Image Analysis Techniques for Fingerprint Recognition

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Abstract

Fingerprint recognition is a method of biometric authentication that uses pattern recognition techniques based on fingerprints image of the individual. Fingerprint patterns are full of ridges and valleys and these structures provide essential information for matching and classification. The steps for fingerprint recognition include image acquisition, preprocessing, feature extraction and matching. A number of pattern recognition methods have been used to perform fingerprint matching. In this paper a survey of fingerprints matching methods are presented, they have been classified into approaches based on minutiae, image transform and hybrid approaches, among them minutiae based methods are widely used, and Hybrid methods are used for more reliable matching with an additional computational cost. Comparison and contrasting of all these methods reveals that a lot of emphasis is put into the design of accurate fingerprint features extractor to improve the classification accuracy.

Keywords- Fingerprint analysis, Biometrics, Minutiae, Image Transforms, Gabor filter

1. Introduction

Biometrics recognition refers to the use of distinctive anatomical and behavioral characteristics or identifiers such as Fingerprints, Face, Iris, Voice, Hand geometry etc. for automatically recognizing a person. The human biometrics recognition technologies are not only rapidly developed but also widely applied to a variety of works such as safeguarding work, legal affairs, personnel authentication, personnel identification, etc.

The advantages of biometric recognition are :1)users do not need to memorize any password,2) users do not need to carry any identification card, 3) users cannot deny their biometric identifications, and 4) reduction in a large amount of expenses on making personal ID cards or relative documents. Among all the biometrics, fingerprint is the most mature and proven technique. A fingerprint is a pattern of ridges and valleys on the surface of the fingertip.

The formation of fingerprints depends on the initial conditions of embryonic development, and their ridge pattern is unchanged throughout the entire life. Both the immutability and the uniqueness properties have determined the use of fingerprint matching as one of the most reliable techniques of people identification [1]. A biometric system can be operated in two modes:1) verification mode and 2) identification mode. A biometric system operating in verification mode either accepts or rejects user claimed identity while a biometric system operating in the identification mode establishes the identity of the user without claimed identity information.

The steps in fingerprint recognition include image acquisition, preprocessing, feature extraction and matching. A fingerprint is the pattern of ridges and valleys on the surface of fingertip. Ridges and valleys of the fingerprint often run in parallel and sometimes they bifurcate and sometimes they terminate. The fingerprint pattern, when analyzed at different scales, exhibits different types of features.

The paper is organized logically into seven parts: Section II and III discuss fingerprint features and gives brief overview of minutiae based matching methods respectively. Section IV discusses the methods based on image transforms. Section V deals with Hybrid methods. Section VI reports comparisons and VII indicates conclusions.

2. Fingerprint Features

The ridge details of the fingerprint are generally described in a hierarchical order at three different levels i.e., level 1, level 2 and level 3 as explained below.

2.1 Level 1 features

At the global level, the ridge line flow delineates a pattern similar to one of those shown in Figure 1. Singular points, called loop and delta (denoted as squares and triangles, respectively in Figure 1), act as control points. Singular points and coarse ridge line shape are useful for fingerprint classification and indexing, but their distinctiveness is not sufficient for accurate matching.

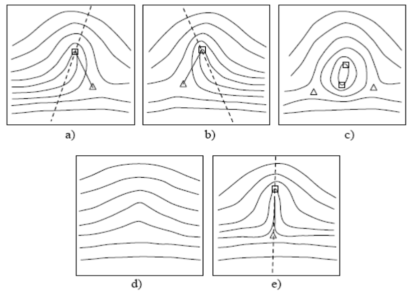

Figure1. Loop and delta (singular points)

2.2 Level 2 features

At the local level, a total of 150 different local ridge characteristics, called minute details, have been identified so far [1]. These local ridge characteristics are not evenly distributed. Most of them depend heavily on the impression conditions and quality of fingerprints and are rarely observed in fingerprints. The two most prominent ridge characteristics, called minutiae (see Figure 2) are: ridge endings and ridge bifurcations. A ridge ending is defined as the ridge point where a ridge ends abruptly. A ridge bifurcation is defined as the ridge point where a ridge forks or diverges into branch ridges. Minutiae in fingerprints are generally stable and robust to fingerprint impression conditions.

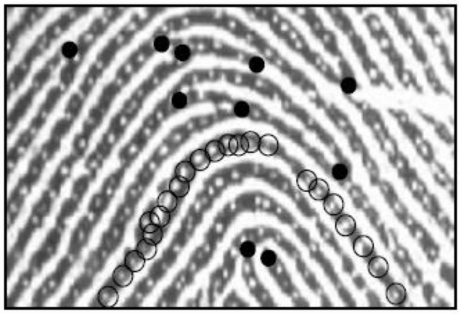

Figure2. Minutiae and sweat pores

2.3 Level 3 features

At the very-fine level, intra-ridge details can be detected. These include width, shape, curvature, edge contours of ridges as well as other permanent details such as dots and incipient ridges. One of the most important fine-level details is the finger sweat pores (see Figure 2), whose positions and shapes are considered highly distinctive [2]. However, extracting very-fine details including pores is feasible only in high-resolution (e.g., 1,000 dpi) fingerprint images of good quality and therefore this kind of representation is not practical for non-forensic applications.

The uniqueness of a fingerprint can be determined by the overall pattern of ridges and valleys and local ridge anomalies. Although fingerprints possess the discriminatory information, designing a reliable automatic fingerprint matching algorithm is a very challenging. As fingerprint sensors are becoming smaller and cheaper, automatic identification based on fingerprints id is becoming more attractive alternative, complement to traditional methods of identification. The critical factor in the widespread use of fingerprints is in satisfying the performance (e.g., matching speed and accuracy) requirements of emerging civilian identification applications.

Various approaches of automatic fingerprint matching have been proposed in the literature. They include correlation based, minutiae based approaches, and image-based approaches as the most prominent classes of fingerprint matching methods.

Fingerprint matching depends on the similarity measure between representative features of fingerprints. Generally, fingerprint recognition is based on a set of relevant local characteristics, such as ridge ending and bifurcation (minutiae). Fingerprint classification is based on fingerprint global features, such as core and delta singularity points. Minutiae-based matching algorithms are the most well-known and widely used for fingerprint matching. For each minutia three features are usually extracted: type, coordinates and orientation. Generally, fingerprint matching is affected by some common problems: too small regions of interest, loss of genuine minutiae, and false minutiae detection. Many approaches have been developed to deal with these issues. Following sections will briefly summarize the most effective solutions.

Many approaches to fingerprint recognition have been presented in the literature. Yet, it is still an actively researched field. Existing approaches can be summarized into four different categories: Minutiae based methods, approaches based on filter, image transform based approaches, hybrid approaches and others. However, many new approaches sprouting out are mainly beyond categorization or a combination of the categories. The steps for fingerprint recognition include image acquisition, preprocessing, feature extraction and matching.

2.4 Performance metrics

Commonly used performance metrics are percentage of recognition accuracy, speed, percentage of False Acceptance Ratio(FAR) and percentage of False Rejection Ratio(FRR) and Receiver Operating Characteristics(ROC) curves. FAR is the probability that the system incorrectly matches the input fingerprint to a non-matching template in the database. It measures the percent of invalid inputs which are incorrectly accepted. FRR is the probability that the system fails to detect a match between the input fingerprint and a matching template in the database. It measures the percent of valid inputs which are incorrectly rejected. ROC plot is a visual characterization of the trade-off between the FAR and the FRR.

3. Brief Overview of Minutiae Based Matching Methods

Minutiae based techniques are most widely used automatic fingerprint recognition techniques. These first locate the minutiae points and then match their relative placement in a given finger and the stored template. Minutiae are the local ridge anomalies – ridge bifurcation or ridge endings etc., [5].The most common minutiae are shown in the Figure 3.

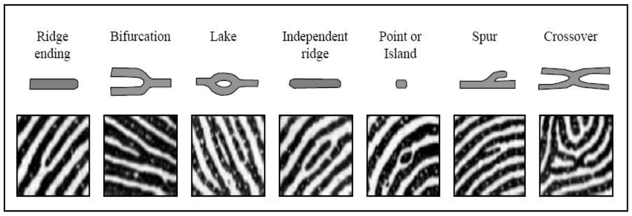

Figure3. Seven most common minutiae

A majority of the existing fingerprint recognition algorithms are based on matching minutia features. Therefore, minutiae extraction is one of the critical steps in fingerprint verification algorithms. Due to different properties of fingerprint sensors and different conditions under which a fingerprint is scanned, the quality of a fingerprint image can vary greatly. Poor quality fingerprint images lead to missing and spurious minutiae that degrade the performance of the matching system.

Minutiae extraction algorithms [5] produce a large number of spurious minutiae such as break, spur, bridge, merge, triangle, ladder, lake, island, and wrinkle, as shown in Figure 4. Therefore, reliably differentiating spurious minutiae from genuine minutiae in the post-processing stage is crucial for accurate fingerprint recognition. The more spurious minutiae are eliminated, the better the matching performance will be. In addition, matching time will be significantly reduced because of the reduced minutiae number. This is very important since the execution time is a critical parameter in an automatic fingerprint recognition system. Lot of emphasis is given to minutiae post processing techniques.

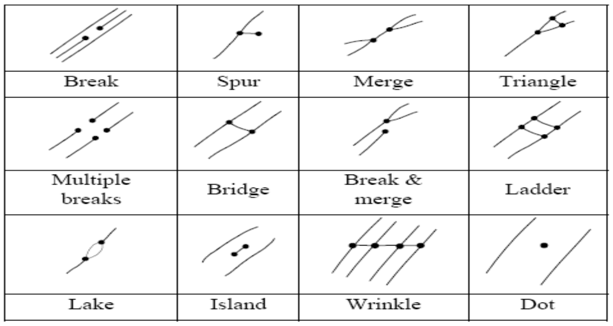

Figure4. Examples of spurious minutiae

Researchers have proposed ideas to reduce spurious minutiae. Paper [3] presents a set of algorithms for the extraction of minutiae from skeletonized binary images which perform well on dirty areas and spurious minutiae are reduced by bridge cleaning based on ridge positions. Several post-processing techniques to efficiently remove spurious minutiae including bridge, triangle, ladder, and wrinkle all together are proposed in [4], the experimental results showed that false minutiae rate drops 56.5% after post-processing. Approaches based on neighborhood information are dealt in [5] where matching of two fingerprints is done based on minutiae neighborhood information using directionally selective steerable wedge filters, and Gabor expansion. The area around the core point is treated as the area of interest for extracting the minutiae features as there are substantial variations around the core point as compared to the areas away from the core point. Paper [6] considered the probability distribution of minutiae and achieved classification accuracy of 86.57%.

Authors of paper [7] have combined texture information and neighboring minutiae to obtain a descriptor which is used for minutiae matching. Paper [8] presents a concept of Eigen-codebook for the minutiae verification mechanism of fingerprint image. Principal component analysis (PCA) is applied to find the optimal projection bases for true minutiae regions and false minutiae regions.

Minutiae are difficult to be extracted robustly in low quality images and easily lead to false recognition, to effectively strengthen the performance of fingerprints matching other discriminatory features can are combined with minutiae feature. In [9] minutiae features and their invariant moments are used as a feature set to match the template and input fingerprint. Paper [11] introduces a fingerprint matching algorithm using both ridge features (ridge count, ridge length, ridge curvature direction, and ridge type) and the minutiae feature to increase the recognition performance against nonlinear deformation in fingerprints. Paper [10] proposes an algorithm which divides fingerprint images into two concentric circular regions – inner and outer – based on the degree of distortion. The algorithm assigns weightages for a minutiae–pair match based on the region in which the pair exists. Minutia extractor is built in [12], minutia marking is done by the average inter-ridge width, minutia unification by decomposing a branch into three terminations and matching in the unified x-y coordinate system and in combination alignment based elastic matching algorithm used which is capable of finding the correspondences between minutiae without resorting to exhaustive research.

Many other approaches exist in the literature - paper[13] introduces a method of robust minutiae matching based on comprehensive minutiae and binary relation between minutiae; paper [14] proposes a method of minutiae extraction considering additional attributes like orientation field and quality map. Minutiae scoring technique is introduced in [15] for fingerprint; paper [16] presented a method of feature extraction using minutiae spectral features; paper [17] has presented a method of fingerprint matching based on five nearest neighbors of center minutiae in the first stage and second stage matching is based on fuzzy logic. Gabor basis functions are used to extract discontinuous points in the fingerprint image and classify the points into core, deltas and minutiae in [18].

4. Methods Based on Image Transforms

Minutia based approaches are the most popular ones being included in almost all contemporary fingerprint identification and verification systems. Although rather different from one other the minutiae-based approaches require extensive preprocessing operations in order to reliably extract the minutia features. The preprocessing operations include image enhancement, orientation flow estimation, ridge segmentation, ridge thinning, and minutiae detection. In addition, a minutiae purification stage is also required in order to reduce the number of false minutiae erroneously detected in noisy fingerprint images. Image-based approaches do not use the minutiae features for fingerprint matching. They are usually applied directly onto the grayscale fingerprint image without pre-processing, and hence they may achieve higher computational efficiency than minutiae- based methods. In addition, the image-based approaches may be the only choice to match fingerprints which have too low image quality to allow reliable minutiae extraction. The main disadvantage of image-based approaches consists in their limited ability to track with variations in position, scale and orientation angle. Usually the variation in position between the two fingerprints is cancelled by choosing a reference point in each fingerprint. Such reference point may be the core point which can be detected using for example methods like those proposed in [23]. Image based approaches include methods based on optical correlation and transform based features**.** The following papers discuss mainly on image transform based methods.

Fingerprint recognition based on features extracted from the wavelet transform of the discrete is image is achieved in [19] [21]. A rectangular region around a core point is cropped and wavelet transformation is applied, the energy of different sub bands give information regarding the ridge spatial frequency as well as the ridge orientation and this information is represented based on standard deviation of each wavelet sub image. [20] proposed an algorithm for fingerprint identification using wavelet packet analysis as best basis selection. Each fingerprint is decomposed using two directional wavelet packet family corresponding to different scales. The energy distribution or the fingerprint in each sub band is extracted as a feature for identification. Critical wavelet coefficients are selected to form a feature vector of the fingerprint. In [22] algorithm based on the wavelet transform, and the dominant local orientation which is derived from the coherence and the gradient of Gaussian. Multiresolution descriptors for fingerprint recognition are presented in [23]. Firstly it computes the Discrete Fourier Transform (DFT) for the given fingerprint image then transform it to polar coordinate (r, θ□) using the centre of mass of the pattern as origin, then apply the Fourier transform along the axis of polar angle θ and the wavelet transform along the axis of radius r. The features thus obtained are invariant to translation, rotation, and scaling. Haar wavelet decomposition [24] is taken on the fingerprint images and then, after the decomposition, the matching is carried out over the Gabor features extracted from the detailed sub-images. [27] Developed fingerprint recognition method using Haar wavelet transform and achieved verification rate of 82.08 overall verification rate (Genuine Acceptance Rate) even by rotating each fingerprint image form 0° to 360° in steps of 10° each with FAR of 0.5. Authors have noted that features extraction time per fingerprint image is 0.58 sec. Fingerprint matching is also experimented using combined approaches where minutiae features are combined with the wavelet based features such a method is applied in [25]. An approach proposed in [26] towards fingerprint recognition is based on wavelet domain features. The 64-subband structure of the FBI (Federal Bureau of investigation) fingerprint compression standard is used to directly extract the wavelet features of the fingerprint image. Paper [28] describes the fingerprint verification based on wavelet transform and the local dominant orientation. Daubechies wavelet is used to decompose the fingerprint image. The local dominant orientation is computed using the coherence, results show 85 percent genuine acceptance rate at 6 percent FAR.

Three different types of transforms, Discrete Cosine Transform (DCT), Fast Fourier Transform (FFT) and Discrete Wavelet Transform (DWT) are used in [29] to create feature vector for fingerprints and are used in matching. First a core point is identified and then around it a image of size 64X64 is cropped in the fingerprint image The transform is applied on the cropped image without any pre-processing. The transform coefficients are arranged in specific manner and are used to obtain the feature vector in terms of standard deviation. The fingerprint matching is based on the minimum Euclidean distance between two feature vectors. Comparison of all the three transforms is presented and it is observed that DCT and DFT gives better result as compared DWT.

5. Hybrid Approaches

The advent of solid-state fingerprint sensors presents a fresh challenge to traditional fingerprint matching algorithms. These sensors provide a small contact area (= 0.6" x 0.6") for the fingertip and, therefore, sense only a limited portion of the fingerprint. Thus multiple impressions of the same fingerprint may have only a small region of overlap. Minutiae based matching algorithms, which consider ridge activity only in the vicinity of minutiae points, are not likely to perform well on these images due to the insufficient number of corresponding points in the input and template images.

A hybrid matching algorithm is presented in [30] to reduce the effect of nonlinear deformation in the fingerprint that uses both minutiae information and texture information for matching the fingerprints. A bank of Gabor filters is used to extract texture features from the template and input images. Results shows that at 1% FAR, the hybrid matcher gives a Genuine Accept Rate of **92%** while the minutiae-based matcher gives a Genuine Accept Rate of **72%.** Gabor filter bank are in [31] to extract fingerprints features. It is found that performance of feature extraction is dependent on mask size and Gaussian deviation value. For Gaussian deviation value 4 and filter mask size 32X32 the percentage of FAR is 6.4%.

In paper [32] a localized texture based representation scheme is presented that relies on visual content for identification and the advantage of this method is it does not require absolute alignment. [33] Proposes a hybrid fingerprint verification system based on local texture pattern obtained using Gabor filtering and wavelet global features obtained by Multiresolution analysis of a fingerprint. The Experimental results show that the system is efficient and suitable for real-time authentication applications with a small size database. Statistical texture analysis of a fingerprint using Spatial Grey Level Dependence method (SGLDM) for discrimination and personal verification is proposed in [34]. Other statistical approach is presented in [35], it reduces multi-spectral noise by enhancing a fingerprint image to accurately and reliably determine a reference point and then extract a 129 X 129 block, making the reference point its center. From the 4 co-occurrence matrices four statistical descriptors are computed. Experimental results show that the proposed method is more accurate than other methods the average FAR is 0.62%, the average FRR is 0.08%, and the Equal Error Rate (EER) is 0.35%.

6. Comparisons

Major categories of fingerprint methods are compared based on the characteristics given in the literature and are tabulated as below (Table 1).

Methods / Metrics	Minutiae based	Filter based	Image transform	Hybrid
Reliability	Difficult to extract minutiae in low quality image	Reliable	Reliable	More reliable
Limiting factors	Image quality	Accurate reference point is required	Accurate reference point is required,	depends
Accuracy	High	Less accurate	Less	High
Time delay	High	Less	Less	High
Algorithmic complexity	High	Less	Less	High
Overhead of preprocessing and post processing steps	High	Not applicable	Not applicable	High
Storage space	Efficient	Less	Less	High
Data size	Not suitable for large databases	Suitable for large databases	Suitable for large databases	Not suitable for large databases
Matching techniques	Sophisticated	Simple	Simple	Sophisticated
Applications	Suitable for forensic applications	Suitable for civilian applications	Suitable for civilian applications	Suitable for forensic applications

Table 1. Comparison of Fingerprint Recognition Approaches

7. Conclusion

Fingerprint is an important and challenging research area of Digital Image processing so this field still attracts many researchers even after many years of research. The demand of research in this area is growing as the world is now much more concerned about safety and security than ever. A fingerprint matching and recognition system not only forbids the unauthorized access to some facility but in case of security breach, allows tracking the criminals. The requirement of fingerprint recognition is now in every field of our daily life. This paper presents a study of various fingerprint recognition algorithms from a different viewpoint - quality, performance and application. By classifying fingerprint recognition approaches into - Minutiae based methods, filter based approaches, Image transform based approaches, and Hybrid approaches, we can clearly see the trade-off between various approaches with respect to their suitability towards finger print applications. Many literature have stated their own sets of encouraging results. However, most of them cannot be compared against each other; either the system or the database is different. It would be interesting for future research to evaluate each of the approaches under a standardized test bed.

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