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Fingerprint orientation field reconstruction by weighted discrete cosine transform

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ABSTRACT

Orientation field represents the topological structure of the interleaved ridge and valley flows in fingerprint images. Although a number of methods have been proposed for orientation estimation, reliable computation of orientation field is still a challenging problem due to the poor quality of some fingerprints. This paper proposes a method to reconstruct fingerprint orientation field by weighted discrete cosine transform (DCT). First, the DCT functions are used to build the basis atoms for linear representation of orientation field. Then, the DCT basis atoms of low and high orders are combined with the weights determined by singularity measurements for orientation reconstruction. The weighted DCT model is further extended for partial fingerprints to gradually and iteratively reconstruct the orientations in noisy or missing parts of fingerprints. The proposed method can perform well in smoothing out the noise while maintaining the orientation details in singular regions. Extensive experiments have been done to compare the proposed method with some existing methods on NIST and FVC fingerprint databases in terms of the reconstruction accuracy of orientation field, fingerprint indexing performance, and fingerprint recognition accuracy. Experimental results illustrate the effectiveness of the proposed method in reconstructing orientation fields, especially for poor quality and partial fingerprints.

1. Introduction

With the increasing demand of information security, biometrics has been widely investigated for person recognition by using one or several physiological or behavioral characteristics such as fingerprint, face and iris [4,5,8,19,27,28]. Compared with other available biometric traits, fingerprint has several advantages, such as the convenience of data collection and high level of user acceptability [27]. The pace of developing fingerprint recognition technology has been accelerated tremendously in a wide range of areas from forensics to commercial services. Although a number of research efforts have been put on developing new feature extraction and classification approaches for improving fingerprint recognition performance, it is still a challenging problem to recognize fingerprints of poor quality, which are degraded by various factors such as dirt, scars and moist on the surface of fingertips.

As an important feature in fingerprint images, local ridge orientation is the angle at which the ridge crosses through an arbitrary neighborhood centered at one pixel, measured with respect to horizontal axis [27]. Fingerprint orientation field is composed of local ridge orientations estimated at discrete positions of fingerprint as shown in Fig. 1(b). It plays important

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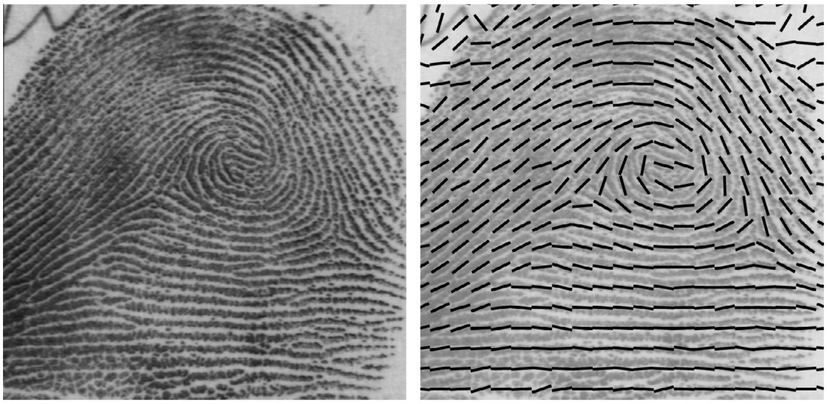

Fig. 1. (a) A gray-scale fingerprint image and (b) its orientation field.

role in fingerprint image enhancement [14,17], fingerprint classification [3,29], fingerprint indexing [16,22,36], and fingerprint matching [14,27], etc.

There have been a large number of research efforts towards the reliable estimation of fingerprint orientations [2,7,11,12,18,15], among which the gradient-based methods [2,7,12] are most popular. Such methods first compute the gradient vectors by taking the partial derivatives of gray values at each pixel, and then estimate the orientation by averaging the squared gradients in a local neighborhood. Although gradient-based methods can estimate the local ridge orientation with high efficiency and resolution, they are known to be sensitive to noise such as dirt, moist, creases and cuts. Hence, after obtaining the initial orientation field with the above methods, post-processing techniques such as smoothing and mathematically modeling are often applied to suppress the heavy noise. The post-processing methods are based on the observation that fingerprint orientation field is typically smooth except for a few singular regions. The smoothing-based methods apply the low-pass filters to smooth the noise-corrupted orientations. They are based on local constraint with limitation in dealing with heavy noise or missing patches in fingerprint, where local information is insufficient to yield a reliable estimation. In contrast, the model-based methods consider the global constraint to mathematically model fingerprint orientation field. These methods are able to overcome the limitations of smoothing-based methods and allow to interpolate the orientations in low quality regions [17,6,13,31].

A number of research efforts have been put on developing mathematical models to fit fingerprint orientation field. Sherlock and Monro [32] presented a zero-pole model, where fingerprint core and delta points are modeled as zeros and poles in the complex plane, respectively. This model is simple and almost perfect in describing the orientations near singular points, but it is poor in the regions far from singular points and fails on arch fingerprints which do not have singular points. Vizcaya and Gerhardt [34] hence modified the zero-pole model with a piecewise linear approximation model around singular points to adjust the influences of zero and pole. Gu and Zhou [10] proposed to describe fingerprint orientation field by a combination model, where a polynomial model was used to approximate the global orientation field while a point charge model was proposed to refine the orientations near singular points. A similar work was presented by Li et al. [20], which combined the piecewise linear model and the high order phase portrait model for the local and global descriptions of orientation field, respectively. All above orientation models require the prior knowledge of singular points to refine the orientation descriptions. However, successful detection of singular points is a nontrivial issue which depends on reliable estimation of orientation field [18,2].

Recently, in some new models, fingerprint orientation field was reconstructed without any prior knowledge of singular points [36,31,24]. Wang et al. [36] proposed a fingerprint orientation model based on 2D Fourier series expansions (FOMFE) which fits the orientation field using a set of trigonometric polynomials. They further extended the FOMFE model to reconstruct the missing orientations of partial fingerprints with the prior knowledge of ridge topology features [35]. Ram et al. [31] proposed to reconstruct orientation field using Legendre polynomials. The above models have been demonstrated to outperform the singular points dependent method in terms of fingerprint enhancement. However, the setting of the basis order plays important role in these models. If the order is set too low, noises can be well smoothed out but the true orientation structure in singular regions will be blurred. On the other hand, if the order is high, the model is able to describe the orientations in singular regions, but it retains the irregularities caused by noise also. Thus, it is still a challenging problem on how to simultaneously smooth out noise and retain the orientation contents in singular regions.

In this paper, we propose to reconstruct fingerprint orientation field by the weighted discrete cosine transforms (DCT). The DCT functions are utilized to compute the basis atoms for linear representation of orientation field. Instead of using a fixed order, we combine the DCT basis atoms of low and high orders with weights evaluated by singularity measurements. Large weights are assigned to the DCT atoms of high orders for reconstructing the orientations in singular regions. The