Accurate and Reliable Line Segment Matching Improvements in Oblique Image Processing

Min Chen¹,²,³,* Shaohua Yan² Shengzhi Huang² Qing Zhu²
¹National Engineering Laboratory for Surface Transportation Weather Impacts Prevention, Broadvision Engineering Consultants, China, 650041;
²Faculty of Geosciences and Environmental Engineering, Southwest Jiaotong University, Chengdu, China, 611756;
³Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, USA;
*COrrespondence: chenminzs@163.com

ABSTRACT

Accurate and reliable line segment matching plays an important role in oblique images processing and analysis. In recent years, as the vital procedure for exploiting line segments from images for solving photogrammetry and computer vision problems, line segments matching has received growing attentions from researchers and many matching methods have been proposed. Image rotation, scale change and short-baseline viewpoint change can be coped easily by some methods. However, for the more challenging transformation between oblique images, large viewpoint change, traditional line segments matching methods cannot obtain reliable matching results. Meanwhile, the weak texture around line segments in oblique images makes the matching more difficult. In order to overcome the aforementioned problems, the epipolar geometry and phase congruency are adopted in this paper to construct a reliable line segments matching method for oblique images. Firstly, line segments are detected from the image pair by using one state-of-the-art line segment detector. Secondly, a feature area localization method is proposed based on the constraint of epipolar geometry to break through the bottleneck of corresponding feature area computation under viewpoint change. Then, the phase congruency model is combined with image color information under the framework of orientation histogram to construct robust line segment feature descriptor. Finally, line segment matching is performed based on descriptor similarity and a hierarchical matching strategy. Experimental results show that the proposed method performs better than traditional methods for oblique images.

KEYWORDS: line segment matching, oblique image, epipolar geometry, phase congruency, hierarchical matching strategy

INTRODUCTION

Many manmade objects on oblique photogrammetric image, such as buildings, roads, can be described by using line segments. Line segment usually locates in object contour, which contains semantic and geometric information and can express the structure of object better. Besides, many line segments can be extracted from some areas with weak texture. It is difficult to compute point correspondences from this kind of areas. Therefore, line segment is a kind of good feature for oblique images matching. According to the constraint information used in the matching procedure, line segment matching methods can be mainly divided into three categories: geometric constraint based methods, local feature descriptor based methods and comprehensive methods by combining geometric constraint and local feature descriptor.

In traditional geometric constraint based methods, some simple geometric information of line segments, such as orientation, distance, length, repeatability and the nearest neighbor relationship are used to find correspondences. This kind of methods is applicable to image sequences and image pairs with narrow baseline (Woo et al., 2009; Chen et al., 2013a). In order to improve the matching reliability, epipolar constraint and trifocal tensor are introduced to constrain feature searching
space (Schmid et al., 1997, 2000). But the differences of endpoints and length between line segments from different images usually result in inaccurate searching area and produce false matches. To acquire more reliable matching results, multiple line segments are usually grouped and the geometric relationship within each group is used as constraints in the matching procedure (Wilson et al., 1997; Bay et al., 2005; Wang et al., 2009b; Ok et al., 2010; Al-Shahri et al., 2014; Yammine et al., 2014). Compared with those methods based on simple geometric information, this kind of method identifies the searching space more accurately and effectively. However, they are not able to acquire satisfied results when handling oblique images with large viewpoint variation. Some methods constructed geometric invariants to find line segment correspondences based on the geometric relationship between point and line segments (Fan et al., 2010, 2012; Chen et al., 2013b). This kind of method identifies the searching area more accurately and effectively. However, a large number of point correspondences should be known in advance. Besides, insufficient quantities or outliers in point matches affect the matching results. Other methods enhance the geometric constraints by introducing priori information, such as DSMs (Taillandier et al., 2004), LIDAR point cloud data (Habib et al., 2010) to improve the matching performance. But these methods are restricted in practical applications due to the requirement of priori information. Besides geometric information, grayscale information around line segment is usually used to describe and match line segment (Wang et al., 2009a; Verhagen et al., 2014; Wang et al., 2014; Li et al., 2016). Similar to point feature descriptor, a feature area around line segment is determined. Then, local variable information such as gradient magnitude, grayscale average and variance are calculated and added up to construct feature descriptor. This kind of method obtains good matching result when handling images with small viewpoint variation or plain image areas with rich texture. However, they are not suitable for oblique images because they directly define the rectangle or circular area around line segment as feature areas. Feature descriptors of correspondences constructed in these areas have low similarity. In recent years, the major trend of line segment matching method is concerned with the combination of geometric constraints with local feature descriptor (Ok et al., 2012; Zhang et al., 2013). This kind of method can acquire more reliable results than the two kinds of method mentioned before. However, the feature area is computed without geometric constraints, making these methods not robust to image viewpoint variation.

In this study, a line segment matching method for oblique images based on epipolar geometry constraint and phase congruency model is proposed. The main contribution of the proposed method is that a method to compute robust feature area for line segments from different oblique images with large viewpoint variation is proposed based on the epipolar geometry constraint. The remainder of this paper is organized as follows. The proposed matching method is described in detail in Section 2. Then Section 3 presents the experimental results, along with the detailed analysis and discussion. Section 4 concludes this paper by discussing the pros and cons of the proposed method and the possible improvements that can be made.

**METHODOLOGY**

In this paper, the matching process is carried out in the following four steps.

1. Line segments are detected from the input images using one state-of-the-art line segment detector LSD (Von Gioi et al., 2012).
2. Epipolar geometry is used to constrain the computation of feature area with image viewpoint invariance.
3. Phase congruency model is combined with the framework of orientation histogram to construct feature descriptor.
4. All detected line segments are classified into salient line features and general line features. A hierarchical matching strategy is proposed to match salient line segments and general line segments, respectively.

The proposed matching method is summarized in Figure 1.
Line Segments Detection

In this study, one state-of-the-art line segment detection method LSD is selected to compute line segments from the input images. Once line segments have been detected, they are classified into two categories: salient line segments and general line segments. The value of gradient magnitude is not the only criterion to evaluate the saliency of line segment, its spatial information is also used. The salient value of each line segment is computed as Equation (1):

\[ s = l^\alpha \cdot g^\beta \]  

Where \( l \) is the length of line segment. \( g \) is the average gradient magnitude of pixels on the line segment. \( \alpha \) and \( \beta \) are two parameters to control the relative importance between the length and the gradient magnitude. In each image, the \( H \) line segments with the greatest saliency are classified as salient line segments. The remaining line segments are regarded as general line segments. Accordingly, the matching procedure in the proposed method includes two steps: salient line segments matching and general line segments matching.

Feature Area Computation

After line segment detection, a feature area is assigned to each line segment. To make the feature area robust to large viewpoint variation between oblique images, the epipolar geometry is used to constrain the feature area determination.

For every two line segment, a line segment pair is constructed if their angle is larger than a threshold \( T_\theta \). The reason to set the angle threshold is that if the angle between two line segments is small, their intersection is far away and even out of the...
image, then the constraint of intersection will greatly decrease. After line segment grouping, for each line segment pair and their intersection on the reference image, the epipolar line of the intersection on the searching image is computed. Then, distances between the intersection of each line segment pair and the epipolar line on the searching image are calculated. Those line segment pairs with distance smaller than a threshold $T_d$ are saved, as shown in Figure 2.

![Figure 2](https://via.placeholder.com/150)

**Figure 2.** The epipolar constraint of intersection. (a) Reference image. $l_1$ and $l_2$ is a line segment pair. The red point $p$ is the intersection of $l_1$ and $l_2$. (b) Searching image. The red dotted line $e_p$ is the epipolar line of the intersection point $p$ on the reference image. $l_1^i$ and $l_2^i$ $(i=1,\ldots,n)$ are line segment pairs meeting the epipolar constraint of intersection.

After that, a repetitive rule is used to narrow down the searching scope further. This repetitive rule assumes that two corresponding line segments should have overlap. Therefore, for each line segment and its two endpoints on the reference image, its corresponding line segment on the searching image should locate between the two epipolar lines of the two endpoints, or intersects with at least one epipolar line as shown in Figure 3 (c)-(f).

![Figure 3](https://via.placeholder.com/150)

**Figure 3.** Repetitive rule. (a) Reference image. $l$ is a line segment with two endpoints $p_1$ and $p_2$. (b)-(f) are five examples describing the relationship between the line segment and epipolar lines on searching image. $l'$ is a line segment on the searching image to be tested whether it meets the repetitive rule. The two dotted lines $e_{p_1}$ and $e_{p_2}$ are the epipolar
lines of the endpoints of $l$. Among the five examples, (c)-(f) meet the repetitive rule in this study.

By performing the previous two constraints, many line segment pairs affecting the matching performance are eliminated. Then, for each line segment pair meeting the two constraints, a feature area is computed as follows:

Firstly, the epipolar lines of the four endpoints of each line feature pair on the reference image are calculated. In the searching image, a quadrilateral area is constructed for each line segment pair by using the two line segments and the four epipolar lines.

Then, the quadrilateral area is fitted to an ellipse according to Equation (2) (Teague, 1980):

$$\begin{align*}
    w &= \frac{\lambda_1}{m} \\
    l &= \frac{\lambda_2}{m} \\
    \theta &= \frac{1}{2} \arctan \left( \frac{2\mu_1}{\mu_2 - \mu_0} \right)
\end{align*}$$

(2)

Where $w$, $l$ and $\theta$ are the major axis, minor axis and orientation of the ellipse. $m$ is the zeroth order moment of the quadrilateral area. $U = [\mu_{20} \quad \mu_1 \quad \mu_2]$ is the secondary moment of the quadrilateral area. $\lambda_1$ and $\lambda_2$ are the eigenvalues of $U$. Each element of $U$ is computed as Equation (3):

$$\begin{align*}
    \mu_{20} &= \sum_{R} (x - x_c)^2 \cdot I(x, y) \\
    \mu_1 &= \sum_{R} (x - x_c) \cdot (y - y_c) \cdot I(x, y) \\
    \mu_2 &= \sum_{R} (y - y_c)^2 \cdot I(x, y)
\end{align*}$$

(3)

Where $R$ denotes the quadrilateral area. $(x_c, y_c)$ is the barycentric coordinate of the area. $(x, y)$ is pixel coordinate. $I(x, y)$ denotes the grayscale value of pixel in the area. In this study, all quadrilateral areas are regarded as binarization area, thus $I(x, y) = 1$.

Following that, an ellipse feature area is determined for each line segment by the ellipse parameter calculated from the quadrilateral area on the reference image and the searching image as shown in Figure 4.
Figure 5. Feature area computation. (a) Quadrilateral area construction. \(l_1\) and \(l_2\) is a pair of line segments on the reference image. \(p_1, p_2, p_3, p_4\) are the four endpoints of the pair of line segments. \(l_1\) and \(l_2\) is a pair of line segments in the searching area. \(e_{p_1}, e_{p_2}, e_{p_3}, e_{p_4}\) are the epipolar lines of \(p_1, p_2, p_3, p_4\), respectively. (b) Ellipse fitting of the quadrilateral area. (c) Feature area computation for line segment. (d) Feature area normalization.

Phase Congruency Based Feature Descriptor Construction

Most of the traditional line feature descriptors are constructed based on the pixel gradient of single grayscale image, which is not suitable to express the poor texture area on oblique images. False matching occurs in this situation as the feature descriptor is not distinctive. To address this problem, the color feature descriptor is constructed by using image multiband information. Meanwhile, as the phase congruency is invariant to contrast and could better express the poor texture compared with the gradient information, the color information and phase congruency model are combined to construct color feature descriptor. The detailed computation is carried out as follows:

Firstly, the phase congruency eigenvalue and direction values (Kovesi, 2003) of for each band of color image in the feature area are calculated and the direction value of each pixel is normalized to the line segment direction.

Secondly, each band image in the feature area is divided into several blocks, and each block contains several image cells. In each block and cell, the eigenvalue and direction values of phase congruency are counted and linked into a phase congruency orientation histogram. Then, a descriptor of each band is constructed based on the orientation histograms of those blocks and cells.

Finally, descriptors of all bands are fused and a color phase congruency feature descriptor is constructed.

Hierarchical Matching Strategy

The hierarchical matching strategy proposed in our previous work (Chen and Shao, 2013b) is adopted in this study. Firstly, salient line segments are matched according to the procedure mentioned above based on descriptor similarity. Secondly, a line segment clustering method is proposed to group general line segments. After the clustering, each general line segment is clustered into a corresponding salient line segment. Then, two networks based on the salient matches are constructed in the two images respectively. In the two networks, each group centered at one salient line segment is a subnetwork. General line segment matching is performed in the corresponding subnetworks by applying the same method as the salient line segment matching. This strategy accelerates the matching process substantially.

EXPERIMENTAL RESULTS

Experimental Dataset

In our experiments, two groups of oblique images are used to evaluate the performance of the proposed method, as shown in Figure 6 and Figure 7. The proposed method is compared with some state-of-the-art line segment matching methods, including MSLD (Wang et al., 2009a), LPI (Fan et al., 2012) and LJL (Li et al., 2015). The implementations of these methods were provided by their authors.
Figure 6. Experimental dataset 1: a pair of oblique images. Image size is 1024 × 1024 pixels. The ground sample distance (GSD) is approximately 0.08 m.

Figure 7. Experimental dataset 2: a pair of oblique images. Image size is 1024 × 1024 pixels. The ground sample distance (GSD) is approximately 0.08 m.

Matching results

In the experiments, parameters of all the aforementioned methods in our experiments are set as the recommendation of their authors. Two indicators, number of correct matches and matching precision (the ratio between number of correct matches and number of total matches), are used to evaluate the matching performance. The statistic results of these methods are summarized in Table 1.

Table 1 shows that the proposed line segment matching method obtains more correct matches and improves the matching performance significantly compared with other methods. Firstly, the proposed line segment feature area determination method is robust to the large viewpoint change between oblique images. Consistent image areas are detected for correspondence, which makes the descriptors of corresponding line segments have high similarity and generate correct matches. Secondly, phase congruency expresses weak texture better than grayscale gradient. The descriptor based on phase congruency has higher distinction than the descriptor based on grayscale gradient in weak texture, which makes the proposed method easier to distinguish correct matches and false matches in such area, like the surface of building. Finally, the hierarchical strategy used in the proposed method makes the matching more efficient and
accurate. Among the compared methods, MSLD produced the worst results in both datasets. This is because the feature area in MSLD is a fixed window which is unable to deal with the large viewpoint change between oblique images. LPI obtained better results than MSLD, but it is still unsatisfactory due to two reasons. Firstly, LPI requires point matches to help the matching of each line segments. However, it is hard to obtain many point matches between oblique images. Secondly, the line segment searching strategy based on similarity in LPI is not very robust to parallel line segment. LJL constructs line segment descriptor from image pyramids based on the relationship between the junction and the two line segments in a LJL to improve the invariance of the method. However, the circle feature area in the method is not robust to image viewpoint change. It produces false matches in the matching results. The line segment matching results of the proposed method are shown in Figure 8.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Method</th>
<th>Number of correct matches</th>
<th>Matching precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MSLD</td>
<td>75</td>
<td>70.09%</td>
</tr>
<tr>
<td></td>
<td>LPI</td>
<td>143</td>
<td>72.95%</td>
</tr>
<tr>
<td></td>
<td>LJL</td>
<td>165</td>
<td>75.32%</td>
</tr>
<tr>
<td></td>
<td>Proposed</td>
<td>274</td>
<td><strong>93.52%</strong></td>
</tr>
<tr>
<td>2</td>
<td>MSLD</td>
<td>104</td>
<td>67.53%</td>
</tr>
<tr>
<td></td>
<td>LPI</td>
<td>189</td>
<td>69.97%</td>
</tr>
<tr>
<td></td>
<td>LJL</td>
<td>277</td>
<td>81.88%</td>
</tr>
<tr>
<td></td>
<td>Proposed</td>
<td><strong>363</strong></td>
<td><strong>90.00%</strong></td>
</tr>
</tbody>
</table>
Figure 8. Matching results of the proposed method. (a) is the matching result of Dataset 1. (b) is the matching result of Dataset 2.

CONCLUSION

In this paper, we propose a line segment matching method for oblique images with large viewpoint change based on the constraint of epipolar geometry and phase congruency. The proposed feature area determination method obtains consistent feature area with similar image content for line segment correspondence under viewpoint change and makes the generated descriptors of corresponding line segments with high similarity. The line segment descriptor is constructed based on phase congruency which is robust to image illumination change and describe weak texture area better than traditional grayscale gradient and statistic information. The hierarchical matching strategy in the proposed method avoids unnecessary iteration and the interference of non-corresponding features, which improves the matching precision and efficiency. The experimental results demonstrate that the proposed method performs better than other state-of-the-art methods between oblique images.

ACKNOWLEDGEMENT

This work is supported by the National Key Research and Development Program of China (No. 2016YFB0502603 and 2016YFB0501403), the National Natural Science Foundation of China (No. 41501492 and 41631174), and Opening Research Fund of National Engineering Laboratory for Surface Transportation Weather Impacts Prevention, China (No. NELXX201601).

REFERENCES


