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Efficient point pattern matching algorithm for planar point sets under transform of translation, rotation and scale

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ABSTRACT

Point pattern matching is an important topic in computer vision and pattern recognition, and finds many applications such as image registration, motion detection, object tracking and pose estimation. In this paper, we propose an efficient algorithm for determining correspondence between two planar point sets under transform of translation, rotation and scale. This algorithm randomly selects some points of a set and extracts their neighbor points. It views the selected points and their neighbor points as local point patterns, and finds the local matched patterns in the other set. Point pattern matching is finally achieved by counting the unique point number of those local matched point patterns with the same transform parameters. Many experiments are conducted to validate efficiency of the proposed algorithm. Running time comparisons with a well-known point pattern matching algorithm are also done and the results show that the proposed algorithm is faster than the compared algorithm.

1. Introduction

Point pattern matching is to find a good correspondence between two given point sets. It is an important topic in computer vision and pattern recognition, and has been widely used in image registration, motion detection, object tracking, automated visual inspection of flat objects, auto-navigation, pose estimation, and so on. Generally, the existing point pattern matching algorithms can be roughly classified into two categories in terms of the point numbers. One is the complete matching. This kind of algorithms handles the point sets with the same point number. The other is the incomplete matching also called partial matching. These algorithms are proposed to calculate the point sets with different point numbers.

Researchers have developed many theories and techniques for point pattern matching. For example, Griffin and Alexopoulos [1] calculated and aligned two pattern controids, constructed a bipartite graph, and achieved the complete matching by determining the maximal cardinality matching of the bipartite graph. Vinod and Ghose [2] viewed point pattern matching as a 0–1 integer programming problem, and exploited an artificial neural network to identify point sets under the transform of translation and rotation. Aiming at noisy point pattern matching, Morgera et al. [3] proposed a hybrid and iterative algorithm accommodating patterns from different dimensions. This algorithm uses singular value decomposition to estimate the rotation matrix and steepest-ascent to find the permutation matrix. Chang et al. [4] exploited 2-D clustering approach to design

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an efficient method for those point sets under the transform of translation, rotation, and scale. Wang and Chen [5] used intrinsic invariant properties of a line segment to design a pattern matching algorithm for point sets under affine transform. In [6], Chui and Rangarajan presented a robust incomplete matching method based on the softassign and the thin-plate spline, which can jointly estimate the correspondence and non-rigid transforms. In another study, Zhang et al. [7] gave a scheme combining a genetic algorithm with partial Hausdorff distance. This scheme is to solve incomplete matching problem under affine transform.

Van Wamelen et al. [8] designed an efficient algorithm with $O(n(\log m)^{3/2})$ time for planar point matching using probabilistic and sorted nearest neighbors, where n and m are the point numbers of two given point sets. In [9], Li et al. introduced a new similarity K-d tree method to establish a one-to-one match. Bishnu et al. [10] proposed a simple and deterministic method for 2-D point sets under translation and rotation. This method runs in $O(n^2\log n)$ time for complete matching and $O(mn^{4/3}\log n)$ time for incomplete matching. In [11], Yin used particle swarm optimization to calculate optimal transform between two point sets, where the transform parameters are encoded as a real-valued vector called particle. In [12], Caetano et al. gave graphical models based point pattern matching algorithm in Euclidean spaces of any dimension. This algorithm runs in a polynomial time and is provably optimal for complete matching between noiseless point sets. In another work, McAuley et al. [13] presented a novel graph with better performance than that of [12], and exploited it to find matched point sets. In [14], Li et al. proposed a dynamic segment-based hierarchical point matching algorithm for self-initialising articulated motion reconstruction from sparse feature points.

Recently, Bhowmick et al. [15] designed a novel data structure called "angular tree" for point pattern matching. In [16], Aiger and Kedem proposed an efficient algorithm for matching point sets under the transform of translation, rotation and scale. This algorithm takes the Hausdorff distance as similarity metric. In another work, Aiger and Kedem [17] designed a matching algorithm using a simple alignment scheme. This algorithm runs roughly in $O(n\log n + km\log n)$ time, where m and n are the point numbers, and k is the number of matched subsets between the point sets. Wang and Zhang [18] designed an algorithm for planar point sets under Euclidean transform. Their algorithm views a point set as a complete graph and then solves the point pattern matching problem by finding congruent complete graphs.

In this paper, we propose an efficient point pattern matching algorithm based on local point pattern determination, which is achieved by contrarotation. Our algorithm can find correspondence between two point sets under transform of translation, rotation and scale. Many experiments are conducted to show efficiency and advantages of our algorithm. The rest of the paper is organized as follows. Section 2 introduces the point pattern matching and Section 3 describes the proposed algorithm. Experimental results are presented in Section 4 and conclusions are finally drawn in Section 5.

2. Point pattern matching

2.1. Problem description

Let $\mathbf{P} = \{p_1, p_2, \ldots, p_n\}$ and $\mathbf{Q} = \{q_1, q_2, \ldots, q_n\}$ be a pair of matched point sets in a 2-D plane, where some points of $\mathbf{Q}$ are transformed from the points of $\mathbf{P}$. If coordinates of the points $(x, y) \in \mathbf{P}$ and $(x', y') \in \mathbf{Q}$ satisfy the formula of a transform T, they are a pair of matched points. In general, if the total number of the matched points between $\mathbf{P}$ and $\mathbf{Q}$ is bigger than a pre-defined threshold, $\mathbf{P}$ and $\mathbf{Q}$ are viewed as a pair of matched point sets. Otherwise, they are not a pair of matched point sets. In practice, matched points can be determined by calculating invariant of the T.

If the planar points (x, y) and (x', y') satisfy the following formula of the transform T_{TRS},

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} t_x \\ t_y \end{pmatrix} + s\begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \tag{1}$$

they are a pair of matched points under the transform of translation, rotation and scale, where θ is the rotation angle, s is the scaling factor, and t_x and t_y are the translations along x-axis and y-axis, respectively. If p_1 and q_1, and p_2 and q_2 are two pairs of matched points under T_{TRS}, the transform parameters can be calculated as follows. Let $(x_i^{(p)}, y_i^{(p)})$ and $(x_i^{(q)}, y_i^{(q)})$ be the coordinates of p_i and q_i, and $T_{\mathrm{TRS}}(p_i) = q_i$ $(i = 1, 2)$. Thus, we have the following results by substituting the coordinates of the matched points into the formula (1).

$$\begin{cases} t_x = x_1^{(q)} - x_1^{(p)} s\cos\theta + y_1^{(p)} s\sin\theta \\ t_y = y_1^{(q)} - x_1^{(p)} s\sin\theta - y_1^{(p)} s\cos\theta \\ \theta = \theta_{\overrightarrow{p_1p_2}} - \theta_{\overrightarrow{q_1q_2}} \\ s = \frac{|p_1p_2|}{|q_1q_2|} \end{cases} \tag{2}$$

where θ is the included angle between the vectors of $\overrightarrow{p_1p_2}$ and $\overrightarrow{q_1q_2}$. From the above analysis, we conclude that parameters of the transform of translation, rotation and scale can be uniquely determined by two pairs of matched points.