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Combining features for distorted fingerprint matching

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Extracting and fusing discriminative features in fingerprint matching, especially in distorted fingerprint matching, is a challenging task. In this paper, we introduce two novel features to deal with nonlinear distortion in fingerprints. One is finger placement direction which is extracted from fingerprint foreground and the other is ridge compatibility which is determined by the singular values of the affine matrix estimated by some matched minutiae and their associated ridges. Both of them are fixed-length and easy to be incorporated into matching score. In order to improve the matching performance, we combine these two features with orientation descriptor and local minutiae structure, which are used to measure minutiae similarity, to achieve fingerprint matching. In addition, we represent minutiae set as a graph and use graph connect component and iterative robust least square (IRLS) to detect creases and remove spurious minutiae close to creases. Experimental results on FVC2004 DB1 and DB3 demonstrate that the proposed algorithm could obtain promising results. The equal error rates (EER) are 3.35% and 1.49% on DB1 and DB3, respectively.

1. Introduction

Fingerprints are graphical patterns of ridges and valleys on the skin surface of fingertips (Maltoni et al., 2009), and the uniqueness of a fingerprint can be determined by the overall pattern of ridges and valleys as well as the local ridge minutiae (ridge ending and ridge bifurcation). Fingerprint recognition has been studied for many years and lots of algorithms have been proposed to improve the performance of automatic fingerprint identification system (AFIS). Minutiae-based matching algorithms are the most popular approaches to fingerprint recognition since it is widely believed that minutiae are the most discriminating and reliable features. Given two minutiae sets, minutiae matching is a complex combinatorial problem, because two fingerprints may be translated, rotated and especially nonlinear distorted with respect to each other, and both minutiae sets may suffer from false, missed, and displaced minutiae. Many researchers have tried to exploit assistant features to reduce the ambiguity between minutiae. Typical assistant features include ridge feature, local minutiae structure and local orientation feature.

Ridge feature is the first local feature introduced in fingerprint matching (Jain et al., 1997). Jain et al. (1997) utilized ridge information as an aid for alignment. In this method, for each minutiae pair (one from the input fingerprint, the other one from the template fingerprint), if their associated ridges were similar the input minutiae set was rotated and translated based on this minutiae pair. Minor modifications of this algorithm have been proposed to establish minutiae correspondence and reduce the computational cost (He et al., 2003; Luo et al., 2000). He et al. (2006) proposed a global comprehensive similarity-based fingerprint matching algorithm, in which minutia-simplex, including a pair of minutiae as well as their associated ridges, was employed to ensure positional constraint. This method obtained a good trade-off between matching performance and computational expense. Wang et al. (2007) proposed a feature called PolyLines to extract ridge information. Three transformation-invariant features were calculated for each ridge sampling point and ridge similarity was based on these features. However, all the features above seem not excellent in case of severe distortion. Ridge counts among matched minutiae pairs (Sha et al., 2006) are high discriminating feature and robust to distortion, but they are difficult to reliably extract in the presence of noise, and then are rarely used in automated systems (Yager and Amin, 2004).

Local minutiae structure, which consists of neighboring minutiae, is one of the most discriminative features used in fingerprint matching. Jiang and Yau (2000) and Jea and Govindaraju (2005) utilized k closest neighboring minutiae points to generate a fixed-length local minutiae feature for each minutia and the similarities between minutiae were based on these features. An advantage of the fixed-length feature is that the similarity between two feature vectors can be computed very fast. But it is sensitive to the order of the neighboring minutiae. Ratha

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et al. (2000) and Chen et al. (2006) adopted similar strategies by defining a feature vector which characterized the rotation and translation invariant relationship between a minutia and its neighbors circled within a radius. Feng (2008) extended this approach by transforming the input minutiae structure to deal with the occlusion problem and giving a specific formula to measure the similarity between two minutiae structures. Cao et al. (2009) modified this formula by taking the position and direction of the neighboring minutiae into account to make the minutiae structure similarity measure more accurate.

Orientation feature, which characterizes the ridge flow in fingerprints, is one of the fundamental statistical feature. It plays an important role in automatic fingerprint identification system (AFIS) process, since it is essential for not only fingerprint enhancement (Hong et al., 1998) but also fingerprint pattern classification (Maio and Maltoni, 1996) and fingerprint matching. The approaches presented in Tico and Kuosmanen (2003) and Tong et al. (2005) built transformation-invariant orientation feature vectors, which comprised the orientation distances of the sampling points surrounding a minutia and the minutia itself. The difference between them is the sampling strategy. Wang et al. (2007) proposed a feature called OrientationCodes, in which the ROI was circularly tessellated through several bands and sectors, and the orientation was estimated by least square error. Gu et al. (2006) and Qi et al. (2005) viewed the orientation field as a global feature and combined it with minutiae to match fingerprints.

However, there are still difficulties in fingerprint matching. Local features, such as orientation descriptor and local minutiae structure, are less sensitive to nonlinear distortion which is small in local region. Adding more local features can reinforce the individuality of fingerprints. However, fingerprints from different fingers may possess similar minutiae, orientation and ridge features in the overlapped region. Fig. 1 shows an example of a pair of fingerprints from FVC2004 DB3. In Fig. 1(c) the minutiae in the overlapped region possess similar local features. In this paper we proposed a novel feature called finger displacement direction which is extracted from fingerprint foreground to reduce the false matching resulted from similar local feature.

Ridges are easily interrupted by noise and local deformation will distort the ridge shapes largely. The length of a ridge may vary in different fingerprints and long ridge has larger variation than short ridge. Therefore, it is hard to select parameters to measure the similarity between ridges. And conventional ridge feature is hard to improve distorted fingerprint matching. A novel feature called ridge compatibility is proposed to deal with this problem. Different from convectional method, ridge compatibility is calculated by the singular values of the affine matrixes, which are estimated by pairwise ridge sampling points associated with matched minutiae.

In addition, we propose a graph-based algorithm to remove spurious minutiae resulted from creases since spurious minutiae degrade heavily the performance of fingerprint matching algorithms (as shown in Fig. 2). Then we combine the proposed two novel features with orientation descriptor and local minutiae structure to improve the matching performance. Experimental results on FVC2004 DB1 and DB3, in which the distortion between some fingerprints from the same finger is large, indicate that the proposed algorithm obtains promising results. The equal error rates (EER) are 3.35% and 1.49% on DB1 and DB3, respectively. Both of them can obtain the third place in FVC2004 ranked by EER.

The rest of the paper is organized as follows: Section 2 gives feature extraction and fingerprint representation. Section 3 presents the minutiae similarity calculation, minutiae pairing and matching score computation. The experimental results are reported in Section 4 and conclusions are drawn in Section 5.

2. Feature extraction

In this section, we will present the strategy to remove spurious minutiae close to creases and extract the features used by the matching algorithm. The orientation field of a gray-scale fingerprint image is computed by the approach proposed by Bazen and Gerez (2002). Foreground of fingerprint image is segmented by the approach in Chen et al. (2004). Then the method proposed by Hong et al. (1998) is used to enhance the image and obtain the thinned ridge map. Minutiae set $M=\{m_i=(x_i, y_i, \theta_i)\}_{i=1}^{n}$ is detected by Hong et al.'s (1998) method, where n denotes the number of detected minutiae, x_i y_i and θ_i denote the x coordinate, y coordinate and the direction of minutia m_i, respectively.

2.1. Spurious minutiae removing

From Fig. 2, we can obtain that the spurious minutiae resulted from a crease have the following characters: (i) The spurious minutiae from the same side of a crease possess similar direction. They are approximately distributed on a line and the distance between two neighboring minutiae is approximately equal to the ridge width. (ii) The nearest two spurious minutiae from different sides of a crease have nearly opposite directions, and the distance between them is approximately equal to the width of the crease.

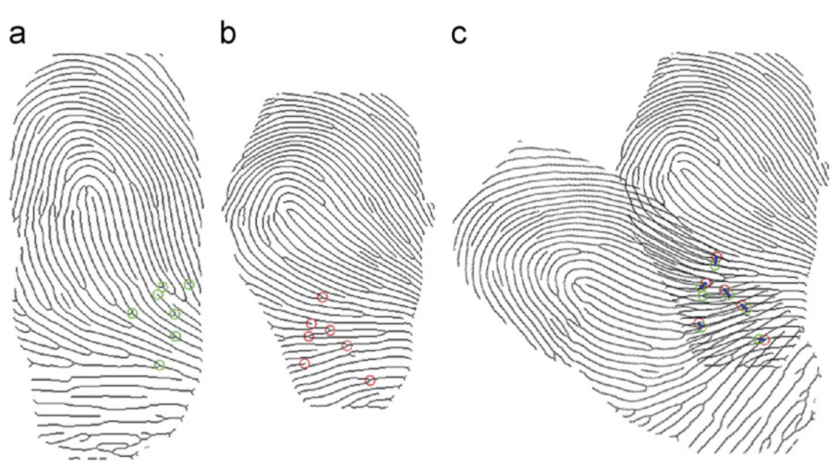

Fig. 1. An example of two fingerprints with similar local feature but different finger placement direction. (a) Skeleton image of 38_1.tif from FVC2004 DB3, (b) skeleton image of 89_1.tif from FVC2004 DB3, (c) registration of (a) and (b).