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Filters to Dictionary based Enhancement Techniques for Latent Fingerprints Matching

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Abstract: Latent fingerprints are the finger skin impressions in a groove and ridge pattern left when fingertips come in contact with any surface. In forensics investigation, latent fingerprints plays as principal evidence to identify and convict criminals. Due to the presence of overlapping noisy patterns and complex ridge structure, they are usually unclear and of poor quality. The discipline of latent fingerprint detection has gain attention of many researchers over the years and many advances have been made but it is still challenging to accomplish the task by offering a quick, reliable and accurate latent fingerprint detection system. The presence of spoiled minutiae information, ridge and overlapping patterns make the task more complicated. The latent fingerprints do not serve any purpose before the enhancement and reconstruction of the ridge patterns, minutiae information and their quality. Prior to latent fingerprint detection and feature extraction, latent fingerprint enhancement is absolutely requisite to improve the quality for accurate fingerprint detection. This paper presents an analysis of various latent fingerprint enhancement techniques by comparing the work of numerous researchers. The paper sheds some light on the issues and challenges in the process of latent fingerprint detection. In addition, the paper also presents various datasets available for latent fingerprint detection.
Keywords: Latent Fingerprint Enhancement; Latent Fingerprint; Minutiae Information; Image Enhancement; Biometric Identification; Forensic Investigation

I. INTRODUCTION

Fingerprints identification is one of the oldest and persistent techniques for personal identification [1]. The identification method is pertinent for the reliable identification of a person and is widely considered in forensics investigations and civil applications [2]. Fingerprints are the skin impressions left on any surface due to the friction ridge of finger. These are the patterns or whorls present on the tip of each finger which are unique for each individual. On the basis of patterns fingerprints are broadly categorised into three types: arches, loops and whorls [3] as presented in fig 1. In an arch pattern, the ridges move in from one side and move out from other side. They are of two types: plain arch and tented arch. Loop pattern is also of two types: ulnar and radial loop. In this pattern ridges move in from one side, loop around and move out with the same pattern. Whereas whirl pattern is a series of circles almost concentric in nature. Plain whirl, double loop whirl, central pocket loop whirl and accidental whirl are types of whirl fingerprint pattern.

Latent fingerprints are finger impressions left unintentionally on any surface at crime scenes. Latent fingerprints are considered as primary evidence to identify and convict criminals due to their property of uniqueness. Fig 2 presents latent fingerprints on different surfaces.

Fig. 1 Fingerprint patterns

The researchers have made many advances in the discipline over the past few years but the task of latent fingerprint detection by a reliable, quick and accurate automated system is still challenging. The basic process of latent fingerprint detection as presented in fig 3 includes: (a) the extraction of the fingerprints from the surface, (b) pre-processing of the fingerprints including reconstruction, enhancement, segmentation, binarisation, thinning etc. (c) fingerprint feature extraction and at last (d) fingerprint matching from the database.

Prior to fingerprint matching and feature extraction, the process of latent fingerprint image enhancement holds utter importance. Before enhancement, latent fingerprint images are of no use. Latent fingerprint images are usually of poor quality due to loss of minutiae information, overlapping patterns and inexplicit ridge structure as presented in fig 2. In addition to their complex and overlapping patterns and spoiled minutiae, sometimes some more information is lost during the extraction of the latent fingerprint from the surface. This makes the task of fingerprint detection more complicated and challenging. The images are enhanced to remove the noise present or to recover the lost minutiae information for accurate fingerprint detection. In this paper, a comparative analysis of various enhancement techniques is done by studying the work of numerous researchers. In addition, from the analysis some research questions are also proposed in this paper.

Fig. 2 Latent fingerprints on different surfaces

Fingerprint detection has come across as one of the most glaring and attentive research discipline over the past few years. It has its applications ranging from personal laptops to law enforcement. Many law enforcement agencies gather the fingerprint record of incarcerated criminals to track their history. Application areas of fingerprints detection are presented in table 1.

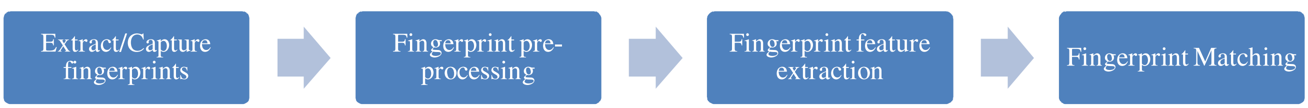

Fig. 3 Basic process of latent fingerprint detection

TABLE 1
APPLICATIONS OF FINGERPRINT DETECTION SYSTEM

Application Areas	Applications
Civil Applications	• Unique Identification of a person e.g. India's Aadhaar card project [4]. • Voter registration and recognition • Biometric identification for Population census • Passport verification for border control • Driving Licence and Identification cards
Personal Security	• Providing biometrics to systems for secure and authenticated access
Forensics Applications	• Crime scene investigation • Cross-border security • Criminal investigation • Financial systems

The rest of the paper is outlined as follows. The various latent fingerprint enhancement techniques are introduced in Section 2. Then, from the work analysis some research questions are proposed in Section 3. Finally, Section 4 concludes the paper

II. MATERIAL AND METHODS

This section presents the basic of latent fingerprint enhancement and methods used for enhancement from filters to dictionary based approach.

A. Basic of Latent Fingerprint Image Enhancement

Gonzalez and Woods [5] stated that there is no theoretical process for image enhancement. It is the viewer who judges the particular method of image enhancement by examining the quality of image and its visual interpretations. In case of latent fingerprint image enhancement two types of images are there: binary fingerprint image and grey scale fingerprint image. In a binary fingerprint image, pixels are assigned with values 1 and 0. The ridge pixels are assigned with value 1 and 0 value is assigned to the non-ridge pixels. In this process the binary fingerprint image is obtained by applying some ridge extraction algorithm on the grey scale fingerprint image. But this process has its limitations. Since the binary image is obtained from grey scale image, it often results in loss of information during the process of ridge extraction. On the other hand, grey scale fingerprint images are well interpreted with frequency and orientation information of ridges. The presence of frequency and orientation information of fingerprint ridges is one of the key reasons for the popularity of grey scale images for latent fingerprint enhancement. The enhancement techniques for grey scale latent fingerprint images are broadly categorized into two categories which are:

1) Spatial domain enhancement techniques
2) Frequency domain enhancement techniques

Spatial domain [5] refers to the pixel image plane. Here the grey scale image pixels are directly processed by image enhancement techniques. The basic process in spatial domain consists of intensity transformation and spatial filtering. In Intensity transformation, every single pixel of image is processed for image threshold and contrast manipulation. The process of spatial filtering is subjected to image sharpening by processing every neighbouring pixel of image. If $f(x,y)$ is the input image, T is the operator defined over neighbouring pixels points of (x,y) and $g(x,y)$ is the desired output. Then, the process of spatial domain can be denoted as:

$$g(x,y) = T[f(x,y)]$$

… equation (i)

In frequency domain, the intensity values of pixels of an image are transformed into frequency components [5]. This method represents the frequency patterns of the variations in the ridge orientations, direction of variations and also the amplitude values of the waveforms. It is easy to remove noise in this method as compared to the spatial domain enhancement. In the process of latent fingerprint enhancement, it is necessary to conserve the overall image impression. So the filtering technique modifies the Fourier transform of the fingerprint image and then its reverse i.e. discrete Fourier transform is computed to get back the original input image. If $f(x,y)$ is the input image, $F(u,v)$ is Discrete Fourier transform of input image $f(x,y)$, $H(u,v)$ is filter function and $g(x,y)$ is the desired output. Then, equation for basic filtering process in frequency domain enhancement is:

$$g(x,y) = \mathfrak{I}^{-1}[H(u,v)\, F(u,v)]$$

… equation (ii)

B. Enhancement Techniques

Latent fingerprint detection is one of the traditional computer applications. Numerous researchers have considered the classical digital image processing techniques for the latent fingerprint image enhancement. In this section, some of the grey scale image based latent fingerprint enhancement techniques are discussed and summarised in table 2.

Latent fingerprints are generally blurred and of poor quality with unclear spatial definition. Ko, Teddy [6] analysed some spatial and frequency domain filters for the latent fingerprint enhancement. The author considered spectral analysis technique to enhance latent fingerprints by enhancing the ridge structure and removing the background structured patterns. The latent fingerprint image data undergoes Fast Fourier Transform for its transformation into frequency domain. The image spectrum obtained is multiplied using some mask filters and then it is transformed back to pixel image plane i.e. spatial domain. The experimental results indicate the importance of frequency domain filters for the latent fingerprint enhancement.

Saatci and Tavsanoglu [7] enhanced the latent fingerprints by dividing the fingerprint image into segments of size 15*15. The fingerprint images are scanned at particular resolution so that the variation between the spatial frequencies of segments is less. The small amount of distance between the ridges of different segments indicates the possibility of optimum spatial frequency. The latent fingerprint enhancement process works in four stages segment by segment. The first stage is contrast stretching in order to improve the quality of images with low contrast. In second stage, cellular neural network based Gabor-type filter (CNN-GTF) is applied to remove the unwanted noise. Then low-pass filter is applied to present the ridge features precisely. Then in the final stage, the greyscale image is converted into binary image for further feature extraction. The author has contemplated of programming a VLSI CNN chip based on CNN-GTF resulting into a swift and accurate fingerprint detection system.

Yang et al. [8] proposed a modified Gabor filter (MGF) design method based on the traditional Gabor filter (TGF) [9]. The parameters in Gabor filter including period if sinusoidal wave, size of convolution mask, standard deviation, Gabor filter orientation and 2-D Gaussian functions are image independent and specified based on some principles i.e. adaptively. On the other hand in TGF, the parameters are image dependent and are specified based on the experience data. The design of the modified Gabor filter is based on the frequency domain whereas latent fingerprint images are enhanced on pixel basis (spatial domain). The experiment results are performed on the datasets including self generated image dataset, images of the dataset at University of Bologna and fingerprint image dataset of NIST. The results obtained indicate the robustness and effectiveness of MGF over TGF.

Wang and Wang [10] designed a bandpass filter for fingerprint enhancement in singular point area. At singular point area there is a prompt change in the direction of ridges and also the curvature of ridge is elevated than the normal [11] [12]. In order to find the singular point area, the fingerprint images are first normalized to remove the noise and finger pressure effects. Then the image is smoothened by Gaussian smoothening and subjected to histogram equalization to make image clearer. The core and delta points of fingerprint image are selected in located the singular point area. The singular point area is divided into different blocks and then it is transformed into Fourier domain. Bandpass filter is applied to filter the image and it is then converted into spatial domain. The filter is designed with parameters related to the ridge frequency and bandwidth. The experimental results are calculated using Veridicom COMS sensor based fingerprint image dataset. The results in the form of accuracy rate are calculated and are compared with the Fourier filter enhancement algorithm [13]. The accuracy rate of proposed algorithm indicates the improvement in fingerprint image quality and accurate minutia extraction.

Chikkerur et al. [14] proposed a fingerprint image enhancement algorithm based on short time Fourier transform (STFT) and contextual filtering. The proposed algorithm works in two stages. In the first stage, STFT defined the intrinsic images i.e. ridge frequency image, ridge orientation image and energy image of the block to compute the region mask. In the second stage context filtering is performed on the intrinsic images by separating the frequency and angular domain. The experimentation is performed on FVC database and NFIS2 software is used for further feature extraction and fingerprint matching.

Yoon et al. [15] proposed a latent fingerprint enhancement algorithm in which the region of interest points and singular points are marked manually. The orientation field estimation algorithm is proposed in which input is the latent fingerprint image with manually marked singular points and region of interest. Further Gabor filter is implemented to enhance the latent fingerprint image. The experiment is conducted on NIST 27 latent fingerprint database. The performance of the proposed algorithm is compared by matching the latent fingerprints with the rolled fingerprints in four different scenarios using VeriFinger SDK 4.2 [16]. The latent examiner classifies the latent fingerprints into 3 categories named as: good, ugly and bad. The fourth category includes all latent fingerprints. Four experiments are conducted with four different input types. The results obtained indicate that the accuracy rate of matching in proposed algorithm is more as compared to other three categories. Further Yoon et al. [17] proposed robust orientation field estimation algorithm accepting manually marked region of interest and singular points as input. The orientation field estimation is based on randomized RANSAC for effective estimation of orientation field in case of fingerprint distortion and noise. The cumulative match characteristics (CMC) curves for four different input types indicates the performance results by randomized RANSAC are effective than estimation results of least square method. Another robust orientation field estimation based latent fingerprint enhancement algorithm is proposed by Feng et al. [18]. The proposed algorithm consists of dictionary for its implementation. The prior knowledge about the structure of the fingerprints is used to build a dictionary of orientation patches. The dictionary is constructed in two phases: the first phase is off-line dictionary construction phase in which different pattern types of high quality fingerprints are selected manually for construction of orientation patches. In second phase which is online orientation filed estimation phase, an orientation filed is estimated automatically by following three steps. In the first step initial orientation estimation is done using Fourier analysis. In the next step, orientation filed is divided into different overlapping patches and subjected to dictionary lookup to replace the noisy patches. The third step consists of context based correction for the optimum orientation patches. The orientation patches in the dictionary are converted into blocks of same size and VeriFinger 6.2 SDK is used for the estimation. The propose algorithm is tested NIST SD4 dataset and Tsinghua OLF dataset. The proposed algorithm is compared with FOMFE [19] based algorithm and STFT [14] based algorithm in terms of average root mean square deviation (RMSD). The calculated results indicate that the proposed dictionary based algorithm outperforms the other two algorithms.

Recently Kao et al. [20] proposed a dictionary based course to refine ridge enhancement technique. The dictionary is a collection of ridge structures which is learnt from latent fingerprint images with high quality. The dictionary consists of two stages: stage 1 is the offline dictionary stage in which coarse level and fine level dictionaries are learnt with different patch sizes. In stage 2, online dictionary segmentation and enhancement is done by first decomposing the latent into cartoon and texture images. Then the texture image is further divided into patches for coarse level and then fine level estimation of the orientation and frequency fields. The background noise is removed by the total variance (TV) decomposition model and the closest neighbouring similar element is used to reconstruct the low quality latent fingerprints. The proposed algorithm in fusion with COTS matcher when evaluated on NIST SD27 and West Virginia University (WVU) dataset shows approx 75% and approx 78% rank-1 accuracy results respectively.

Liu et al. [21] proposed a latent fingerprint enhancement algorithm based on the total variance (TV) decomposition model and sparse representation based on multi-scale patches. The total variance decomposition model is used to remove the structured background noise. The latent fingerprints are decomposed into cartoon and texture images. A reference dictionary is build based on the frequency and orientation of latent using Gabor functions. The sparse value is calculated using the dictionary. The weak or low quality texture images are then enhanced using the multi-scale based sparse representations. The cumulative match characteristics (CMC) curve result of proposed algorithm outperforms when compared with three other enhancement algorithms [9] [18] 14]. Further Wei and Liu [22] improves the improves the proposed algorithm by removing the structured noise using total variance decomposition model and reconstructing the low quality fingerprints using orientation based sparse representation.

III. RESULTS AND DISCUSSION

The analysis of the work ensued some research questions which are proposed in this section.

A. What are the publically available latent fingerprint datasets?

The publically available datasets for latent fingerprint detection are NIST SD-27, IIIT-D latent fingerprint, IIIT-D SLF and latent fingerprint overlapped dataset. The datasets differ from each other in terms of characteristics and number of images as presented in table 3.

1) *NIST SD-27*: The NIST SD [23] is a greyscale fingerprint special database composed by National Institute of Standard and Technology united with Federal Bureau of Investigation. The dataset is a collection of total number of 258 latent cases collected from crime scenes along with matching fingerprint mates. NIST SD-27 is a publically available dataset which is commonly can be used to develop and examine fingerprint detection systems.

TABLE 2
GREY SCALE IMAGE BASED LATENT FINGERPRINT ENHANCEMENT TECHNIQUES

Author	Objective	Approach	Database	Analysis
Ko, Teddy [6]	Enhancement	Spectral Analysis by Non-Linear spatial filters and Frequency domain filters	Manually generated dataset	Flat fingerprints can be easily enhanced by adjusting brightness or colour map using spatial filters. Latent fingerprints require frequency domain filters or sometimes both spatial and frequency domain filters for image enhancement.
Saatci and Tavsanoglu [7]	Enhancement	Cellular Neural Network-Gabor Type filter	Manually generated dataset	The use of Gabor filters with their frequency and orientation selective property along with the process of fingerprint image segmentation results into an optimal filtered image for each segment.
Yang et al. [8]	Enhancement	Modified Gabor filter	Manually generated dataset, Dataset at University of Bologna and Fingerprint image dataset of NIST	Proposed modified Gabor filter eliminates the disadvantage of image dependency for filter parameter selection. In case of fingerprint images with heavy noise, the proposed modified filter did not show effective results.

Wang and Wang [10]	Enhancement	Fourier domain based bandpass filter	NIST 27 and Veridicom COMS sensor based fingerprint image dataset	The curvature of the ridge in singular point area is usually higher than normal curvature which is smoothened by an isotropic filter proposed in [16].
Chikkerur et al. [14]	Enhancement	Short time Fourier transform (STFT)/ Contextual filtering	FVC fingerprint image dataset	The image is converted into overlapping windows including ridge frequency image, ridge orientation image and energy image, coherence image. Thus utilizing the entire image contextual information.
Yoon et al. [15]	Enhancement	Orientation field estimation/ Gabor filter	NIST 27 latent fingerprint database	The proposed algorithm is based on the opinion that the important manual input should be reduced rather than completely removing it.
Yoon et al. [17]	Enhancement	Robust Orientation field estimation/ Gabor filter	NIST 27 latent fingerprint database	The latent fingerprint image is divided into blocks of equal size and short term Fourier transform (STFT) is used to detect the peaks values in the local image magnitude spectrum.
Feng et al. [18]	Enhancement	Robust Orientation field estimation	NIST SD4 and Tsinghua OLF dataset	The proposed algorithm is inspired from the natural language processing based spelling correction techniques. Set of reference orientation patches are constructed by the greedy algorithm using the existing orientation patches
Kao et al. [20]	Segmentation and Enhancement	Dictionary based coarse to fine ridge enhancement technique	NIST SD27 latent fingerprint database WVU database	The proposed algorithm removes the structured noise and the presence of low quality ridge structure in latent fingerprints.
Liu et al. [21]	Enhancement	Total Variance decomposition Model and Multi-scale based sparse representation	NIST SD27	The proposed algorithm eliminates the overlapping structured small noises and also restores the distorted ridge structures.
Wei and Liu [22]	Enhancement	Total Variance decomposition Model and orientation guided sparse representation	NIST SD27	The proposed algorithm works in case f heavy structured noises. The Gabor dictionary based sparse representation is implemented iteratively for poor quality regions to restore the ridge structure of distorted regions.

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2) *IIIT-D Latent Fingerprint:* Sankaran et al. [24] prepared IIIT-D Latent Fingerprint dataset which is a collection of 1046 latent fingerprints corresponding to 150 classes. The dataset consists of prints of 5 subjects captured under a semi-controlled environment. The dataset is publically available and contains variations in terms of noise and fingerprint quality.
3) *IIIT-D SLF*: IIIT-D SLF is a simultaneous latent fingerprint database prepared by Sankaran et al. [25]. The database consists of fingerprints settled on a background with ceramic tiles in a semi controlled environment. The publically available dataset contains different fingerprint combination of total number of 30 subjects.
4) *Latent Fingerprint Overlapped Database*: The latent fingerprint overlapped database is developed by feng et al. [26] which is a collection of 100 overlapped latent fingerprints. The fingerprints are roughly taken on a white plain paper, enhanced using black powder process and then are converted into electronic form using HP scanner. The authors made the dataset publically available to motivate and stimulate research on latent fingerprint detection.

TABLE 3
PUBLICALLY AVAILABLE LATENT FINGERPRINT DATASETS

Dataset	Total Images	Classes	Resolution	Characteristics
NIST SD-27[23]	258	258	500 ppi and 1000 ppi	Manually annotated features along with latent to rolled fingerprint matching.
IIIT-D Latent Fingerprint [24]	1046	150	500 ppi and 1000 ppi	Images are captured by a camera and then enhanced using black powder process
IIIT-D SLF [25]	1080	300	500 ppi	Simultaneous latent fingerprints are obtained after cropping images of latent fingerprints.
Latent Fingerprint Overlapped Database [26]	100	12	500 ppi	Fingerprints of two fingers are roughly taken and then enhanced using black powder dusting process.

Among the four publically available datasets, NIST SD-27 is the most commonly used latent fingerprint dataset. NIST SD-27 is a special dataset containing latent fingerprints collected from different crime scenes. The dataset has been used by many researchers over the years to develop and test the latent fingerprint enhancement and matching system [10] [12] [18] [20] [21] [23] [24] [25].

B. What is the Need of Fingerprint image enhancement?

Fingerprints are considered as the most important and effective evidence for person identification. Fingerprints are unique in nature. The property of uniqueness of fingerprints is determined by the characteristics of ridges and their relationships [27] [28]. Ridges are collection of patterns present on the surface of fingertips. More than 100 ridge characteristics have been identified including ridge ending, island and short ridge but the two most eminent characteristics are: ridge ending and ridge bifurcation [28] (also called as minutiae) as presented in fig 4.

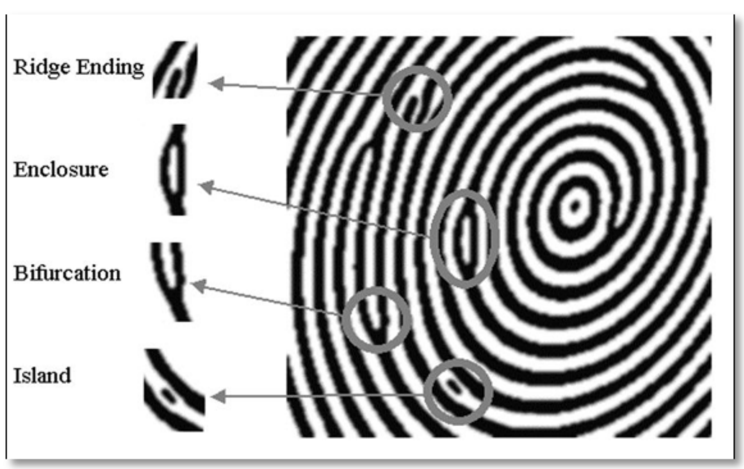

Fig 4. Characteristics of fingerprints

In an ideal situation, fingerprints can be easily detected using the minutiae information. But in case of latent fingerprints, the spoiled minutiae information and spurious minutiae makes the task of fingerprint detection extremely difficult. In addition, some other factors like impression conditions, acquisition devices or different skin conditions including dryness and cuts also influence the quality of the fingerprint. In poor quality fingerprints the structure of ridges is not properly defined which may lead to:

1) Ignoring genuine minutiae
2) Generation of spurious minutiae
3) Orientation and position errors etc.

Thus, it is extremely important to enhance the fingerprint image before the minutiae extraction in order to achieve accurate and reliable results. The process of fingerprint enhancement not only improves the ridge structure in latent fingerprints but also improves the quality of the fingerprint image. Fingerprint enhancement ensures a robust and reliable fingerprint detection system with accurate results.

C. What are issues and challenges in fingerprint enhancement and matching?

Fingerprint matching and recognition is considered as the one of the most authentic and genuine personal identification system. But the task is not simple enough as it seems. Researchers have been working on this discipline from over the years. Numerous issues and challenges have been encountered by them and some of them are:

1) Low quality fingerprint images results into spoiled minutiae information and missed features. It sometimes leads to redundant or spurious features and thus resulting into degradation of the system's performance.
2) Use of multiple sensors either for interoperability or for fusion is a recent issue in the discipline of fingerprint enhancement and matching.
3) Another recent issue that have come to notice is that fingerprint systems are vulnerable to fake fingerprints.
4) Fingerprints obfuscation is also one of the primary issues which should be taken care especially in border security. Fingerprint detection systems are unable to identify the true identity of a person with altered fingerprints.
5) Genetic clone or identical twin fingerprints are also one of the key issues raising the demand of an efficient and robust fingerprint detection system.
6) Coercion, circumvention, denial of service, collusion, repudiation etc. are some of the common attacks that can alter the fingerprint detection system.

D. How to evaluate different fingerprint enhancement techniques?

Gonzalez and Woods [5] in their book "Digital Image Processing using MATLAB" state that there is no theoretical process for image enhancement. The viewer itself is the judge of the particular method of image enhancement by examining the quality of image and its visual interpretations. However, Wang and Wang [10] evaluated their proposed latent fingerprint enhancement technique by comparing it with Fourier enhancement technique [13] in terms of average accuracy rate. The accuracy rate (AR) was calculated by using the formula presented in equation (iii).

$$AR = \frac{Mr - Mm - Ms}{Mt}$$

… equation (iii)

Where *Mr* is the true minutiae extracted from defined singular point area. *Mm* is the missing minutiae, *Ms* is the spurious minutiae and *Mt* is true minutiae identified by fingerprint proficient. Average accuracy rate of 81.84% is achieved by proposed algorithm.

Many researchers evaluated the system performance in terms of receiver operating characteristic (ROC) [14] and cumulative match characteristics (CMC) [15] [17] [21] [22] curves by comparing their proposed system with other existing systems using some open source fingerprint matching software e.g. VeriFinger SDK [16].

Feng et al. [18] compared the proposed robust orientation filed estimation algorithm with FOMFE [19] based algorithm and STFT [14] based algorithm. The average root mean square deviation (RMSD was calculated and results indicate that the proposed dictionary based algorithm outperforms the other two algorithms. Kao et al. [20] evaluated the proposed segment and enhancement technique by calculating the rank-1 accuracy results. The proposed algorithm in fusion with COTS matcher when evaluated on NIST SD27 and West Virginia University (WVU) dataset shows rank-1 accuracy approx 75% and approx 78% rank-1 accuracy results respectively.

IV. CONCLUSION

In contrast to the favoured belief, it is still a challenging task to develop reliable and prompt latent fingerprint detection. Latent fingerprints play a key role in many forensic investigations to identify and convict criminals. Due to spoiled minutiae information, overlapping patterns and inexplicit ridge structure, the task of fingerprint detection becomes more complicated and challenging. Latent fingerprints images are enhanced to remove the noise present and to recover the information loss. In this work, a comparative analysis of the different latent fingerprint enhancement technique is presented. Earlier, various spatial domain and frequency domain filters were used for the latent fingerprint enhancement. Flat fingerprints can be easily enhanced using spatial domain filters but due to distorted ridge structure, latent fingerprints require frequency domain filters along with spatial filters. The legibility of the latent fingerprints was improved but the enhancement technique using single filter was unable to alter the ridge structure. Later, the latent fingerprint enhancement techniques based on the ridge orientation and frequency were proposed. The region mask of the fingerprint was evaluated based on the ridge frequency and orientation thus utilizing the entire contextual information. However, the results obtained were not satisfactory in case of heavy noises. More recently, ridge structure dictionary based latent fingerprint image enhancement technique has been proposed. The prior knowledge about the structure of the fingerprints is used to build a dictionary of orientation patches. The total variance (TV) decomposition model is used to decompose image into cartoon and texture images. The cartoon images are mostly structured noises which are removed by TV model and texture images are used for further processing. Dictionary based approach is inspired from the term "light-out" which was suggested in order to introduce a autonomous fingerprint matching system without any human intervention. The approach removes structured noise and enhances the image by utilizing the ridge structure. Dictionary based approach is appropriate for latent fingerprint image enhancement but researchers are still working to further improve enhancement techniques in order to achieve the objective of an autonomous system without any human intervention.

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