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Advances in Biometric Recognition Techniques: A Review of Finger and Hand Vein Identification Methods

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ABSTRACT

This review article systematically investigates the advancement in finger and hand vein biometric recognition technologies from 2011-2015, highlighting three key studies that have been identified in the area. The article starts with the study on using near-infrared imaging for finger vein recognition by Lee, Jung, and Kim in 2011 and tracks the development of the technologies. The significant developments applicable over the past few years include the design of a dual-camera system by Lu, Yoon, and Park in 2014 and research on hand vein-based multimodal biometric recognition by Bharathi, Sudhakar, and Balas in 2015. All the methodologies, results, and technological improvements innovated through the research have been elaborately explained in the paper, focusing on a vast comparative view with respect to the developments made in vein recognition technologies and advancements developed through them. It would address challenges such as scalability, cost, and user acceptance, and future directions like integration with emerging fields such as Artificial Intelligence (AI) and the Internet of Things (IoT). The review concludes that it is hard to overestimate the importance of these biometric technologies in the current security context and how they have immense potential to raise personal identification and authentication systems to a whole new level in the future. This article presents major strides not only made in vein biometrics but also puts a foundation for future research in this field that is quickly shaping up.

Keywords: Biometric recognition, Near Infrared Imaging, Multimodal Biometric Recognition, Vein Recognition, Equal Error Rate

1. Introduction

Biometric recognition technologies have proven to be a cornerstone in the security field and personal identification. They managed to revolutionize the area of differentiating individuals around various circumstances. These systems use distinct biological characteristics, such as fingerprints, facial features, iris patterns, and vocal characteristics among others, thus offering secure and effective methods of identification and authentication. The major benefit that these technologies have over traditional methods, such as passwords or PINs, which can easily be forgotten, or raise serious concern in case of loss or theft.

The significance of the typical biometric system in the fields of security and identification can never be overstated. Biometrics provide a very strong defence mechanism at such a time when the number of security breaches and identity thefts is on the increase. When systems based on biological characteristics are able to offer increased security and convenience, the incidents of unauthorized access or fraud are reduced to a great extent with that biometric system. Biometric systems find application in myriad sectors including but not limited to law enforcement, border control, banking and even personal devices like smartphones thereby setting up the spotlight on the versatile and ubiquitous utility of biometric systems.

Among the many different biometric methods, vein recognition has garnered significant attention because of its high dependability and distinct benefits. The vein pattern, whether on fingers or hands, is highly unique to every individual with great consistency over time even for identical twins. (Choi, 2009) This exceptional combination of uniqueness, stability, and the arduousness to be imitating vein patterns ultimately offers vein recognition an exceptionally strong biometric modality. In this regard, the approaches towards vein recognition technologies as identified in the scholarly works of Lee, Jung, and Kim (2011), Lu, Yoon, and Park (2014), and Bharathi, Sudhakar, and Balas (2015) can be considered as notable because of their contribution made to the mentioned field of study. Such studies emphasize the effectiveness of near-infrared imaging and dual-camera systems to improve vein recognition accuracy and robustness, to make apparent the future applications of such approaches over various practical domains. The presentation from the multimodal biometric systems study by Bharathi et al. (2015) further shows that vein recognition proves flexible when used in combination with other biometric modalities. This portrays a situation whereby combined biometric systems could be able to come up with more effective security and identification solutions in the coming days.

2. Overview of Finger and Hand Vein Biometric Methods

Analyzing vein biometric techniques on the fingers and hands reveals a complex landscape where technology meets the unique patterns of human vascular structures. These biometric systems harness the unique vein patterns present in an individual's fingers and hands, leveraging the singular nature of these vascular configurations. Unlike surface-level biometrics such as fingerprints, vein patterns are situated below the skin's surface, adding a new dimension of identification.

2.1 Explanation of Finger and Hand Vein Recognition Technologies

Broadly, the finger and hand vein recognition technologies work by capturing and analyzing the distinct patterns of blood vessels lying underneath the skin. Various advanced imaging methodologies, more specifically near-infrared imaging, are used to enhance the visibility of these vein patterns. Lee, Jung, and Kim (2011) further expound on the use of near-infrared imaging in finger-based biometric techniques and elaborate that this precise aid lights up underlying vein patterns invisible to the naked human eye. Similarly, research by Lu, Yoon, and Park (2014) investigates the use of a dual-camera system to thoroughly capture vein patterns, hence improving the precision and dependability of finger vein recognition.

The procedure consists of illuminating the finger or the hand with near-infrared light that penetrates the skin and is absorbed by the haemoglobin contained in the blood. A camera sensor records the resulting contrast between the veins and the tissue surrounding them as a digital representation of the vein pattern. In order to aid in identification, this image is then processed and compared to the vein patterns that are already saved in database.

2.2 Advantages Over Other Biometric Methods

The finger and hand vein recognition technologies provide several advantages over the conventional biometric approaches. The uniqueness of vein patterns stands to be the most prominent. Every person has a unique set of vein patterns that are extremely difficult to replicate or forge, as emphasized by Bharathi, Sudhakar, and Balas (2015). In fact, variation in the vein pattern has even been observed among identical twins, thus highlighting how truly unique the vein pattern is as a biometric attribute. (Kumar et al., 2009)

Another notable advantage lies in the challenge posed by forging or replicating vein patterns. Unlike fingerprints or facial features, which at the most can be imitated or duplicated but not reproduced in their exact form - vein patterns are hidden underneath the skin and thus almost impossible to replicate without some sophisticated means. (Zhou et al., 2014) The hidden nature of vein patterns further strengthens the security of the biometric system as an unauthorized person can seize these patterns very rarely without consent from the user.

Other than this, the vein patterns remain reasonably constant throughout a person's lifetime unless there is considerable change in health or physiology. This type of stability will guarantee that the biometric data will be precise and accurate for an extended period hence minimal updating or re-enrollment.

Basically, the discovery of finger and hand vein biometric techniques emerges as a promising and reliable solution for biometric authentication. The uniqueness of vein pattern, resistance to forgery, and stability were established by the researchers Lee et al. (2011), Lu et al. (2014), and Bharathi et al. (2015) and currently represent this type as advanced and reliable biometric security and authentication tool within the ever-changing environment of technological innovation.

3. New Finger Biometric Method Using Near Infrared Imaging (2011)

Some of the most influential works in the field of finger biometrics include the work by Eui Chul Lee, Hyunwoo Jung, and Daeyeoul Kim back in 2011, among many others reviewed herein. In their work, the researchers came up with a novel approach to finger biometrics using near-infrared imaging. This particular study has remained one of the landmark studies on the technological breakthroughs of the entire biometric sector in relation to finger vein recognition.

3.1 Summary of the Method Using Near-Infrared Imaging

The method discussed by Lee, Jung, and Kim is based on the application of near-infrared (NIR) imaging that captures complex vein patterns observed in human fingers. The basic idea of the approach is that the amount of light absorbed by haemoglobin in blood in the near-infrared spectrum is greater in comparison with surrounding tissues, and for this reason, when a finger is exposed to near-infrared light, the vein patterns become observable. So, Experts can capture images of vein patterns, transform them into digital format, and store them for subsequent analysis and identification purposes.

Block diagram of the suggested method

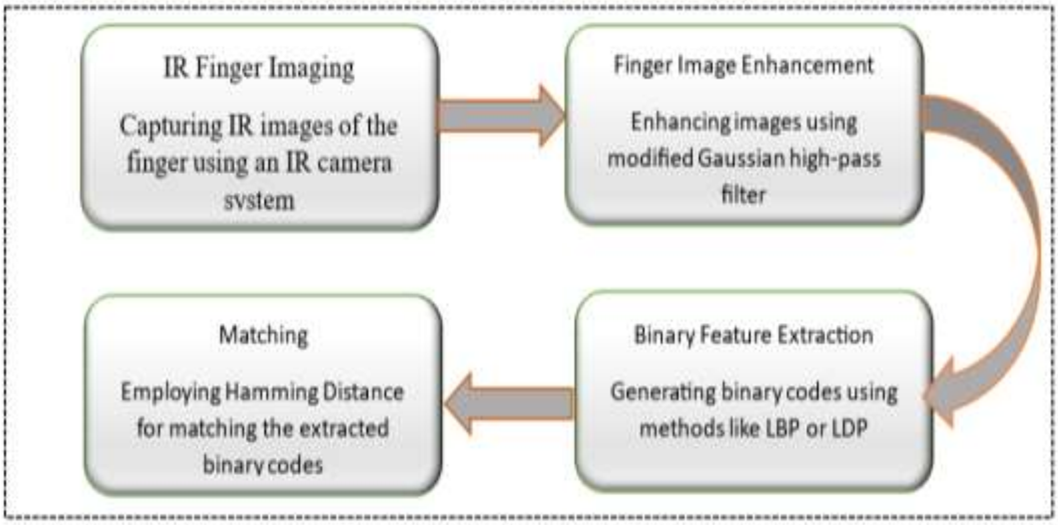

Figure 1

3.2 Key Findings and Technological Advancements

In the research conducted by Lee et al., it has been illustrated that near-infrared imaging technique plays a crucial role in enhancing the clarity and visibility of the vein patterns. (Lee et al., 2011) The improved clarity provided in that method is of prime importance and can contribute towards improving the accuracy levels for vein pattern identifications. They also illustrated that near-infrared imaging can identify complex vein features that are not achievable using the traditional imaging process. (Lee et al., 2011) This method, therefore, enables a more reliable and, hence, more accurate biometric identification process.

The approach is robust to external factors like skin conditions or light changes. Traditional biometric measures like fingerprint recognition are affected by external factors like dirt and moisture on the skin. So, the approach introduced by Lee et al. has a more accurate and steadfast solution which reveals the veins on the surface just a few millimetres into the skin.

3.3 Discussion on the Application and Effectiveness

The use of near-infrared (NIR) imaging techniques in the domain of biometric recognition has profound implications. Specifically, such a measure must be taken quite seriously when such techniques may be deployed to protect high-security setups such as banking environments, corporate security applications, and secure data access. What sets this method apart is the ability to avail biometric data that are both correct and tamper-proof, making it highly appropriate in instances where security is paramount.

In addition, the same is effective due to its non-invasive and user-friendly characteristics. Unlike other biometric systems, the NIR imaging for vein recognition is relatively simple and non-intrusive, requiring almost no physical contact or complicated alignment needed for these counterparts. This brings simplicity for enhanced user acceptance and comfort, ultimately enhancing overall system effectiveness.

The work done by Lee, Jung, and Kim, therefore, is one of the significant breakthroughs in finger biometric technology. Their novel application of near-infrared imaging set a benchmark for future research in the field of biometric security and has given a new dimension to biometric recognition.

4. Finger Vein Identification System Using Two Cameras (2014)

In 2014, Yu Lu, Sook Yoon, and Dong Sun Park proposed a novel method for identifying veins in the fingers using a dual-camera system. This approach was a milestone in the science of biometric identification because it came up with new perspectives on the accuracy and efficiency of the finger vein recognition method.

4.1 Overview of the Dual-Camera System for Enhanced Identification

Block diagram of the proposed method

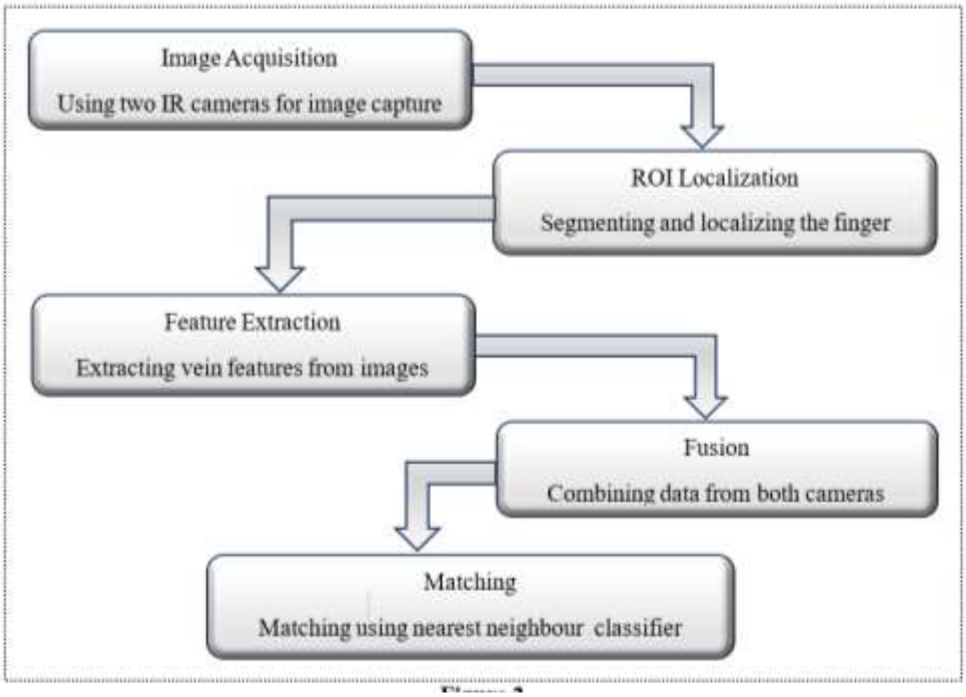

Figure 2

Lu, Yoon, and Park propose a two-channel camera system for thorough and minutely detailed imaging of finger vein patterns. Unlike traditional single camera setups where only one angle point exists, this dual cam system takes shots from two different perspectives. (Lu et al., 2014) A novel approach that enables a more realistic picture of the vein pattern because it overcomes the limitations of single-view imaging, i.e. distortion and partial view problems is a three dimensional reconstruction from two views.

The two cameras are strategically positioned such that each imaging the different facets of the finger thus imaging wider area. (Lu et al., 2014) The system ability to see the complex vein patterns and areas that may be hard to perceive in a single camera is considerably enhanced by this strategic arrangement.

4.2 Comparative Analysis with Single Camera Systems

This study compared a dual-camera system to normal single-camera systems. The dual-camera approach, on the other hand, revealed an improved precision in vein pattern detecting. This two-sided approach made it possible to achieve a more thorough survey of the vein pattern with an increased recognition level.

Also, it was noted that the dual-camera system was resistant to problems due to finger placement and variable brightness levels associated with these external factors. However, with several views, the system guarantees continuous and dependable capture of vein contour in view of these factors.

4.3 Assessment of Accuracy and Efficiency Improvements

The accuracy and efficiency of the dual-camera system are among its most notable advancements. Lu, Yoon and Park's study showed that a system with a camera may be able to identify individuals with a higher degree of accuracy using vein patterns as compared to a single camera setup. This advancement is as a result of complete data capturing of the event and ability to address most errors caused by single camera systems.

Another thing, the study concluded that the dual-camera system could do pattern matching more accurately. The efficiency in this case is important since fast and reliable recognition is needed for practical purposes like in access control or timing-sensitive authentication.

Briefly, the study of Lu, Yoon, and Park provides a breakthrough in finger vein biometric technology. Their two-camera system not only resolves shortfalls of the normal single-camera systems but also raises the efficiency and precision of the biometric identification.

5. Hand Vein-based Multimodal Biometric Recognition (2015)

S. Bharathi, R. Sudhakar, and Valentina E. Balas conducted a detailed study on hand vein recognition integration with existing technology. Biometric system security and efficiency benefit from this step.

5.1 Exploration of Multimodal Biometric Recognition Using Hand Veins

Sudhakar, Bharathi, and Balas investigate the idea of combining unique and consistent hand vein patterns with other conventional biometric parameters in a multimodal biometric system. This multimodal method combines biometric modalities to overcome the limitations of single-modal systems.

This study shows how multiple imaging techniques can identify hand vein patterns by fusing data with fingerprints or facial features. (Bharathi et al., 2015) The researchers also pointed out that multidimensional data integration and interpretation require advanced image processing and pattern recognition techniques.

Block diagram of the proposed method

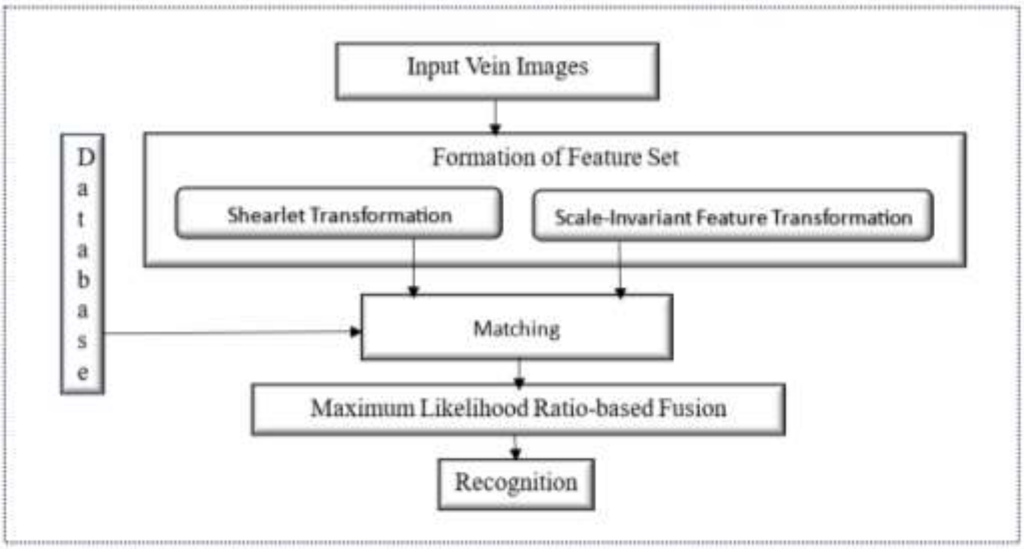

Figure 3

5.2 Discussion on Integrating Hand Vein Recognition with Other Biometric Methods

Bharathi et al. devote a lot of time discussing the integration strategies of combining hand vein recognition with other biometrics. They examine a range of fusion approaches considering issues related to compatibility of data, synchronisation of distinct biometric sensors among others as well as enhancements of recognition algorithms. The work focuses on the technical challenges with respect to the integration of multiple modalities in multimodal biometric recognition, suggesting means for easy and reliable identification across different modes.

Additionally, the authors provide possible use cases of these multimodal systems such as high-security access controls and biometric identifications. Further, they indicate that the use of hand veins in combination with other biometrics is far superior to spoofing only one kind of trait at a time. (Akhtar, 2012)

5.3 Evaluation of Performance and Security Enhancements

Bharathi, Sudhakar, and Balas provide empirical evidence proving that their multi-modal approach improves performance and security over single-modality systems. This study shows that by combining hand vein patterns with other biometric information, the error level could be significantly reduced, leading to higher accuracy, lower false acceptance and false rejection rates and stronger systems.

Notably the security enhancements here. The authors claim that multimodality approach can overcome deficiencies of traditional single-mode systems like faking or bypass. The system necessitates three biometric verifications that guarantee improved safety thereby making it harder for an individual without authorization to gain access into the information.

Finally, the study undertaken by Bharathi, Sudhakar, and Balas adds immensely useful information on improving sophisticated biometric systems. This opens new ways of improving the efficacy and accuracy of biometrics technology by looking at hand veins as a possible point of contact.

6. Comparative Analysis

A comparative study of the three fundamental studies concerning vein recognition technology is Lee et al (2011), Lu et at (2014), and Bharathi et al (2015) during a vital of four years is discussed here.

6.1 Comparison of the Methodologies and Findings of the Three Studies

Table 1

Focus	Key Techniques Used	Biometric Traits Utilized	Notable Findings
Finger Vein Identification System	Two cameras with different fusion techniques	Finger veins	Utilizes a dual-camera system to generate more discriminative information, enhancing matching accuracy. Tested on 436 fingers from 109 subjects.
Finger Biometric Method	Infrared imaging, Modified Gaussian high-pass filter, LBP and LDP methods	Finger veins and geometries	Achieves a low error rate of 0.13% by using a method that captures multimodal features of finger veins and geometries.
Multi-Biometric Recognition Technique	Shearlet transform, SIFT, Maximum likelihood ratio-based fusion	Finger vein, Palm vein, Dorsal vein of the hand	Employs multi-biometrics to enhance security, using advanced feature extraction techniques and fusion method.

A new approach involving near-infrared imaging of finger veins was proposed by Lee et al. (2011). This was one of the first times NIR light was used to improve visualization of vein patterns to generate high resolution images of subcutaneous veins. The most important outcome was the improved accuracy and the robustness of the technique with respect to extraneous variables to provide a basis for future developments in vein recognition technology.

In 2014, Lu et al. enhanced this field even more with their two-camera system for finger veins biometrics. It was different method where from the previous single camera systems, multiple cameras to provide views were used which capture vein patterns from the different angles. The comparative analysis with single-camera systems demonstrated that the dual camera was more precise and effective, stressing a need for comprehensive data capture for successful biometric recognition.

In a 2015 research study, Bharathi et al. examined multimodal biometric recognition based on hand veins. Unlike the single reliance on vein pattern, it combined hand vein recognition to other biometric modalities and this was an indication of the more robust and dependable biometric systems. The importance of multimodal biometric systems was highlighted in this study, especially concerning higher security level and lower susceptibility to spoofing.

6.2 Discussion on the Evolution of Technology from 2011 to 2015

In the last five years, from 2011 to 2015, vein recognition technology has undergone several improvements, which include improved imaging technologies and improved recognition algorithms. There was also an incremental development in multi-dimensional methodologies for early detection of breast abnormalities such as near-infrared imaging method proposed by Lee et al. According to Lu et al., the switch from single-camera to dual-camera systems indicates an increasing awareness of the need for detailed imaging in vein identification. Concluding this phase of development, Bharathi et al.'s research on multimodal systems establishes vein recognition as a critical component of reliable biometrics systems.

6.3 Insights into the Trends and Improvements in Vein Recognition Technology

In these years, the trends in vein recognition have shown an unmistakable direction towards increased accuracy, reliability, and security. From its original emphasis on improving image quality and pattern recognition accuracy, the system evolved towards tackling broader issues including system robustness and multi-factor authentication. Bharthi et al. noted the incorporation of multiple biometric characteristics as an emerging trend with a focus on high-resolution but flexible systems suitable for various uses.

Lastly, the comparison of these three studies shows how dynamic this subject is moving on with great speed. Vein recognition technology grew from fundamental works in near infrared imaging to the latest multimodal systems due to constant quest for improved security, greater precision and ease of use.

7. Future Directions and Challenges

The research by Lee, Jung, and Kim (2011), Lu, Yoon, and Park (2014), and Bharathi et al. (2015) not only discussed the current state of things in vein biometric technology but also indicated some scopes for future research and potential pitfalls to be avoided within this area.

7.1 Potential Areas for Future Research in Vein Biometric Technology

The exploration of vein biometric technology, as demonstrated in these studies, opens several avenues for future research. One such area is the further enhancement of imaging techniques. While near-infrared imaging has proven effective, there is room for exploring other wavelengths or imaging methods that could offer even higher clarity and accuracy in vein pattern recognition.

The development of algorithms for real-time processing and analysis of vein patterns is another promising area. The technology will find more applications in time-sensitive environments and, in that perspective, demand quick and accurate processing. Research into algorithms that can rapidly and accurately match vein patterns with existing databases will be crucial.

Further research can also be done into how vein biometrics can be used in connection with other physiological or behavioural biometrics. While Bharathi et al. have initiated this discussion, there is great room for research in those areas to achieve better optimization of these multimodal systems, particularly in the areas of data fusion and synchronization techniques.

7.2 Discussion of Challenges such as Scalability, Cost, and User Acceptance

However, notwithstanding these developments, the technology still poses various challenges for vein biometrics to become a mainstream, more user-friendly modality. In scalability, the biggest challenge that the technology poses is in its deployment in large-scale environments. In order to process large databases and numerous transactions quickly, the system needs to be scalable.

The cost is another key factor. The potential for widespread use is limited by the high cost of high-quality imaging equipment and complex software. More widespread use necessitates research into less expensive options that do not skimp on safety or quality.

Gaining acceptance from end users is another significant obstacle. The public's opinion differs about vein recognition, even though it is less intrusive than other biometric technologies. Hence, continuous research on user-friendly designs that simultaneously ensure privacy and data safety is necessary to promote user adoption.

7.3 Speculation on the Integration of Vein Recognition with Emerging Technologies (e.g., AI, IoT)

The integration of vein recognition technology with emerging fields like Artificial Intelligence (AI) and the Internet of Things (IoT) holds immense potential. (Saracco, 2021) AI can play a pivotal role in enhancing the accuracy of vein pattern recognition through machine learning algorithms that can learn and adapt to varied vein patterns more efficiently.

In the context of IoT, vein recognition can provide secure and convenient user authentication for various connected devices. As IoT devices become more prevalent in everyday life, ensuring secure access becomes imperative, and vein recognition could offer a reliable solution.

In summary, the future of vein biometric technology, as hinted at in these studies, is promising but not without challenges. The development and widespread use of this technology relies on resolving these issues through ongoing research and innovation.

8. Conclusion

The literature review for the studies carried out by Lee, Jung, and Kim (2011), Lu, Yoon, and Park (2014), and Bharathi, Sudhakar, and Balas (2015) is provided in a structured manner, with appropriate sections prepared straightforwardly to describe the developments and prospects in the domain of finger and hand vein biometric recognition technologies. These combined scholarly works indicate the significant advances that have been achieved in this field, laying the groundwork for future developments.

The journey commences with the pioneering work of Lee et al. (2014), where near-infrared imaging for finger vein recognition is unveiled - a uniqueness in terms of enhanced visibility and vein pattern acquisition accuracy. This process is paradigm-changing in the biometric recognition research field and gives a very strong and dependable solution away from conventional practices.

Later, Lu et al. went even further in the field by proposing a novel dual-camera configuration for finger vein identification systems. This inventive approach overcomes the limitation of single-camera systems with the acquisition of more complete and accurate vein patterns, which contributes to improved performance in biometric systems because higher reliability and efficiency are achieved.

Bharathi et al. conducted research on hand vein-based multimodal biometric recognition that, in turn, opens up newer horizons for more secure as well as versatile biometric systems. Their research on the fusion framework of hand vein recognition with other biometric modalities reveals new areas for improved security and performance in the case of the numerous biometric authentication applications depicted in the open literature.

In this review, we have scrutinized the EER (Equal Error Rate) values from these pioneering research papers, which deal with varying types of biometric authentications and feature extraction methods. EER stands as the fundamental measure of the biometric systems, giving the value in which the False Acceptance Rate (FAR) is equal to the False Rejection Rate (FRR), thus providing a fair measure of the performance of the system. (El-Abed et al., 2012)

The investigation conducted by Lee, Jung, and Kim (2011) concentrated on the contribution of finger geometry and finger vein components in biometric systems. It unveiled EER values for Binarization (23.16% for finger geometry, 0.38% for combined components) and LDP (Local Directional Pattern, 17.86% for finger geometry, 0.13% for combined components). This delineates a substantial enhancement in accuracy when amalgamating finger geometry with vein patterns.

Lu et al. assessed many feature extraction methods and presented EER values for Maximum Curvature (ranging from 3.03% to 4.43%), LBP (Local Binary Patterns, ranging from 1.29% to 2.84%), and CompCode (ranging from 0.50% to 1.39%). These findings reveal variances in system performance contingent on the feature extraction technique employed, with CompCode manifesting the most minimal EER values.

Bharathi et al. reported EER values of 0.01% and 0.04% in their study, signifying an extraordinarily elevated level of accuracy within vein-based authentication systems. This underscores the efficacy of the methodologies and imaging techniques harnessed in these systems.

Collectively, these outcomes furnish invaluable insights into the contemporary landscape of biometric authentication technologies. The diminished EER values, notably in advanced feature extraction techniques and amalgamated biometric attributes, underscore an ongoing trajectory toward fortified security and dependability within biometric systems. This progression bears pivotal significance for the evolution of more impregnable and user-friendly authentication solutions across diverse applications.

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