DOI: 10.21917/ijivp.2020.0314

AN ANALYTICAL STUDY ON THE LATENT FINGERPRINT RECOGNITION TECHNIQUES

Tarun Kumar and Ravi Shankar Garg
Department of Computer Science and Engineering, Radha Govind Group of Institutions, India

Abstract

Tracing and recognizing the unique identity of the perpetrators of crime is a critical factor in detecting, apprehending, and eventually penalizing the culprits. There are numerous ways to detect the crime suspect, like onsite presence, availability of relevant documents, fingerprints, smart phone data, habitual trails, and other evidences procured from the crime scene. But, the most convincing evidence for identifying a culprit is the availability of the impressions of fingerprints accidentally left by the person on the objects in the crime scene. The partial finger impressions those are accidently left by criminals on different objects at the crime scene are referred as latent fingerprints. These latent fingerprints have to be analyzed using efficient research techniques, because a mistake in the analysis would mean the incarceration of an innocent person while the real culprit may walk free. So, researchers have developed numerous research concepts and techniques for the analysis of the feature components and the detection of latent fingerprints. Features are the essential components to determine the minutiae information of fingerprints. In this research work, the different techniques adapted by researchers for the detection of latent fingerprints are analyzed and discussed. This work, also compares the different techniques based on the datasets used for the research and feature analysis approach, and the latent fingerprints detection techniques.

Keywords:

Fingerprint Detection, Latent Fingerprint, Recognition Technique

1. INTRODUCTION

The security based on the biometric recognition system is the most reliable source for the identification of any individual [1]. The popular biometric technologies are based on the signature based identification, iris scan, face recognition, palm prints, and fingerprints. Among the mentioned successful technologies, the fingerprints recognition system is the most successful biometric approach (after iris scan approach) for the human identity detection [2].

The minutiae of fingerprint patterns are composed of features like dots, delta, core, ridge enclosure, ridge endings, independent ridge, and bifurcation. In simple terms, minutiae of fingerprints are the patterns of ridges and valleys available on the fingers. Fingerprints are further of three types: latent, plain, and rolled [3]. Latent fingerprints are the partial, noisy, unclear fingerprints that are mainly collected from the crime scenes. Rolled fingerprints are the complete fingerprints obtained under the supervised circumstances by rolling the fingers from nail end to other end. On the other side, plain fingerprints are also complete fingerprints but without rolling and without any other special environments. This research work mainly focuses on the latent fingerprint recognition techniques.

The researchers are attracted to the concepts of latent fingerprints identification due to its incessant use by law enforcement agencies for determining crime suspects [4]. The fingerprints are the unique feature components of humans and each person has a unique fingerprint pattern of their own. The detection of fingerprints at the crime location can clearly define the presence of any person at the crime site. The identity of a person can be revealed by matching the latent fingerprints with the original plain or rolled fingerprint of the person available in the fingerprint data records. The latent fingerprints are matched with the plain or rolled fingerprints based on the minutiae information of the fingerprints. The latent fingerprints captured from the crime site can be of good, bad, or extreme bad quality. The Fig.1 illustrates some of the latent fingerprint impressions.

Fig.1. Latent Fingerprint Impressions

The identification of human identity based on the latent fingerprints is a procedure composed of different steps. These steps are data collection, segmentation, pre-processing of fingerprints, features extraction and analysis, post-processing, and matching. The workflow of this automated latent fingerprint recognition system is illustrated in Fig.2.

The workflow of latent fingerprint recognition system is composed of the steps mentioned in Fig.2. The initial step is the collection of latent fingerprints from the different sites. The collected fingerprints are processed to segment the region of interest from the captured data. The segmented fingerprints are pre-processed with the sub-steps of enhancement and binarization. The enhancement of fingerprints is performed to reduce the noise level and improvement of image quality. The enhanced fingerprints are binarized to convert the grey level pixels in binary colors. These pre-processed finger images are utilized for the extraction and analysis of feature components. In feature analysis, different components and minutiae based features are extracted. Further, the images are post-processed to remove the false minutiae information. The final step of the latent fingerprints is the matching of latent fingerprint with complete finger impressions data. Based the matching process, the identity of crime suspect can be determined.

In this research paper, different techniques of latent fingerprint detection are discussed. The overall procedure to recognize the latent fingerprints is similar. This paper is structured in four sections. The organization of the different sections of paper is as follows: The current section has illustrated the basic fundamentals of finger impressions, minutiae information, latent fingerprints, and workflow of latent fingerprints identification system. Section 2 illustrates the popular datasets of latent fingerprint. Section 3 focuses on the different techniques and comparison of latent

fingerprint recognition techniques. The last section 4 depicts the conclusion of the research work with some future viewpoints.

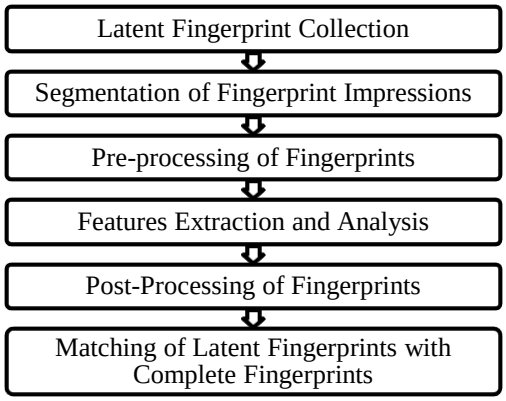

Fig.2. Workflow of Latent Fingerprint Recognition

2. LATENT FINGERPRINT DATASETS

Latent fingerprint recognition is a factual approach for the identification of human identity. The different methods can be applied to appropriately recognize the latent fingerprints. Although the researchers can prepare their own datasets for the latent fingerprint recognition process, it is essential to test the novel methods with the benchmark datasets. The testing of novel techniques on the benchmark datasets ensures the effectiveness of the novel technique by making the comparison on the same dataset. The popular benchmark datasets are discussed here:

- *WVU Dataset*: WVU dataset is latent fingerprints database created by the West Virginia University [5]. The dataset consists of 449 latent fingerprint images and their respective 449 rolled fingerprint images. This dataset is not openly available for public use.
- *IIIT Latent Fingerprint Dataset*: This dataset is created by the scholar team of IIIT-D (Indraprastha Institute of Information Technology, Delhi), India [6]. The dataset consists of 10 fingerprint impressions produced by 15 subjects. The dataset is not available for open usage but can be attained from the University for Research Purpose. There are total 1046 latent fingerprint images available in this dataset of image quality 500 PPI and 1000 PPI.
- *IIIT-D SLF Dataset*: This dataset is also produced by the IIIT, Delhi. Here, SLF stands for Simultaneous Latent Fingerprints. The dataset consist of total 1080 images of 15 subjects and their respective slap finger impressions [7]. This database is also not publically available but can be obtained for the research purpose.
- *NIST SD-27*: This is a special database created for the research purpose by the NIST [8]. The overall dataset consists of total 258 latent fingerprints and their respective 258 rolled fingerprints. The overall dataset is categorized in three categories based on quality of images as Good, Bad, and Ugly. The Good category carries 88 images, and Bad and Ugly category contains 85 fingerprint images each.

3. LATENT FINGERPRINT RECOGNITION TECHNIQUES

The attention of users has swiftly increased due to the wide usage of fingerprint matching systems for the biometric systems in corporate offices and smart phones. The Indian government has also stored the fingerprint record of all the citizens during the allocation of Aadhaar Card Identity. The essential usage of finger impressions is required by the law enforcement agencies for the detection of criminal or crime suspects available at the crime cite. As discussed earlier, these finger impressions can be acquired in the latent form. This section discusses the research studies of different authors who have adapted numerous techniques for the recognition of latent fingerprints. The section also highlights the different techniques, datasets, and remarks of the different authors for the considered work (refer to Table.1).

Kumar and Velusamy [9] have adapted the kernel based machine learning approach for the recognition of latent fingerprint by evaluating the similarity score. The research database of NIST special database 27 and FVC2002 has been utilized for the experimentation. In this experimentation, the authors have used only the eight images from the FVC2002 database and two images from the NIST SD 27 dataset. The implementation results evaluated using the simulation on MATLAB software indicate the 1.6% increase in the similarity score using kernel approach in comparison with other existing approach. The bad quality images from the latent dataset of NIST SD27 were used by authors.

Pérez et al. [10] proposed three different versions of cluster of minutiae matching algorithms to handle the distortions of latent fingerprints and identification of latent fingerprints. The proposed version includes the Minutia Cylinder-Codes, Minutia m-triplets, and neighboring minutiae-based descriptor (NMD). The authors have conducted a lot of experimentations on the databases of FVC2006, FVC2004, FVC2002, NIST SD14, NIST SD4, IIIT-D latent fingerprint database, and NIST SD-27. The experimentation results for the different categories (Good, Bad, and Ugly) of NIST SD-27 database were also evaluated separately. In the overall scenario, the authors have reported the better performance results of proposed clustering based algorithms in comparison with their respective versions.

Silpamol and Thulasidharan [11] focused on the detection and rectification of distorted fingerprints before the final matching of latent fingerprints. The authors have utilized the dictionary based approach for the prior information utilization. The distortion detection involves the steps of consideration of grey scale image, edges restoration using Sobel operator, orientation map extraction, core point detection, ROI selection, applicability of Gabor filter for edges clarification, period map extraction, Haar wavelet transformation, feature vector evaluation, and classification of fingerprints as normal or distorted. Further the rectification of distorted fingerprints was performed using the steps of distortion value evaluation, obtain the transform matrix results using principle component analysis, consideration of reference data with lower Euclidean distance, and geometric transformation for the image rectification. The final latent fingerprint matching was performed based on the pose, orientation, and dictionary lookup.

Table.1. Research Studies for the Latent Fingerprint Recognition

Author and Year	Fingerprint Matching Technique	Used Dataset	Remarks
Kumar and Velusamy [9]	Kernel Approach	NIST SD-27 and FVC2002	The authors have reported the 1.6% increase in similarity score of kernel approach in comparison with existing approach but the testing was performed only on limited images
Medina-Pérez et al. [10]	Minutia Cylinder-Codes, Minutia m-triplets, and neighboring minutiae-based descriptor (NMD)	FVC2006, FVC2004, FVC2002, NIST SD14, NIST SD4, IIIT-D latent fingerprint database, and NIST SD-27	In the overall scenario, the authors have reported the better performance results of proposed clustering based algorithms in comparison with their respective versions
Silpamol and Thulasidharan [11]	Dictionary Lookup	Tsinghua Distorted Fingerprint dataset, NIST SD-27, and FVC2004	The proposed system can detect the latent fingerprints with more accuracy after the rectification of distorted fingerprints.
Aravindan and Anzar [12]	Wavelet SIFT	MESCEF, FVC2002 and CASIA database	The authors have noted the outperformed recognition accuracy of Wavelet SIFT in comparison to SIFT and minutiae matching approach
Cao and Jain [13]	Virtual Texture Templates	NIST SD-27	The research results indicated the improvement in the computation time and recognition accuracy for the latent fingerprints
Venkatesh et al. [14]	Adaptive Neuro Fuzzy Inference System	NIST SD-27, FVC 2006 database-1, and FVC 2006 database-2	The authors have reported the outperformed results of ANFIS technique in comparison with other considered techniques
Ezeobiejesi and Bhanu [15]	Deep Convolutional Neural Network	NIST SD-27 and NIST SD-4	The evaluation results indicate the superiority of proposed technique with rank-1 identification rate of 81.35%
Jindal and Singla [16]	Cuckoo Search Algorithm	NIST SD-27	The authors have reported the identification rate for the good, bad, and ugly categories as 97.72%, 87.05%, and 83.52% respectively
Manickam et al. [17]	Type-2 Intuitionistic Fuzzy Set for latent fingerprints enhancement and Euclidean Distance for the matching using minutiae and SIFT features	FCV 2004 and IIIT-D Latent Fingerprints Database	The overall results indicate the improvements in the results with the efficiently enhancement of the latent fingerprints
Pavithra and Suresh [18]	Deep Convolutional Neural Network	Annotated database of 2000 fingerprints captured from crime sites	The experimentation results indicate the superior identification accuracy of CNN approach (80% identification accuracy) in comparison with SVM classifier

Aravindan and Anzar [12] have initially prepared the research database of fingerprints as MES College of Engineering Fingerprint (MESCEF). The authors have captured the fingerprint impressions of 125 individuals and produced 2500 images. The obtained fingerprint images were cropped in different orientations for the experimentation. The research methodology of Wavelet SIFT (Scale Invariant Feature Transform) has been proposed for the fingerprint recognition. The major purpose of the work was to produce the alignment free research approach. The authors have also combined the MESCEF database with FVC2002 and CASIA database with fingerprint images of 50, 25, and 25 individuals respectively.

Cao and Jain [13] have introduced the concept of virtual texture templates for the improvement of latent fingerprint recognition. The authors have majorly focused on the improvement of rank-1 accuracy, performance, and time consumption. The 100k virtual patches of fingerprints have been considered from NIST SD 14 dataset to improve the training of fingerprints using the convolutional neural networks. This has improved the recognition accuracy due to the consideration of extra patch from original complete fingerprints. The modified second order graph based matching and templates of three different types have been used. The analysis results indicate the improvement of 8.9% of rank-1 accuracy in comparison with existing technique. The average matching time also improved from 11ms to 7.7ms.

Venkatesh et al. [14] considered the adaptive neuro fuzzy inference system (ANFIS) for the recognition of latent fingerprints. The authors have mainly focused on classifying the overlapped latent fingerprints by evaluating the different layers using multiple criteria decision analysis approach. The research datasets of NIST SD-27, FVC 2006 database-1, and FVC 2006 database-2 were utilized for the performance assessment of ANFIS technique. The method of k-fold cross validation was used

for the evaluation of proposed ANFIS technique. The authors have reported the effective result for the proposed ANFIS technique in terms of recognition rate, classification, and rank-1 accuracy as compared to the existing techniques of Naïve Bayes, multilayer perceptron, and support vector machine.

Ezeobiejesi and Bhanu [15] have used the infusion of patches and minutiae based latent fingerprint recognition approach. The similarity was determined with the learning on both the patches and minutiae and only with the usage of patches for the learning. The learned patches were utilized for the evaluation of similarity among the latent and complete fingerprints by using deep convolutional neural network. The performance of the proposed system was tested on the 258 latent images of NIST SD-27 dataset with the combined 2257 complete fingerprints of NIST SD-27 and NIST SD-4 datasets. The evaluation results indicate the superiority of proposed technique with rank-1 identification rate of 81.35% which was earlier 74% in the existing concepts.

Jindal and Singla [16] used the nature inspired computing concept of cuckoo search algorithm for the matching of latent fingerprints with rolled fingerprints. The authors have used the enhancement methodology of dictionary based approach with Gaussian filter to reduce the noise value of latent fingerprints. The minutiae based finger features were utilized for the matching. The cuckoo search algorithm uses the ability of determination of best nest of similar attributes to store their egg in other bird's nest. This attributes helped in the evaluation of best match for the latent fingerprint with their respective rolled fingerprints. The experimentation was conducted on the all the categories (Good, Bad, and Ugly) of NIST SD-27 dataset. The authors have reported the average similarity score of 88.50%. The identification rate for the good, bad, and ugly categories were 97.72%, 87.05%, and 83.52% respectively.

Manickam et al. [17] have majorly focused on the importance of enhancement of latent fingerprints along with the matching. The overall process composed of steps of pre-processing, enhancement, features extraction, and matching. The pre-processing conducts the steps of binarization and thinning. The method of type-2 intuitionistic fuzzy set was adapted for the enhancement of the latent fingerprints. Further, features based on minutiae information and SIFT (Scale Invariant Feature Transformation) points are extracted. The extracted features were utilized for the matching of latent fingerprints with complete fingerprints using Euclidean distance. The overall procedure was tested on the datasets of FCV 2004 and IIIT-D latent fingerprints database.

Pavithra and Suresh [18] have used the deep convolutional neural network (CNN) for the identification of latent fingerprints. The research experimentation was conducted on the annotated database of 2000 fingerprints collected from the crime sites. Among the total 2000 fingerprints, 500 fingerprints were used for the testing evaluation and 1500 used for the training of the neural network. The implementation was performed on the Open CV-Python framework. The database was also evaluated using support vector machine (SVM) classifier. The experimentation results indicate the superior performance identification accuracy of proposed CNN approach (80% identification accuracy) in comparison with SVM classifier.

4. CONCLUSION AND FUTURE SCOPE

Latent fingerprints available at the crime location are the most usable fingerprints captured from the crime sites for recognizing the identity of criminals or suspects. The recent usability of fingerprint in the biometric systems has also allured the researchers towards the matching of fingerprint concepts.

This research paper has presented the existing research work of different authors who have adapted different research methodologies for the recognition of latent fingerprint with experimentation on different databases. The authors have used different feature extraction and enhancement approaches to illustrate the importance of different steps in the latent fingerprint recognition system. It is inferred that the use of minutiae based features for the matching of latent fingerprints with complete fingerprints is the most preferred approach. The recognition methodologies are also analyzed with the different results for the different datasets.

In total, it is observed that the consideration of multiple integrated techniques can efficiently recognize the latent fingerprints with higher recognition rates. For future scope, the integration of minutiae based features with multiple techniques is recommended for the efficient recognition of latent fingerprints.

REFERENCES

[1] S. Prabhakar, S. Pankanti and A.K. Jain, "Biometric Recognition: Security and Privacy Concerns", *IEEE Security and Privacy*, Vol. 1, No. 2, pp. 33-42, 2003.

[2] C. Kose and C. Iki, "A Personal Identification System using Retinal Vasculature in Retinal Fundus Images", *Expert Systems with Applications*, Vol. 38, No. 11, pp. 13670-13681, 2011.

[3] A.K. Jain and J. Feng, "Latent Fingerprint Matching", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 33, No. 1, pp. 88-100, 2010.

[4] D. Maltoni, D. Maio, A.K. Jain and S. Prabhakar, "*Handbook of Fingerprint Recognition*", Springer, 2009.

[5] K. Cao, D.L. Nguyen, C. Tymoszek and A.K. Jain, "End-to-End Latent Fingerprint Search", *IEEE Transactions on Information Forensics and Security*, Vol. 15, No. 2, pp. 880-894, 2019.

[6] A. Sankaran, T.I. Dhamecha, M. Vatsa and R. Singh, "October. On Matching Latent to Latent Fingerprints", *Proceedings of IEEE International Joint Conference on Biometrics*, pp. 1-6, 2011.

[7] A. Sankaran, M. Vatsa and R. Singh, "Hierarchical Fusion for Matching Simultaneous Latent Fingerprint", *Proceedings of IEEE International Conference on Biometrics: Theory, Applications and Systems*, pp. 377-382, 2012.

[8] Michael D. Garris and R. Mccabe, "NIST Special Database 27 Fingerprint Minutiae from Latent and Matching Tenprint Images", Available at: https://www.nist.gov/publications/nist-special-database-27-fingerprint-minutiae-latent-and-matching-tenprint-images, Accessed on 2000.

[9] S. Kumar and R.L. Velusamy, "Kernel Approach for Similarity Measure in Latent Fingerprint Recognition",

Proceedings of International Conference on Emerging Trends in Electrical Electronics and Sustainable Energy Systems, pp. 368-373, 2016.

[10] M.A. Medina Perez, A.M. Moreno, M.A.F. Ballester, M. Garcia Borroto, O. Loyola Gonzalez and L. Altamirano Robles, "Latent Fingerprint Identification using Deformable Minutiae Clustering", *Neurocomputing*, Vol. 175, pp. 851-865, 2016.

[11] K.V. Silpamol and P.P. Thulasidharan, "Detection and Rectification of Distorted Fingerprints", *Proceedings of IEEE International Conference on Intelligent Computing and Control*, pp. 1-7, 2017.

[12] A. Aravindan and S.M. Anzar, "Robust Partial Fingerprint Recognition using Wavelet SIFT Descriptors", *Pattern Analysis and Applications*, Vol. 20, No. 4, pp. 963-979, 2017.

[13] K. Cao and A.K. Jain, "Latent Fingerprint Recognition: Role of Texture Template", *Proceedings of IEEE International Conference on Biometrics Theory, Applications and* Systems, pp. 1-9, 2018.

[14] R. Venkatesh, N.U. Maheswari and S. Jeyanthi, "Multiple Criteria Decision Analysis Based Overlapped Latent Fingerprint Recognition System using Fuzzy Sets", *International Journal of Fuzzy Systems*, Vol. 20, No. 6, pp. 2016-2042, 2018.

[15] J. Ezeobiejesi and B. Bhanu, "Patch Based Latent Fingerprint Matching using Deep Learning", *Proceedings of 25th IEEE International Conference on Image Processing*, pp. 2017-2021, 2018.

[16] R. Jindal and S. Singla, "An Optimised Latent Fingerprint Matching System using Cuckoo Search", *International Journal of Intelligence Engineering and Systems*, Vol. 11, No. 5, pp. 11-20, 2018.

[17] A. Manickam, E. Devarasan, G. Manogaran, N. Chilamkurti, V. Vijayan, S. Saraff, R.J. Samuel and R. Krishnamoorthy, "Bio-Medical and Latent Fingerprint Enhancement and Matching using Advanced Scalable Soft Computing Models", *Journal of Ambient Intelligence and Humanized Computing*, Vol. 10, No. 10, pp. 3983-3995, 2019.

[18] R. Pavithra and K.V. Suresh, "Fingerprint Image Identification for Crime Detection", *Proceedings of IEEE International Conference on Communication and Signal Processing*, pp. 797-0800, 2019.