Latent Fingerprint Matching

Anil K. Jain, Abhishek Nagar and Karthik Nandakumar

Abstract

Latent fingerprint identification is of critical importance in forensics. While tremendous progress has been made in the field of automatic fingerprint identification, latent fingerprint matching continues to be a difficult problem because the challenges involved in latent print matching are quite different from rolled (full) fingerprint matching. Poor quality of friction ridge impressions, small finger area and large non-linear distortion are the main factors that affect latent fingerprint matchers. We propose a system for matching latent images with full fingerprints that uses minutiae as well as ridge information as the discriminative features. We have developed a minutiae-based fingerprint matcher that takes into account the specific characteristics of the latent matching problem. The ridge correlation matcher determines the degree of similarity in the ridge flow patterns of latents and full-print images. Experimental results on the NIST Special Database-27 which consists of 258 latents and their corresponding full fingerprint images indicate that the fusion of minutiae and ridge correlation matchers leads to good recognition performance despite the inherently difficult nature of the problem.

Index Terms

Latent fingerprints, fingerprint matching, minutiae matcher, ridge-correlation.

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I. INTRODUCTION

Fingerprint images can be broadly classified into three categories, namely, (i) rolled/full, (ii) plain/flat and (iii) latent [1]–[3] (see Figure 1). Rolled fingerprint images are obtained by rolling a finger from one side to the other (“nail-to-nail”) in order to capture all the ridge-details of a finger. Plain impressions are those in which the finger is pressed down on a flat surface but not rolled. While plain impressions cover a smaller area than rolled prints, they typically do not have the distortion introduced during rolling. Rolled and plain impressions are obtained either by scanning the inked impression on paper or by using live-scan devices. Since rolled and plain fingerprints are acquired from co-operative subjects, they are typically of high quality and rich in information content. In contrast, latent fingerprints are lifted from surfaces of objects that are inadvertently touched or handled by a person through a variety of means ranging from simply photographing the print to more complex dusting or chemical processes [4], [5]. It is the latent fingerprints that are of utmost importance in forensics to apprehend a criminal or to verify the identity of a suspect.

(a) (b) (c)

Fig. 1. Three types of fingerprint images. (a) Rolled/full print, (b) Plain/flat print and (c) Latent print.

Latent fingerprints obtained from crime scenes have served as crucial evidence in forensic identification for more than a century. However, there have been instances where mistakes in latent fingerprint identification have led to wrongful convictions. One of the most high profile cases in which such a mistake was made is the case of Brandon Mayfield who was wrongly apprehended in the Madrid train bombing incident after a latent fingerprint obtained from the bombing site was incorrectly matched with his fingerprint [6]. An extensive account of similar cases have been brought to light by Innocence project [7]. Due to these incidents and findings, the importance of latent fingerprints as forensic evidence has been undermined. This is evident from a recent ruling of a Baltimore court [8] which excluded fingerprints as evidence in a murder trial because the prosecutor was not able to justify the procedure followed for latent fingerprint matching as being sufficiently error free.

It is often argued that matching a latent fingerprint to a full-print is more of an "art" than "science" [9] because the matching is based on subjective appraisal of the two fingerprints in question by a human examiner. Moreover, the decisions made by latent examiners are required to be "crisp", i.e., an examiner can provide only one of the three decisions, viz., individualization (identification or match), exclusion (non-match) and inconclusive [4], [5]. Often latent examiners have a huge backlog of cases and are usually under time pressure to evaluate a fingerprint pair, particularly in high profile cases. Therefore, it is very important that the cases sent to latent examiners be efficiently selected and prioritized so that he/she can spend adequate amount of time in matching them. One way to achieve this goal is to design an efficient and highly accurate automatic latent to full-print matching system which should be able to provide a quantitative estimate of the probability that two fingerprints being compared belong to same finger.

In order to deal with efficiency, the concept of "Lights-Out System" for fingerprint matching has been introduced [2]. A "Lights-Out System" for fingerprint identification is characterized by no human intervention throughout the whole identification process. Such a system should automatically extract features from fingerprints and match them with a gallery database to obtain a set of possible "hits" with high confidence so that no human intervention is required. However, in latent matching only "Semi Lights-Out Systems" are feasible due to the limitations of existing technology. In a "Semi-Lights-Out System" some human intervention is allowed during feature extraction e.g. orienting the fingerprint, marking the region of interest, etc. A "Semi Lights-Out System" outputs a list of candidates that need to be examined by a latent examiner to accept or reject a fingerprint pair as a match.

Although tremendous progress has been made in developing automated fingerprint identification systems (AFIS), most of these systems work well only in scenarios where the matching is performed between rolled or plain fingerprint images. The results of Fingerprint Vendor Tech-

TABLE I

PERFORMANCE OF A REPRESENTATIVE LATENT MATCHER (LATENT VS. ROLLED OR LATENT VS. PLAIN) ON A DATABASE OF MORE THAN 40 MILLION SUBJECTS [2]

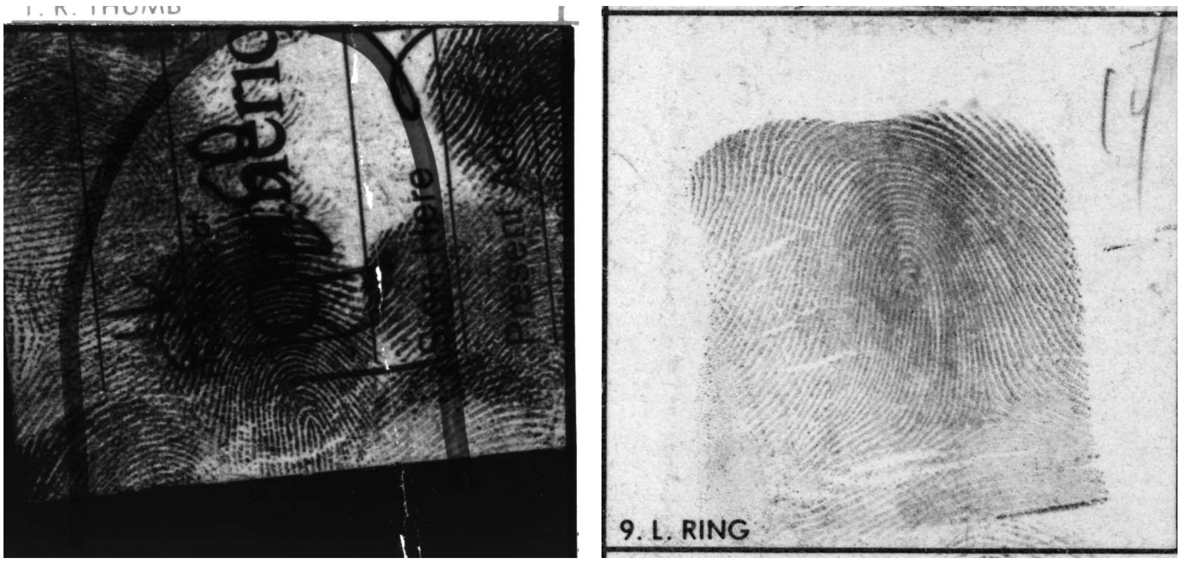
Quality of Latents	Type of Mate		
	Latent vs. Rolled	Latent vs. Plain	Latent vs. Mixed Rolled/Plain
Good and Better	94%	63%	78%
Average Case Work	54%	39%	47%

nology Evaluation (FpVTE) conducted by NIST [10] show that the most accurate commercial fingerprint matchers can achieve a rank-one identification rate of more than 99.4% on a database of $10,000$ plain fingerprint images (see results of Medium Scale Test on page 56 in [10]). On the other hand, the accuracy of latent to full print match continues to be quite low. The NIST latent fingerprint testing workshop reports that the rank-one accuracy of an automatic latent matcher can be as low as 54% on a large database of more than 40 million subjects [2] (see Table I).

AFIS systems have not been very effective so far in matching latent fingerprints because the challenges involved in latent print matching are quite different from full (rolled or plain) fingerprint matching. The difficulty in latent matching is due to three main reasons: (i) poor quality of latent prints in terms of the clarity of ridge information, (ii) latent print area can be quite small compared to the full print and (iii) large non-linear distortion due to pressure variations. Figure 2 shows a sample latent image from the NIST Special Database-27 along with its corresponding full print image. In Figure 2(a), the ridge information in the middle of the image is obscured by the presence of background noise, extraneous markings and other spurious friction ridges surrounding it. Further, while a typical rolled fingerprint has more than 60 minutiae, a typical latent fingerprint may have only 15 usable minutiae [2]. Thus, latent fingerprint identification is a difficult problem which needs immediate attention.

The latent identification process can be divided into four steps, namely, (i) Analysis, (ii) Comparison, (iii) Evaluation and (iv) Verification. This process is commonly referred to as the ACE-V procedure in latent fingerprint literature [11].

- Analysis refers to assessing the latent fingerprint to determine whether sufficient ridge information is present in the image to be processed and to mark the features along with the



(a) (b)

Fig. 2. A sample fingerprint pair from the NIST Special Database-27. (a) Latent print, (b) full print.

associated quality information. The latent print analysis is usually performed manually by a human expert in total objectivity (without having access to a reference print). Features in a fingerprint can be divided into three levels. Level 1 features usually refer to features based on global pattern of the fingerprint. Level 2 features refer mainly to minutiae points and Level 3 features refer to the other characteristic features like ridge shape, pores, incipient ridges, creases, worts, etc. Note that level 1 features are not very informative for matching and are typically used for fingerprint classification which can facilitate exclusion of full prints whose patterns do not match with the query latent print. Level 2 features however are considered the most informative features in a fingerprint.

- Comparison refers to the stage where an examiner compares a latent image to a reference print to ascertain their similarities or dissimilarities. Features at all three levels are compared at this stage.
- Evaluation stage refers to classifying the fingerprint pairs as individualization (identification or match), exclusion (non-match) or inconclusive.
- Verification is the process of re-examination of a fingerprint pair independently by another examiner in order to verify the results of the first examiner.

(a) (b)

Fig. 3. A sample fingerprint pair from the NIST Special Database-27 with minutiae, incipient ridges, dots and pores marked. (a) Latent print with manually marked features, (b) full print with automatically extracted minutiae. Pores are shown as small dots, incipients are shown as thick cyan lines, dots are shown as yellow squares and minutiae are marked with stars with tail oriented along minutia direction.

In this study, we assume that the analysis of the latent print has been performed manually by a latent examiner who has marked the minutiae details, the ridge flow information and other level 3 features such as incipient ridges. We focus mainly on the comparison stage where the manually marked features in the latent are matched against the features extracted automatically from the full-print images (see figure 3). Our contributions are three-fold: (i) we present a minutiae-based matcher that takes into account the specific characteristics of matching a latent with its corresponding full-print; (ii) we develop a ridge-correlation based matcher to ascertain the similarity in the ridge structure between the latent and full-print images; (iii) we perform a fusion of the minutiae and ridge-correlation matchers to improve the overall matching accuracy.

II. Minutiae-based Matching

Minutiae-based matching is an important part of the overall matching procedure proposed in this study. Matching latent fingerprints with full-prints is quite different in certain aspects and in fact more difficult than matching a rolled or flat print with a print obtained in a similar manner. We therefore make the following assumptions that are reasonable while matching a latent with

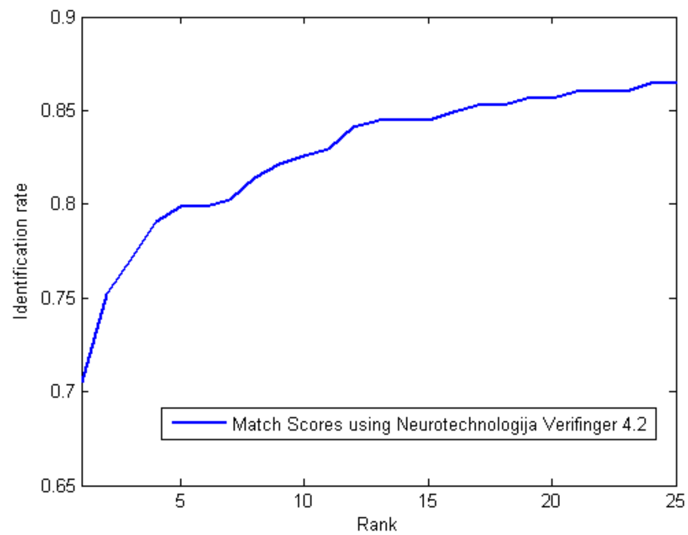


Fig. 4. Cumulative Match Characteristic (CMC) curve corresponding to matching manually marked latent minutiae with manually marked full-print minutiae using Neutechnologija Verifinger 4.2.

a full-print.

1) The latent print is fully contained in its corresponding full-print.
2) Given that the minutiae in latent are marked by a latent examiner, there is little chance of a spurious minutia being present in the latent.
3) Full-print is typically of good quality and hence the chances of missing a minutiae in the full-print is negligible.

Based on the above assumptions, when latent print is matched against its corresponding full-print, all the latent minutiae are expected to have a match in the full-print while the converse need not be true.

Commercial minutiae-based matchers are typically designed for full-print to full-print matching and do not take into account the specific characteristics of latent to full-print matching. Hence, they fail to perform well for the task of latent minutiae matching. For example, the COTS matcher in [12] has a rank-one accuracy of 95% on the Medium Scale Test in FpVTE [10]. However, the same matcher has a rank-one accuracy of about 70% when matching latent minutiae to full-print minutiae in the NIST-SD27 database (see Figure 4).

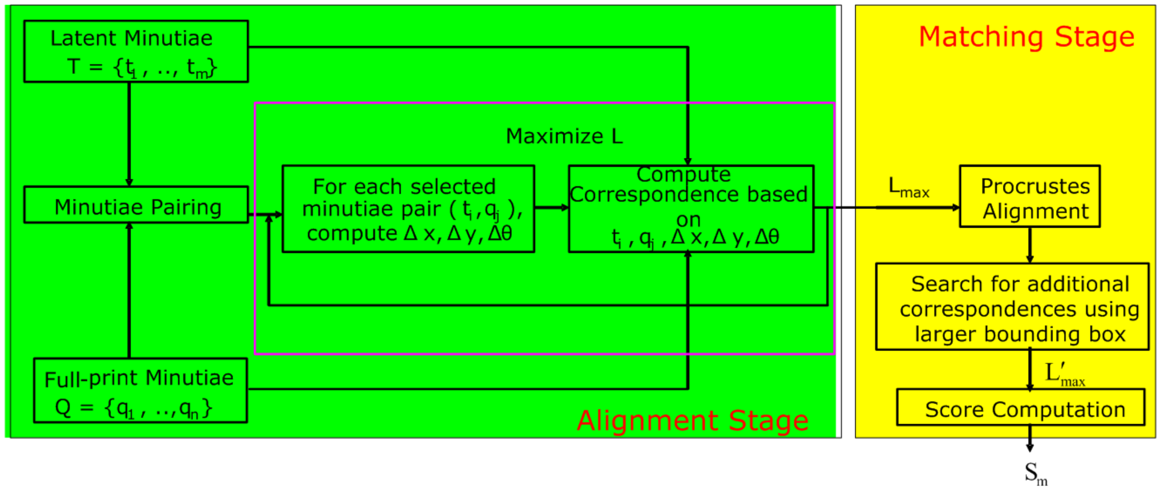


Fig. 5. Schematic diagram of the proposed minutiae-based matcher for matching latent images to full-print images.

The specific nature of latent to full-print matching requires a fingerprint matcher designed exclusively for this purpose. The schematic diagram of the proposed minutiae-based matcher is shown in Figure 5. Due to the poor quality of latent fingerprints, minutiae location and direction are noisy even though they are manually marked by a latent examiner. In addition, the relative deformation present between two fingerprints being compared makes minutiae matching more difficult. Therefore, we detect the minutiae correspondences in two stages. In the first stage we obtain the initial minutiae correspondences as follows. Let $T = \{t_1, t_2, \cdots, t_m\}$ be the set of m minutiae in the latent image, where $t_i = (x_i^t, y_i^t, \theta_i^t), i = 1, 2, \cdots, m$ represents the location (x_i^t, y_i^t) and direction (θ_i^t) of the i^{th} minutia point. Let $Q = \{q_1, q_2, \cdots, q_n\}$ be the set of n minutiae in the full-print, where $q_j = (x_j^q, y_j^q, \theta_j^q), j = 1, 2, \cdots, n$. For every possible minutiae pairing $(t_i, q_j), i = 1, 2, \cdots, m$ and $j = 1, 2, \cdots, n$, we compute the relative translation $(\Delta x_{ij}, \Delta y_{ij})$ and rotation $(\Delta\theta_{ij})$ between the two minutiae. If the absolute value of the rotation parameter $(|\Delta\theta_{ij}|)$ is greater than a threshold (say 45 degree), the minutiae pair is rejected. Otherwise, using these alignment parameters all the other minutiae in the full-print image are aligned with respect to the latent minutiae. After alignment, the minutiae are converted into polar coordinates with the matching pair as the center as follows