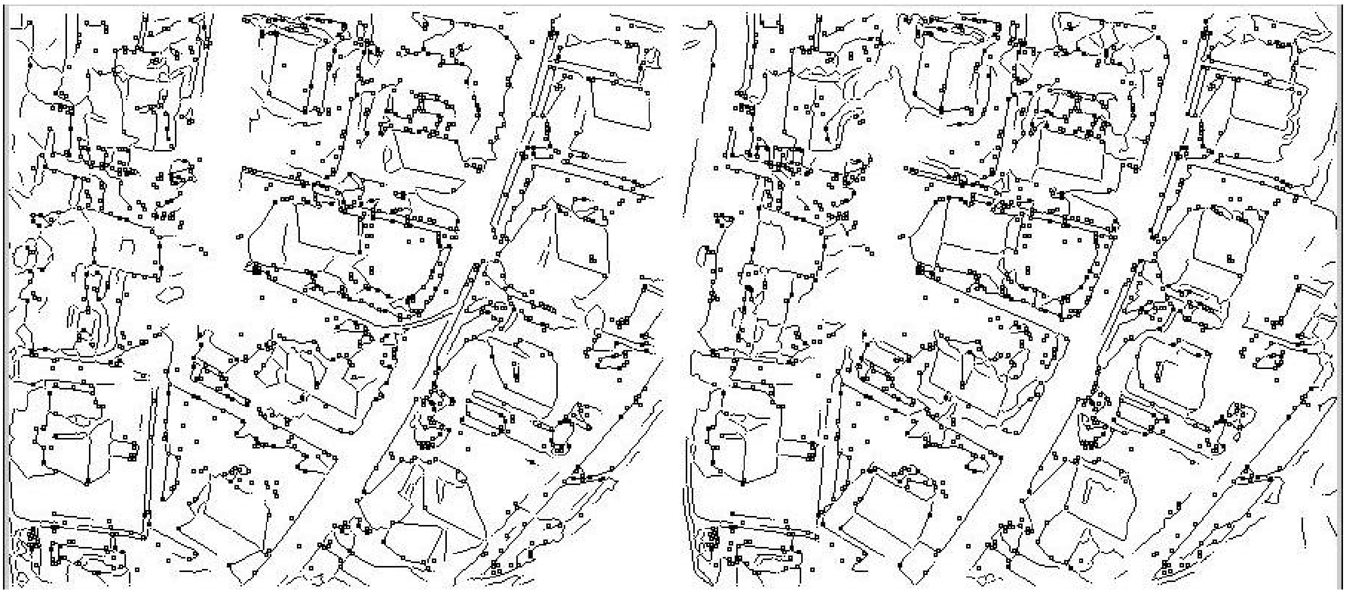
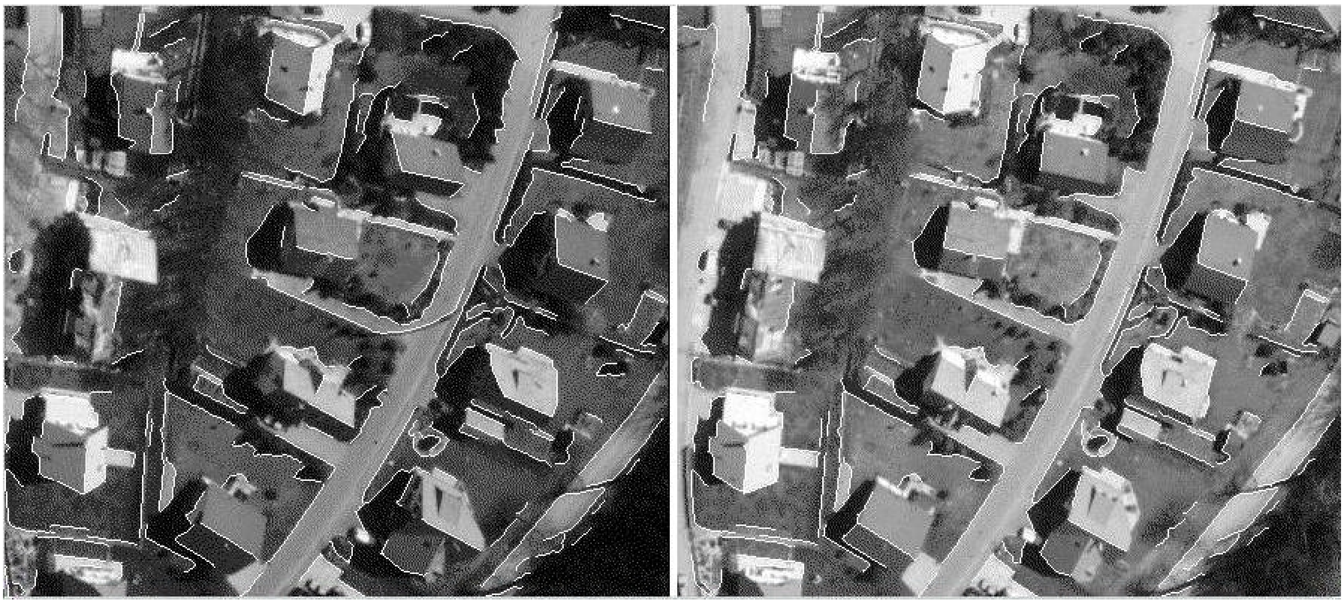


(a) edge lines and matched points set



(b) matched lines (white line)

Figure 7. Test results for Avench dataset