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Automatic segmentation for separation of overlapped latent fingerprints

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***Abstract*—** Fingerprints are commonly used biometric trait used for identification. Latent prints are the fingerprint impressions which are inadvertently left by a person on different surfaces that come in contact with the finger at the crime scene. These latent fingerprints are used as evidence in the forensics to identify the suspect. Sometimes one fingerprint gets overlapped on another fingerprint, due to which it becomes difficult to extract features from the fingerprint and identify the suspect. Till now, overlapped and non-overlapped regions were segmented manually, which need extra human effort and consumes a lot of time. So, separating overlapped fingerprint automatically is necessary to identify the correct person. In this paper, machine learning algorithm is used to segment the overlapped fingerprint regions automatically by extracting features using Random Decision Forest (RDF) classifier and then separating the two fingerprints. Also, a database of overlapped latent fingerprints is collected using the touch less based sensor called Reflected Ultra Violet Imaging System (RUVIS). This device is used to search, view, detect and capture the latent fingerprints on non-porous surfaces. The performance of the proposed approach is evaluated on the developed database by computing False Rejection Rate (FRR).

***Keywords*—** Biometrics, latent fingerprints, Overlapped fingerprints, Random Decision Forest, Reflected Ultra Violet Imaging System.

I. INTRODUCTION

Latent prints are the impressions which are left on the surface that comes in contact with the finger due to the ridges which are present on the finger. When a finger is placed on a surface, an impression is left behind due to sweat, oil content, and amino acid present on the ridges of the finger. These impressions are left on the crime scenes and become forensic evidence to find the criminal. In crime scenes, suspected criminal cannot be identified as the latent images may be merged with some background images or may have overlapped images from same person or different person. Overlapped fingerprints are mainly lifted from crime scenes [1]. Such overlapped fingerprint images are useful in forensic evidence for identifying the suspects. Fingerprint features may not be accurate due to overlapping and low quality which leads to incorrect identification of person by fingerprint expert. There are different types of surfaces on which the impressions are left like, i) Porous surface absorb sweat and water contents which are present on the finger very quickly after the deposition due to which fingerprints are not visible through naked eye. For e.g. paper, currency, etc. ii) Non-Porous surfaces do not absorb sweat and for a very long time the fingerprint impression remain on the surface and are visible through naked eye. For e.g. Glass, metal surfaces, etc. iii) Semi-Porous surfaces absorb sweat slowly after deposition and remain on the surface for short time. For e.g. Waxed surface, papers with glossy finish, etc.

In this paper, separation of overlapped fingerprints is done to separate the two fingerprints with automatic segmentation of region masking and match the separated fingerprints with the original fingerprints from the database using machine learning algorithm. Random decision Forest (RDF) classification technique is used to segment the boundaries of the two fingerprints effectively by extracting features from the fingerprints [10]. Overlapped latent fingerprints were collected with the touch less based sensor called Reflected Ultra Violet Imaging System (RUVIS). This system is used to search, view, detect and capture latent fingerprints without using chemicals or dusting powders. Figure 1 show the overlapped image collected from RUVIS device.

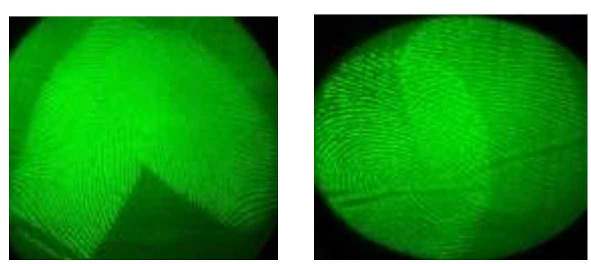

Figure 1. Overlapped images collected from RUVIS device

Rest of the paper is organized as follows, Section I describes the introduction of the overlapped latent fingerprints, Section II describes the related work in this field, Section III describes the methodology used to segment and separate the fingerprints with work flow, Section IV describes the database creation from RUVIS device and Verifier 300LC scanner, Section V describes the results and discussion, Section VI concludes the research work with the future directions.

II. RELATED WORK

The research work of various researchers who have worked in this direction is summarized in this section.

Chen et al. (2011) [1] proposed relaxation labeling algorithm for separating the overlapped fingerprint. Method requires the manual marking of region masking for the fingerprints and singular points. This method was not automatic and needed extra human effort. Experiments were performed on publicly available databases having only good quality images and did not evaluate performance on real overlapped latent fingerprints. Shi et al. (2011) [2] proposed constrained relaxation labeling algorithm to separate the overlapped orientation fields. Method requires only the manual marking of region masking for fingerprints. System was not automatic as manual region masking was needed. Results were performed on publicly available Tsinghua SOF database [1]. Feng et al. (2012) [3] proposed an efficient and robust relaxation labeling algorithm to separate the overlapped latent fingerprints. This method also requires manual marking of region masking for the fingerprints. The approach is different from Chen et al.'s method where constrained relaxation labeling method was used to separate two overlapped fingerprints. The results were performed on publicly available Tsinghua SOF database. Zhao and Jain (2012) [4] proposed a model based separation algorithm to separate the overlapped latent fingerprints. This method was not automatic and needed manual marking of the orientation cues, which lead to extra human effort. The algorithm reconstructs the orientation fields of the fingerprints through modeling orientation fields by using the orientation cues that were marked manually in fingerprints. Experiments were performed on publicly available databases and showed improved results in separating performance than previous method having additional manual marking. Zhang et al. (2014) [5] proposed an adaptive orientation model fitting algorithm for separating the overlapped latent fingerprints. In this method, Gabor filter is used for the initial orientation field estimation from the overlapped fingerprint. Using global orientation models, the separated orientation fields were smoothed. This method also requires the manual marking of region masking of fingerprints and was not automatic method. The experiment was performed on publicly available Tsinghua OLF database. Jeyanthi et al. (2015) [6] proposed an automatic fingerprint recognition system which is based on neural network for overlapped latent images. The neural network classifier is trained to classify the images as overlapped or normal image. Level 1, 2, 3 features were obtained using National Fingerprint Image Quality (NFIQ) software. Algorithm which reconstructs orientation field based on minutiae is used in which it takes manually marked minutiae in latent as input and gives an orientation field. Results were evaluated from NIST SD27 latent, SLF, Tsinghua University and FVC databases. Jeyanthi et al. (2015) [7] proposed an automatic fingerprint recognition system that detects overlapped fingerprints using an ANFIS classifier. The overlapped and non-overlapped images were distinguished as small, medium and large. System also needs manual marking of region masking. Results were taken from 150 normal, 12 latent and 150 overlapped images out of which 14 normal, 2 latent, and 20 overlapped images were incorrectly classified by ANFIS model. Experiment was performed on Tsinghua University, SLF, NIST SD27 latent and FVC databases. Branka et al. (2016) [8] proposed a separation algorithm based on neural networks for latent overlapped fingerprints. Neural network was used to separate the mixed orientation fields, which were enhanced using the global orientation field model and to correct remaining errors. Their system uses manual marking for region masking of fingerprints and is not fully automatic. It was tested on publicly available Tsinghua OLF database. Branka et al. (2016) [9] proposed a method based on Convolution Neural Network (CNN) for segmentation of fingerprints region of interest. Experimental results were performed on a database of 200 fingerprint images which were publicly available using and without using Gaussian noise. This method was competitive with Neural Network and Fourier coefficients based method for fingerprint images without noise. Segmentation was not performed on overlapped images. Sankaran et al. (2016) [10] proposed a segmenting algorithm to automatically segment the latent fingerprints and differentiate between ridge and non-ridge patterns. Approach works on machine learning algorithm in which 5 different categories of features were extracted to segment the latent fingerprint. These features distinguish foreground and background region using Random Decision Forest classifier (RDF). The results were evaluated on three publicly available databases. Tejas et al. (2017) [11] proposed an algorithm to automate the region masks using blurring, erosion and dilation and then separate the overlapped fingerprint. Experimental results were performed on FVC 2004 and FVC 2006 datasets. Improvement is needed to accurately mark the regions with dark backgrounds or high distorted background. Maheswari et al. (2012) [12] proposed an enhanced active contour based segmentation for fingerprint extraction. The proposed algorithm used region growing algorithm, active contour model and wavelet decomposition to segment the fingerprint from the background. Qian et al. (2013) [13] proposed separation of contactless captured high resolution overlapped latent fingerprints for parameter optimization and evaluation using relaxation labeling algorithm. High resolution chromatic white light sensor was used to capture the overlapped latent fingerprint without damaging the fingerprints. Experiment was performed on 20 authentic overlapped fingerprints with 4 templates of two different kinds using NIST Biometric Image Software. Total of 160 samples were used to perform matching after the separation of overlapped fingerprints. Equal error rate computed was 8.3% which is less than Chen et al.'s approach. Qian et al. (2014) [14] proposed a context based parameter optimization approach of separating contactless captured high resolution overlapped latent fingerprints using relaxation labeling algorithm. High resolution of 2450 ppi chromatic white light sensor is used to capture the overlapped latent fingerprint without destroying the fingerprints. Manually region masking is performed; no automatic region masking is performed. Results were evaluated on 60 authentic overlapped fingerprints from 3 different surfaces having equal error rate of 5.7% and 100 overlapped images from Tsinghua University database having equal error rate of 17.9%. Jeyanthi et al. (2013) [15] proposed separation and recognition of overlapped latent fingerprints using relaxation labeling algorithm. The regions of the overlapped fingerprints were manually marked which needs extra effort and time, no automatic regions were marked. Level 1, 2, 3 features were extracted. Experiments were performed on publically available database having overlapped and latent fingerprints from Tsinghua University database and Simultaneous latent fingerprint from IIIT Delhi database. True positive, false positive, false negative were calculated for the matching performance.

Table 1 show a comparison of different techniques used for separation of overlapped fingerprints.

Table 1. Literature Review Comparison

Paper	**Separation/ Segmentation Technique**	**Automatic / Manual Region Segmentation**
Chen et al. (2011) [1]	Relaxation Labeling	Manual
Shi et al. (2011) [2]	Constraint Relaxation Labeling	Manual
Feng et al. (2012) [3]	Constraint Relaxation Labeling	Manual
Zhao and Jain (2012) [4]	Model based Separation	Manual
Zhang et al. (2014) [5]	Adaptive Orientation Model Fitting	Manual
Jeyanthi et al. (2015) [7]	Neural Networks	Manual
Branka et al. (2016) [8]	Neural Networks	Manual
Sankaran et al. (2016) [10]	Random Decision Forest	Automatic
Tejas et al. (2017) [11]	Image Processing	Automatic

Separating overlapped latent fingerprints is a challenging task. In crime scenes, it is necessary to separate the overlapped fingerprints to identify the correct suspect. Different techniques are proposed by various authors to separate the overlapped latent fingerprints. All the existing techniques use manual segmentation of region masks which needs extra human effort, consumes a lot of time and the regions are not accurately marked where the boundaries of the overlapped region is present. The boundaries may have features which are useful for matching. So, automatic region masking needs to be done effectively so that features can be extracted from the fingerprint after the separation and person can be identified.

III. METHODOLOGY

The key contribution of this paper is to propose system which works on the segmentation of overlapped fingerprint regions effectively by extracting features from the fingerprint using RDF classifier and then separate the two fingerprint images. When two fingerprint images are separated, the fingerprints gets distorted due to which it becomes difficult to match the fingerprints. To resolve this problem, the separated fingerprints are reconstructed using morphological operation. Finally the two separated fingerprint images will be matched with the template database and matching performance will be evaluated using False Rejection Rate (FRR). Overlapped latent fingerprints were collected using RUVIS device (288 images). Figure 2 shows the proposed work flow.

Steps of work flow:

Step1: Acquire the input of overlapped latent fingerprints.

Step2: Preprocessing- Apply filters such as Gaussian filter, Averaging filter to enhance the image.

Step3: Extract features to obtain robust representation of fingerprint ridge patterns such as ridge orientation, inter ridge distance, etc.

Step4: Extracted features are then used for classification. RDF will classify the boundaries of two overlapped fingerprints using the extracted features and then segment those boundaries.

Step5: Separate the segmented regions of overlapped fingerprints by using Gabor filter. Gabor filtering can connect broken ridges and remove intervening ridges.

Step6: Reconstruct the separated fingerprint images using morphological operation.

Step7: Evaluate matching performance of the segmented overlapped images to acquire accuracy using FAR and FRR.

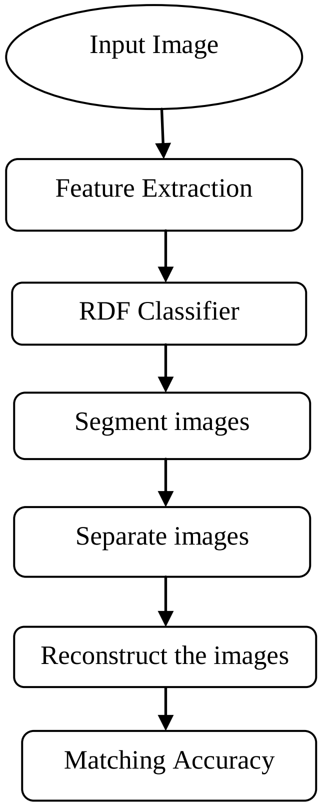

Figure 2. Work Flow

A. Preprocessing

Preprocessing needs to be applied on RUVIS images which have high illumination in them that needs to be controlled. So, contrast of the images is adjusted to control the illumination of light from the images which were collected from the RUVIS device. Figure 3 (A) shows the sample of overlapped input image. Image processing filters are applied to enhance the image such as Gaussian filter, averaging filter. Colored images are converted to grayscale image and then image sharpening is used to sharpen the images as shown in figure 3 (B).

Image binarization was applied to binarize the image which converts gray levels to black and white image and then thinning was applied on that image to reduce the thickness of ridges. Figure 3 (C) shows the binarized image.

(A)

(B) (C)

Figure 3. (A) Input image (B) Sharpened image (C) Binarized image

B. Feature Extraction

Feature extraction is the important step for identification purpose. Features are extracted from the fingerprint to obtain robust representation of ridge patterns such as ridge orientation, inter ridge distance. Features are used to distinguish overlapped and non-overlapped fingerprints. Features that are considered are:

1. Intensity feature

Intensity is calculated from the pixels of overlapped fingerprint which lies between 0-255 in range. The overlapped region has high intensity value and non-overlapped region has low intensity value.

2. Ridge orientation

Ridge orientation is used to calculate the direction of the ridges present in the fingerprint. It is calculated by using gradient along x and y directions. There will be two mixed orientations in the overlapped region and one orientation in the non-overlapping regions.

3. Inter-ridge distance

Inter-ridge distance calculates the distance between the ridges. The overlapped area will have low inter-distance value and it will have higher value in the non-overlapped area. It calculates the ridge peaks between the consecutive peaks of the ridges.

C. Segmentation & Separation

Random decision forest is supervised machine learning technique which is used for classification and regression. It is an ensemble classifier that consists of multiple decision trees and creates a forest in which random splitting of trees are made. It can handle missing values and this classifier does not overfit the model. RDF gives high performance accuracy with larger number of dataset having high number of trees.
Extracted features are given as input to the RDF. RDF will classify the regions into overlapped and non-overlapped regions. It will create multiple decision trees and split the decision from the random feature sample. RDF will classify the effective boundaries of two overlapped fingerprints using

the extracted features to segment the regions. Finally the segmented fingerprints are separated from the overlapped fingerprint by tuning both fingerprints with the Gabor filter. Gabor filter is used for edge detection to extract ridges, remove the intervening ridges and connect the broken ridges. The separated fingerprints are then reconstructed to remove the distortion in the fingerprints using morphological operation ‘imreconstruct’.

D. Matching

The both separated fingerprints needs to match with the authentic user to identify them correctly. To perform matching, level 2 features i.e. minutiae points are extracted from the ground truth fingerprint images and from the both separated fingerprints. The minutiae points of separated fingerprints are then matched with the corresponding ground truth fingerprints.

IV. DATABASE CREATION

Overlapped latent fingerprints are collected using a touch less sensor called RUVIS (Reflected ultra violet imaging system). RUVIS is used to search, detect, and capture the latent fingerprints without touching them and works on non-porous surfaces where fingerprints are not visible. Figure 4 (A) shows RUVIS mounted on a tripod and UV lamp. Fingerprints were captured by mounting camera on the RUVIS. 288 overlapped latent fingerprints of 16 users were collected from the glass surface. 18 overlapped latent fingerprints were collected per person where 3 impressions of thumb & thumb, thumb & index finger, index & index finger of both left and right hand were acquired. Figure 5 shows samples of overlapped latent images collected from RUVIS database. Ground truth images were acquired using Verifier 300LC scanner. Figure 4 (B) shows the Verifier 300LC scanner. Two impressions each of thumb and index fingers of both left and right hands were acquired. 8 images are captured per person. Database of 16 users are acquired having total of 128 samples of fingerprints. Figure 6 shows the ground truth images collected from Verifier 300LC scanner. Table 2 describes the total images that are collected from RUVIS database and ground truth images collected from Verifier 300LC scanner.

(A) (B)

Figure 4. (A) RUVIS mounted on a tripod and UV lamp (B) Verifier 300LC scanner

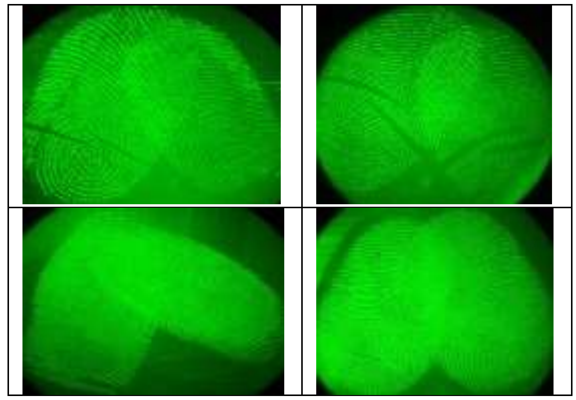

Figure 5. Overlapped latent fingerprints collected from RUVIS database

Figure 6. samples of ground truth images collected from Verifier 300LC scanner

Table 2. Database images

Images	No. of Users	No. of impressions per finger	No. of impressions per user	No. of total images
RUVIS Database (overlapped)	16	3	18	288
Verifier 300LC (Plain fingerprints)	16	2	8	128

V. RESULTS AND DISCUSSION

The results of separated overlapped latent fingerprints is shown in figure 7, where first column shows the overlapped latent fingerprint, second column shows the 1st separated left fingerprint image and third column shows the 2nd separated right fingerprint image.

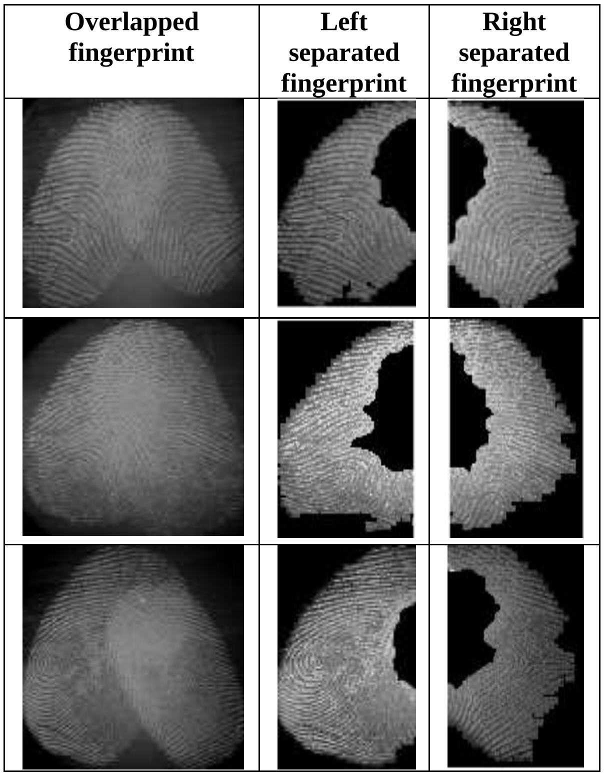

Figure 7 Results of separated overlapped latent fingerprints

Experiment was performed on database which was collected using RUVIS device. Database of 16 users having 3 impressions each of thumb & thumb, thumb & index finger, index & index finger of both left and right hand are taken. Thus, total 288 overlapped samples are considered. The matching is performed on 576 individual separated fingerprints from 288 overlapped samples. Separated fingerprints are matched with the ground truth images acquired using Verifier 300LC scanner. Performance is evaluated by calculating the False Rejection Rate (FRR) of the separated individual fingerprints. Total number of true attempts is 576 and the total number of false rejections is 34. So, FRR is computed as:

FRR = (No. of false rejection/Total no. of true attempts)*100

FRR = (34/576)*100 = 5.9%

Hence, FRR is evaluated to be 5.9%.

VI. CONCLUSION AND FUTURE SCOPE

Separating the overlapped latent fingerprints is necessary to identify the suspect in crime scenes when one fingerprint gets overlapped with another fingerprint. Marking the regions in an overlapped image is a time consuming task and needs extra human effort. Machine learning algorithm was used to automatically segment the regions to distinguish between overlapped & non-overlapped areas. The segmented region was then separated. Experiment results were evaluated on overlapped database created using RUVIS. Matching performance using FRR is evaluated to be 5.9%. This study can be extended for acquiring overlapped fingerprints from various surfaces like porous surfaces, non-porous surfaces, curved surfaces as it is a challenging task. Segmentation results could be further improved by exploring various other techniques. There is still improvement needed to fully automate the system and separate more than two overlapped images.

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