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A Brief Overview of Several Challenges in Finger Vascular Pattern Recognition

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ABSTRACT

Finger vascular pattern recognition biometrics are gaining popularity because they are hard to duplicate and more convenient. However, the challenges addressed during this research are not well-known to the public. Therefore, this paper presents an overview of challenges in finger vein pattern recognition. The challenges described arise from three possible things, namely imaging devices, finger physiology, and the surrounding environment. An illustrative experiment for one of the challenges has been carried out by producing that overexposure illumination during the image acquisition process can cause loss of vein pattern images. In addition, the experiment results on one of the finger images with different skin colors (light and dark) are shown in the histogram of the two images, where there is a slight difference in the graph pattern. From this paper, it is expected that the results of the illustrative experiments, as well as the general issues presented in this study, will inspire further research. Some of the work in this paper is part of the Ph.D thesis of Pesigrihastamadya Normakristagaluh.

Keyword : Biometrics; Finger vascular pattern; Image processing.

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1. INTRODUCTION

Biometrics is the study of how to distinguish a person's identity through their characteristics, such as the following: physiological characteristics (including physical and chemical) or behavior [Jain et al., 2007]. Biometric modalities that are often used in data processing or security investigations include fingerprints, iris, and face. In addition, there is also a modality that uses the structure of blood vessels in the human body called vascular pattern biometrics (veins). This biometric has recently become increasingly popular, with more opportunities to be explored, and as an alternative to other biometric modalities [Uhl et al., 2020]. Finger vein recognition (FVR) is part of vascular biometrics that uses finger blood vessel patterns to identify or distinguish a person. This finger vein recognition includes veins and arteries, therefore it is more properly referred to as vascular pattern recognition, but vein recognition is more common. Therefore, the term used in this paper is finger vascular pattern recognition (FVPR). In the following, finger vascular pattern recognition provides several benefits, like other biometric modalities such as fingerprint, iris, or face recognition.

- FVR can discriminate between individuals compared to more stable modalities such as iris patterns and is suitable for use in personal authentication [Yanagawa et al., 2009].
- Vascular patterns can only be obtained from living human bodies, not from dead bodies [Miura et al., 2004].
- The modality of finger vein patterns is the same over time, meaning young finger veins have the same pattern as older fingers [Syazana-Itqan et al., 2016].
- Finger vein scanners use a contactless camera to capture an image of the finger [Uhl et al., 2020].
- Finger vein patterns are captured from blood vessels inside the finger [Kienle et al., 1996], making them difficult to duplicate [Lee and Park, 2009]. This can be exemplified by the fact that FVR cannot leave traces like fingerprints.
- Finger vein recognition is robust to several issues, such as motion blur, sensor aging, and image compression (lossless) [Kauba et al., 2018b], [Kauba and Uhl, 2015].

Several researchers have conducted several reviews and studies [Uhl et al., 2020] or [Syazana-Itqan et al., 2016] which focus more on describing methods to improve the performance of finger vein pattern recognition accuracy. However, they discussed the causes that may partially reduce image quality. This paper will briefly overview several challenges in finger vein pattern recognition that can affect image quality. It also presents a simple illustrative experiment for one of those challenges. Furthermore, this paper provides insight into the variation of light intensity or illumination given to the finger and its relation to the physiology of the finger, which can affect the quality of finger vascular pattern images.

The outline of the writing in this paper is as follows. A brief overview of several challenges in finger vein pattern recognition is provided in Section 2. Section 3 briefly explains the research method and continues with the illustrative experiment in Section 4. Then in Section 5 a discussion of the results is carried out. Finally, Section 6 contains a summary of this paper.

2. Research Stages

The main challenge of finger vascular pattern recognition is related to improving the algorithm in all aspects of the dataset and image quality. The following will discuss several possible causes of image quality degradation in finger vascular patterns, including those related to the image acquisition device, finger physiology, and the surrounding environment.

2.1 Imaging Device

This session presents device parts for capturing finger vein images (scanner) that may affect image quality. The camera (sensor) and light (illumination) are included in this component. Furthermore, the illumination section is generally separated into three, including the light's wavelength, width, and direction.

A. Illumination Wavelength

Tissues are heterogeneous and are composed of different structures, including soft tissues, blood vessels, and hard tissues (bone), and have different optical properties, such as penetration, absorption, scattering, and remittance of light at different wavelengths [Kienle et al., 1996]. Because hemoglobin is the body's main oxygen carrier, it will absorb light more strongly in blood vessels. Deoxygenated hemoglobin is found in veins and oxygenated in arteries [Swarbrick and Boylan, 1999]. The first challenge, in this case, the researchers have attempted to discover the optimal wavelength range of the light to demonstrate the optical properties of tissues. Rogan et al. measured the optical properties of tissues (human brain white matter, canine prostate, and pig liver) in the wavelength range of 330-1100 nm [Roggan, 1993]. Every tissue has specific absorption bands at 420 and 550 nm, which are associated with hemoglobin's strong absorption. The scattering rises dramatically after coagulation, whereas the absorption stays relatively constant.

Many popular methods of blood vessel imaging in medical applications rely on the absorption of infrared (IR) light by blood. For example, Mancini et al. [Mancini et al., 1994] and Fuksis et al. [Fuksis et al., 2010] used near-infrared (NIR) to evaluate vessels' oxygenation. In the results, Mancini et al. found that light is equally absorbed by oxygenated and deoxygenated hemoglobin at 800 nm; however, deoxygenated hemoglobin is mostly responsible for absorption at 760 nm. Furthermore, Fuksis et al. observed that the transmission approach produced nearly the same results as the reflection method at 760nm and that applying an IR optical filter increased image quality acquired at 850nm. Most researchers in finger vein recognition also use infrared light to illuminate the finger [Ibrahim et al., 2012]. According to Walus et al.'s impact light wavelength range research, the optimal wavelength range for finger vein recognition is between 875 and 890 nm [Walus´ et al., 2017]. This wavelength range falls within the near-infrared (NIR).

B. Illumination Width

Most finger vein imaging devices use NIR-LEDs as an illumination source. Kim et al. [Kim et al., 2009] introduced finger vein recognition using a NIR laser as an illumination source. Their research showed that the finger vein images are more uniform when using the NIR laser (Fig 1). Kauba et al. [Kauba et al., 2018a] and Lee et al. [Lee et al., 2017] also employed the laser to illuminate the finger and compare it to NIR-LEDs. The laser can generate narrow light and reduce light leakage (Fig 2a and b) and overexposure in border areas (Fig 2c and d). Both cases are due to the standard NIR-LED having a fairly large light angle (width). This raises the question of the second challenge, namely how to imitate a narrow beam like a laser using NIR-LED light..

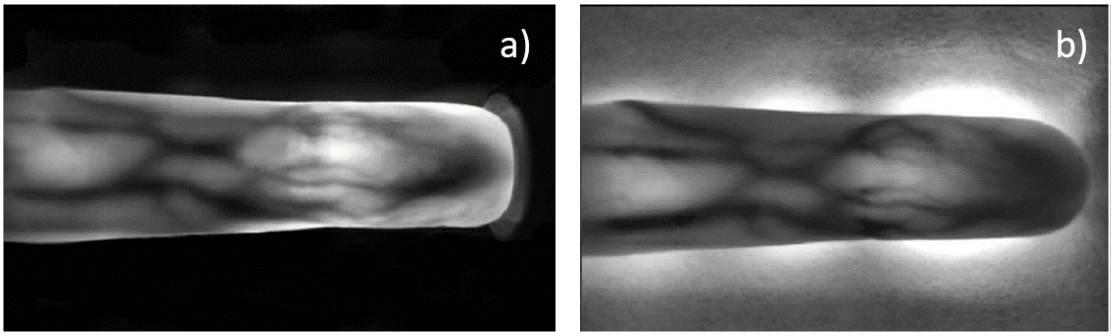

Fig. 1. Finger vein images, adapt from [Kim et al., 2009], were captured using a) NIR laser and b) NIR-LEDs.

C. Illumination Direction

The third challenge is choosing the ideal illumination direction for the finger vein scanner. The capture of finger vein NIR images can be classified into four groups according to the type of illumination: top illumination [Ton and Veldhuis, 2013], bottom illumination [Zhang et al., 2013], one-side (right or left) illumination, and both-side (right and left) illumination [Ramachandra et al., 2019]. Figure 3 shows NIR images were captured using various directions of illumination with different finger vein imaging devices.

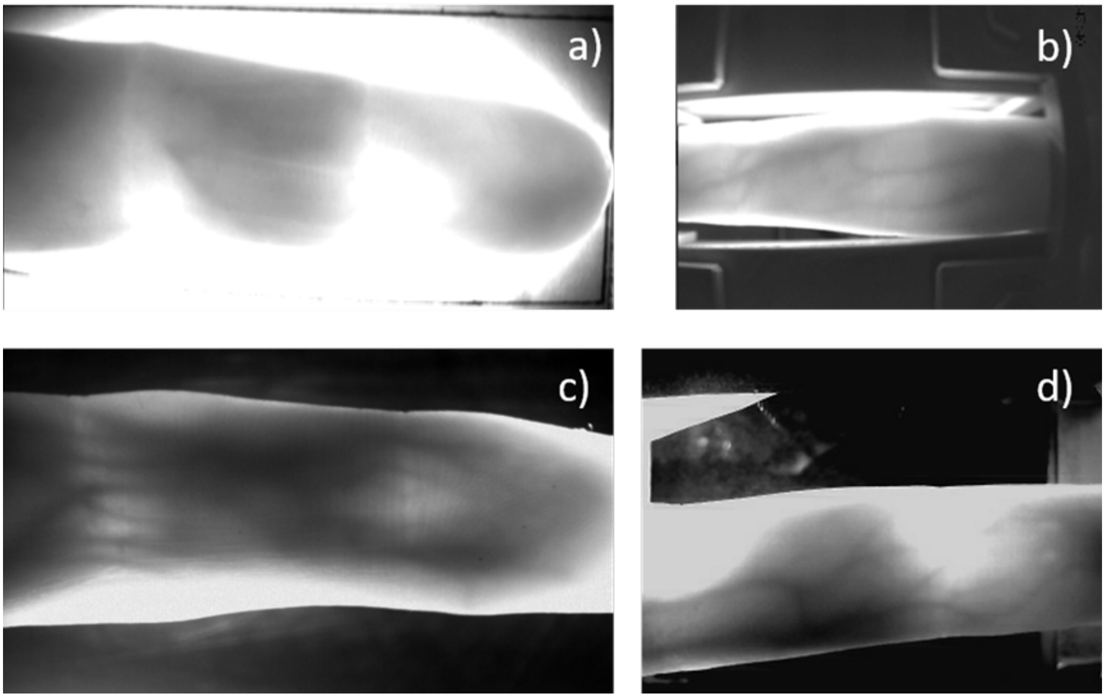

Fig. 2. Publicly available datasets have the same issue of light leakage on a) Hong Kong Polytechnic University [Kumar and Zhou, 2011] and b) Tsinghua University (THU-FVFDT) [Yang et al., 2009], and overexposure at the finger border on c) University of Twente (UTFVP) [Ton and Veldhuis, 2013] and d) Shandong University (SDUMLA-HMT) [Yin et al., 2011].

Normakristagaluh et al. [Normakristagaluh et al., 2024] have researched to find out the impact of illumination direction and width. They used illumination from the top and one side (right or left) in their scanner. Their findings compared the images from different illumination directions and fused those images. The results revealed that the top illumination has the highest accuracy, and there are no overlaps between the verification performance of any illumination direction. Moreover, the experiments support their qualitative model about the impact of illumination direction on the process of vein pattern appearance. They also produce a new dataset with minimized finger misplacement, including translation and rotation.

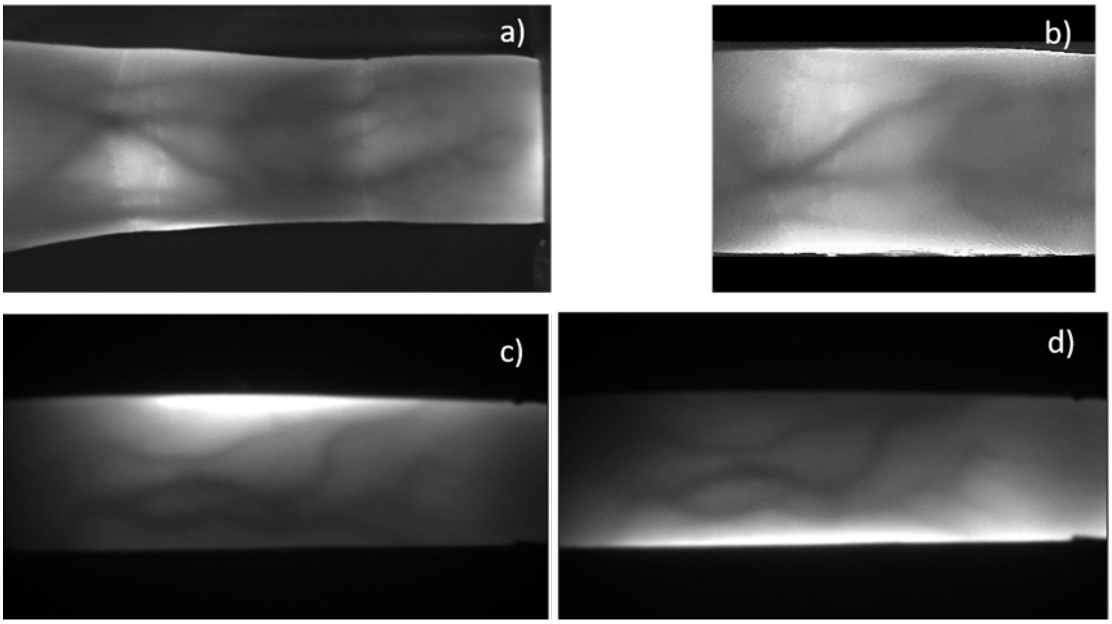

Fig. 3. Examples of finger vein images were captured using a) top illumination (UTFVP [Ton and Veldhuis, 2013]), b) both-side illumination [Xpo- Technology, 2019], c) right-side illumination, and d) left-side illumination (UTFVPv3 [Normakristagaluh et al., 2024]).

D. Camera Sensors

The camera in commercial devices has different characteristics from academic-purposed sensors. Academic finger vein scanners have been built with various designs and specifications to enhance recognition performance and image quality. Many academic scanners usually have modular components that are larger than commercial products. The fourth challenge is designing the optimal finger vein scanner and its configuration. NIR cameras with an NIR/IR filter and lens are commonly used in academic scanners. There are differences in camera quality between various scanners, ranging from high-end [Ton and Veldhuis, 2013] to low-end web cameras [Pham et al., 2015]. Figure 4 shows that finger vein scanners were designed and built by the University of Twente. Additionally, image quality can also be influenced by the camera's configuration, such as settings for focus, white balance, saturation, wide, and exposure.

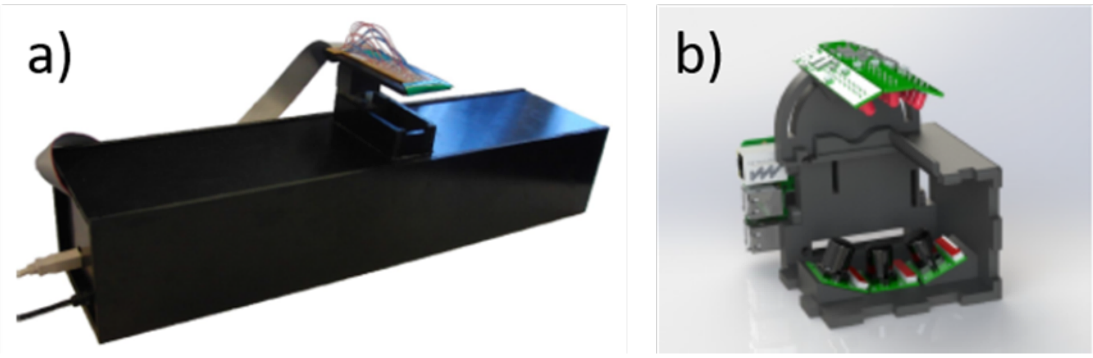

Fig. 4. Finger vein scanner of DMB group of the University of Twente using: a) high-end camera (UTFVPv1 [Ton and Veldhuis, 2013]) and b) low-cost camera (UTFVPv2 [Veldhuis et al., 2020]).

2.1 Physiology of Finger

This part presents several aspects of finger physiology including inherited traits, deficiencies, and the imaging process. The following is a detailed description of all those parts.

A. Inheritance Characteristics

The fifth challenge is dealing with the fundamental physiology of the human finger. In this instance, basic human traits such as gender, skin color, hair on finger skin, and race are frequently inherited from their parents (see Figure 5). Ton et al. [Ton, 2012] explored the gender influence on recognition performance in his master thesis and discovered that female performance was lower than male performance. The possible reason is that men have higher hemoglobin levels than women. However, they claimed that the reliability of these findings is low due to a lack of volunteers.

B. Defectiveness

The sixth challenge is dealing with defectiveness in the finger vein. In this case, possible causes include blood vessel disease (eg atherosclerosis), injury, or stress/stretching. Ton et al. [Ton, 2012] in their master's thesis experimented to see the performance of finger vein pattern recognition that was given stretching and stressing treatments. They even gave treatment by dipping the finger in cold water. Their research showed a difference in the results of finger vein pattern recognition with those treatments, but it was not too significant because the dataset was too small.

C. Imaging Process

The seventh challenge is a misplacement of finger position in 3-D space relative to the sensor plane during the imaging process. Finger vein recognition can be affected by incorrect finger placement, for example, translation on 3D space [Kauba et al., 2018b], bending [Chen et al., 2017], and rotation. Figure 6 shows misplacement examples found on the UTFVP dataset [Ton and Veldhuis, 2013]. Several studies have been performed to address this issue, using algorithms or providing finger position instruction during the imaging process. An example that has been worked on is finger vascular pattern recognition using ICP on the contours [Normakristagaluh et al., 2019]. They compared the alignment algorithms iterative closest point (ICP) and center line (CL) by measuring the performance of finger vein pattern recognition on the same dataset UTFVP owned by the University of Twente (UT).

2.2 Surroundings Environment

The eighth challenge may come from the surroundings factor during the imaging process. In this case, environmental factors such as ambient light, moisture (humidity) level, dust, temperature, and electromagnetic radiation may impact the image quality while recording finger veins [Hou et al., 2022].

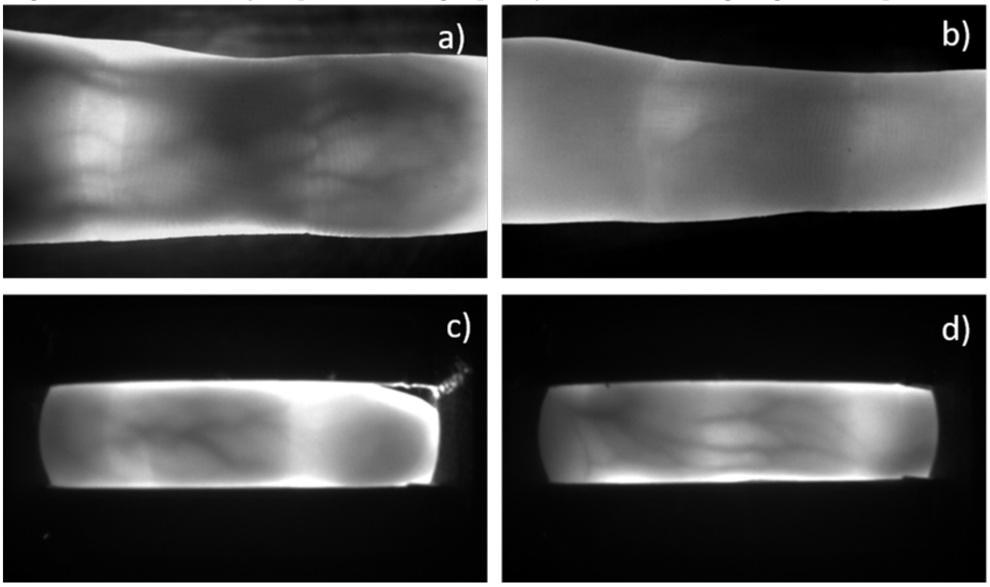

Fig. 5. Examples of NIR finger vein images of inheritance traits based on: gender for a) male and b) female (UTPVP [Ton, 2012]), and finger skin for c) fair/ light and d) dark (UTFVPv3 [Normakristagaluh et al., 2024]).

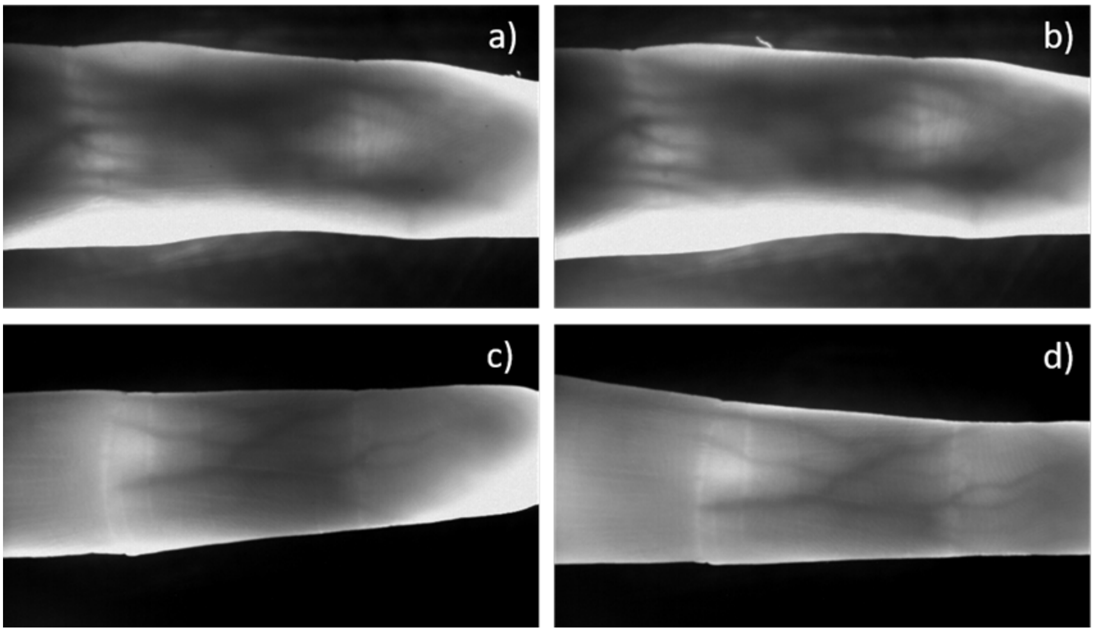

Fig. 6. Finger vein NIR images (UTFVP dataset): a) and b) have a rotation issue, c) and d) have a translation issue.

3. RESULTS AND DISCUSSION

This session presents one of the most prominent approaches for extracting finger vein patterns utilized by biometric researchers. This approach will be evaluated on an image from a publicly available dataset, as seen in the previous image 2. The findings are preliminary results for investigating one of the potential challenges of finger vascular pattern recognition. In 2007, a method was designed by Miura et al. that can extract vein centerlines consistently without being affected by fluctuations in vein width. This method is called maximum curvature [Miura et al., 2007] and is claimed to produce accurate vein pattern matching. Three different steps in this algorithm are described as follows. The first step is the extraction of the vein centerline, where it is obtained by calculating the local maximum curvature of the cross-sectional profile. This can be accomplished using the vein profile, which is defined as a concave curve that fluctuates with sufficiently large curvature. This first step is divided into 4 different stages:

- Calculate the curvature of the extracted vein profile.
- Detect the vein centerline, considering that the local maximum centerline of curvature indicates the centerline of the vein.
- Assign a score to the centerline. This score indicates the probability that the centerline of the vein is assigned for each obtained centerline.
- Calculate all profiles in one direction either vertically, horizontally, or diagonally to obtain the vein pattern in the entire image.

The second step is to connect the vein midpoints and remove noise using a filtering operation that compares the pixel values and decides whether to draw a horizontal/vertical/diagonal line or to cover the gaps by examining the neighboring pixel values. The third step is image labeling, where the vein pattern is a binary pixel using a certain threshold. This threshold is set to optimize the dispersion of values over the vein pattern.

3.1 ILLUSTRATIVE EXPERIMENT

An illustrative experiment was conducted on one of the images mentioned in the previous session where there was a problem regarding the intensity of light or illumination given to the finger which could affect the image quality. In this experiment, the maximum curvature algorithm was applied to image 2, and the results can be seen in image 7 in green. This algorithm was implemented on the image with the same problem, namely light leakage and overexposure on the side of the finger image. Normakristagaluh et al. [Normakristagaluh et al., 2024] have conducted several experiments on the impact of illumination on finger vascular pattern recognition. Their research shows how the influence of the direction and width of light can affect the accuracy of finger vein pattern recognition. In addition, they found that the finger vein pattern that appears in the NIR image is a shadow projection of the blood vessels closest to the finger's skin.

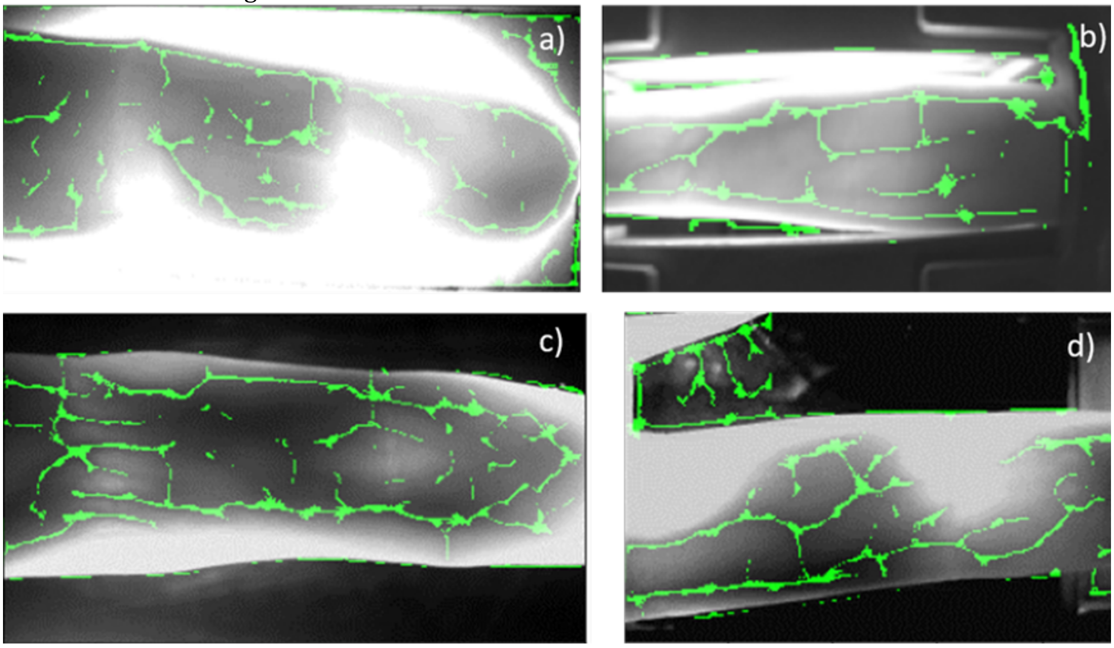

Fig. 7. An example of vein pattern extraction on a finger in one of the images in the public dataset (shown in Figure. 2).

In Figure 7, it can be seen that the intensity of lighting given to the finger greatly affects the formation of the finger vein pattern. The finger vein pattern will be broken when the light intensity is too strong or large (Figures 7a. and d. clearly show the green vein line looks broken). This is what raises a new problem that is also a challenge in recognizing finger vein patterns, namely setting the appropriate light intensity to improve the recognition accuracy.

The light intensity can also be related to the color of the finger skin, as an example of bright/light and dark skin color (5.c and d). Both of those images in the example are illustrated in a histogram graph (in Figure 8). In this histogram, it can be seen that there is little difference between bright and dark skin colors under the same intensity. The two histograms overlap around the middle grayscale values, which probably indicates comparable illumination effects or the same structures as veins. The brighter areas (above 0.7) show a different separation, where the light skin is reflecting more and the dark skin is less reflection. However, this cannot be ascertained if illumination with varying intensity on different skin colors and its effect on finger vein recognition.

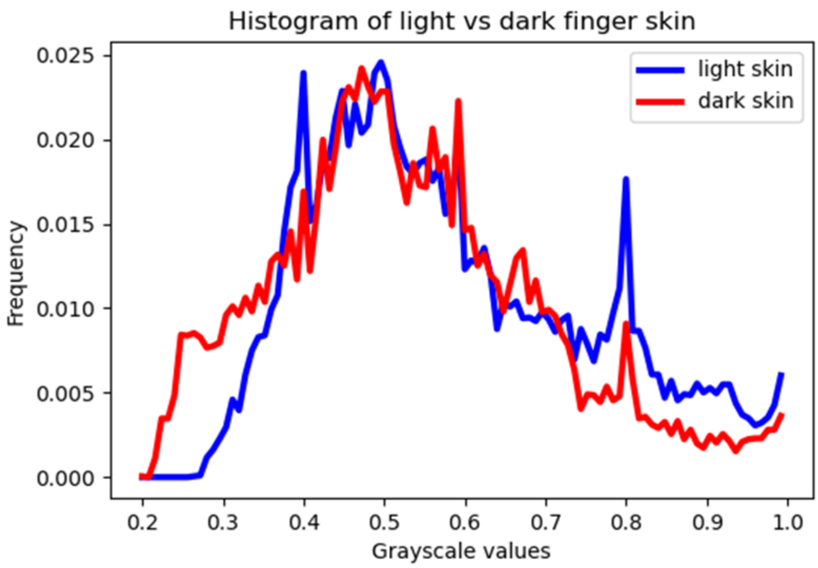

Fig. 8. Histogram for NIR finger pattern images for fair/light and dark skin (refers to Figs 5.c and d).

4. CONCLUSION

This paper describes a brief overview of some challenges in biometrics of finger vascular pattern recognition. Image acquisition plays an important role in improving image quality in finger vein pattern recognition which includes not only the capturing devices but also the physiology of the finger. Illustrative experiments show how light intensity affects image quality. Too bright light given to the finger can cause loss of vein patterns captured by the camera. In addition, one of the finger physiologies, namely the skin of the finger, can affect image quality and the performance of finger vein pattern recognition. Further research is required to demonstrate the effect of the illumination configuration on the physiology of the finger skin using a large dataset in order to assess the performance of finger vein pattern recognition.

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