Journal of Data Acquisition and Processing
ISSN: 1004-9037
https://sjcjycl.cn/
DOI: 10.5281/zenodo.755228

AN EFFICIENT FINGERPRINT IMAGE ENHANCEMENT TECHNIQUE USING ENHANCED DEEP U-NET ARCHITECTURE

[1]Ms. S. Neethu, [2]Mr. N. Thameejdheen, [3]Ms. J. Vaishnavi.
[1]Assistant Professor, Department of Computer Applications, Dr. SNS Rajalakshmi College of Arts & Science, Coimbatore.
[2]PG Student, II MCA, Department of Computer Applications, Dr. SNS Rajalakshmi College of Arts & Science, Coimbatore.
[3]PG Student, II MCA, Department of Computer Applications, Dr. SNS Rajalakshmi College of Arts & Science, Coimbatore.

Abstract: - For decades, fingerprint recognition has been prevalent for security, forensics, and other biometric applications. However, the availability of good-quality fingerprints is challenging, making recognition difficult. Fingerprint images might be degraded with a poor ridge structure and noisy or less contrasting backgrounds. Hence, fingerprint enhancement plays a vital role in the early stages of the fingerprint recognition/verification pipeline. One of the open issues in fingerprint verification is the lack of robustness against image quality degradation. The performance of a fingerprint recognition system is heavily affected by fingerprint image quality. Several factors determine the quality of a fingerprint image: skin conditions (e.g., dryness, wetness, dirtiness, temporary or permanent cuts and bruises), sensor conditions (e.g., dirtiness, noise, size), user cooperation, etc. Some of these factors cannot be avoided and some of them vary along time. Poor quality images result in spurious and missed features, thus degrading the performance of the overall system. Therefore, it is very important for a fingerprint recognition system to estimate the quality and validity of the captured fingerprint images. The degraded images can either reject or adjust some of the steps of the recognition system based on the estimated quality. The main problem in applying filtering techniques (Gabor filter) is, the ridge orientation and frequencies of the fingerprint that are used to model the filter are estimated from the original low quality fingerprint images. Thus, false ridges that are oriented in unwanted direction at the damaged ridges are enhanced and introduce false features. This causes computation inefficient and lowers the performance and accuracy of the recognition system. The proposed work produces quality result in the basis of efficient technique.
Keywords: Image Enhancement, Fingerprint, U-Net Architecture, Security, Deep Learning.

1. INTRODUCTION

Biometric recognition is defined as the "automated recognition of individuals based on their behavioural and biological characteristics". A biometric characteristic requires mainly two attributes for an unambiguous recognition: uniqueness and stability over time. On the one hand side, a biometric trait shall be unique for every individual, i.e. the biometric trait must be different for different individuals. No two individuals shall share the same biometric characteristic [1]. Only uniqueness of a trait allows to unambiguously recognizing an individual. If a biometric trait is not unique, several individuals share the very same trait and biometric recognition will therefore be ambiguous. On the other side, a biometric characteristic shall be stable over time. Such stability allows a repeatable usage of the biometric characteristic for recognition. Only if stability is given, the biometric characteristic is usable for long term biometric recognition. There are several biometric characteristics which fulfil both requirements. Each may be used for biometric recognition. However, only three of those characteristics are used most often in public responsibilities or in commercial domain: fingerprint, face, and iris [2].

Finger-scan technology is the most widely deployed biometric technology, with a number of different vendors offering a wide range of solutions. The fingerprint biometric provides a high level of recognition accuracy. Fingerprint is the pattern of intervening ridges and valleys on the tip of a finger. These fingerprints offer potential individuality which means that no two persons have the same fingerprint. The wide spread use of the fingerprints for personal identification began only in the 20th century. The pattern of ridges on each finger is claimed to be unique and immutable, enabling its use as a mark of identity In fact, even identical twins can be differentiated based on their fingerprints [3]. These fingerprint images are majorly classified under two criteria: Alternating Crest (ridges) and Troughs (valleys). These are associated with the smooth surface fingerprint images. The ridges are the dark lines and valleys are the light lines in the fingerprint image pattern. The distance between these ridges and valleys are the major parameters. The ridges and valleys decide the uniqueness of an individual for the authentication purpose in the bio-identification system. Fingerprint images are rarely of perfect quality. They may be degraded and corrupted with elements of noise due to many factors including variations in skin and impression conditions. This degradation can result in a significant number of spurious minutiae being created and genuine minutiae being ignored. In order to increase identification rate for latent fingerprints, enhancement is employed to improve latent fingerprint quality before feeding into the AFIS. Latent fingerprint enhancement can help improve the clarity of ridge structure, recover corrupted regions, remove structured noise, and increase ridge/valley contrast in some degree. These tasks are not only similar with image deblurring, denoising and super-resolution, but also including the special aspect of latent fingerprints such as removing structured noise. After enhancement, more reliable feature extraction, and then higher identification rate can be obtained for latent fingerprint identification [5].

1.1. Noisy in Fingerprint Images

Classic fingerprint image enhancement methods focus on how to separate noise from the meaningful ridge pattern and remove it. Information in the frequency domain and orientation field are widely used because the orientation and frequency characteristics of noise are different from the ridge pattern part, which makes it easier to enhance the useful region.

However the fingerprint images contain noise caused by factors such as dirt grease, moisture and poor quality of input devices and storage devices .So in a noisy fingerprint image ridges are not well defined and hence cannot be correctly detected. Noise might result in creation of false ridges and ignoring the genuine ridge lines ,fig 2. Shows a noisy finger print image images are prone to a variety of types of noise [4]. Noise is the result of errors in the image acquisition process that result in pixel values that do not reflect the true intensities of the real scene. There are several ways that noise can be introduced into an image, depending on how the image is created. For example: If the image is scanned from a photograph made on film, the film grain is a source of noise. Noise can also be the result of damage to the film, or be introduced by the scanner itself If the image is acquired directly in a digital format, the mechanism for gathering the data (such as a CCD detector) can introduce noise. Electronic transmission of image data can introduce noise.

Due to the presence of noise the false ridges may highly decrease the matching performance of the system .Using this fingerprint technology there are advantages in day to day activities like fingerprint recognition devices for desktop and laptop access are now available from many different vendors [8]. With these devices users no longer need to type passwords instead only a touch provides instant access . This is also used in checking fingerprint for new applicants to social service benefits to ensure recipients do not fraudulently obtain benefits under fake name.

Fig.1: - Noisy Fingerprint Image

Fingerprint enhancement has been actively studied in the past decades. As one classical pre-processing technique in fingerprint recognition, many conventional methods have been proposed and studied in the fingerprint community.

II. LITERATURE REVIEW

The key focus of this review is an up-to-date summary of recent novel approaches. The systematic search procedure was set primarily following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. Over the last thirty years, there have been important developments in deep learning methods. These developments had a significant impact on a wide range of applications dealing with computer vision and pattern recognition [10]. The research field of automatic fingerprint recognition is among the most interesting topics, due to the requirement to increase the recognition accuracy rate. Additionally, deep learning methods avoid the focus on methods devoted to minutiae extraction as handcrafted features, shifting the interest to the analysis of the whole image. The latest investigations devoted to the field of fingerprint image organization are reviewed in this section.

Cheng, Y. H., et al., (2023) proposed a deep learning-based approach for fingerprint image enhancement [6]. Actually, a U-Net model with a depth of six achieves superior performance, surpassing other depths, and the inclusion of attention gate further enhances the results. Traditional algorithms often require adjusting parameters based on individual fingerprint images, resulting in inconsistent enhancement results. The proposed method not only retains more fingerprint features but also produces smoother structures and reduces noise surrounding the fingerprint image. Experimental results demonstrate the effectiveness of U-Net architecture with different depths and the impact of incorporating attention gate. The proposed works finding contribute to advancing fingerprint image enhancement techniques, bolstering the accuracy and performance of fingerprint identification systems in applications such as forensic analysis and biometric authentication.

Saeed, F., Hussain, M., & Aboalsamh, H. A. (2022), addressed the primary issues with fingerprint recognition systems is their high processing complexity, which is exacerbated when they are gathered using several sensors [7]. The authors proposed and designed the architecture of a CNN model is a laborious and time-consuming task. The proposed a technique for automatically determining the architecture of a CNN model adaptive to fingerprint classification; it automatically determines the number of filters and the layers using Fukunaga–Koontz transform and the ratio of the between-class scatter to within-class scatter. It helps to design lightweight CNN models, which are efficient and speed up the fingerprint recognition process. The designed models outperform the well-known pre-trained models and the state-of-the-art fingerprint classification techniques.

Ahsan, M., et al., (2021), introduces an intelligent computational approach to automatically authenticate fingerprint for personal identification and verification [9]. The feature vector is formed using combined features obtained from Gabor filtering technique and deep learning technique such as Convolutional Neural Network (CNN). Principle Component Analysis (PCA) has been performed on the feature vectors to reduce the overfitting problems in order to make the classification results more accurate and reliable. A multiclass classifier has been trained using the extracted features. Experiments performed using standard public databases demonstrated that the proposed approach showed better performance with regard to accuracy (99.87%) compared to the more recent classification techniques such as Support Vector Machine (97.86%) or Random Forest (95.47%).

Chhabra, M., et al., (2023) concentrate an early fingerprint distinction technique based on colour and saliency masks is proposed to detect potentially relevant areas out of the entire image area for further processing, using a non-learning approach [11]. The authors used the hybrid approach of CNN to effectively capture feature distinction from potential features similar to that of object detection and classification. The use of the pre-trained convolutional neural network with a stack of autoencoders for image classification and segmentation produces better results than a naive convolutional neural network. The experiments are conducted on the IIIT-D database. The efficiency and effectiveness of the model over good quality images is evaluated by experimenting over different patch sizes, with and without the use of dropout in CNN, with and without use of Autoencoder with CNN.

Dincă Lăzărescu, A. M., Moldovanu, S., & Moraru, L. (2022), deals with the low quality of fingerprints, which can impede the identification process [12]. The proposed model consists of the following steps: a preprocessing stage which deals with edge enhancement operations, data resizing, data augmentation, and finally a post-processing stage devoted to classification tasks. Primarily, the fingerprint images are enhanced using Prewitt and Laplacian of Gaussian filters. The innovation of the model is in the manner in which the number of epochs is selected, which improves the performance of the classification. The number of epochs is defined as a hyper-parameter which can influence the performance of the deep learning model. The proposed method achieved a very good performance compared to the traditional hand-crafted features despite the fact that it used raw data and it does not perform any handcrafted feature extraction operations.

Kaijun, Z., et al., (2024), proposed a low-illumination palmprint image enhancement method based on wavelet transform and GUNet (insertion of Integrated Attention Gate at the UNet jump connection) [13]. Firstly, the input image is decomposed by wavelet transformation to obtain the decomposition result of the original image, that is the high-frequency image and the low-frequency image. Secondly, the high-frequency image is enhanced by the GUNet neural network to enhance the palmprint texture, and low-frequency images use weighted averaging to smooth low-frequency information other than palm texture information. After that, the palmprint image with a clear palmprint texture is obtained by the wavelet inverse transformation. Experimental results show that the proposed approach has higher Peak Signal-to-Noise Ratio (PSNR), Structural Similarity (SSIM) and Visual Information Fidelity (VIF) indicators than some existing methods, which suggest palmprint image with low-illumination can be significantly enhanced.

III. PROPOSED METHODOLOGY

Fingerprint is a significant biometric among other biometrics traits. Fingerprint is an utmost kind among of another significant biometrics. Biometric recognition refers greater security and convenience that traditional methods of person recognition based on official documents, PINs, and passwords. Biometric is a group number of technologies that used to authenticate persons using their physical traits such as fingerprints, iris, retina, speech, face, palm-print patterns or behavior traits including gait, hand written signature and keystrokes movement [14].

Fingerprint is an essential unique pattern to identify individual characteristics. Ridge pattern on the fingertips has to be differentiating from each other, even in practical, twins do not match the same templates or structures. Fingerprints become a key unique of recognition system platform to identify personal identity and authentications to user have a right to login to use the system or access to cross a security control. Fingerprint refers to a complex of pattern's combination that presenting about the friction ridges and valleys on the surface of a fingertip. Fingerprint is one of the most complexity systems, which requires a constant and continuous on contribution with other researchers and scholars in research and development (R & D) institutions.

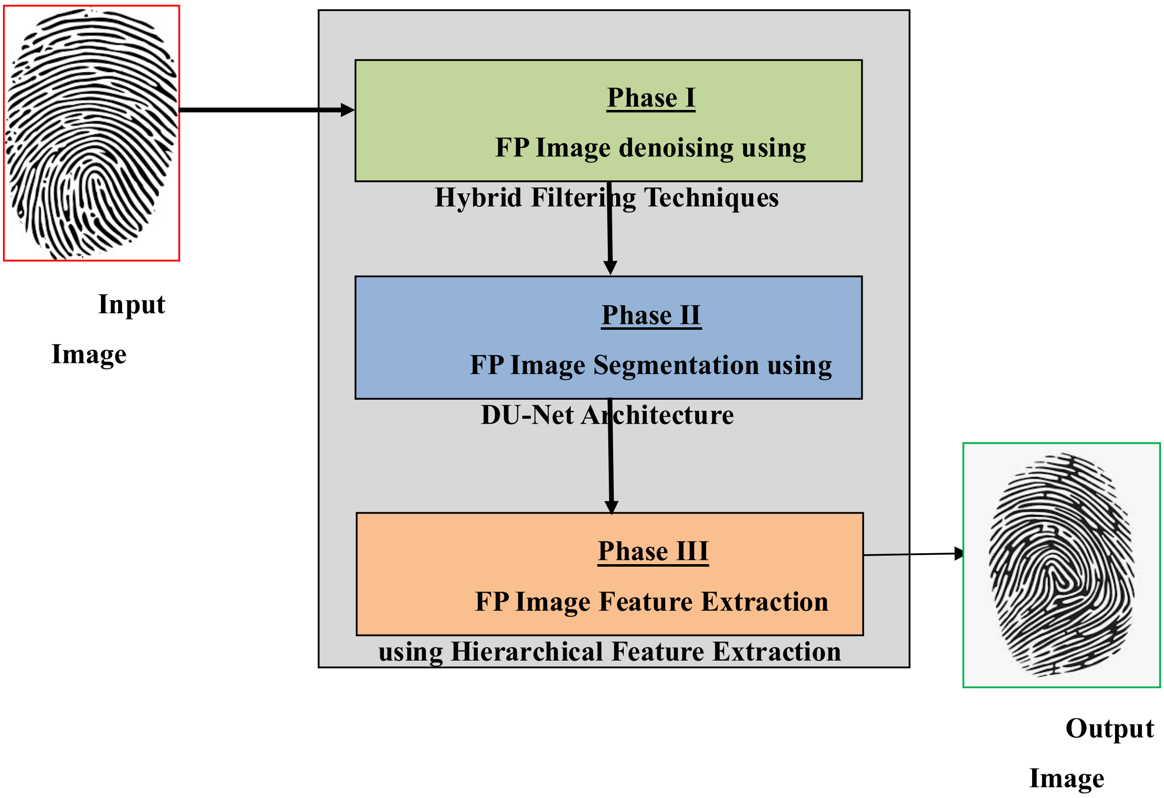

Fig. 2: - Workflow of the Proposed Work

Fingerprint has received more and more attention for security in a wide range of applications and Smartphone until nowadays and keep continue to the future [15]. Fingerprint has an answered to proof a person's identification and peoples will no cheating the system machines. Fingerprint authentications are more useful than a combination of secret characters (passwords) authentication that has some obvious drawbacks, stolen, lost, or forgotten and so on. Fingerprint recognition need a bit require effort from the users, it cannot copy, stolen or shared with others.

Phase –I: - Fingerprint Image Denoising using Filtering Techniques

Image denoising is the major and a predominant task in image processing. The de-noising method involves excluding noise from an image to regain its novelty [16]. During the de-noising process, the noise level can be reduced in the corrupted image but cannot be eliminated, theoretically. In the proposed scheme, denoising is performed by combining median and average filtering technique. The filtering process is carried out sequentially. In the preliminary stage of the algorithm, noisy image is first considered as individual segments of predefined size (3 X 3). The middle pixel is the element of interest. Due to the grid nature of an image, each pixel is strongly correlated with the neighbouring pixel. Drastic change in the pixel value when compared with all the neighbouring pixels in the segment leads to noise or other in ambiguities associated with that pixel. The Pixel value of the element of interest is compared with all the neighbouring pixels, in the intermediate stage of the algorithm.

Phase-II: - Fingerprint Image Segmentation using DU-Net Architecture

One major obstacle in fingerprint recognition process is the various types of noise present in the fingerprint image. In order to eliminate the noises the enhancement process is accomplished and there is a need for segmentation of those images. Fingerprint image segmentation is an important task in fingerprint recognition. In this process the features of the fingerprint are organized in such a way to identify its type and to optimize the ingredients for further processing. Various models have been analyzed on fingerprint image segmentation is proposed. The proposed work introduces the Dilated U-Net (DU-Net) architecture for efficient fingerprint image segmentation. The proposed DU-Nets is to transform low-quality latent image into the segmentation mask and high-quality fingerprint through the pixels-to-pixels and end-to-end training. Finally, the test latent fingerprint is segmented and enhanced with the DU-Nets to improve the image quality in one shot.

Phase-III: - Hierarchical Feature Extraction for Fingerprint Image

Feature extraction involves in simplifying the amount of resources required to describe a large set of data accurately [17]. When performing the analysis of complex data one of the major problems arises based on the number of variables involved. In the proposed research, a multi level feature set has been established with three different types of feature set. The proposed work introduces a model called "Hierarchical Feature Extraction Model". The proposed model is Minutiae based method. It is most popular and widely used technique, being the basis of the fingerprint comparison made by fingerprint examiners. Minutiae are extracted from the two fingerprints and stored as sets of points in the two-dimensional plane. Generally, ridge ending, ridge bifurcation and its corresponding locations are considered for minutiae based fingerprint matching.

To improve the performance of the matching algorithms and fingerprint analysis, an efficient algorithm has been proposed. The step by step procedure for the vertical orientation is carried out with necessary illustration is provided. For the performance evaluation, line (ridge) based algorithm using connected component analysis.

IV. PERFORMANCE ANALYSIS

The proposed technique is implemented using Matlab Software. The proposed methods are compared with the various existing approaches [18]. The proposed work performance is evaluated using various metrics, such as,

- **Correlation Coefficient**

  The correlation coefficient is a statistical performance evaluation criterion for correlation between the actual and predicted values. Criterion for correlation between the actual and predicted values. A perfect statistical correlation will have the value of correlation coefficient as 1 and for no correlation the value is 0.

- **Mean Absolute Error (MAE)**

  The MAE measures the average magnitude of the errors in a set of forecasts, without considering their direction. It measures accuracy for continuous variables. MAE measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation where all individual differences have equal weight.

- **Root Mean Square Error (RMSE)**
  The RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable. RMSE is a good measure of accuracy, but only to compare prediction errors of different models or model configurations for a particular variable and not between variables, as it is scale-dependent.
- **Relative Absolute Error (RAE)**
  Relative Absolute Error (RAE) is a way to measure the performance of a predictive model. It's primarily used in machine learning, data mining, and operations management. The Relative Absolute Error is expressed as a ratio, comparing a mean error (residual) to errors produced by a trivial or naive model.
- **Root relative squared error (RRSE)**
  The root relative squared error (RRSE) is relative to what it would have been if a simple predictor had been used. Thus, the relative squared error takes the total squared error and normalizes it by dividing by the total squared error of the simple predictor.

V. CONCLUSION

The work conducted in this paper is mainly devoted to fingerprint identification using a hybrid U-Net architecture that can perform fingerprint classification by considering whole fingerprint images. The proposed algorithm uses poor-quality original raw fingerprint images. These were processed using Prewitt and Laplace filters to enhance the edges and, in order to reduce the expensive training cost, data resizing was applied. Hyper-parameter tuning, using various epoch numbers, was considered to improve the performance of classification. For future developments, we are interested in improving the performance of classification by using other pre-processing techniques correlated to extensive hyper-parameter tuning. Additionally, other fingerprint databases will be used to assess the generalization capabilities of U-Net architectures.

REFERENCES

[1] Chowdhury, A. M., & Imtiaz, M. H. (2022). Contactless fingerprint recognition using deep learning—a systematic review. Journal of Cybersecurity and Privacy, 2(3), 714-730.

[2] Wong, W. J., & Lai, S. H. (2020). Multi-task CNN for restoring corrupted fingerprint images. Pattern Recognition, 101, 107203.

[3] Khan, M. A., Khan, T. M., Bailey, D. G., & Kong, Y. (2016). A spatial domain scar removal strategy for fingerprint image enhancement. Pattern Recognition, 60, 258-274.

[4] Tang, Y., Gao, F., Feng, J., & Liu, Y. (2017, October). FingerNet: An unified deep network for fingerprint minutiae extraction. In 2017 IEEE International Joint Conference on Biometrics (IJCB) (pp. 108-116). IEEE.

[5] Wan, G. C., Li, M. M., Xu, H., Kang, W. H., Rui, J. W., & Tong, M. S. (2020). XFinger-net: pixel-wise segmentation method for partially defective fingerprint based on attention gates and U-net. Sensors, 20(16), 4473.

[6] Cheng, Y. H., Su, S. G., Lin, Y. L., & Hsu, H. C. (2023, August). Fingerprint Image Enhancement Method Based on U-Net Model. In International Conference on AI-generated Content (pp. 332-340). Singapore: Springer Nature Singapore.

[7] Saeed, F., Hussain, M., & Aboalsamh, H. A. (2022). Automatic fingerprint classification using deep learning technology (DeepFKTNet). Mathematics, 10(8), 1285.

[8] Militello, C., Rundo, L., Vitabile, S., & Conti, V. (2021). Fingerprint classification based on deep learning approaches: experimental findings and comparisons. Symmetry, 13(5), 750.

[9] Ahsan, M., Based, M. A., Haider, J., & Kowalski, M. (2021). An intelligent system for automatic fingerprint identification using feature fusion by Gabor filter and deep learning. Computers and Electrical Engineering, 95, 107387.

[10] Joshi, I., Utkarsh, A., Kothari, R., Kurmi, V. K., Dantcheva, A., Roy, S. D., & Kalra, P. K. (2023). On estimating uncertainty of fingerprint enhancement models. In Digital Image Enhancement and Reconstruction (pp. 29-70). Academic Press.

[11] Chhabra, M., Ravulakollu, K. K., Kumar, M., Sharma, A., & Nayyar, A. (2023). Improving automated latent fingerprint detection and segmentation using deep convolutional neural network. Neural Computing and Applications, 35(9), 6471-6497.

[12] Dincă Lăzărescu, A. M., Moldovanu, S., & Moraru, L. (2022). A fingerprint matching algorithm using the combination of edge features and convolution neural networks. Inventions, 7(2), 39.

[13] Kaijun, Z., Duojie, L., Guangnan, L., Xiancheng, Z., & Yemei, Q. (2024). Gunet: a novel and efficient low-illumination palmprint image enhancement method. Signal, Image and Video Processing, 1-9.

[14] Liu, Y., Zhou, B., Han, C., Guo, T., & Qin, J. (2020). A novel method based on deep learning for aligned fingerprints matching. Applied Intelligence, 50, 397-416.

[15] Dalvi, N., An, M. K., Islam, A. R., & Pham, V. (2023, December). Improving Fingerprint Classification Accuracy Using Image Enhancement Deep Learning Models. In 2023 IEEE International Conference on Big Data (BigData) (pp. 3245-3254). IEEE.

[16] Bilal, A., Sun, G., & Mazhar, S. (2021). Finger-vein recognition using a novel enhancement method with convolutional neural network. Journal of the Chinese Institute of Engineers, 44(5), 407-417.

[17] Zia, T., Ghafoor, M., Tariq, S. A., & Taj, I. A. (2019). Robust fingerprint classification with Bayesian convolutional networks. IET Image Processing, 13(8), 1280-1288.

[18] Nogueira, R. F., de Alencar Lotufo, R., & Machado, R. C. (2016). Fingerprint liveness detection using convolutional neural networks. IEEE transactions on information forensics and security, 11(6), 1206-1213.