Robust Image Matching using Statistical Modeling and Geometric Similarity

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Abstract - We propose a robust image matching method using statistical modeling and clustering of geometric similarity between matching-pairs. Local feature matching is an uncertain process which may provide incorrect matches due to some causes that include among other factors, the uncertainty in feature location. Since the statistical modeling of the Log Distance Ratio (LDR) for outliers are significantly different from those of inliers. Although fast and efficiently, LDR has some weakness, especially related to the inability to take into consideration the uncertainty in the feature location and performance degrades when strong perspective transform. We add a method that clustering the similarity of geometric relationship. The proposed method robustly matches images, even with various kinds of transformation.

Keywords: Image Matching, Statistical Modeling, Geometric Similarity

1 Introduction

Image matching is a fundamental step for computer vision, such as object detection, recognition, tracking and augmented reality. This is mostly achieved relying on local feature computed in the neighborhood of detected features. Early research used neighbor-pixel information around the features. However, these methods may result in many incorrect matches, known as outlier. This is overcome by RANSAC [1], which is a good outlier-removal method. RANSAC has been adopted in many application, proving its effectiveness: nevertheless, it presents some well-known drawbacks, due to its iterative process, which results in significant computational complexity in existence of many outliers.

Recently the Log Distance Ratio (LDR) [2] is presented to detect outliers to a low-complexity through statistical modeling. It found that inliers have a specific ratio when LDR is calculated using feature coordinates. The effectiveness of the presented approach is adopted as the standard in Moving Picture Expert Group (MPEG) - Compact Descriptors for Visual Search (CDVS) [3]. Although fast and efficiently, LDR still presents some weakness, especially related to the inability to take into consideration the uncertainty in the feature location. Furthermore, performance degrades when strong perspective transform. To overcome the weakness in LDR, we present a method that clustering the similarity of geometric relationship.

In the following section, we briefly the LDR for outlier detection. Section 3 introduces the proposed robust image matching method.

2 The Log distance ratio statistic

Suppose that for a given two images the features have been found and matched (x₁,y₁), (x₂,y₂),...,(xᵣ,yᵣ), where xᵣ is the feature coordinates in the first images and yᵣ is the feature coordinates in the second image that is matched to xᵣ.

The LDR sets (Z) of all matching-pairs is given by the following:

\[ Z_{i,j} = \ln \left( \frac{||x_i-x_j||}{||y_i-y_j||} \right), Z = \{ z_{i,j} | i \neq j \} \quad (1) \]

where the symbol \( ||\cdot|| \) denotes the Euclidean distance. It may be observed that the LDR for inliers is distributed in a manner that is distinctively different to how the LDR for outliers and mixed pairs are distributed. This behavior is studied by first forming a histogram \( h(k) \) for these values, by counting the occurrences over each bin,

\[ h(k) = \#(Z \cap \zeta_k). \quad (2) \]

The bins \( \zeta_1, ..., \zeta_K \) are adjacent intervals. The inlier behavior can be expressed by the double inequality

\[ a \| x_i - y_j \| \leq \| y_i - y_j \| \leq b \| x_i - x_j \|. \quad (3) \]

where \( a \) and \( b \) define the boundaries of the LDR for inliers. The inliers would contribute to bins contained in \([-\ln b, -\ln a]\) which for most cases is a limited portion of the histogram. The outlier behavior is modelled and is express through a discrete probability density function, called outliers model function, as \( f(k) \). Exploiting this, the match between two images can be determined. Pearson’s good-of-fit test is used to compare \( h(k) \) and \( f(k) \). Equation 4 is used to compute this similarity. A greater value for \( c \) implies that the difference between \( h(k) \) and \( f(k) \) is large, and that the matching pair has numerous inliers.

\[ c = \sum_{k=1}^{K} \frac{(h_k - nf_k)^2}{nf_k} \geq \chi^2_{1-a,K-1}. \quad (4) \]

\( n \) is the total number of matching pairs, and \( \chi^2_{1-a,K-1} \) is the threshold of \( \chi^2 \) having \( K-1 \) degrees of freedom. It can see that the LDR of matching pairs is narrow with numerous inliers, and that a match can be rapidly identified by calculating this difference. The exact number of inliers can be estimated by solving the eigenvalue problem described in [2].
3 Clustering of inliers for similarity of geometric relationship

The LDR used just distance ratio between matching-pairs, so it includes the location uncertainty. We used a method of clustering inliers with similar geometric models. Letting two matching pairs be \( M_i \) and \( M_j \), transformations \( T_i \) and \( T_j \), and translations \( t \) can be calculated from each matching-pair, using the enhanced WGC method, as shown in Equation 5:

\[
\begin{align*}
X'_q &= s' \begin{bmatrix} \cos \theta' & -\sin \theta' \\ \sin \theta' & \cos \theta' \end{bmatrix} X_p \\
t &= \left| q'(x_q, y_q) - q(x_q, y_q) \right|.
\end{align*}
\]

\( s \) is scale, \( \theta \) is the dominant orientation. Using Equation 5, the matching-pairs can be expressed as \( M_i = (x_i, y_i), (x'_i, y'_i), T_i \) and \( M_j = (x_j, y_j), (x'_j, y'_j), T_j \) and the geometric similarity of the two matching-pairs is calculated using Equation 6:

\[
d(M_i, M_j) = \frac{1}{2} \left( \|X'_i - T_i X_j\| + \|X'_j - T_j X_i\| \right).
\]

where \( X_k = [x_k, y_k]' \), \( X'_k = [x'_k, y'_k]' \), \( k = i, j \). If transformation \( T_i \) and \( T_j \) are similar, \( d(M_i, M_j) \) will be close to zero. Using this relationship, it can be assumed that the matching-pairs with a small \( d(M_i, M_j) \) have a similar geometric relationship. Hierarchical clustering groups the clusters through linkages by calculating the similarity within each cluster. Figure 2 shows the matching results of hierarchical clustering based on geometric similarity between matching pairs. Hierarchical clustering finally forms a single cluster. Therefore, clustering must be stopped at some point. During the linkage of clusters, clustering is stopped when the geometric similarity of the matching-pairs exceeds a set threshold. However, if such a thresholding method is the only one used, the number of clusters becomes excessive, with most of the clusters likely being false. Therefore, clustering validation is used to remove false clusters. If the number of matching-pairs that form the clusters is too small, it is less likely that the resulting clusters become objects. Hence, two methods are used for clustering validation. First, if the number of matching-pairs that form the cluster is greater than \( r_m \). Secondly, if the area of the matching-pairs that form the cluster is larger than a certain portion of the entire area. The area of the matching pairs that form the cluster is calculated using a convex hull.

4 Experiments

In order to evaluate the performance of the proposed matching method, the Stanford Mobile Visual Search (SMVS) dataset [3]. (4,200 query images, total 12,800 images)

<table>
<thead>
<tr>
<th></th>
<th>TPR</th>
<th>FPR</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDR [2]</td>
<td>83.51%</td>
<td>6.41%</td>
<td>88.55%</td>
</tr>
<tr>
<td>Proposed [2]</td>
<td>89.78%</td>
<td>7.12%</td>
<td>91.33%</td>
</tr>
</tbody>
</table>

5 Conclusions

We have proposed a robust image matching using statistical modeling and clustering of geometric similarity. It may apply to various computer vision applications such as object detection, recognition and so on.

6 Acknowledge

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7 Reference

