Latent Fingerprint Preprocessing: Orientation Field Correction using Region Wise Dictionary

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Abstract*— Latent Fingerprint Images have been extensively used by law enforcement agencies in investigating the crime spot and use the necessary information obtained as evidence to validate the criminal in Court. Although an important breakthrough in this direction has already been made in plain biometrics recognition, still identifying biometric such as Face in CCTV footage and Latent Fingerprint in uncontrolled, uncooperative, and hostile environment is an open research problem. Poor quality, lack of clarity, absence of proper mechanism make the latent fingerprint preprocessing problem one of the persistent and challenging problem to extract the reliable features. Dictionary based learning technique has given significant result, in contrast to conventional orientation field estimation methods by reconstructing orientation field to enhance the latent fingerprint image. Distorted orientation field is corrected using orientation patches of good quality fingerprint from region wise dictionary. This paper proposes a fresh idea to construct the dictionary by region wise to correct the orientation field in latent image. To verify the accuracy of enhanced image, a statistical observation has been done and got the promising results. This study concentrates on latent fingerprint preprocessing module towards reliable and efficient (optimal) Latent Fingerprint Identification.

***Keywords*— Latent Fingerprint, Orientation Field Correction, Region Wise Dictionary, Preprocessing.**

I. INTRODUCTION

Fingerprint detection and analysis is one of the most common and important techniques for criminal investigation used by law enforcement agencies for over 100 years [1]. Fingerprints have the most distinctive patterns in comparison to other publicly available biometric traits, such as Face, Iris etc. The uniqueness and persistence characteristic of finger among all biometric traits make it easy to figure out the unsolved problem and helps the law enforcement agencies to convict the individual person in identifying the suspect. Most of the criminal disputes have been solved with the help of fingerprint evidence found at the crime scene without making any further comprehensive investigation [2]. The area of fingerprint has evolved from forensic science to digital forensics or in another word, from criminal investigation to e-crime prevention in digital identity world. In digital forensics, fingerprints are used as digital identity management to protect confidential information and prevent e-crime in a highly secure communication environment [3], [4], [5], and [6], such as cyber security, defense technology, banking sector, e-administration, and Crime and Criminal Tracking Network and Systems (CCTNS).

Fingerprint analysis is based on location of minutiae and singular point (Core and Delta) detection in the image. It is categorized into three tiers based on global to local or coarse to fine pattern properties of fingerprint feature selection and extraction process, which are described in three steps as mentioned below:

1. *Level-1:* Singular point (core and delta points) and ridge flow configurations such as orientation field and frequency field are known as global features. These features are mainly used for classification based on type of pattern such as arch, loop, and whorl [7].
2. *Level-2:* Minutiae points or ridge end and bifurcation are known as level-2 features (which are known as ridge discontinuities). These characteristics are widely used in fingerprint matching algorithms [8], [11].
3. *Level-3:* To extract the features such as pores and ridge contours, require a very high quality (minimum 500 dpi resolution) fingerprint image. When compared to exemplar fingerprint, numbers of minutiae features in latent fingerprint are very less. These local or fine level features of level-2 are used as extended feature to recognize the latent fingerprint more uniquely [9], [10].

The Quality of latent fingerprint is very short due to the unclear ridge structure, complex background, and even overlapping pattern when compared to exemplar fingerprint (or rolled and plain fingerprint as shown in Fig. 1). This causes the latent fingerprint matching problem very challenging in terms of accuracy and reliability [1], [12], [13], and [14]. Latent fingerprints are used as a major source of evidence in criminal identification by law enforcement agency for conviction of unknown identity by matching with a known database. Latent fingerprints are collected from crime spot by a specialist, trained in forensics technique to press out the fingerprint from the target surface using some chemical and physical methods [15]. These records are retained in a file for future use, which can be further processed, match an unknown

(a) (b) (c)

Fig. 1: Exemplar print (known as Rolled and plain impression of fingerprint taken in controlled environment) (a) Rolled Fingerprint taken as nail to nail impression (b) Plain Fingerprint (c) Latent Fingerprint of Bad quality image from NIST SD27.

fingerprint in an available criminal database. These records are maintained by police or National Crime Record bureau. Latent fingerprint identification is performed with the help of ACE-V technique (a semi-automatic approach) [1], [16]. Before the technology such as NGI (Next Generation Identification) [17], latent prints were checked manually by the experts and require about 10 days to one month to complete the whole procedure. With enhanced technology such as AFIS/IAFIS the time to identify a suspected person based on latent print found at the crime scene has been cut down from one month to one day. Now a days, with the advancement of technology all information are stored and accessible electronically via a strong and secure network by several organizations e.g., e-governance, business, banking etc., [17], [18]. However, to extract reliable features in the latent fingerprint, a strong orientation field correction approach is required for enhancing the latent image. This paper proposes a new method to construct the dictionary as region wise and corrects the distorted orientation field in latent fingerprint image. To construct an effective orientation field for image enhancement, the region wise dictionary gives an optimal solution, in terms of accessing and organizing the dictionary.

The composition of this paper is as follow: Section II examines the existing work for latent image preprocessing techniques from classical approach to modern approach. Section III briefly describes the design concept of offline and online steps. In offline step dictionary are constructed as region wise. In online step the region wise dictionary is passed down to correct the orientation field toward the enhancement of latent fingerprint image (An Image preprocessing module for reliable feature extraction). Section IV explains the experimental part and finally conclusion and future work are given in Section V.

II. BACKGROUND

Orientation field reconstruction is an indispensable step to improve the clarity and quality of the latent image, which are picked up in uncontrolled environment such as crime scene. There are many orientation field estimation methods to raise the quality of fingerprint image from Conventional approach [19] to the modern approach [20]. Conventional approach does not utilize prior knowledge of ridge structures, which later laid foundation to the modern approaches that utilize the prior knowledge of ridge structures to make preprocessing step more intelligent like human thinking. Conventional methods fail to enhance latent fingerprint due to presence of disturbances e.g., lines, markings etc. Poor quality and low visibility of ridge structure in latent fingerprint image make it difficult to measure the correct orientation field.

A. Conventional approach

Conventional algorithms for latent fingerprint image enhancement are inspired from digital image processing techniques such as: Contrast adjustment, Image filtering (e.g., Gabor and contextual filter), Morphological Operation (e.g., Dilation and Erosion), De-blurring, ROI-base processing, Neighborhood and block processing, and Image arithmetic [21]. In fingerprint literature these techniques are used to connect broken ridge, remove noise and speckles, and sharpen the image to identify key features for recognition. Most of the orientation field estimation approaches are coarsely divided into three groups.

- *Local analysis:* Local orientation based method finds the local ridge orientation at pixel level using local neighborhood, 32*32 for 500 dpi image. Gradient, slit, and frequency based local analysis techniques are three commonly used methods [20], [22], [23].
- *Global analysis:* Global orientation model uses a geometric function, which are defined in the complex plane and use global approximation model through parametric functions. FOMFE uses the concept of Fourier expansion for two non-linear differential equations in 2-dimensional phase plane [22], [24], [25], [26].
- *Hybrid approach:* Local analysis does not enhance the low quality image correctly; it produces more spurious minutiae, while global analysis requires manually marked singular points. To compute orientation field of low quality image, the combined approach global and local analysis performs well. This approach considers pieces of information flow from global features which makes good use of inherent properties such as continuous ridge flow that are perpendicular to the flow. Reconstruction of orientation field is done by tracing ridge and valley structure line to a local parallel line segment. This is done by constructing the coherent structure of continuous ridge and valley patterns. Global features are used as a clue to enhance the quality of fingerprint image by advancing the preprocessing step. This eliminates the disturbance produced by scars, moisture, contamination, or dryness of fingerprint at fine level [25], [26].

B. Modern approach

There is no doubt that machine intelligence is not equal to humans. In case of feature extraction on low quality fingerprint such as latent fingerprint, human accuracy is much better than machines. Modern approaches are based on machine learning technique, which utilize prior knowledge of the ridge structure by constructing the dictionary of good quality orientation patches to correct the broken and unclear ridge structures. Orientation field based correction approach to enhance the latent fingerprint image has achieved immense progress, when compared to the conventional approaches [19], [20]. Feng et al. [20] constructed a global dictionary by manually selecting good quality orientation patches from good quality fingerprint. Offline and online stages were used to enhance the latent fingerprint using the global dictionary of good quality orientation patches. Global dictionary has drawback of choosing wrong patches by searching the top region patches in central (Highly Curved Shape) region. This leads to extra processing time and produce wrong orientation patches as mentioned by Yang et al. [28]. To define a minutiae and non minutiae in latent fingerprint image, Anush et al. [27] worked towards automatically finding the feature and non feature value in latent image using a spectral analysis method, which is a neural network base learning approach.

III. PROPOSED REGION WISE DICTIONARY

Latent preprocessing step consists of the offline region wise dictionary construction process and online orientation field correction step using the region wise dictionary lookup function. In offline process, region wise dictionary of overlapping orientation patches is constructed manually by choosing the good quality fingerprint of different types of patterns (arch, loop, and whorl). In online process, for a given input latent fingerprint image, the corresponding orientation field is automatically corrected through the following stages:

1. *Orientation field estimation (OFE):* Initially, orientation field is estimated from input latent fingerprint using Gradient based or Fourier analysis methods.
2. *Region wise Dictionary lookup:* The latent image is divided into the same regions as in the offline stage of overlapping patches. Look up function finds the most similar patch by looking up the dictionary of corresponding region and replaces it with highest similarity index above a threshold (which is 0.8 in our experiment).
3. *Context-based correction of orientation field:* Ambiguity occurs if more than one patch are retrieved, having similarity index more then 0.8. This ambiguity problem is cleared by utilizing contextual information and computing the list of candidate orientation patches by comparing the neighborhood orientation patches, to find the most similar patch [20].

A. Region wise Dictionary: Basic Idea

Different region of fingerprint has different type of pattern characteristics as shown in Fig.2 (a) and Fig.2 (b). This concept utilizes the global level feature characteristics based on region, for corresponding region wise processing of orientation patch in the dictionary. The top tip of the finger has high curvature such as parabolic shape curve, central region has singular point (core), and bottom part has mainly less curve almost linear shape and singular point (Delta). Thus to search pattern related to the top portion of finger in lower and central region of the finger takes extra processing. To resolve the above ambiguity, the proposed region wise dictionary searches the corresponding region in the relevant region of dictionary, e.g., region 1 pattern will be searched in region 1 dictionary and so on, to give better and optimistic search result in term of accuracy and process execution time.

(a) (b)

Fig.2 (a) Top, Central, and Bottom Region (b) View of Region1 to Region 6

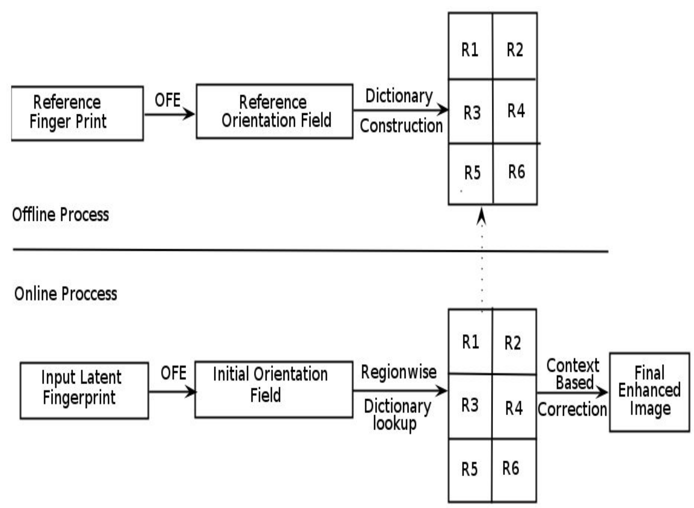

Fig.3 Flow Diagram for Offline process: Region wise dictionary construction and Online Process: Orientation field correction using region wise dictionary.

B. Design Concept: Algorithm

Offline Process: The construction overview of region wise dictionary procedure is as follows:

- Each fingerprint is divided into R_i region (where i=1 to 6 as shown in Fig. 2(b)). The entire image is provided as input in the form of an array e.g., row major order. This array is divided in to 6 parts based on the index of the array. For example, if the array size is 24*24, then the input fingerprint image is divided it six sub-arrays of 4*4 sizes. Each region starts from the index, where the last region ends.

- The fingerprint is further divided into overlapping orientation patches (with varying overlapping factor).
- Each orientation patch consists of b x b (In this experiment b=10) orientation elements, where b is number of orientation element in one patch. Each orientation element is a block of size 16*16 pixels.
- The dictionary entry consists of orientation patch and the region of the finger to which it belongs.

The dictionary construction algorithm is as follows:
Step 1: If the dictionary is empty, then add the orientation patch into the dictionary along with the region of the finger to which it belongs.
Step 2: If the dictionary is not empty, then check the orientation patch with all other orientation patches in the dictionary belonging to the same region. If it is adequately different from the rest of the orientation patches then add it to the dictionary.
Step 3: Repeat the above steps until all the patches have been added to the dictionary.

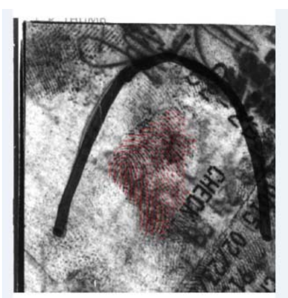

Fig. 4(a) Input Latent Image

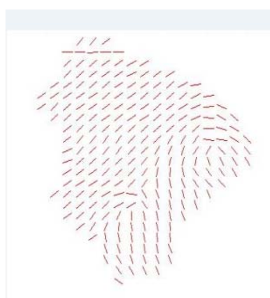

Fig. 4(b) Corrected Orientation Field

Fig. 4(c) Final enhanced Image

Fig. 4(d) Binary form of enhanced Image

Fig. 4 The output of an online process step by step for a Bad quality latent from NIST SD27.

Online Process: The overview online process for latent image enhancement procedure is as follows:

- The initial orientation field of the latent image is derived using a simple gradient algorithm.
- The initial orientation field of the latent image is divided into orientation patches of equal size as in the available dictionary.
- For an endorse orientation patch having at least one foreground block, candidates reference orientation patch list is extracted from the dictionary, which is further classified in proportion to the similarity rank of the initial patch. Highest rank patch is replaced to initial spot.
- The similarity S (A, B) between endorse orientation patch A and a reference patch B is estimated by comparing their orientation elements.
- Let n_f and n_s be the number of orientation elements in the endorse orientation patch and the number of orientation elements whose dispute are less than a predefined threshold (empirically put $\pi/12$). The similarity between two different patches is given as S (A, B) = n_s/n_f.

The proposed algorithm for latent image enhancement is described as follows:
Step 1: Choose the first initial candidate.
Step 2: Extract the region of the chosen initial candidate.
Step 3: Since the impression from a latent form a continuous image we extract the region of the first initial candidate and select the n_c candidates for each orientation patch using the reference orientation patches belonging to the selected orientation patch region and the neighboring regions of the selected orientation patch. For example, let's say the first initial candidate belongs to region 3 of the finger. Hence we can estimate the next orientation patches by comparing it with the orientation patches in the dictionary belonging to the region 1, 3, 4, 5 and no other regions. This decreases the searching time and give us a better estimate of the fingerprint.
Step 4: After estimating n_c candidates, for each orientation patch in the latent fingerprint, context based orientation field correction is done to find most similar patch from the list of candidates patches.

Fig. 3 gives the flow diagram for offline process and online processes in systematic design way of propose work.

IV. STATISTICAL OBSERVATION

Feng et al. [20] already mentioned that the accuracy of manually marked feature is more compared to the latent fingerprint enhancement algorithm. The accuracy of enhanced image obtained using region wise dictionary approach proposed in this paper is compared with manually enhanced image as a baseline, to observe the outcomes for different overlap factor (delta). The variable delta is a metric used for finding the overlapping factor within fingerprint regions for different orientation patches. Delta value 0 means distinct regions or non overlap patch and delta value 1 means completely overlapping region. Delta value 1 gives maximum similarity score of 84.23% as shown in Table 1. Fig. 5 gives a statistical analysis of observed minutiae similarity score at different variation of delta. The observation listed in Table 1 is done on NIST SD27 latent database, a publicly available database for latent fingerprint testing and [20] public dataset.

The proposed work is implemented in MATLAB (R2012b). The output of an enhanced image is shown in Fig. 4(c), for a bad quality latent fingerprint taken from NIST SD 27 database.

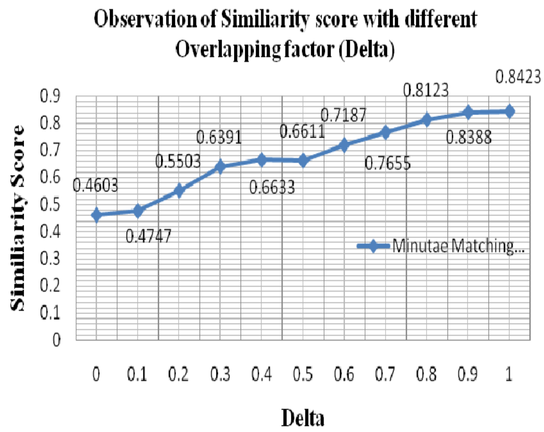

Fig. 5 Statistical observations based on minutiae similarity score for variable delta

Table 1. Observed similarity score for enhanced Latent image for variable Delta

Observation	Delta (Overlap Factor)	Minutiae Matching score
1	1.0	0.8423
2	0.9	0.8388
3	0.8	0.8123
4	0.7	0.7655
5	0.6	0.7187
6	0.5	0.6611
7	0.4	0.6633
8	0.3	0.6391
9	0.2	0.5503
10	0.1	0.4747
11	0.0	0.4603

V. CONCLUSION

In this paper, an efficient and optimal scheme is proposed to correct orientation field using region wise dictionary to enhance the latent fingerprint image. In this work, fingerprint is divided into six regions to create the region wise dictionary of overlap patches. A statistical observation made in Section IV to shows that, accuracy of enhanced image in term of minutiae match score is nearest to manually enhance image. The region wise dictionary creation concept has natural phenomena in creating efficient dictionary as discussed in Section III.A, which is the motivational foundation for this research. This paper discusses the conceptual overview of our proposed work with an output snapshot and enhanced image, and comparison of minutiae matches result in form of similarity score. This is a fundamental concept toward the foundation of new research field in fingerprint research. The aim of this work is to create a new direction for fingerprint research using new machine learning algorithm. In future, more regress performance analysis will be done using the above concept on different datasets, and plan to modify the region wise lookup using some new machine learning approach to find more accurate patch.

REFERENCES

1. A. Sankaran, M. Vatsa and R. Singh, "Latent Fingerprint Matching: A Survey", *IEEE* Access, Vol. 2, pp. 982-1004, 2014.
2. S. Yoon and A. K. Jain, "Longitudinal Study of Fingerprint Recognition", *MSU Technical Report*, MSU-CSE-14-3, June 9, 2014.
3. Mohanty I. and R. L. Velusamy, "Recovery of Live Evidence from Internet Applications", *Advances in Computer Science, Engineering & Applications, Advances in intelligent systems and Computing,* Vol. 167, pp 823-834, 2012.
4. Vassil Roussev, "Hashing and Data Fingerprinting in Digital Forensics", *IEEE Security & Privacy*, Vol. 7, No. 2, pp. 49-55, March/April 2009.
5. Thomas J. Smedinghoff, "Solving the legal challenges of trustworthy online identity", *International Journal of Computer Law & Security, Elsevier Publications*, Vol.28, 2012, pp. 532-541.
6. OECD (2011), "Digital Identity Management for Natural Persons: Enabling Innovation and Trust in the Internet Economy - Guidance for Government Policy Makers", *OECD Digital Economy Papers*, No. 186, OECD Publishing, Paris.
7. A. K. Jain and K. Cao, "Fingerprint Image Analysis: Role of Orientation Patch and Ridge Structure Dictionaries", *in Geometry Driven Statistics, I. L. Dryden and J. T. Kent (eds.), John Wiley and Sons*, 2015.
8. Maltoni, Davide, Dario Maio, Anil K. Jain, and Salil Prabhakar. "Handbook of fingerprint recognition", *Springer Science & Business Media,* 2009.
9. M. Vatsa, R. Singh, A. Noore, and S.K. Singh," Quality Induced Fingerprint Identification using Extended Feature Set", *In Proceedings of IEEE Conference on Biometrics: Theory, Applications and Systems*, 2008.
10. Q. Zhao and A. K. Jain, "On the Utility of Extended Fingerprint Features: A Study on Pores", CVPR, Workshop on Biometrics, San Francisco, June 18, 2010.
11. A. K. Jain and J. Feng, "Latent Fingerprint Matching", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 33, No. 1, pp. 88-100, January, 2011.
12. Q. Zhao and A. K. Jain, "Model-Based Separation of Overlapping Latent Fingerprints", *IEEE Transactions on Information Forensics and Security*, Vol. 7, No. 3, pp. 904-918, 2012.
13. B. T. Ulery, R. A. Hicklin, J. Buscaglia, and M. A. Roberts, "Accuracy and reliability of forensic latent fingerprint decisions," *Proceedings of the National Academy of Sciences*, 2011.
14. S. Yoon, J. Feng, and A. K. Jain, "Altered Fingerprints: Analysis and Detection", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 34, No. 3, pp. 451-464, March 2012.

15. Chris Lennard, the Detection and Enhancement of Latent Fingerprints, *13th INTERPOL Forensic Science Symposium, Lyon, France*, October 16-19, 2001.
16. R. Cappelli, D. Maio, and D. Maltoni, “Semi-automatic enhancement of very low quality fingerprints,” in, pp. 678–683 *Proc. ISPA,* 09.
17. The FBI’s Next Generation Identification (NGI), *http://www.fbi.gov/about-us/cjis/fingerprints biometrics/ngi*.
18. Conference of State/UT IT Secretaries *http://www.deity.gov.in IT_Secy_Conf_Part_II, 11Dec12*.
19. L. Hong, Y. Wan, and A. K. Jain, “Fingerprint image enhancement: Algorithm and performance evaluation,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 8, pp. 777–789, 1998.
20. J. Feng, J. Zhou, and A. K. Jain, "Orientation Field Estimation for Latent Fingerprint Enhancement", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 35, No. 4, pp. 925-940, April 2013.
21. Rafael C. Gonzalez, Richard E. Woods, Digital Image Processing (3rd Edition), Prentice-Hall, Inc., Upper Saddle River, NJ, 2006.
22. F. Turroni, D. Maltoni, R. Cappelli, and D. Maio, “Improving fingerprint orientation extraction,” *IEEE Transactions on Information Forensics and Security*, vol. 6, no. 3-2, pp. 1002–1013, 2011.
23. S. Chikkerur, A. N. Cartwright, and V. Govindaraju, “Fingerprint enhancement using STFT analysis,” *Pattern Recognition*, vol. 40, no. 1, pp. 198–211, 2007.
24. Y. Wang, J. Hu, and D. Phillips, “A fingerprint orientation model based on 2D Fourier expansion (FOMFE) and its application to singular-point detection and fingerprint indexing,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 29, no. 4,pp. 573–585, 2007.
25. S. Huckemann, T. Hotz, and A. Munk, “Global models for the orientation field of fingerprints: An approach based on quadratic differentials,” *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 30, no. 9, pp. 1507–1519, 2008.
26. C. Gottschlich, P. Mihailescu, and A. Munk, “Robust orientation field estimation and extrapolation using semilocal line sensors,” *IEEE Transactions on Information Forensics and Security*, vol. 4, no. 4, pp. 802–811, 2009.
27. A. Sankaran, P. Pandey, M. Vatsa, R. Singh, “On Latent Fingerprint Minutiae Extraction using Stacked Denoising Sparse Auto Encoders”, *In Proceedings of International Joint Conference on Biometrics*, 2014.
28. X. Yang, J. Feng, J. Zhou, "Localized dictionaries based orientation field estimation for latent fingerprints", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 36, no. 5, pp. 955-969, 2014.