Contact-less Palm/Finger Vein Biometrics

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Abstract:
Finger and palm vein recognition, based on near infra-red images of the vein pattern of the finger or the palm, are promising biometric authentication methods. The main advantage of vein recognition over fingerprints is its touch-less nature, making it more robust to spoofing and more comfortable to the user. To this point, vein recognition has mainly been developed by private companies rather than by academic institutions and there are only a relatively limited number of scientific publications on the topic. This paper presents two palm vein and one finger vein imaging prototypes developed in our institution. An image database has also been acquired with each of these three prototypes.

1 Introduction

Fingerprint recognition, available now on several smart phones (e.g. Samsung Galaxy S6, Apple iPhone 6), is one of the few biometric authentication methods available nowadays alongside iris and face recognition. A promising technique, first described in the eighties and subject to academic research since the mid nineties, is vein recognition.

This authentication method is based on the pattern of the blood vessels of a person's hand or finger. This pattern seems not to evolve with time and contains enough discriminant information to be used as a person recognition method. The image of the veins, located about 3 mm under the surface of the skin, is typically acquired using near infra-red (NIR) illumination in reflection mode (Fujitsu [Fuj, WESS05]) or in transmission mode (Hitachi [Hit]). Infra-red LEDs are used to deliver the illumination and the reflected or transmitted light is typically acquired by a CCD or CMOS camera equipped with a filter that only lets infra-red light through. Vein recognition is based on the fact that veins carry haemoglobin absorbing near infra-red light (wavelengths between 700 and 1000 nm). Therefore, when using NIR illumination veins appear as specific and unique black structures that can be used for authentication using standard pattern recognition methods. This authentication method is very interesting and promising, not only because of its non-invasive and user-friendly nature, but also because it is touch-less and therefore doesn't leave marks on the acquisition system, as opposed to finger marks left on the sensor with fingerprint recognition. This touch-less nature makes vein recognition more robust to spoofing attacks and also more comfortable and hygienic to the user who is then more likely to adopt it. A spoofing attack is a situation in which one person successfully masquerades as another by falsifying data and thereby gaining an illegitimate advantage.

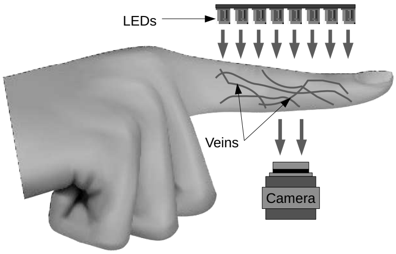
To this point, vein recognition has mainly been developed by private companies rather than by academic institutions. The main reason lies in the difficulty of creating an acquisition system as it requires multi-disciplinary expertise in optics, electronics and computer science. Buying an existing system is not a solution for academic institutions for research purposes given the prohibitive prices, the availability to private companies only and the imposed non-disclosure agreements. As a consequence, there are only a limited number of scientific publications on vein recognition and many questions remain without an answer.

This paper presents two palm vein (one using multi-spectral illumination) and one finger vein acquisition systems developed in our institution, as well as the three related image databases.

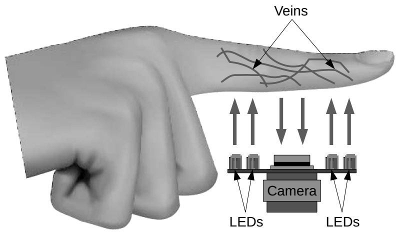
2 Current State of Research and Development

Since the early 2000s and the work of Hitachi and Fujitsu on finger and palm vein recognition [MNM02, WESS05], the availability of open databases for research remained scarce, as the development of acquisition systems is a difficult task, requiring multiple competencies (optics, electronics, embedded devices). A few acquisition systems were however produced by research teams. For example, Zhang et al. presented in [ZKYW03, ZLYB07] a palm vein system that was successfully used to extract palm structures in the NIR and visible domains. Diestler et al. [DJM+11], Lee [Lee12], Kabacinski et al. [KK11] developed their own system to acquire palm vein structures. Moreover, the last cited authors acquired a publicly available image database [CIE]. Other databases of palm vein images are also accessible, such as the Hong Kong Polytechnic University database [MSP] or the National Laboratory of Pattern Recognition database [CAS]. It is noticeable that these last two databases were acquired using multi-spectral illumination. Badawi [Bad06] worked on a closely related system acquiring the vein structure of the back of the hand.

Likewise, several acquisition systems dedicated to finger vein recognition have been developed but only a few accessible databases exist. For example, Ton et al. [TV13] presented such a system. Likewise, Raghavendra et al. [RRSB14] developed a multi-spectral acquisition system to capture finger vein patterns and finger prints. Examples of accessible databases are the Shandong University database [SDU], the Hong Kong Polytechnic University database [HKP], the Chonbuk National University database [MMC], the Sains University database [FV-] and the Idiap Research Institute database [VER]. Finally, Vanoni et al. [VTESM14] presented a review of different databases.



(a) Finger vein acquisition using transmitted light. The NIR LEDs are placed on one side of the finger and the camera is placed on the other side of the finger.



(b) Finger vein acquisition using reflected light. Both the NIR LEDs and the camera are placed on the same side of the finger.

Figure 1: Finger vein recognition using transmitted light (left) and reflected light (right).

3 Acquisition Systems

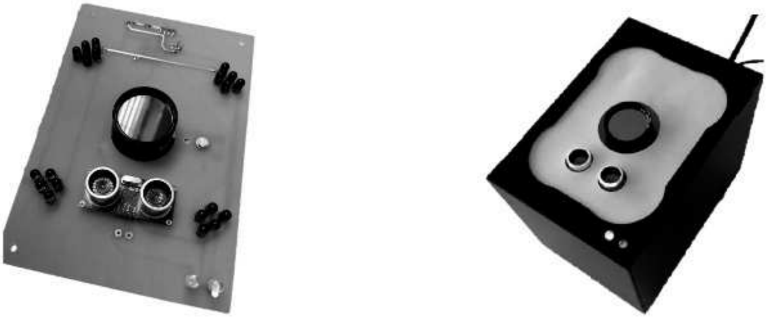
3.1 Working Principles

Most vein imaging systems rely on NIR illumination as the contrast between veins and other tissues is higher than with visible light and they can however rely on cheap CMOS or CCD cameras. Vein recognition systems use either a transmission method or a reflection method.

In the transmission method (Fig.1a), mostly used to capture finger vein pattern images, the finger is placed between the illumination source and the image sensor. The image sensor captures the light that passed through the finger. As the veins absorb the NIR light, less light will go through the veins and they will appear as a dark pattern.

In the reflection method (Fig.1b), mostly used to capture palm, back of hand and wrist vein pattern images, the illumination source and the image sensor are located on the same side of the hand. The light enters the finger and is diffused in the tissue. Part of this diffused light is reflected back towards the surface of the finger and is then captured by the image sensor. The image is created by differences in the intensity of the reflected light. As the veins absorb the NIR light, less light is reflected from these areas and the veins will appear as a dark pattern whereas the image will be brighter for the rest of the hand.

Three different prototypes will be presented in this section, the first two dedicated to palm vein recognition and the third one to finger vein recognition. All prototypes use reflection method and are touch-less. The hand is not mechanically guided in front of the camera.



(a) PCB with the 20 LEDs, the camera (middle) and the ultrasound sensor.

(b) The PCB is integrated in a box and covered with the PTFE sheet.

Figure 2: First reflection-based palm vein imaging prototype.

3.2 First Palm Vein Prototype

The first palm vein prototype developed was using a unique wavelength for the NIR illumination. Different wavelengths were tested in the NIR, namely 770 nm, 880 nm, and 940 nm. Although 940 nm sits at the limit of the sensibility of the chosen camera (IEEE 1394 Sony ICX618 659x494 CCD camera), this wavelength was selected as it provided the best contrast. The set-up was completed by a 920 nm long-pass filter to block the ambient light that can significantly alter the contrast.

Twenty 940 nm NIR LEDs (TSAL6400) were mounted on a printed circuit board (PCB) for a total power consumption of 2.7 W and a total radiant flux of 700 mW. The LEDs were mounted in the edges of the PCB to provide a uniform illumination of an object situated between 10 and 20 cm in front of the board. Figure 2a shows the PCB. The camera and the long-pass filter can also be seen in the middle of the PCB, as well as an ultrasound distance sensor that was used to cut the lighting when the hand was not in the working range (12.5 to 16.5 cm). To optimize the uniformity of the illumination, a 1mm thick PTFE (Teflon) sheet was added in front of the LEDs. The acquisition device can be seen in Figure 2b.

3.3 Second Palm Vein Prototype

As single wavelength acquisition systems can easily be cheated using a vein structure printed on a standard laser printer [TM15], the second prototype was using multi-spectral illumination of the palm vein structure. The increased spoofing difficulty lies in finding or developing an ink responding to the three different wavelengths in the exact same way as human body tissues. The acquisition system is based on three wavelengths, namely blue, far-red, and infra-red. Blue illumination enhance the skin surface structure, whereas far-red and infra-red mainly show the vein structure.

(a) PCB with the 38 LEDs, the camera (middle) and the ultrasound sensor.

(b) The PCB is integrated in a box and covered with the PTFE sheet.

Figure 3: Second reflection-based multi-spectral palm vein imaging prototype.

The ultrasound distance sensor and the CCD camera selected for the first prototype were also used for this second prototype. However, the GigE Vision standard was preferred to IEEE 1394 for more efficient communication and control between the prototype and the computer. Figure 3b shows the second prototype.

Illumination Optimization To optimize the image contrast and the uniformity of the illumination, a simulation of the illumination depending on the position of the LEDs was performed. The optimal positioning of the infra-red LEDs consists in two concentric circles of respectively 14 cm and 7 cm of diameter containing 22 NIR LEDs and 8 NIR LEDs evenly positioned, respectively. The CCD camera lies at the center of these concentric circles. As the use of three wavelengths made impossible the inclusion of a long-pass filter to suppress ambient light, the illumination power was instead considerably increased. Four blue LEDs (LZ100B200, total radiant flux of 3.9 W and total power of 13.3 W), four far-red LEDs (LZ100R300, total radiant flux of 2.8 W and total power of 9.6 W) and thirty NIR LEDs (SFH4046, total radiant flux of 1.2 W and total power of 3.4W) were used for the multi-spectral illumination. The acquisition cycles through the three wavelengths at fifteen frames per second. Figure 3a shows the PCB with the different LEDs, the camera and the ultrasound sensor.

Figure 4 shows three images of the same palm captured at the different wavelengths. With the blue illumination (Figure 4a), the main visible feature is the skin structure, whereas with the far-red and the NIR illumination (Figures 4c and 4b), the main feature is the vein pattern.

(a) Blue (460 nm). (b) Far-red (740 nm). (c) Infra-red (940 nm).

Figure 4: Palm images of the same hand using the multi-spectral acquisition system.

3.4 Finger Vein Prototype

When using the reflection method, the contrast is usually weaker on finger vein images than on palm vein images. This is due to the fact that finger veins are located deeper than palm veins. The finger vein prototype is therefore optimized to deliver a very homogeneous illumination to guarantee quality finger vein images. The prototype was also developed for mobile applications. Indeed, the small color image sensor is similar to those found in smart phones, the control software is running on a smart phone (Android) and interacts with the prototype through USB communication. The dimensions of the prototype are 52 mm x 114 mm x 47 mm. Figure 5b shows the finger vein prototype.

(a) PCB showing the LEDs disposition. (b) General view of the prototype. (c) Optimized homogeneous illumination.

Figure 5: Reflection-based finger vein imaging prototype.

Illumination The illumination is based on the same principles described in Paragraph 3.3 but with additional LED orientation optimization. Due to the relatively small dimensions of the prototype, the illuminated area is larger than the PCB surface. To avoid saturation in the central spot and insufficient illumination on the edges, some LEDs are not mounted flat on the PCB so that not all illumination beams are perpendicular to the PCB plane.

The 850 nm LEDs are organized in three groups of four LEDs, as shown in Figure 5a. The central group provides global illumination using wide angle 120° VSMG3700 LEDs. The two other groups, one positioned orthogonally (+) and one in cross (×), compensate to provide an optimized homogeneous illumination using 20° SFH4059 LEDs. These last eight LEDs are orientated away from the center and mounted on the PCB with a 20° angle with respect to the plane of the PCB. The resulting optimized illumination is shown in Figure 5c. This optimized LED disposition and orientation provides by itself a very homogeneous illumination. Therefore, the use of a diffusing sheet as for the palm vein prototypes previously presented is unnecessary.

The power of each LED group is adjustable by software allowing fine tuning of the illumination. The optimal illumination is reached with a relative power of 1.0 for the central LEDs an of 0.3 for the orthogonal and cross LEDs. The central LEDs have a total radiant flux of 160 mW and a total power of 600 mW whereas the orthogonal and cross LEDs have a total radiant flux of 320 mW and a total power of 900 mW.

Camera The imaging device use for the finger vein prototype is a low-cost OV7670 Color 640x480 pixel CMOS sensor coupled with a wide angle 2.1 mm lens allowing image acquisition from a minimal distance of 10 cm. An infra-red long-pass filter is used to filter out visible light. A relatively low cut-off wavelength of 740 nm has been chosen to allow further modification of the illumination wavelength.

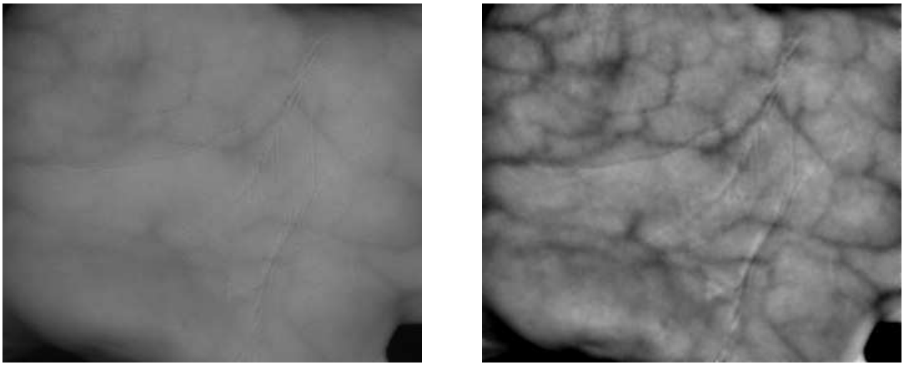
This finger vein prototype shows that the Bayer pattern used in most single-chip digital image sensor to create color images, does not significantly alter infra-red vein imaging. This means that for a future integration of a similar miniaturized system on a smart-phone or a tablet, the embedded camera can be used for normal photography as well as for finger vein authentication. Smart phones are currently equipped with an infra-red filter to prevent inaccurate colors in images caused by NIR light naturally present in ambient light. It is possible to get around this problem by using a dual band-pass filter passing all visible light as well as a specific narrow NIR band.

4 Databases

A publicly available finger or palm vein image database has been captured with each of the three prototypes presented in this paper. This section presents the details of these three databases. The second (multi-spectral palm vein) database and the third (finger vein) database were acquired simultaneously. Further research combining and/or comparing palm vein and finger vein is therefore possible using these two databases.

4.1 Palm Vein Database

The palm vein database for palm vein recognition consists of 2200 images from 110 subjects. This database was acquired in our premises using the first prototype described in Section 3.2. Each of the 110 subjects presented their both hands and five palm images were recorded per hand. Each subject participate in two recording sessions. The database consists therefore of 2200 palm vein images. (110 subjects x 2 hands x 2 sessions x 5



(a) Raw image. (b) Processed image.

Figure 6: Raw (left) and processed (unsharp mask, right) palm vein images (after extraction of the region of interest) of the same hand using the first palm vein prototype (940 nm).

images = 2200 images). The database is composed of 40 women and 70 men whose ages are between 18 and 60 with an average of 33. The format of the images is PNG and the image resolution is 640 x 480.

Figure 6a shows a typical raw palm vein image after extraction of the region of interest (ROI). Figure 6b shows the same image after applying a simple unsharp mask to enhance the contrast and therefore better show the vein pattern. The ROI is extracted according to the following procedure. First a threshold (value 50) is applied to the 8-bit raw images. This basically turns the hand to white and the background to black. Then the contours of the hand are extracted using standard edge detection. Only the surface with the maximum area (the hand) is kept, the other possibly existing surfaces are discarded. The next step consists of a closing of the image (about 80 iterations) to split the palm and the fingers. A rectangular boundary box is then applied to the remaining palm surface and is accepted as ROI if it contains more than 20'000 pixels and less than 240'000 pixels.

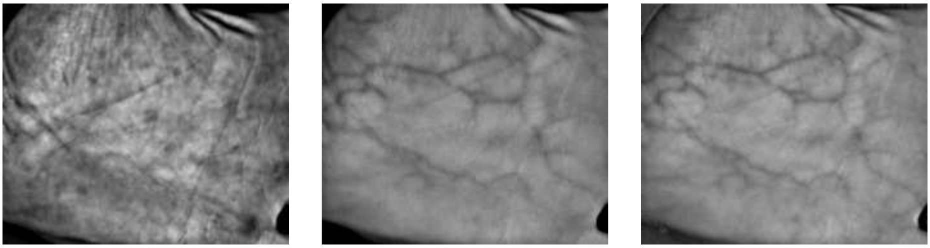
4.2 Multi-spectral Palm Vein Database

The second palm vein database for palm vein recognition consists of 2520 images from 84 subjects. The database was acquired in our premises using the multi-spectral prototype described in Section 3.3.

Each of the 84 subjects presented both their hands and five images were recorder per hand at each of the three wavelengths. Each subject participated in a single recording session. The database consists therefore of 2520 palm vein images (84 subjects x 2 hands x 3 wavelengths x 1 session x 5 images = 2520 images). The database is composed of 24 women and 60 men whose ages are between 15 and 61 with an average of 32. The format of the images is PNG and the image resolution is 656 x 490.

Figure 7 shows a typical set of images of this second database after extraction of the region of interest. The top row images (a, b and c) show the raw images acquired at 460 nm, 740 nm and 940 nm, respectively. The bottom row shows the same images after applying the same unsharp mask mentioned in Section 4.1. The region of interest (ROI) is extracted following the technique described in Section 4.1.

(a) Blue (460 nm). (b) Far-red (740 nm). (c) Infra-red (940 nm).



(d) Blue (460 nm). (e) Far-red (740 nm). (f) Infra-red (940 nm).

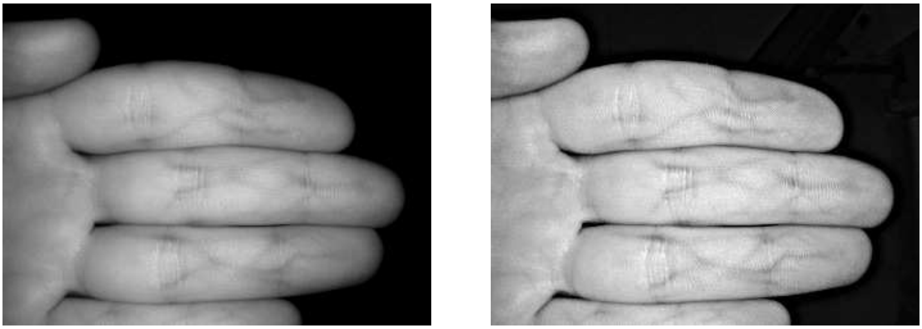
Figure 7: Raw (top row) and processed (bottom row) palm vein images (after extraction of the region of interest) of the same hand using the multi-spectral acquisition system.

4.3 FingerVein Database

The finger vein database for finger vein recognition consists of 840 images from 84 subjects. The database was acquired in our premises using the finger vein prototype described in Section 3.4.

Each of the 84 subjects presented both their hands and five images were recorded per hand. Each subject participated in a single recording session. The database consists therefore of 840 palm vein images (84 subjects x 2 hands x 1 session x 5 images = 840 images). The gender and age statistics of this database is identical to those of the multi-spectral palm vein database as it was acquired with the same subjects. The format of the images is PNG and the image resolution is 640 x 480.

Figure 8a shows a typical raw finger vein image after extraction of the region of interest (ROI). Figure 8b shows the same images after applying the same unsharp mask mentioned in Section 4.1.



(a) Raw image. (b) Processed image.

Figure 8: Raw (left) and processed (unsharp mask, right) finger vein images of the same hand using the finger vein prototype (850 nm).

5 Conclusion

This paper presents three different palm or finger vein imaging prototypes developed in our institution in the framework of previous projects. The vein image databases acquired with each of these three prototypes are also described in details in this paper. These databases are also publicly available. The qualitative quality of the acquired palm vein images is similar to the one of images in scientific publications or in publicly available databases. However, they were collected with European subjects, contrary to most other publicly available databases that were collected with Asian subjects. The difference in skin color and thickness of these two general ethnic groups could have an impact on recognition algorithms. Furthermore, the presented databases show a wide variety of skin surface and thickness due to the age of the subjects (15 to 60) and their job (e.g. office, mechanical workshop). Finally, the quality of the acquired finger vein images is difficult to assess, as no other publicly available database is based on reflected light.

5.1 Future Work

Several research trails could be followed in the future. These prototypes can always be improved, especially in terms of illumination quality and homogeneity as well as robustness to environmental conditions to provide the best finger or palm vein images possible. In parallel to the improvement of the hardware, our research team will soon start deep investigations on the software development. This includes algorithm development for raw image processing, feature selection, feature extraction and finally classification to turn the image acquisition prototypes into fully operational finger or palm vein authentication systems. The presented multi-spectral palm vein and finger vein databases, acquired simultaneously, will be extended to reach at least one hundred subjects.

Another future topic will consist in investigating the feasibility of a reliable multi-spectral low-cost mobile finger vein authentication system that could be embedded or plugged to a smart phone or a tablet. Several challenges will have to be addressed during the development of such a system. For example, for volume reduction, the system will work with reflected light rather than transmitted light. The system will still have to provide good quality images and perform well in uncontrolled environments to be accepted as an alternative authentication method while consuming a minimum of energy for a minimum impact on the battery of a mobile device.

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