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Noisy and incomplete fingerprint classification using local ridge distribution models

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ABSTRACT

Fingerprint images acquired from live-scan devices may have various noises, such as cuts and smears and be incomplete due to shifted and partial scanning. We propose a novel fingerprint classification method that is able to effectively classify noisy and incomplete fingerprints, which are acquired by live-scan devices. Fingerprint images are divided into blocks of 16×16 pixels and representative directional values of each block are extracted. Based on the representative directional values, the core blocks including the core points are identified by core block Markov models. Then, fingerprints are divided into 4 regions with respect to the core blocks and each region is modeled with the distribution of the ridge directional values in its region. Fingerprint classification is carried out by using the regional local models. If a fingerprint is given, each local model determines the probabilities that the given fingerprint belongs to all the fingerprint classes. The final decision on the classification is made by probabilistic integration of the classification results of local models. Since the proposed method analyzes ridges based on blocks of 16×16 pixels and classifies based on regional local models, it can be robustly applied to noisy and incomplete fingerprint images. A performance evaluation based on the live scanned fingerprint databases FVC 2000, 2002, and 2004 shows a good classification accuracy of 97.4%.

1. Introduction

Fingerprint classification is a process of classifying fingerprints into predefined classes, according to the various features of fingerprints [1,2]. Such fingerprint classification has usually been conducted for successful user identification in large scale fingerprint recognition systems [1,3–5].

The features of fingerprints generally used in fingerprint classification are ridge directions and singularities of fingerprints. Singularities include core points where a large change in ridges occurs, and deltas where ridges flowing in three different directions meet [2,3]. Locations and number of such singularities and directions of ridges are important features of a fingerprint. Therefore, acquiring a clean and perfect image of a fingerprint is crucial for accurate classification. Unlike in the past, images of fingerprints are often acquired through live-scan devices with recent advances in the technology. Fingerprints acquired through a live-scan device yield quality that is less consistent than that of fingerprint images acquired through paper and ink [3,13].

Fig. 1 illustrates fingerprints of various qualities. Fig. 1(a) is a plain fingerprint acquired from paper and ink, and Fig. 1(b)–(e) are fingerprints acquired with a live-scan device. Compared with the image in Fig. 1(a), the images in Fig. 1(b)–(e) are of low quality. Ridges are cut in Fig. 1(b) and are smeared in Fig. 1(c). It is difficult to accurately detect singularities and ridge directions of fingerprints with such noise. Fig. 1(d) and (e) are incomplete fingerprints: a fingerprint shifted towards one side or a partial fingerprint. These fingerprints lose the ridge information of some parts of the fingerprints.

However, it is difficult to apply the existent approaches to such fingerprint images of various qualities. Most existent approaches were developed based on fingerprints acquired by paper and ink, of which the quality is rather consistent, and thus from which it is easy to obtain singularities and ridges information.

Existing fingerprint classification methods are categorized into singularity information based and ridge information based. Singularity information based methods extract core and delta points, and classify fingerprints based on the number and position of singularities with some additional information [1–4,9,23–25]. Since delta points are not easy to correctly extract, some researchers focused on the core point information which are relatively easy to obtain [10,11,15,22]. In order to apply these methods, singularities should be correctly extracted from fingerprints. So, fingerprint images need to be neat and clean.

Approaches based on ridge information extract directional values from pieces of ridges and construct a ridge flow model from the directional values [5–8,12–14]. Since the directional values of ridges are easier to extract than singularities, these approaches are more robust than singularity information based approaches. However, if

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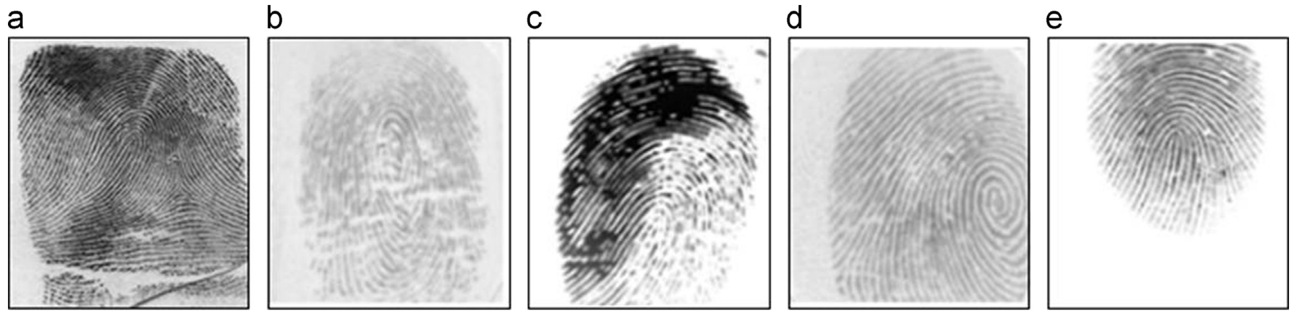

Fig. 1. Fingerprints of various qualities: (a) plain, (b) cut, (c) smeared, (d) shifted, and (e) partial.

the overall flow information of ridges cannot be analyzed owing to cut and smeared ridges or partially scanned (incomplete) fingerprints, the accuracy can be degraded.

Those approaches are developed for fingerprint images that are complete and of good quality. If those methods are applied to fingerprint images that are incomplete and of low quality, which are frequently acquired by live-scan methods, such as Fig. 1(b)–(e), the classification performance may not be acceptable.

We propose a novel fingerprint classification method that is applicable to fingerprints with various noises, such as cuts and smears, and in an incomplete state, due to shifted and partial scanning. These imperfections are often acquired from live-scan fingerprint acquisition methods.

In the proposed method, fingerprint ridges are analyzed not by pixel units but by block units, to minimize the distortion of ridge information caused by noise. The whole image of a fingerprint is divided into blocks of 16×16 pixels. The ridges in each block are analyzed and representative ridge directional values of blocks are extracted. Since ridges are analyzed by blocks, our method is more robust to noise, than the methods that analyze every ridge. In order to properly handle incomplete (shifted or partial) fingerprints, the proposed method first finds the core block including the core point of a fingerprint based on the representative directional values of blocks. A fingerprint image is divided into 4 regions by the core block, and the distribution of ridge directional values of each region is compared with the model of the corresponding region of each fingerprint class. Based on the classification results of each region model, the final decision on the classification is generated by probabilistic integration. Since the proposed method is based on regional local models, it can be robustly applied to incomplete fingerprint images. Even though the ridge information of a region is not obtainable, it is possible to flexibly perform fingerprint classification using the information of the other three regions because each region has the characteristics of its class.

FVC 2000, 2002, and 2004 fingerprint databases of various qualities and completeness were used to evaluate the performance of the proposed method. The proposed method yielded an average classification accuracy of 97.4%, regardless of the quality and completeness of fingerprints.

Section 2 describes the related research on the conventional fingerprint classification approaches, and Section 3 proposes a probability based fingerprint classification model using regional patterns. Section 4 presents classification results and analyzes the performance with respect to the qualities and states of the fingerprints. Finally, Section 5 concludes the paper.

2. Related work

The existing approaches of fingerprint classification can be roughly categorized into singularity information based methods [2–4,9–11,22–25] and ridge information based methods [5–8,12–14].

Singularity information based methods extracted singularities from fingerprints and performed fingerprint classification based on the information of singularities. Srinivasan et al. [2] and Weng et al. [3] classified fingerprints using the locations of singularities or the distances between them. Feng et al. [4], Liu et al. [9], Li et al. [24], Guo et al. [23] and Msiza et al. [25] proposed more elaborate approaches. Feng et al. analyzed the relation between the positions of singularities by a symmetrical axis; Liu et al. and Li et al. computed the orientation information of ridges by the singularities; and Msiza et al. classified fingerprints by using the relationship between singularities and coordinate geometry. Guo et al. [23] defined a set of rules to describe each class using the positions and the numbers of singularities.

Even though delta points in singularities play an important role in fingerprint classification, they are difficult to accurately extract from fingerprint images owing to noise, and easy to miss because delta points are usually located on the bottom of fingerprints. Therefore, some researchers proposed methods that extracted only core points and classified fingerprints with ridge information around the core points. Wang et al. extracted a core and classified fingerprints using curvature and ridge directions adjacent to the core point [10]. Jain et al. divided a fingerprint into several sectors by the core point, extracted direction characteristics of each sector, and performed the classification using the directional information [11]. Ou extracted a core point that was the center of a fingerprint, divided the fingerprint image by the coe point, and classified the fingerprint using HMM [15]. Bhuyan et al. [22] generated numeric code sequences from the ridge flow patterns with respect to core points, and built fingerprint classification model by applying a clustering algorithm. Since core points and the ridge patterns around those usually have distinctive information of each class, the approaches showed relatively good performance.

For singularity information based approaches, it is crucial to accurately extract singularities. If singularities are not accurately extracted, the performance may be degraded. Fingerprints scanned by a live-scan device can be of low quality or incomplete, and thus it is not easy to accurately extract singularities. So, singularity based approaches may not be proper for classification of fingerprints scanned by live-scan devices.

Approaches based on ridge information classified fingerprints using the flow information of ridges. Karu et al. constructed ridge models using the ridge flow information of each class, and extracted rule sets from the ridge models to classify fingerprints [6]. Chang et al. extracted geometrical patterns of ridges using ridge flow directions and built models of fingerprint classes by integrating the patterns [12]. Henry expressed fingerprint images as strings with the named patterns of ridge changes and classified fingerprints by the string matching of each fingerprint [5]. However, when undefined patterns appeared in the fingerprints, such methods that defined the patterns of ridge flow for fingerprint classification failed to classify a fingerprint. In order to resolve this problem, some approaches were proposed, based on the intersection points of