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An Advanced Technique for User Identification using Partial Fingerprint

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***Abstract* — User identification is a very interesting and complex task. Invasive biometrics is based on traits uniqueness and immutability over time. In forensic field, fingerprints have always been considered an essential element for personal recognition. The traditional issue is focused on full fingerprint images matching. In this paper an advanced technique for personal recognition based on partial fingerprint is proposed. This system is based on fingerprint local analysis and micro-features, endpoints and bifurcations, extraction. The proposed approach starts from minutiae extraction from a partial fingerprint image and ends with the final matching score between fingerprint pairs. The computation of likelihood ratios in fingerprint identification is computed by trying every possible overlapping of the partial image with complete image. The first experimental results conducted on the PolyU (Hong Kong Polytechnic University) free database show an encouraging performance in terms of identification accuracy.**

Keywords: User identification, Partial fingerprint, Minutiae, Roto-translation parameters

I. INTRODUCTION

Fingerprint identification is a well-researched problem, and automatic fingerprint identification/verification techniques have been successfully adapted to both civilian and forensic applications for many years. Successful implementation of such recognition systems includes the Automatic Fingerprint Identification System (AFIS) [1]. Many works on multimodal biometric identification systems have been proposed to overcome limits of unimodal approach [2]. Although, automated fingerprint identification and verification systems, software and hardware implementation, have been widely adopted in commercial and security applications for access and denial operations [3] [4] [5] [6], the technology also lends itself to other emerging areas of interest [7] [8] [9] [10]. One of the most important areas of considerable utility to law enforcement agencies is concerning to partial fingerprints identification. Since the fingerprint templates constitute the largest data in the biometric field, considering partial fingerprint samples, the amount of data in the database shall be decreased and this will consequently lead to a faster processing for fingerprint identification [11].

Matching the small parts (partial) fingerprint to the stored images in database usually shows different problems. The partial fingerprints (for example, obtained from a crime scene) are normally small, noisy and have the following characteristics:

- a less minutiae number with respect to complete fingerprint image;
- high probability of loss of singular points (core and delta);
- unspecified roto-translation problems due to uncontrolled acquisition environments;
- distortions introduced by human skin such as elasticity;
- difficult to ascertain correspondence of obtained partial fingerprint to one of the fingers.

In literature the minutiae based approaches are widely used in fingerprint identification systems. Minutiae points are local ridge characteristics: ridge ending or ridge bifurcation. Usually, fingerprint area contains about 30 to 60 minutiae points depending on the finger size and the sensor area dimension. In addition, since the minutia-based fingerprint representation is an ANSI-NIST standard [6] [12] [13], all approaches and techniques implemented following these identification guidelines have the advantage of being directly applicable to existing systems and databases.

In this work an identification technique based on minutiae extraction in complete and partial fingerprint images is proposed. This technique is based on the weighted distance between fingerprint pairs, template and test, for identifying an enrolled user in a database containing partial fingerprint image. The computation of likelihood ratios in fingerprint identification is performed by trying all the possible overlapping between image test and template. After all scores for each minutia of the test image are obtained, the final matching score between the roto-translated test and the template is calculated by adding only 12 of the highest scores.

The paper is structured as follows. Section II reports the main related works. Section III describes a standard identification fingerprint system. Section IV proposes the implemented identification technique based on partial

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fingerprint image. Section V shows the obtained experimental results. Finally, section VI reports the conclusions and future works of this work.

II. Related Works

In forensic field and applications, the most important issues are focused on matching partial fingerprints [14]. In many cases, the partial fingerprint images that lifted from crime scenes are broken and unclear, so the useable parts of the partial fingerprint images are restricted in small areas. To overcome the common problems to work with partial fingerprint images many researchers have proposed a set of methodologies and technologies to implement enhanced automated user identification systems.

In the follows, a briefly overview about the main approaches proposed in literature.

In [15] the authors have proposed a fingerprint recognition system deals with filter bank to match partial fingerprints. The method uses both local and global details in a fingerprint and defined as fixed length feature vector. Final matching is done by calculating Euclidean distance between the two corresponding feature vectors. With more details, finger code is calculated by rotating the input images. Normalization is applied after cropping and sectoring the fingerprint image and finally Gabor filters are used with same angle of rotation. The obtained results proved that their method is better in false acceptance and total error rate when compared to the minutiae based approach.

In [16] the authors have implemented an algorithm to obtain a high accuracy performance using both full and partial fingerprints. The proposed algorithm regards ridges more effectively by utilizing representative ridge points. These points are represented similar to minutiae and used together with minutiae in existing minutiae matchers with simple modification. In order to demonstrate the performance two minutiae-only matchers have been used. The effectiveness is more significant in the case of partial fingerprint matching when only 15 minutiae are available as the error rate decreases 5-7.5%.

In [13] the authors have proposed an approach that uses localized secondary features derived from relative minutiae information. A flow network-based matching technique is introduced to obtain one-to-one correspondence of secondary features. A two-hidden-layer fully connected neural network is trained to generate the final similarity score based on minutiae matched in the overlapping areas. This method balances the tradeoffs between maximizing the number of matches and minimizing total feature distance between query and reference fingerprints.

In [17] the authors have addressed the problem on large capacity of fingerprint databases, sampling the full fingerprint through checkerboard algorithm. A standard 8x8 checkerboard has been adopted wherein selected blocks are considered as samples for Artificial Neural Network (ANN) training. They wanted to reduce the computational cost will reduce the memory size of a fingerprint template to 50%. Also, 25% of the whole fingerprint is done to further reduce the memory size.

In [18] the authors proposed a novel fuzzy logic method for matching partial fingerprints. The inputs of the proposed fuzzy logic algorithm are the correlation degree and the relative surface of the input fingerprint. However, applying correlation-based algorithms directly is very time consuming process, because a large number of rotations and translations are needed. In order to reduce the computational time, the authors proposed algorithm tries to correlate a set of minutiae from the input with another one from the template. The correlation degree and the relative surface of the input fingerprint are fuzzified with a proposed membership function.

In [19] the authors starting from the common multimodal approach in biometric field have proposed a method for partial fingerprint matching based on score level fusion by using pore and SIFT features. This work can be divided in two main steps: firstly, the pore feature and SIFT feature points are extracted; secondly, the Matching algorithm is performed and matching score is calculated. The accuracy of the proposed method is observed to be about of 97% for image size of 60% of original image partial and with 500ppi/1000ppi resolution fingerprint image.

In [20] the authors presented suitable technique for partial fingerprint matching based on pores and their Local Binary Pattern (LBP) features. The first step involves extracting the pores from the partial image. Then rotation invariant LBP histograms are obtained from the surrounding window. Finally chi-square formula is used to calculate the minimum distance between two histograms to find best matching score.

In this work, a minutia based approach has been used to increase the accuracy performance in fingerprint identification systems. Since the minutia-based fingerprint representation is an ANSI-NIST standard [6] [13], the proposed approach has the advantage of being directly applicable to existing databases.

III. Fingerprint Recognition System

Biometric recognition systems, using physiological characteristics for users identification, have become most popular, mainly for their high capabilities of user discrimination (selectivity) to prevent unauthorized access to systems, data, and resources [3] [5] [21] [27]. On the other hand, the immutability of the features renders biometric-based identification systems extremely strong and robust.

Recognition fingerprint systems can be divided in two main classes. The first class uses micro-features (minutiae) based approaches for matching algorithms, while the latter class uses macro-features (core and delta singularity points) information for classification and identification tasks [22]. The classical comparison of more distinctive points (minutiae based approaches, see Figure 1) obtains higher recognition rates [23] [24]. Also, biometric features have not the same distinctiveness degree and lack of universality (for example, some people do not have the biometric feature needed by the system). Recent approaches developed to overcome these problems are multimodal biometric systems and related fusion strategies [2] [4] [27] [29]. However, for both unimodal and multimodal systems the common technique used to have higher identification rate is based on micro-features extraction in acquired complete images.

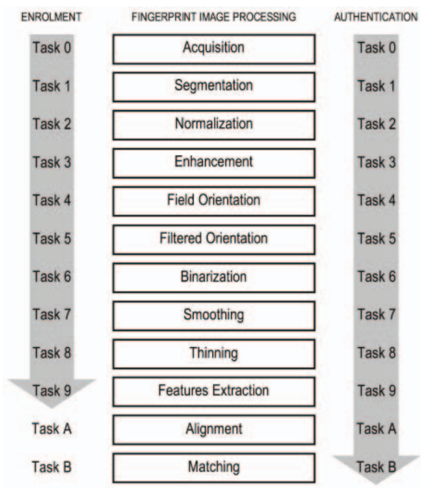


Figure 1. Standard fingerprint recognition systems based on minutiae: enrolment and identification phases.

IV. The Proposed Identification Technique Based on Partial Fingerprint

The proposed approach starts from partial fingerprint minutiae extraction and ends with the final score calculation between similar fingerprints pair.

1) *Minutiae Extraction Step and Alignment*

The proposed identification technique provides the computation of likelihood ratios between a pair of images, test and template, respectively a partial fingerprint of an unknown user and a complete one stored in a database. The comparison process requires the extraction of the minutiae from both the fingerprint images (see Figure 2). In order to obtain all fingerprint minutiae the well-known Jain approach has been used [25].

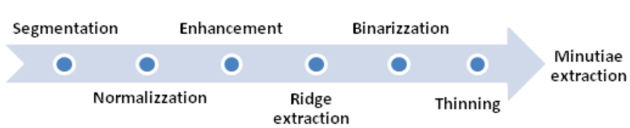
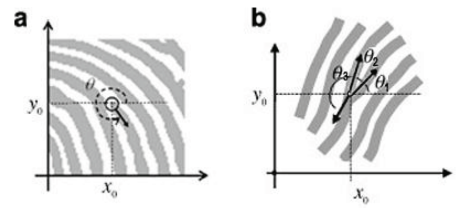


Figure 2. Minutiae extraction phase.

Each minutia is described by the type (termination or bifurcation), the x-y Cartesian coordinates and one angle for terminations or three angles for bifurcations with respect to the x axis (see Figure 3).



Type	x	y	θ_1	θ_2	θ_3

Figure 3. Minutia description: a) termination; b) bifurcation.

The computation of likelihood ratios in fingerprint identification is obtained by trying all the possible overlapping of the image test to template. The obtained roto-translation parameters are based on the identification of two similar pairs of minutiae belongs to test and template images (see Figure 4).

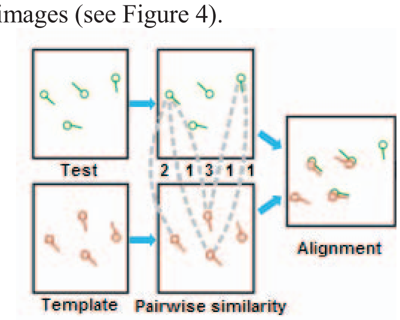
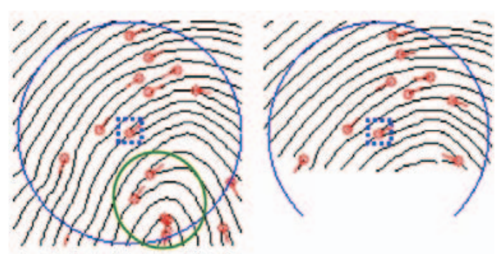


Figure 4. Roto-translation parameters calculation.

A threshold (the *beta* parameter, experimentally fixed to 175 pixels) based on Euclidean distance is used to generate the minutiae pairs for the two images (see Figure 5). This value considers the fingerprint skin elasticity.



Type 1	Type 2	x_1	y_1	x_2	y_2	θ_{11}	θ_{12}	θ_{13}	θ_{21}	θ_{22}	θ_{23}

Figure 5. The blue circle represents the *beta* parameter in the minutiae pairs generation step between the template (left) and the test (right) image.

Successively, an identification phase using the Euclidean distance and "*1:N*" tests between each minutiae pair of test image and all template ones is performed. The algorithm calculates roto-translation parameters if the value of Euclidean distance is lower than a threshold (the *delta* parameter, experimentally fixed to 20 pixels).

The rotation parameter is based on the differences between the corresponding angles in the selected minutiae pairs. If the gap between each of these differences with respect to the other is lower than a threshold (the *gamma* parameter, experimentally fixed to 1.5 radians) the rotation parameter is the average of the calculated differences.

In the same way, the translation parameter is based on the differences between the respective Cartesian coordinates in the selected minutiae pairs. If the gap between each coordinate distance is lower than a threshold (the *alpha* parameter, experimentally fixed to 30 pixels) the translation parameter is the average of the respective calculated differences.

The roto-translation is performed by applying the following formula (1):

$$\begin{pmatrix} x' \\ y' \\ \theta' \end{pmatrix} = \begin{pmatrix} \cos\Delta\theta & -\sin\Delta\theta & 0 \\ \sin\Delta\theta & \cos\Delta\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ \theta \end{pmatrix} + \begin{pmatrix} \Delta x \\ \Delta y \\ \Delta\theta \end{pmatrix} \quad (1)$$

where the triplet $(x\ y\ \theta)^T$ contains the initial values, $\Delta\theta$ is the angle of rotation, Δx and Δy are the deviations respectively along x and y direction.

2) Matching Algorithm Step

The matching algorithm is performed between the roto-translated test and template image. For each test image minutia, all template image ones are considered to calculate the differences between respective coordinates x-y ($\overline{diff}_{xy}$) and angles ($\overline{diff}_{theta}$). Only when these differences are lower than two thresholds (the $xy_{threshold}$ and the $theta_{threshold}$, experimentally fixed to 15 pixels, for the Cartesian coordinates, and to 0.785 radians for the angles, respectively) the first partial score is obtained and mapped into [0, 1] range. The complete score is calculated by the following formula (2):

$$s_i = 0.75 * \left(1 - \frac{\max\left(\overline{diff}_{xy}\right)}{xy_{threshold}}\right) + 0.25 * \left(1 - \frac{\max\left(\overline{diff}_{theta}\right)}{theta_{threshold}}\right) \quad (2)$$

Among all complete scores, only the greater is considered. Therefore, the final matching score, between the roto-translated test and the template images, is calculated adding the 12 highest obtained scores. In accordance with the USA guidelines in the forensic field, when two fingerprints have a minimum of 12 corresponding minutiae, these are regarded as coming from the same finger [23].

Figure 6 shows an outline of the algorithm in its various phases.

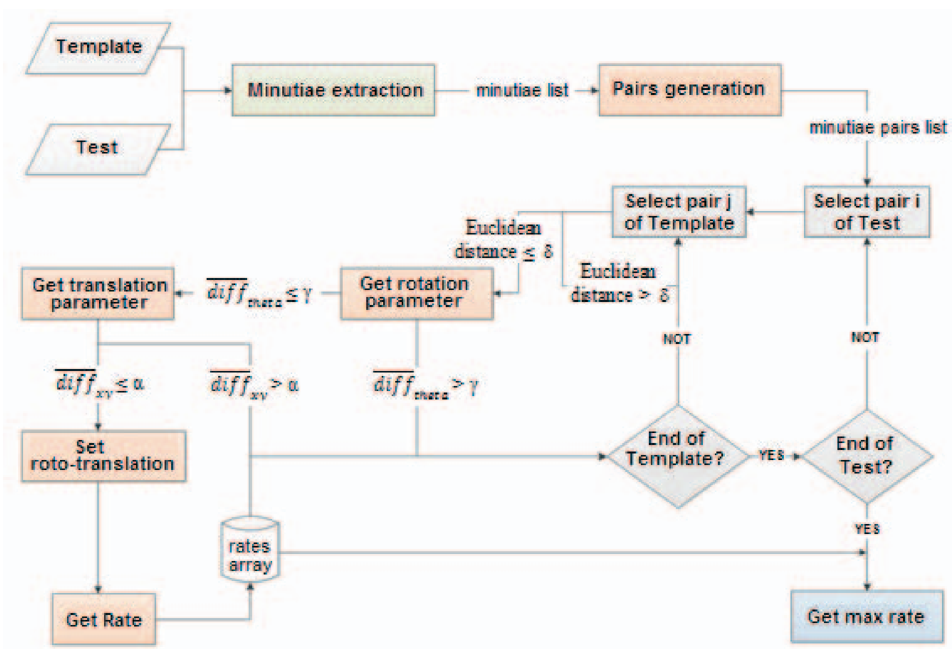


Figure 6. Outline of the dataflow diagram of the proposed system phases.

V. EXPERIMENTAL RESULTS

In order to evaluate the performance of the proposed approach, the implemented system has been tested using a database free downloaded containing complete and partial fingerprint images. Some interesting characteristics of the used database have been reported in the subsection V.1. The evaluation of the accuracy performances of the proposed identification system has been performed using the well-known False Recognition Rate (FRR) and False Acceptance Rate (FAR) indexes. The obtained experimental results, in terms of figures and rates, have been outlined in the subsection V.2.

1) Database description

The team working in the Biometrics Research Centre (UGC/CRC) of the Hong Kong Polytechnic University has developed a high resolution fingerprint imaging device and has used it to constructed large-scale high resolution fingerprint databases (HRF) free downloaded [26]. This database contains complete (5 templates) and partial (1 test) fingerprint images for each user. Each image name has been described using three numbers in the following way: first number represents the user, second number represents the finger, and third number represents the different acquisition (*image 7.4.2* => second acquisition of the forth finger of the seventh user).

An optical fingerprint imaging device has been used to acquire images with a resolution around 1,200dpi and of sizes 320*240 pixels and 640*480 pixels (see Figure 7).

In this paper a random dataset of 40 users has been extracted from the full database to obtain first experimental results.

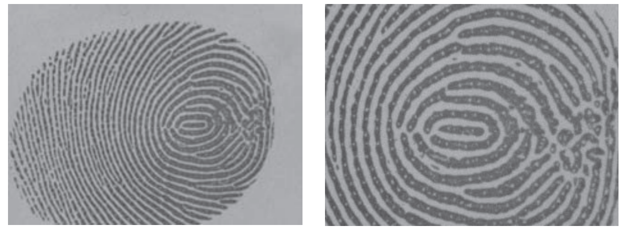


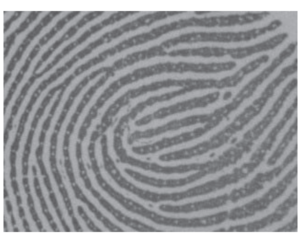
Figure 7. An example of high resolution fingerprint images of PolyU HRF database [26]: a) complete image and b) partial image.

1) Identification System Accuracy

In order to identify the individual to whom belongs a considered partial fingerprint, the following steps are performed:

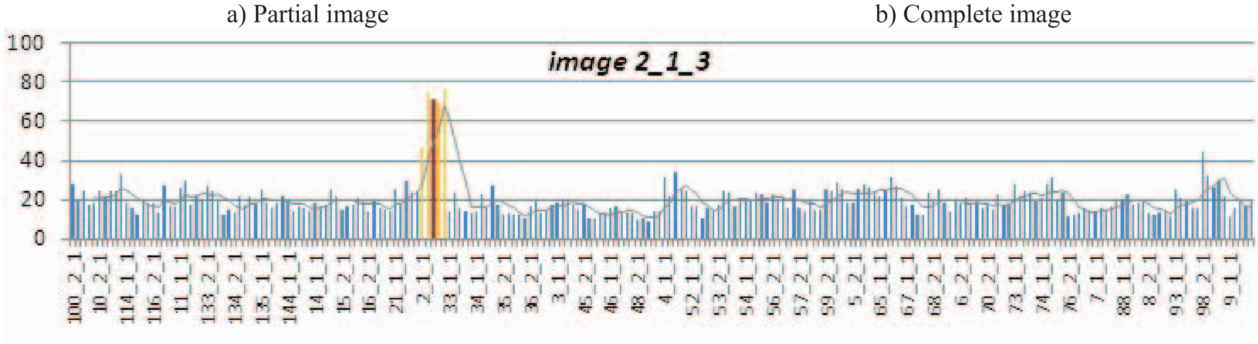
1. all computations of likelihood ratios;
2. the average value for each user (five fingerprint images for enrollment phase);
3. the maximum value of these averages.

The obtained results have shown the group to which the finger test belongs has always a wide margin than the other groups. Moreover, the average value of the winner group in each user identification process has a likelihood ratio higher than 50% (considered range 0%÷100%, see Figures 8, 9 and 10). Finally, following the guidelines proposed in [26] the system shows an interesting and encouraging FAR=0% and a FRR=0%.



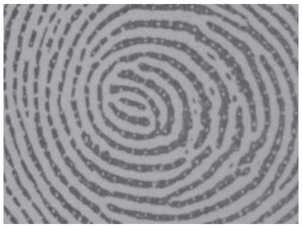
a) Partial image

b) Complete image



c) Likelihood ratios

Figure 8. An example of a processed fingerprint: a) the partial image; b) the complete image; c) the lines representing the different likelihood ratios: the red line represents the correspondent template image of the test *image 2_1_3*. The yellow lines represent the other fingerprint images acquisition of the same user. The blue lines represent the fingerprint images of other users.



a) Partial image

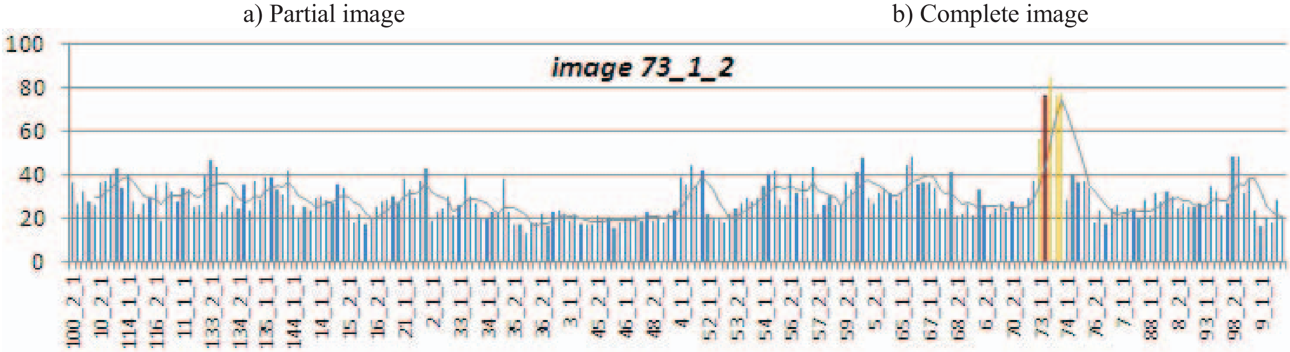
b) Complete image

c)

Figure 9. An example of a processed fingerprint: a) the partial image; b) the complete image; c) the lines representing the different likelihood ratios: the red line represents the correspondent template image of the test *image 3_1_1*. The yellow lines represent the other fingerprint images acquisition of the same user. The blue lines represent the fingerprint images of other users.

a) Partial image

b) Complete image



c)

Figure 10. An example of a processed fingerprint: a) partial image; b) the complete image; c) the lines representing the different likelihood ratios: the red line represents the correspondent template image of the test *image 73_1_2*. The yellow lines represent the other fingerprint images acquisition of the same user. The blue lines represent the fingerprint images of other user.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper an advanced technique for user identification based on partial fingerprint has been proposed. This work starts from having a group of five fingerprints enrolled users. The system has been developed performing fingerprint local analysis and micro-features extraction. The computation of likelihood ratios in fingerprint identification has been computed by trying all the possible overlapping between the partial image and the complete image. The first experimental results conducted on the free PolyU database [26] show a good performance in terms of identification accuracy, since the average values of the winner group in each user identification process has a likelihood ratio higher than 50%. Finally, the system has shown an interesting and encouraging FAR = 0% and a FRR = 0% with a dataset of 40 users.

Future works will be aimed to expand the test database to verify the robustness of the proposed approach.

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