International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Dorsal Vein Recognition System Using Texture Features

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Submitted: 18/01/2024 **Revised**: 27/02/2024 **Accepted**: 04/03/2024

Abstract: Biometric technology will be employed to establish individual authenticity, with Dorsal Palm vein recognition serving as the method for identifying individuals based on their Dorsal vein image. This technique proves instrumental in recognizing a person's image within secure systems. Vein patterns exhibit significant variability among individuals, remaining stable and unaffected by the ageing process, with no substantial changes observed in adults. Since veins are internal, the system's integrity is heightened, remaining impervious to external skin conditions. The vein pattern recognition software interprets vessel patterns of black lines on the palm. It conducts a comparison between the translated vein pattern and a pre-registered template pattern. The paper delves into the extraction of minutiae points, marked as features. Palm vein recognition finds application in various sectors, including Security Systems, Log-in Control, Healthcare, Banking and Financial Services, etc.

Keywords: *Biometric, Feature extraction, Feature matching, Dorsal vein*

1. Introduction

In the realm of Information Technology, individuals are intricately connected to society through various networks. The demand for precise and automated personal identification is evident in many applications. Security considerations, alongside identification, hold paramount importance. Each biometric characteristic possesses distinct advantages and limitations. Among these characteristics, vein patterns emerge as a significant biometric identifier. Vein patterns exhibit substantial variability across individuals, remaining stable and unaffected by the ageing process without significant changes in adults. The internal nature of veins enhances the security of systems, as they are impervious to external skin conditions [1,2].

The detection and capture of Dorsal vein patterns are facilitated through infrared sensors. The discernibility of these patterns relies on variables such as age, skin thickness, ambient temperature, physical activity, and the depth of veins beneath the skin. Vein pattern recognition requires only low-resolution infrared imaging coupled with straightforward image processing. Exposing the hand to Near-Infrared (NIR) light allows for capturing the vein structure.

The texture features of palm veins have a vital role in the success of this biometric system. The intricate network of veins creates a unique texture map that serves as a personalized identifier. Texture features refer to the fine details and irregularities within this map, capturing the subtle nuances of the palm vein patterns. The use of texture features enhances the accuracy and reliability of the Palm Vein Recognition System, making it resilient against forgery attempts and unauthorized access [3].

One of the key advantages of utilizing texture features in palm vein recognition is the resistance to external factors that often affect other biometric methods. Factors such as age, external lighting conditions, and even injuries to the hand have minimal impact on the stability and consistency of palm vein patterns. As a result, the system remains robust and reliable, ensuring a seamless and secure authentication process.

This introduction sets the stage for a comprehensive exploration of the Palm Vein Recognition System, delving into the technological advancements that make it a formidable player in the realm of biometric authentication. As we delve deeper into the intricate world of palm vein patterns and their texture features, we uncover the innovative solutions that this technology offers to address the escalating challenges of identity verification in today's digital landscape. The research in this paper sheds light on the design of a system for palm vein recognition using texture features [6].

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2. Literature Survey

Biometric recognition involves using unique anatomical features and behavioural characteristics for the automated identification of individuals.

Zhao, Wang, and Wang [1] introduced a novel biometric methodology leveraging hand-dorsal for the extraction of vein structures. The devised technique enables the utilization of cost-effective devices while achieving comparable success in vein network extraction as observed in scenarios deploying high-quality imaging apparatus. The paper elucidates the underlying principle of vein imaging, introduces an innovative approach to enhance contrast in acquired vein images, and establishes an algorithm tailored for extracting vein patterns from images of lower quality. Additionally, a pioneering denoising algorithm is proposed to further refine the integrity of the extracted vein patterns. The research findings demonstrate the efficacy of the proposed method, opening avenues for practical and economical applications of biometric vein recognition systems.

Zhou and Kumar [2] addressed the exploration of viable methodologies for automated personal identification through the utilization of palm vein imaging. The proposed approach is subjected to rigorous evaluation using the CASIA database, comprising 100 subjects, and attains the optimal equal error rate. Furthermore, a score-level combination strategy is introduced to amalgamate diverse palm vein representations. The outcomes of this amalgamation strategy consistently exhibit enhancements in both authentication and recognition performance, thereby contributing to the advancement of effective and robust palm vein identification systems.

A research study by M Deepamalar and M Madheswaran [3] introduces a novel palm vein recognition system that employs a multilevel fusion of multimodal features and a neural network classifier. It elaborates on a detailed multimodal analysis for biometric authentication. The system extracts shape and texture features, obtaining multimodal characteristics. Vein patterns are classified using a neural network classifier to facilitate decision-making. The system's effectiveness in biometric authentication applications is evident through its notably low matching error rate and minimal false acceptance or rejection rates.

Dhole and Patil [5] explore non-invasive hand geometry measurements without the use of pegs for personal identification. This work focuses on the user-friendly aspects of hand geometry, emphasizing its suitability for identification in low-security applications. The study contributes to the understanding of hand geometry-based biometric systems.

The study in paper [6] delves into hand dorsal vein recognition, addressing the technical aspects such as sensor technology, algorithms, and system evaluation. The interdisciplinary approach involving imaging systems and techniques contributes to the broader field of biometric recognition, providing insights into the challenges and advancements in hand dorsal vein recognition.

Li et al. [7] propose a recognition system for dorsal hand veins using a fusion of ResNet and HOG features. This work addresses challenges in small-scale sample databases, showcasing a fusion approach to enhance recognition accuracy. The integration of deep learning (ResNet) with traditional features (HOG) contributes to the robustness of the system.

Kumar and Singh [8] explored the use of deep learning for dorsal vein recognition. The use of advanced deep learning techniques highlights a contemporary approach to improving recognition accuracy. The paper contributes to the evolving field of biometrics by leveraging the capabilities of deep learning models.

Zhong and Shao [9] focus on the challenges of dorsal hand vein recognition in uncontrolled environments, introducing a biometric graph-matching approach. This work addresses the need for robust recognition systems that can perform effectively in various conditions, contributing valuable insights for real-world applications.

Cimen et al. [10] proposed a novel dorsal hand vein authentication system. It employed the fractal dimension box-counting method. The introduction of fractal dimension analysis adds a unique dimension to dorsal hand vein recognition, showcasing innovation in feature extraction techniques for improved system performance.

Wan, Chen, and Yang [11] presented CNN based dorsal hand vein recognition system The use of deep learning, specifically CNNs, demonstrates the effectiveness of neural network architectures in feature extraction and recognition tasks within the context of dorsal hand vein biometrics.

While the literature provides valuable insights into the domain of vein recognition using texture features, several open research issues and problems remain. Some potential areas for further investigation include:

2.1. Robustness to Environmental Variability:

Addressing the robustness of vein recognition systems to environmental factors such as varying lighting conditions, temperature changes, and different imaging devices remains a challenge. Developing methods to enhance system performance under diverse environmental scenarios is crucial for real-world applications.

2.2. Large-Scale Database Studies:

The majority of the reviewed studies involve relatively small-scale databases. Researching larger and more diverse datasets could reveal additional challenges and variations, helping to improve the generalizability and reliability of vein recognition systems.

2.3. Interoperability and Standardization:

Achieving interoperability and standardization in vein recognition systems is essential for widespread adoption. Researchers should explore methods to establish common standards, protocols, and interoperable systems to facilitate seamless integration across different platforms.

2.4. Ethical and Privacy Concerns:

With the increasing prevalence of biometric technologies, it is imperative to address ethical considerations and privacy concerns. Subsequent research efforts should focus on developing robust privacy-preserving techniques and ensuring the ethical deployment of vein recognition systems, particularly in sensitive applications.

2.5. Multimodal Integration:

Investigating the integration of multiple biometric modalities, such as combining vein recognition with other biometric traits (e.g., fingerprints, face), could lead to more robust and secure identification systems. Research in this area could explore fusion techniques and their impact on overall system performance.

2.6. Adversarial Attacks and Security:

Assessing the vulnerability of vein recognition systems to adversarial attacks is essential for ensuring their security. Exploring potential vulnerabilities and developing countermeasures to thwart attacks is a critical area of research in enhancing the reliability and trustworthiness of vein recognition systems.

2.6. Real-time Processing and Efficiency:

Many applications require real-time processing of biometric data. Investigating techniques to improve the efficiency and speed of vein recognition systems, especially when dealing with large datasets or in resource-constrained environments, is an open research problem.

3. Proposed Methodology:

Taking into account the above-listed open research problems and the significance of image texture features in biometric identification it is proposed to implement and design a system for palm vein recognition using texture features. The detailing of the steps involved are illustrated in fig. (1)

The system comprises three phases which include Image Preprocessing, Feature Extraction, and Feature Matching.

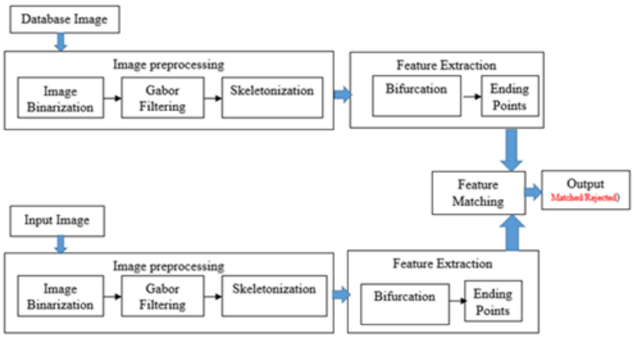

Fig 1: Dorsal Vein Recognition System Using Texture Features

3.1. Image Preprocessing: This stage includes a series of preprocessing operations such as image binarization, Gabor filtering, and skeletonization.

3.1.1. Binarization: Image binarization, also known as thresholding, involves converting a grayscale image into a binary image with only two intensity levels: black (binary 0) and white (binary 1). In the context of Dorsal vein images, binarization aims to transform an 8-bit gray palm vein image into a 2-bit image, assigning 0-values to ridges and 1-values to furrows. Following this operation, the ridges in the Dorsal vein are accentuated in black, while the furrows appear in white. To achieve this, a locally adaptive binarization method is employed to process the palm vein image. This technique ensures that the binarization process is tailored to the local characteristics of the image, enhancing the precision of the transformation

3.1.2. Gabor Filtering: A Gabor filter is a Gaussian envelope with the sinusoidal plane of particular frequency and orientation represented by equation (1)

$$G(x, y) = s(x, y)g(x, y) \quad (1)$$

Where,

$$s(x, y) = e^{-j2\pi(u_0 x + v_0\, y)} \quad (2)$$

$$g(x, y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{(-\frac{1}{2}x^2\sigma_x^2 + y^2\sigma_y^2)} \quad (3)$$

In equations (2) and (3) σx and σ_y represent spatial extent and bandwidth along the respective axes, uo, and vo are the shifting frequency parameters.

3.1.3. Skeletonization (Thinning): A skeleton can be effectively used to represent a palm vein pattern. The skeleton algorithm utilizes local threshold and mean value to halve out vein patterns. It utilizes thinning [12] which is a method to convert an image into a single pixel value and is represented by equation (4).

$$A \otimes B = A - (A \circledast B) = A \cap (A \circledast B)^C \quad (4)$$

where structuring elements{B}is given by equation (5)

$$\{B\} = \{B^1, B^2, B^3, \dots \dots .., B^n\} \quad (5)$$

Here, B^{i} represent a rotated version of B^{i-1}.

Using this concept, thinning can now be defined as a sequence of structuring elements as in equation (6)

$$A \otimes \{B\} = ((\dots\dots((A \otimes B^1) \otimes B^2)\dots.) \otimes B^n) \quad (6)$$

It describes a process wherein A undergoes thinning through a single pass with B1, followed by thinning the resulting structure with one pass of B2, and so forth until A is thinned with one pass of Bn. This iterative process is reiterated until no additional modifications occur.

Fig. 2 shows the result of image preprocessing which shows image binarization and skeletonization.

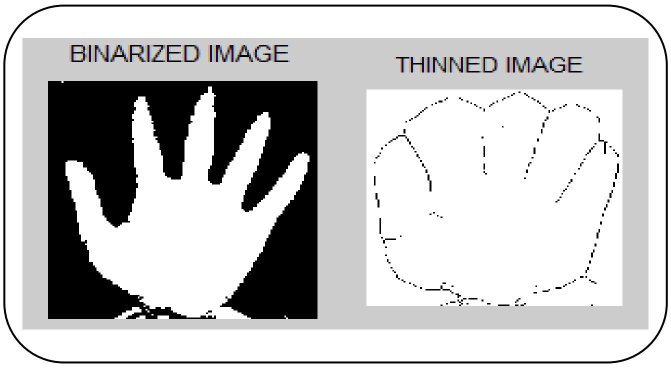

Fig. 2: Image Preprocessing

The Region of Interest i.e. ROI which is part of an image from where a maximum number of veins can be extracted is part of the further image pre-processing. To enhance the effectiveness and efficiency of the identification process, it is crucial to establish a coordinate system that remains invariant or robust to variations, or nearly so. Intuitively, the palm itself is linked to the coordinate system, and, therefore, the web between the index finger and middle finger, along with the web between the ring finger and little finger, serves as the reference points for constructing the coordinate system.

To accommodate potential scale variations in the acquired contactless palm vein images, the determination of the location and size of the ROI relies on the measurement between the two webs (LW), as depicted in the subsequent equation (7) and (8).

$$LD = \alpha LW \quad (7)$$

$$Lroi = \beta Lw \quad (8)$$

Where $Lroi$= side length of ROI,

LD= distance between the ROI and the reference line,

LW= distance between the two webs,

α and β = the factors that control respectively the location and size of the ROI.

Fig. (3) shows the ROI selected.

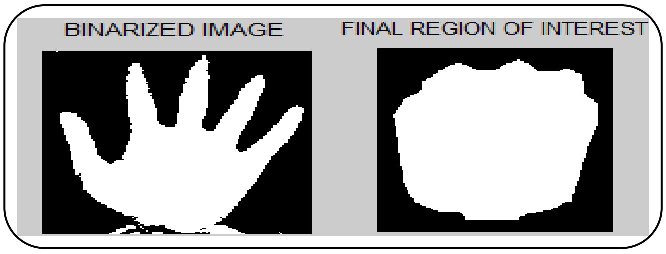

Fig. 3: ROI selected image

3.2. Feature Extraction: This stage includes operations such as bifurcation and extraction of end-points from thinned images. Bifurcation comprises Minutia Marking.

3.2.1. Minutia Marking: Following the thinning of palm veins, the process of marking minutiae points becomes comparatively straightforward. Typically, for every 3x3 window, if the central pixel is designated as 1 and possesses precisely three one-value neighbors, it is identified as a ridge branch [13], as illustrated in Fig. 4(a). Conversely, if the central pixel is marked as 1 and has only one one-value neighbor, it is recognized as a ridge ending, as depicted in Fig. 4(b).

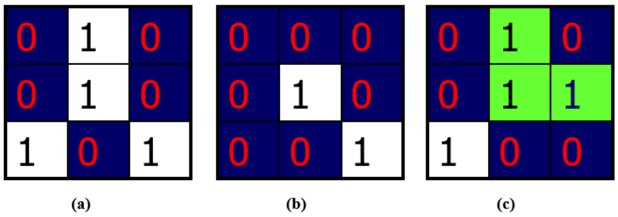

Fig. 4: Minutia Marking, (a) Bifurcation, (b) Termination, (c) Triple counting branch

In Fig. 4(c), a unique scenario is depicted where a genuine branch is triple-counted. Assuming the topmost pixel with a value of 1 and the rightmost pixel with a value of 1 each have an additional neighbor outside the 3x3 window, both pixels would be identified as branches. However, in reality, only one branch is present in that small region. Therefore, a validation routine is introduced, stipulating that none of the neighbors of a branch can themselves be branches, as detailed in [4].

The distance between two adjacent ridges is the average inter-ridge width(D). To find the value of D, the sum of all pixels of the thinned image row is calculated. The row length is then divided by the number above to get the width. To increase accuracy, this line scanning process is repeated on multiple lines, and column scanning is also performed. The last step is to average each ridge width to obtain the D value.

Minutiae has three parameters 1) x-coordinate, 2) y-coordinate, and 3) orientation [14]. For a bifurcation point, each of the three ridges emanating from it possesses its direction. Determine the direction of the bifurcation by choosing the smallest of three angles on the x-axis as illustrated in Fig. 5. The three new terminations correspond to the three neighboring pixels of the bifurcation. Each of the three ridges connected to the bifurcation is now associated with a termination, creating a comprehensive characterization of the minutia.

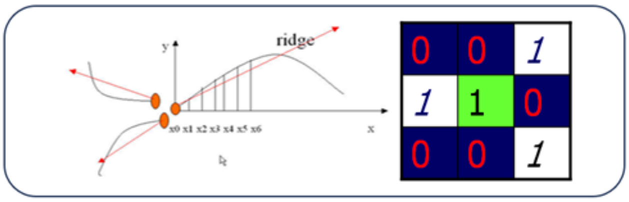

Fig. 5: A bifurcation to three terminations

Minutia points as well as thinned ridges in the palm vein image are marked with unique ID for further management. The marking process is done by morphological processing.

3.2.2. Minutia Post-processing: It includes False Minutia Removal. The pre-processing stage cannot entirely rectify all issues present in the palm vein image. Notably, false ridge breaks caused by an inadequate amount of ink and ridge cross-connections resulting from excessive inking remain unresolved. Certain artifacts are occasionally introduced during the earlier stages, which subsequently contribute to the emergence of spurious minutiae. Recognizing these false minutiae as genuine ones could significantly impact the accuracy of matching. Therefore, it is imperative to implement mechanisms for the removal of false minutiae to ensure the effectiveness of the palm vein verification system. Fig. 6 shows different types of false minutia specified in the following diagrams:

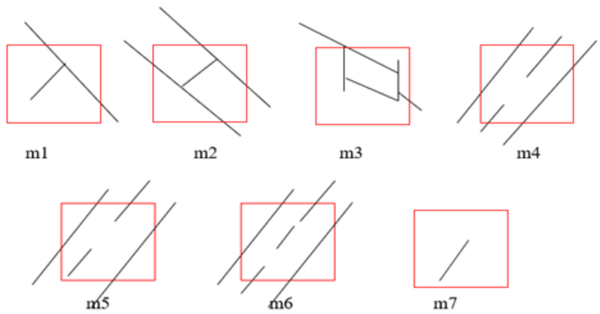

Fig. 6: False Minutia Structures

m1 is the peak of the valley. m2 is a spike that does not connect two protrusions. m3 has two close bifurcations on the same ridge. m4 has almost the same direction and is shorter. m5 is in a similar situation to m4 but is short enough that part of the crack occurs at the other end. m6 maintains the information of m4 but has the additional feature that the third protrusion is located in the middle of the two parts of the crack. Only a brief appearance in the m7 Start window. The process for removing incorrect content is as follows:

1. If the distance between a bifurcation and a termination point is less than D and two detail points on the same ridge (table m1). Delete both. where D is the average interridge width representing the distance between two adjacent ridges.
2. Remove two forks if the distance between them is less than D and they are on the same ridges (e.g. m2, m3).
3. If the two endpoints are a distance D and their directions together form a small angle. The situation they are interested in is that there is no other space between the two terminals. These last two were considered false points caused by explosion and dislocation. (m4, m5, m6).
4. If two terminations are located in shorted from D, remove two terminals (m7).

The process of eliminating false minutiae offers two notable advantages. Firstly, it leverages ridge ID for minutiae discrimination, presenting a more precise definition of seven specific types of false minutiae compared to the loosely defined categories in alternative methods. Secondly, the sequence of removal procedures is thoughtfully designed to mitigate computational complexity. For instance, procedure 3 efficiently addresses cases involving m4, m5, and m6 in a singular check routine. Subsequently, following the execution of procedure 3, the quantity of false minutiae conforming to the m7 case experiences a notable reduction.

3.3 Feature Matching

Matching algorithms for the feature model should be flexible because there need to be two features with the same parameters (x, y, θ) to get an exact match, but this is not good due to the small degradation in minutiae and imprecise quantization. When the minutiae elements to be matched fall within a rectangle and differ slightly, two minutiae are considered a pair. In the diagram template, each feature either has no matching detail or has only one minutia.

The ultimate match ratio between two palm veins is calculated as the number of matched pairs divided by the number of minutiae in the template palm vein. The resulting score, represented as 100 times the ratio, ranges from 0 to 100. If the score surpasses a predetermined threshold, it signifies that the two palm veins originate from the same palm.

During the matching process, the obtained database is compared with the input image using Euclidean distance computed using equation (9). If a match is identified, the match is accepted; otherwise, it is rejected.

$$D(z,a) = [(z_1 - a_1)^2 + (z_2 - a_2)^2 + \cdots + (z_n - a_n)^2]^{\frac{1}{2}} \qquad (9)$$

4. Results

The results of proposed method are summarized as follows.

Fig.7 shows the result of palm recognition indicating all intermediate stages for the matched case. Fig. 8 shows the result for a dorsal view of the palm image

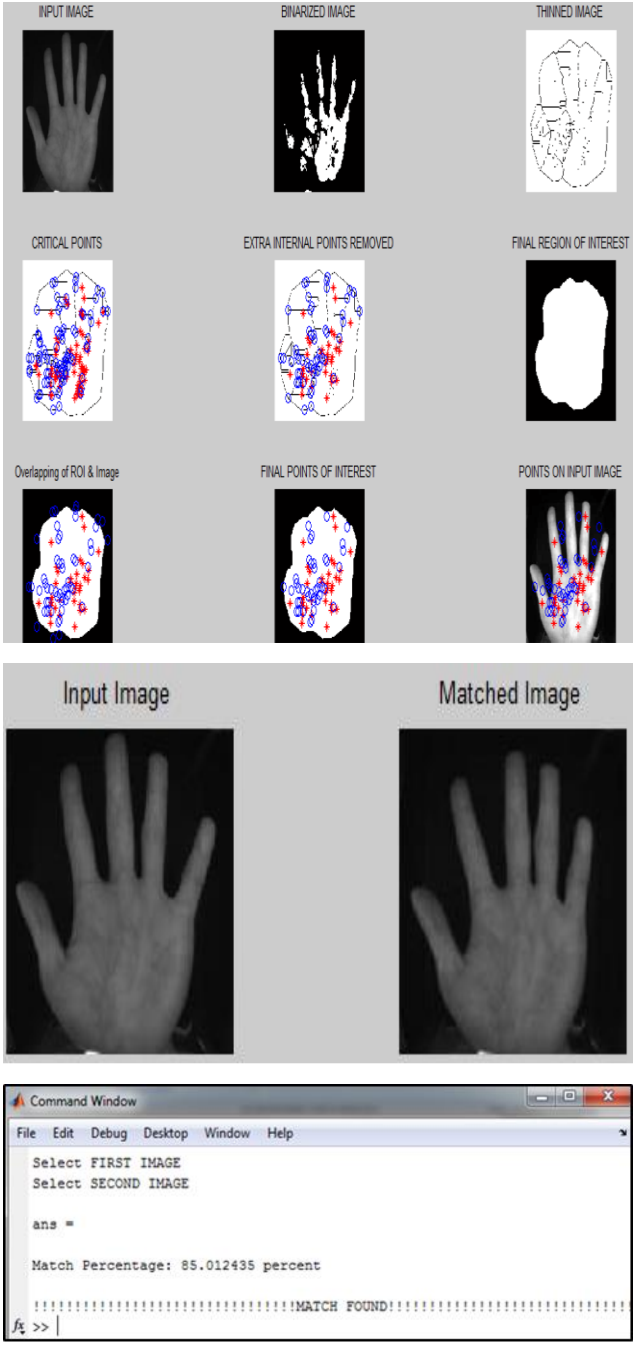

Fig. 7: Palm Recognition

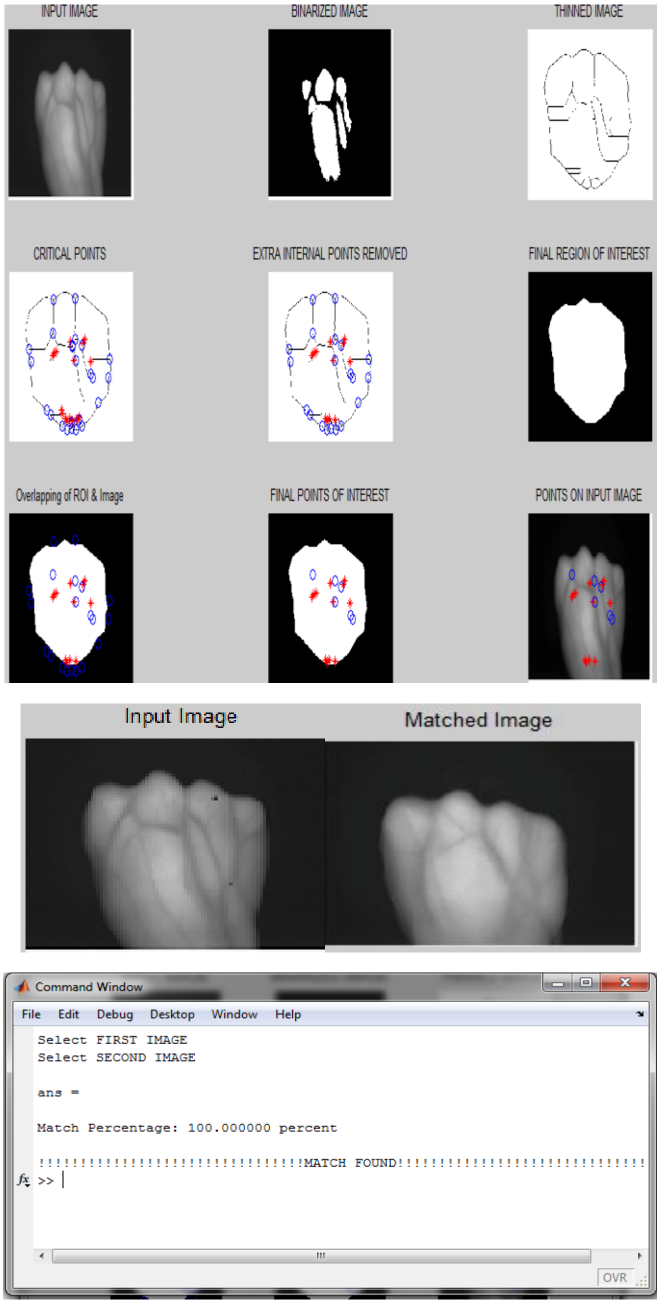

Fig. 8: Dorsal Palm View Recognition

5. Conclusion

A methodology for cost-effective vein pattern recognition, specifically designed for low-quality images is studied in this research. The initial steps involve binarization and morphological operations, including thinning, on the input image. Subsequently, the region of interest (ROI) is calculated based on these operations.

Matching of images is executed using Euclidean distance. The matching score between the test image and every image in the database is computed and displayed in the command window. This process facilitates the identification of the correct match.

In conclusion, the proposed system successfully identifies individuals based on their palm vein patterns, and dorsal vein patterns demonstrating the feasibility of this approach even with low-quality images

6. References and Footnotes

Author contributions

Jayamala Patil: Conceptualization, Methodology, **Sampada Dhole:** Data curation, Software **Vinay Mandlik:** Visualization, Investigation, Editing. **S. M. Jagdale:** Software, Validation, **Roma Rakesh Jain:** Field study **Vinod H Patil**: Original draft preparation, Reviewing.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] Shi Zhao, Yiding Wang, and Yunhong Wang, “Extracting Hand Vein Patterns from Low-Quality Images: A New Biometric Technique Using Low-Cost Devices”, Fourth International Conference on Image and Graphics.,2007.

[2] Yingbo Zhou, Ajay Kumar Department of Computing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, “Contactless Palm Vein Identification using Multiple Representations”,2010

[3] M Deepamalar and M Madheswaran, “An Improved Multimodal Palm Vein Recognition System Using Shape and Texture Features” International Journal of Computer Theory and Engineering, Vol. 2, No. 3, June,2010.

[4] Dhole S.A. and Patil V.H., “Minutiae Based Fingerprint Identification”, Journal of Signal and Image Processing, Bioinfo Publication, Volume 3, Issue 3,2012

[5] Mrs. S. A. Dhole and Prof. Dr. V.H. Patil, “Person Identification Using Peg Free Hand Geometry Measurement”, International Journal of Engineering Science and Technology (IJEST), Vol. 4, No. 6, June 2012

[6] R. Raghavendra; Jayachander Surbiryala; Christoph Busch, “Hand dorsal vein recognition: Sensor, algorithms, and evaluation” 2015 IEEE International Conference on Imaging Systems and Techniques (IST), 16-18 September 2015

[7] Jindi Li, Kefeng Li, Guangyuan Zhang, Jiaqi Wang, Keming Li, and Yumin Yang,” Recognition of Dorsal Hand Vein in Small-Scale Sample Database Based on Fusion of ResNet and HOG Feature”, Electronics 2022, 11, 2698.

[8] Rajendra Kumar, Ram C. Singh, “ Dorsal Hand Vein Recognition Using Very Deep Learning", Macromol. Symp.2021

[9] Dexing Zhong, Huikai Shao, "Towards application of dorsal hand vein recognition under uncontrolled environment based on biometric graph matching", IET(The Institution of Engineering and Technology) Biom., 2019, Vol. 8 Iss. 2, pp. 159-167.

[10] Murat Erhan Cimen, Omer Faruk Boyraz, Mustafa Zahid Yildiz, Ali Fuat Boz, "A new dorsal hand vein authentication system based on fractal dimension box-counting method", Optik Volume 226, Part 1, January 2021

[11] Haipeng Wan, Lei Chen, Jian Yang, "Dorsal hand vein recognition based on convolutional neural networks", IEEE International Conference on Bioinformatics and Biomedicine,2017.

[12] Rafael C. Gonzalez, Richard E. Woods, “Digital Image Processing”, 3rd edition, Pearson Publication.

[13] Dod, Shiwani, “Design of Biometric Fingerprint Image Enhancement Algorithm by Using Iterative Fast Fourier Transform” (April 27, 2016). Available at SSRN: https://ssrn.com/abstract=2771013 or http://dx .doi.org/10.2139/ssrn.2771013.

[14] Sangram Bana, Dr. Davinder Kaur, “Fingerprint Recognition using Image Segmentation”, International Journal of Advanced Engineering Sciences and Technologies, Vol No. 5, Issue No. 1, ISSN: 2230-7818, pp.12 – 23, 2011.

[15] Patil, J.K., Dhole, S.A., Mandlik, V.S., Patil, V.D., “Detection of Lung Cancer from CT Scan Images using GLCM Features”, *14th International Conference on Advances in Computing, Control, and Telecommunication Technologies, ACT 2023*, 2023, 2023-June, pp. 2551–2557.

[16] Dhole, S.A., Patil, J.K., Jagdale, S.M., Reddy, H.G.G., Gowda, V.D., “Multimodal Biometric Identification system using Random Selection of Biometrics”, *SSRG International Journal of Electrical and Electronics Engineering.* 2023, 10(1), pp. 63–73.

[17] *Patil, J.K., Mali, P.S., Tirmare, A.H., Mandlik V.S. “A Novel Method of Traffic Rule Compliance Detection Using Morphological Operations at Toll Booths”, SSRG International Journal of Electrical and Electronics Engineering*., 2023, 10(1), pp. 148–159.

[18] Dhole, S.A. Patil, A.A., “Image Quality (IQ) based liveness detection system for multi-biometric detection”, Proceedings of the International Conference on Inventive Computation Technologies, ICICT 2016, 2016, 1, 7823297.

[19] Dhole, S.A., Patil, V.H. “An efficient secure multimodal biometric fusion using palm print and face

image", International Journal of Applied Engineering Research, 2016, 11(10), pp. 7147–7150.

[20] Dhole, S.A. Patil, V.H. , "Face recognition using curvelet transform", International Journal of Applied Engineering Research, 2015, 10(14), pp. 33949–33954.

[21] Amol K. Kadam, Dr. Konda Hari Krishna, Neeraj Varshney, A. Deepak, 5Hemant Singh Pokhariya, Dr. Sandip Kumar Hegde, Dr. Vinod H. Patil, "Design of Software Reliability Growth Model for Improving Accuracy in the Software Development Life Cycle (SDLC)" International Journal of Intelligent Systems and Applications in Engineering, 12(1s), pp. 38-50, 2024

[22] Suryawanshi, R., Kadam, A., Anekar, D., Patil, V. "An Innovative Approach for Predicting Software Defects by Handling Class Imbalance Problem" International Journal on Recent and Innovation Trends in Computing and Communication, Volume 11, Issue 9, pp. 498-505,2023.

[23] Dr Vinod H Patil, Dr Anurag Shrivastava, Devvret Verma, Dr A L N Rao, Prateek Chaturvedi, Shaik Vaseem Akram, "Smart Agricultural System Based on Machine Learning and IoT Algorithm", 2nd International Conference on Technological Advancements in Computational Sciences (ICTACS), 2022. DOI: DOI: 10.1109/ICTACS56270.2022.9988530

[24] Dr Vinod H Patil, Dr Pramod A. Jadhav, Dr C. Vinotha, Dr Sushil Kumar Gupta, Bijesh Dhyani, Rohit Kumar," Asset Class Market Investment Portfolio Analysis and Tracking", 5th International Conference on Contemporary Computing and Informatics (IC3I), December 2022. DOI: 10.1109/IC3I56241.2022.10072525

[25] Dr. Vinod H Patil, Prasad Kadam, Sudhir Bussa, Dr. Narendra Singh Bohra, Dr. ALN Rao, Professor, Kamepalli Dharani," Wireless Communication in Smart Grid using LoRa Technology", 5th International Conference on Contemporary Computing and Informatics (IC3I), December 2022, DOI: 10.1109/IC3I56241.2022.10073338

[26] Vinod H. Patil, Dr Shruti Oza, Vishal Sharma, Asritha Siripurapu, Tejaswini Patil, "A Testbed Design of Spectrum Management in Cognitive Radio Network using NI USRP and LabVIEW", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-2S8, August 2019.

[27] Vinod H. Patil, Shruti Oza, "Green Communication for Power Distribution Smart Grid", International Journal of Recent Technology and Engineering™ (IJRTE), ISSN:2277-3878(Online), Reg. No.: C/819981, Volume-8, Issue-1, Page No. 1035-1039, May-19.

[28] Patil, V.H., Oza, S., Sharma, V., Siripurapu, A., Patil, T.," A testbed design of spectrum management in cognitive radio network using NI USRP and LabVIEW", International Journal of Innovative Technology and Exploring Engineering, 2019, 8(9 Special Issue 2), pp. 257–262

[29] Vinod Patil et al, "A Model Design of Green Communication for Smart Grid Systems" SSRG International Journal of Electrical and Electronics Engineering, ISSN: 2348-8379, Volume 10 Issue 5, pp. 227-239, May 2023. https://doi.org/10.14445/23488379/IJEEE-V10I5P121

[30] S. Bussa, A. Bodhankar, V. H. Patil, H. Pal, S. K. . Bunkar, and A. R. . Khan Qureshi, "An Implementation of Machine Learning Algorithm for Fake News Detection", International Journal on Recent and Innovation Trends in Computing and Communication, ISSN: 2321-8169, Volume: 11 Issue: 9s, pp. 392–401, Aug. 2023. DOI: https://doi.org/10.17762/ijritcc.v11i9s.7435

[31] Patil, V. H. ., A. . Deepak, H. . Sharma, L. . Vaishnavi D. A., U. . Singh Aswal, K. K. . Bajaj, and A. . Shrivastava. "Development of Functional Test Cases Using FSM and UML Activity Diagrams for MDT". International Journal of Intelligent Systems and Applications in Engineering, vol. 12, no. 14s, Feb. 2024, pp. 12-21, https://ijisae.org/index.php/IJISAE/article/view/4576.