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Sparse coding based orientation estimation for latent fingerprints

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ABSTRACT

Fingerprint orientations are often used to describe the ridge flow patterns, providing useful features for further fingerprint processing and recognition. Although significant advances have been achieved for orientation estimation, it is still challenging to reliably estimate the orientations for latent fingerprints, which are usually of poor quality with unclear ridge structure and various overlapping patterns. Motivated by the recent success of sparse coding in image denoising and reconstruction, this paper proposes an orientation estimation algorithm based on dictionary learning and sparse coding for latent fingerprints. First, a texture image is obtained by decomposition of latent image with a total variation model. The structured noise is greatly reduced from the texture image. Second, we propose a multi-scale sparse coding method for iterative estimation of local ridge orientations on the texture image. Multi-scale dictionaries are learned from the orientation fields of good quality fingerprints to capture the prior knowledge of various orientation patterns, and sparse coding is iteratively applied with the increase of patch sizes to correct the corrupted orientations of latent fingerprint. The proposed algorithm can work well to reduce the effect of various noise and restore the corrupted orientations while maintain the details of singular region. Experimental results and comparisons on NIST SD27 latent fingerprint database are presented to show the effectiveness of the proposed algorithm.

1. Introduction

Fingerprint is a kind of human biometrics on finger tips, which have been widely used for personnel recognition in the commercial and forensic areas. According to different acquisition processes, fingerprints can be classified into three categories: rolled, plain and latent fingerprints. Fig. 1(a)–(c) show a sample of the rolled, plain and latent fingerprints, respectively. Different from the rolled and plain fingerprints, latent fingerprints are the finger skin impressions left at the surface of crime scene by accident. Usually, such impressions need to be processed and enhanced using some physical or chemical techniques for image acquisition [1]. Latent fingerprints have been used as an important evidence to identify criminals in law enforcement agencies for more than one century. They were manually matched against previously enrolled full (rolled or plain) fingerprints by latent examiners to find the suspects before introduction of automated fingerprint identification system (AFIS) [2,3]. After over thirty years of development, there are tremendous advances made on AFIS for full fingerprints [4–10]. However, compared to the rolled and plain fingerprints, latent fingerprints are usually of poor quality, caused by partial finger impressions, unclear ridge structure and various non-fingerprint overlapping patterns such as lines, printed letters, handwritings or even other fingerprints, etc. [11]. Although AFIS has achieved good performance for full fingerprints, there is a considerable performance drop when it is directly used for latent fingerprints. It is still a challenging problem for latent fingerprint processing and identification.

In recent years, some efforts have been made to improve the performance of latent fingerprint identification [12–17]. Arora et al. proposed a method to incorporate the top-down information or feedback from an exemplar to refine the features extracted from a latent for improving latent fingerprint matching accuracy. In addition, some methods have been proposed to improve the image quality of latent fingerprints to AFIS [13–17]. In these methods, the reliable estimation of local ridge orientation plays important role for enhancement and segmentation of latent fingerprint images. Fingerprint orientation estimation has been widely studied in the literature [18–21]. One popular method is based on the gradients, which 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 [18,19,22]. Although the gradient-based methods have the advan-

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(a) (b) (c)

Fig. 1. Three types of fingerprints: (a) rolled, (b) plain and (c) latent.

tages of high efficiency and resolution, they are known to be sensitive to noise such as dirt, moist, creases and cuts. A probabilistic method was proposed to use the short time Fourier transform (STFT) analysis for estimation of local ridge orientation [20]. Although this method can achieve more robustness, it still cannot work well for the heavy noise. Hence, after obtaining the initial orientation field with the above methods, post-processing techniques such as smoothing and mathematically modeling are further applied to suppress the heavy noise. The smoothing-based methods apply the low-pass filters to smooth the orientation fields. They are based on local constraint with limitation in dealing with heavy noise or missing patches, 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 [14,21,23–25].

The singular points (i.e., core and delta points) are important landmark points which determines the ridge flow structure of fingerprint. Some mathematical models have been proposed to use this information for reconstruction of fingerprint orientation field. Sherlock and Monro [23] 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 [24] 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 [26] 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. [27], 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 models require the prior knowledge of singular points to refine the orientation descriptions. However, successful detection of singular points is a nontrivial issue for latent fingerprints [18,28].

Instead of using the prior knowledge of singular points, some researchers proposed to model fingerprint orientation field as a fitting problem with a set of basis functions such as Fourier series, discrete cosine transforms and polynomials [10,21,25]. Wang et al. [21] proposed a fingerprint orientation model based on 2D Fourier series expansions (FOMFE) which fits the orientation field with a set of trigonometric polynomials. Ram et al. [25] proposed to reconstruct orientation field using a set of Legendre polynomials. The above mathematical models have been demonstrated to outperform the singular points dependent methods for reconstruction of orientation field. However, the setting of model parameters such as the basis order plays important role for reliable orientation estimation. If the basis 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 too high, the model is able to describe the orientations in singular regions, but it retains the irregularities caused by noise.

Although the above mathematical methods can achieve good performance for full fingerprints, they cannot provide satisfactory results for most latent images. A few of recent studies have focused on the computation of orientation fields for latent fingerprints [14–16]. A method was proposed for orientation field estimation with the manual markup of singular points [15]. The STFT method was applied to obtain multiple orientation elements in each image block, and a set of hypothesized orientation fields were generated with a hypothesize-and-test paradigm based on randomized RANSAC. Feng et al. [14] proposed a robust method to estimate orientation field using the prior knowledge of fingerprint ridge structure, which is represented by a dictionary of reference orientation patches and context information. In this method, the initial orientation field is computed with the conventional methods and divided into overlapping patches firstly. For each initial orientation patch, its six nearest neighbors in the dictionary are then viewed as possible candidates for replacing the noisy initial orientation patch. Finally, the compatibility between neighboring orientation patches is considered to find the optimal combination of candidate orientation patches based on minimization of an energy function using loopy belief propagation. Since the orientations at different locations of fingerprint have different characteristics, they further proposed a orientation field estimation algorithm based on a set of localized dictionaries [16]. In this method, the pose of fingerprint is estimated using a probabilistic voting algorithm and a set of localized dictionaries are learned from orientation patches sampled from a set of registered training orientation fields. Finally, the candidate orientation patches are found for each initial orientation patch by looking up the localized dictionaries. This method outperforms the orientation field estimation based on one global dictionary. However, it depends on the reliable pose estimation.

Although some research efforts have been made on the estimation of orientation fields for latent fingerprints, the performance is still far from satisfactory. One of the challenging problems is how to simultaneously smooth out noise and retain the orientation contents in singular regions. The dictionary based method has the advantage in adequately utilizing the prior knowledge of various orientation patterns. As a powerful statistical image modeling technique, sparse coding has been successfully used in various image processing and recognition applications [29–31]. Motivated by the recent success of sparse coding in image denois-