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Latent Fingerprint Matching Techniques: A Survey

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Abstract

This paper presents a forensics application of latent fingerprint matching techniques. In crime scenes latent fingerprint identification is an important task to catch the criminals. Due to latent poor quality only the small amount of finger area is known, it is necessary to extract all the features in latent finger image for an efficient matching. The various latent enhancement techniques and matching algorithms are discussed.

Keywords: *Latent features, Matching techniques, Altered fingerprints, Segmentation.*

1. Introduction

Despite advances made in areas such as DNA profiling, fingerprints are still considered to be the best form of personal identification for criminal investigation purposes. A wide range of optical, physical and chemical techniques is available for the detection and enhancement of latent finger marks. The best results are generally obtained if a logical sequence of techniques is applied. For a given set of circumstances, the choice of the best detection techniques, or sequence of techniques, will depend on several factors that include:

- The nature of the surface (eg. porous, non-porous, rough or smooth),
- The presence of any particular contaminants (eg. blood),
- Environmental factors (eg. whether or not the surface is or has been wet) and,
- The likely age of any evidential finger marks.

In any fingerprint detection sequence, heavy emphasis should be placed on optical techniques, as these are non-destructive and may significantly improve the results obtained by physical or chemical methods [1].

Latent fingerprints are inadvertent impressions left by fingers on surfaces of objects. While tremendous progress has been made in plain and rolled fingerprint matching, latent fingerprint matching continues to be a difficult problem. Poor quality of ridge impressions, small finger area, and large non-linear distortion are the main difficulties in latent fingerprint matching, compared to plain or rolled fingerprint matching [2].

Latents are partial fingerprints that are usually smudgy, with small area and containing large distortion. Due to these characteristics, latents have a significantly smaller number of minutiae points compared to full (rolled or plain) fingerprints. The small number of minutiae and the noise characteristic of latents make it extremely difficult to automatically match latents to their mated full prints that are stored in law enforcement databases. Although a number of algorithms for matching full-to-full fingerprints have been published in the literature, they do not perform well on the latent-to full matching problem. Further, they often rely on features that are not easy to extract from poor quality latents [15].

Latent fingerprint matching process usually done based on the minutiae points and the orientation field in the finger image. The feature extraction is an important task in latent finger images, generally they include

- Preprocessing(Latent finger image enhancement),
- Segmentation and
- Extracting features in latent finger image.

After extracting all the features, the matching process will be done based on those features.

2. Preprocessing

The preprocessing is a process of enhancing the latent finger image quality. Due to latent poor quality, they contain unclear ridge structure and occlusion with complex background or even other latent prints [4].

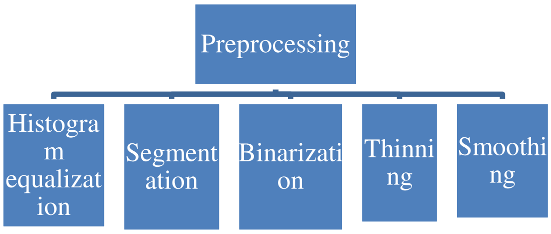

Fig.1. Preprocessing Techniques

The preprocessing includes a *histogram equalization* technique, to convert the poor quality latent image into proper illumination in order to get the clear ridge structure. The *Segmentation* process includes the foreground and background separation of finger area, because the latents are distorted or overlapped with other latent prints. The *Binarization* is a process of converting fingerprint gray-scale image into binary image. The *Thinning* is a process where the finger image is thinned to have one pixel finger image, which results the useful and useless ridges into clear. The *Smoothing* process is based on the fact; variations in ridge orientations are flow across the surface of the finger image. By applying a smoothing mask results, a smoothed version of the ridge orientation map.

3. Feature Extraction

The feature extraction process plays a major role in latent fingerprint matching, due to latent poor quality only the small amount of finger area is known, it is necessary to extract all the features in latent finger image for an efficient matching. The features in the latent finger images are;

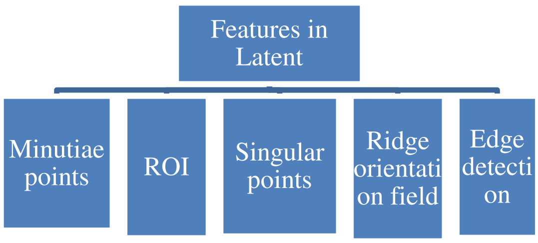

Fig. 2. Features present in latent prints

The *Minutiae points* are specific points in a finger image they are determined by the termination or the bifurcation of the ridge lines. The *Region of Interest (ROI)* is a closed region that is bounded at the outer most trim of the latent. Only the fingerprint features in the ROI are regarded as valid [4]. The S*ingular points* are singularities observed in almost all the fingerprints fall into one of the following categories: (i) no singularity (i.e., arch type of fingerprints), (ii) one core and one delta (i.e., loop and tented arch type), and (iii) two cores and two deltas (i.e., whorl and twin loop type) [4]. The *Orientation field* describes the global structure of fingerprints. It provides robust discriminatory information other than traditional widely-used minutiae points [5]. The E*dge detection* is a basic process in feature extraction technique. The points at which image brightness changes sharply are normally organized into a set of curved line segments termed edges. The main goal of the edge detection process is detection and localization of image edges.

4. Latent Fingerprint Matching

The small number of minutiae and the noise characteristic of latents make it extremely difficult to automatically match latents to their mated full prints that are stored in law enforcement databases. For fingerprint matching, there are two major problems which need to be solved.

1. Align the two fingerprints to be compared.
2. Compute match score between the two fingerprints [15].

In which alignment of two fingerprints are made by considering the most similar minutiae pair and also the ridge orientation field which results better matching performance.

5. Literature Review

Many global approaches that use additional features have been explored to minimize error rate in matching the latent fingerprints. The literature survey on various existing latent fingerprint matching techniques were did in this section,

***The Peng Shi, Jie Tian, Senior Member, IEEE, Qi Su, and Xin Yan* [6]** Work on "A Novel Fingerprint Matching Algorithm Based on Minutiae and Global Statistical Features". In this paper, they introduced similarity of global statistical features, which was combined by two statistical quality features of both fingerprints: the quality distribution and the mean ridge width, and proposed a novel similarity measure algorithm based on them. In their algorithm first, they get the raw similarity measure between two minutiae sets. Then, similarity of ridge width between two fingerprints was calculated, and was combined with the similarity of minutiae sets. Finally, judge whether the match between two templates belongs to the genuine match or the impostor match by a fuzzy calculation of the quality contrast between both fingerprints image, and complete the matching process by calculating the final similarity measure with the global statistical features.

***Soweon Yoon, Student Member, IEEE, Jianjiang Feng, Member, IEEE, and Anil K. Jain, Fellow, IEEE* [7]** Work on "Altered Fingerprints: Analysis and Detection". They considered the problem of fingerprint alteration or obfuscation. Fingerprint obfuscation refers to the deliberate alteration of the fingerprint pattern by an individual for the purpose of masking his identity. Fingerprint image quality assessment software (e.g., NFIQ) cannot always detect altered fingerprints since the implicit image quality due to alteration may not change significantly. They classify altered fingerprints into three categories based on the changes in ridge pattern due to alteration: 1) Obliteration, 2) Distortion, and 3) Imitation. They proposed an algorithm called Automatic Detection of Altered Fingerprints.

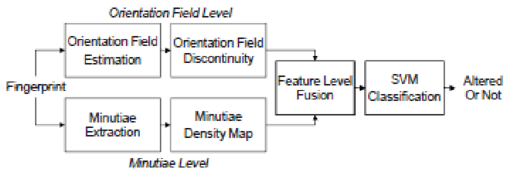

Fig. 3. Flowchart for proposed algorithm [7]

At a false positive rate of 0.3 percent, the proposed algorithm can correctly detect 66.4 percent of the subjects with altered fingerprints, while 26.5 percent of such subjects are detected by the NFIQ algorithm.

***Xinjian Chen, Jie Tian, Senior Member, IEEE, Xin Yang, and Yangyang Zhang* [8]** Work on "An Algorithm for Distorted Fingerprint Matching Based on Local Triangle Feature Set". In this paper, they proposed a method for deformed fingerprints matching. A fuzzy feature match (FFM) based on a local triangle feature set to match the deformed fingerprints. The fingerprint is represented by the fuzzy feature set: the local triangle feature set. The similarity between the fuzzy feature set is used to characterize the similarity between fingerprints. A fuzzy similarity measure for two triangles is introduced and extended to construct a similarity vector including the triangle-level similarities for all triangles in two fingerprints. Accordingly, a similarity vector pair is defined to illustrate the similarities between two fingerprints. Finally, the FFM method maps the similarity vector pair to a normalized value which quantifies the overall image to image similarity within the real interval [0, 1].

***Heeseung Choi, Maurilio Boaventura, Ines A.G. Boaventura, Anil K. Jain* [9]** Work on "Automatic Segmentation of Latent Fingerprints". In this paper, they proposed a new latent fingerprint segmentation algorithm that identifies the region of interest, namely the friction ridge pattern, and suppresses the background. The segmentation algorithm utilizes both ridge orientation and frequency features. A flowchart of the proposed method,

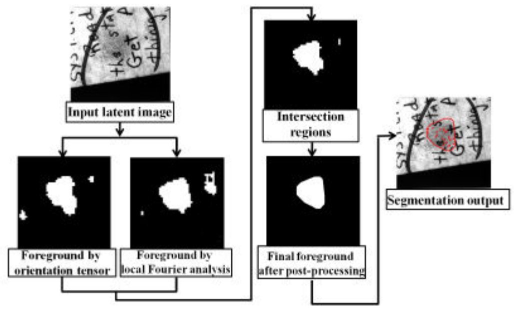

Fig. 4. Latent fingerprint segmentation algorithm [9].

They considered a fingerprint as a texture pattern (oriented line pattern within a certain valid range of frequency), and utilize both fingerprint orientation and frequency information to segment latents. The main difficulty in latent fingerprint segmentation is the presence of structured noise (e.g., arch, line, character and speckle). The orientation tensor approach is used to extract the symmetric patterns of a fingerprint as well as to remove the structured noise in background. Local Fourier analysis method is used to estimate the local frequency in the latent fingerprint image and locate fingerprint region by considering valid frequency regions. Candidate fingerprint (foreground) regions are obtained for each feature (orientation and frequency) and then an intersection of these regions is used to localize the latent fingerprint region.

***Jianjiang Feng* [10]** Work on "Combining minutiae descriptors for fingerprint matching". In this paper, they present texture-based descriptors, minutiae-based descriptors and the combination of them. Texture-based descriptors consist of ridge orientation and frequency information at some sampling points around a minutia. Local minutiae structures have been used by many researchers to increase the distinctiveness of minutiae. Two types of representation, fixed-length feature vectors and unfixed-length feature vectors, have been adopted by different researchers to describe local minutiae structures. In this paper, local minutiae structures are termed minutiae-based descriptors. Since texture-based descriptors and minutiae-based descriptors capture contemporary information, and further improve the discriminating ability of descriptors by combining two descriptors using the product rule,

$$sc = st \cdot sm,$$

Were sc, st and sm representing the similarity of combined, texture-based and minutiae-based descriptors, respectively. The combined texture-based and minutiae-based descriptors can increase the discriminating ability of descriptors.

***Jianjiang Feng, Soweon Yoon, and Anil K. Jain* [11]** Work on "Latent Fingerprint Matching: Fusion of Rolled and Plain Fingerprints". In this paper, they proposed a new method which fuses the two types of fingerprints which are rolled and plain fingerprints. The rolled fingerprints are of larger size and contain more minutiae and plain fingerprints are less affected by distortion and have clearer ridge structure, this can improve the accuracy of latent matching. To fuse the rolled and plain fingerprints they considered three different levels as rank, score and feature levels. In rank level, two rank level fusion methods are adopted: highest rank and Borda count. In the highest rank method, fingers are sorted with respect to the higher rank of plain and rolled fingerprints. The Borda count method uses the sum of the ranks of plain and rolled fingerprints to sort fingers. In the Score level, five score level fusion rules are tested: min, max, sum, product and boosted max. The purpose of the boosted max is to boost the score of genuine matches. In the feature level, three types of region are identified: common region and the rolled-only region, the ridge orientation and quality of the rolled fingerprint are adopted. In the plain-only region, the ridge orientation and quality of the plain fingerprint are adopted. The eventual goal of fusing rolled and plain fingerprints is to obtain full fingerprints of high quality.

***Anil K. Jain, Fellow, IEEE, and Jianjiang Feng* [12]** Work on "Latent Fingerprint Matching". In this paper, they proposed a system for matching latent fingerprints found at crime scenes to rolled fingerprints enrolled in law enforcement databases. In addition to minutiae, they also use extended features, including reference points (singularity), overall image characteristics (ridge quality map, ridge flow map, and ridge wavelength map), and skeleton. The effect of the secondary features (dots, incipient ridges, and pores) has also been examined. The baseline matching algorithm takes only minutiae as input and performs the three type of matching as follows, 1) Local minutiae matching, In this step, the similarity between each minutia of latent fingerprint and each minutia of rolled fingerprint is computed. 2) Global minutiae matching, given the similarity among all minutia pairs, the one-to one correspondence between minutiae is established in the global minutiae matching stage. Greedy strategy is used to find matching minutia pairs in the decreasing order of similarity. 3) Matching score computation, computing matching scores or simply scoring is typically approached in two ways: formula-based and classifier-based. In formula-based approach, an empirically chosen formula is used to compute matching scores. In classifier-based approach, scoring is regarded as a two-category classification problem. A pair of fingerprints is classified by a traditional classifier, such as Artificial Neural Network (ANN) or Support Vector Machine (SVM), as a genuine match or an impostor match based on a feature vector extracted from matching these two fingerprints. In the baseline algorithm, a neighboring minutiae-based descriptor is used, since only minutiae information is available. The various extended features indicate that singularity, ridge quality map, and ridge flow map are the most effective features in improving the matching accuracy.

***Soweon Yoon†, Jianjiang Feng‡ and Anil K. Jain†* [13]** Work on "Latent Fingerprint Enhancement via Robust Orientation Field Estimation". In this paper, they proposed a latent fingerprint enhancement algorithm, which only requires minimal markup (ROI and singular points) to improve the automatic matching accuracy. The orientation field of the latents is estimated by R-RANSAC which is effectively used to find a correct orientation field model in the presence of noise and distortion. The estimated orientation field is used to enhance ridge structures by Gabor filtering. Given a set of orientation element groups as the input, hypotheses for residual orientation field are built based on the randomized Random Sample Consensus (R-RANSAC) algorithm. Generally, RANSAC algorithms consist of three basic steps: (i) select a set of initial data points randomly, (ii) build a hypothesis, and (iii) evaluate the hypothesis. A set of data points that are consistent with a given hypothesis is called consensus set. The proposed algorithm significantly improved the matching performance of a commercial matcher when the enhanced latents are fed into the matcher.

***Soweon Yoon†, Jianjiang Feng‡ and Anil K. Jain†* [14]** Work on "On Latent Fingerprint Enhancement" In this paper, they proposed a latent fingerprint enhancement algorithm which requires manually marked region of interest (ROI) and singular points. The core of the proposed enhancement algorithm is a novel orientation field estimation algorithm, which fits orientation field model to coarse orientation field estimated from skeleton outputted by a commercial fingerprint SDK.

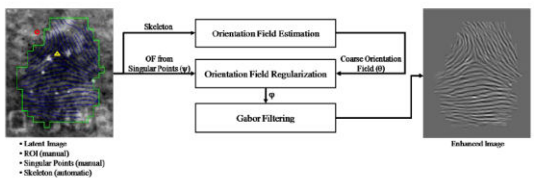

Fig. 5. Proposed latent enhancement algorithm [14].

Most orientation field estimation algorithms consist of two steps: initial estimation using a gradient-based method followed by regularization. The regularization may be done by a simple weighted averaging filter or more complicated model-based methods. To make regularization effective, it is better to use only reliable initial estimate or to give it larger weight. However, very limited information is available at this stage to estimate the reliability of initial estimate. To overcome this limitation, they estimate a coarse orientation field from skeleton image generated by a commercial SDK. This coarse orientation field is further regularized by fitting an orientation field model to it. The matching accuracy of the commercial matcher was significantly improved.

***Alessandra A. Paulino, Student Member, IEEE, Jianjiang Feng, Member, IEEE, and Anil K. Jain, Fellow, IEEE* [15]** Work on "Latent Fingerprint Matching Using Descriptor-Based Hough Transform". In this paper they proposed an algorithm which uses a robust alignment algorithm (descriptor-based Hough transform) to align fingerprints and measures similarity between fingerprints by considering both minutiae and orientation field information. To be consistent with the common practice in latent matching (i.e., only minutiae are marked by latent examiners), the orientation field is reconstructed from minutiae. Further, a fusion of the proposed algorithm and commercial fingerprint matchers leads to improved matching accuracy.

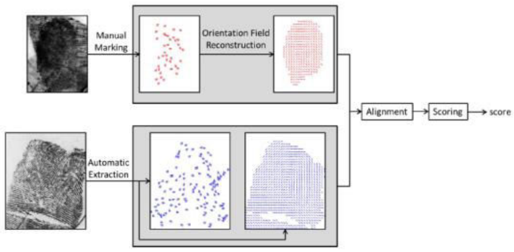

Fig. 6. Overview of proposed approach [15].

The proposed matching approach uses minutiae and orientation field from both latent and rolled prints. Minutiae are manually marked by latent examiners in the latent, and automatically extracted using commercial matchers in the rolled print. Based on minutiae, local minutiae descriptors are built and used in the proposed descriptor-based alignment and scoring algorithms. Orientation field is reconstructed from minutiae location and direction for the latents as proposed in and orientation field is automatically extracted from the rolled print images by using a gradient-based method. Local Minutia Descriptors have been widely used in fingerprint matching. A minutia cylinder records the neighborhood information of a minutia as a 3-D function. Orientation Field Reconstruction can be used in several ways to improve fingerprint matching performance, such as by matching orientation fields directly and fusing scores with other matching scores, or by enhancing the images to extract more reliable features. Orientation field estimation using gradient-based method is very reliable in good quality images. However, when the image contains noise, this estimation becomes very challenging.

6. A Comparison of Existing Latent Fingerprint Matching Techniques

Method	Approach	Database	Performance Evaluation	Matcher	Limitation
The Peng Shi, Jie Tian, Senior Member, IEEE, Qi Su, and Xin Yan [6]	Similarity Measure with Global Statistical Features	FVC2004	Avg EER of 4.43%	N/A	• The combined similarity will have less help on improving the accuracy of the matching algorithm. • Another limitation of the combined similarity is it can only be used in matching between the fingerprints which are collected by the same type of sensor.

Soweon Yoon, Student Member, IEEE, Jianjiang Feng, Member, IEEE, and Anil K. Jain, Fellow, IEEE [7]	Altered Fingerprints: Analysis and Detection	NIST SD14	False positive rate of 0.3% and correctly detect 66.4%	N/A	• Need to improve the altered fingerprint analysis technique.
Xinjian Chen, Jie Tian, Senior Member, IEEE, Xin Yang, and Yangyang Zhang [8]	An Algorithm for Distorted Fingerprint Matching Based on Local Triangle Feature Set	NIST 24 and FVC2004	EER on NIST 24 is 3.11%. EER on FVC2004 DB1 is 4.06%.	N/A	• For the genuine match, the overlapping area between the template and input fingerprint should be large.
Heeseung Choi, Maurilio Boaventura, Ines A.G. Boaventura, Anil K. Jain [9]	Automatic Segmentation of Latent Fingerprints	NIST SD27 and WVU	Rank-1 identification accuracy of 16.28%, 35.19% in NIST SD27 and WVU DB	COTS Matcher	• Need a robust confidence measure for segmentation output
Jianjiang Feng [10]	Combining minutiae descriptors for fingerprint matching	FVC2002	Avg EER of 0.26%	N/A	• Need to speed up the algorithm
Jianjiang Feng, Soweon Yoon, and Anil K. Jain [11]	Latent Fingerprint Matching: Fusion of Rolled and Plain Fingerprints	ELFT-EFS Public challenge Dataset	Rank-1 identification rate of 83.0%	N/A	• Does not appear to be a common practice in law enforcement.
Anil K. Jain, Fellow, IEEE, and Jianjiang Feng [12]	Latent Fingerprint Matching	NIST SD27	A rank-1 identification rate of 74.0% and a rank-20 identification rate of 82.9% were achieved.	N/A	• Approaches used in matching ridge skeleton and minutiae are different. • The approach used to match the detailed ridge features is different. • The approach to utilizing negative evidence is different.

Soweon Yoon†, Jianjiang Feng‡ and Anil K. Jain† [13]	Latent fingerprint enhancement algorithm	NIST SD27	For bad and ugly quality latents, the proposed algorithm performs much better compared to least-squares estimation method or no enhancement case.	Commercial Matcher, Neurotechnology VeriFinger SDK 4.2.	• Very poor quality latents are still challenging. • Need to improve the performance of the orientation field estimation algorithm for bad and ugly quality latents in NIST SD27.
Soweon Yoon†, Jianjiang Feng‡ and Anil K. Jain† [14]	Latent Fingerprint Enhancement	NIST SD27	N/A	Commercial Matcher,	• For bad quality latents, the proposed algorithm does not give better performance. • Large manual inputs.
Alessandra A. Paulino, Student Member, IEEE, Jianjiang Feng, Member, IEEE, and Anil K. Jain, Fellow, IEEE [15]	Latent Fingerprint Matching Using Descriptor-Based Hough Transform	NIST SD27 and WVU	Rank-1 Accuracy 53.5%	COTS Matcher	• Do not perform well, when image contains nose. • Matching, time consuming process.

7. Problem Domain

In latent fingerprint matching, a number of problems arise such as,

1. More noise is present in the latent finger image.
2. Highly distorted prints.
3. May be overlapped with other prints or contain any dust particles.
4. Poor Quality latents which do not have any clear ridge structure.
5. Latent prints contains the ridge breaks, spikes, etc.,
6. Preprocessing techniques need to enhance the ridge features.
7. Filtering techniques need to extract the useful ridge features and also separate the useless ridges.
8. Need to detect the edges in the latent prints.
9. Needs a gradient based techniques to get the fine illumination.
10. Number of algorithms is available for full to full matching. But, they do not perform well on the latent to full matching problem.
11. Usually matching latent prints take large time.
12. Maintaining large database is complex one.

8. Proposed Method

The proposed work is based on the texture-based descriptors, to improve the matching accuracy especially when the overlap between the latent and rolled prints is small. First the latent fingerprints are preprocessed using existing techniques, in order to get the ridge structure available in latent fingerprints. After that using affine transform, the global and the local features of latent fingerprint are extracted and also concentrate on the mixture contour technique. Finally using the COTS matcher, compute the matching based on the similarities present in the latent fingerprints. This method gives the better matching performance and also planned to include the indexing method to the database in order to improve the matching speed.

9. Conclusion

The latent fingerprints are the usual kind of fingerprint evidence which was found during the crime scenes. Due to its poor quality it goes under several enhancing process to obtain the clear ridge information. The literature survey on various existing latent fingerprint matching techniques was done in this paper. The ultimate goal is to provide the better matching performance to the latent fingerprints.

10. ACKNOWLEDGEMENT

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