Vein pattern recognition. Image enhancement and feature extraction algorithms

Septimiu Crisan, Ioan Gavril Tarnovan, Titus Eduard Crisan.

Department of Electrical Measurement, Faculty of Electrical Engineering, Technical University of Cluj-Napoca,
Str.C.Daicoviciu nr.15, 400020 Cluj-Napoca, Romania,
E-mail:crisans@mas.utcluj.ro

Abstract - Vein pattern recognition is one of the newest biometric techniques researched today. While the concept behind the method is quite simple, there are various challenges to be found throughout the design and implementation of a vein scanning device concerning the hardware lighting system and the actual algorithms used for processing the acquired images. In order to keep the scanning errors to a minimum the image acquired from the camera should be almost noiseless and the algorithms should be able to detect the vein pattern in various real life conditions. Many implementations of this method are now in a commercial phase and there is a great need for a system that can detect, analyze and extract the correct human vein pattern while keeping a low cost and reducing the computational needs of the image processing algorithms.
This paper will offer some hardware implementation solutions based on our research and different algorithms will be discussed.

I. Introduction

A biometric system is essentially a pattern-recognition system that recognizes a person based on a feature vector derived from specific physiological or behavioral characteristic that the person possesses [1]. A vein pattern detection has been proved to fully comply with this definition [2,3] and it provides many important biometric features:

- uniqueness and permanence of the pattern
- non-contact detection procedure
- almost impossible to forge or copy.
- The biometric parameter is hidden from general view
- The vein pattern is intricate enough to allow sufficient criteria for positively detecting various subjects even identical twins

The vein detection process consists of an easy to implement device that takes a snapshot of the subject's veins under a source of infrared radiation at a specific wavelength. The system is able to detect veins but not arteries due to the specific absorption of infrared radiation in blood vessels. Almost any part of the body could be analyzed in order to extract an image of the vascular pattern but the hand and the fingers are preferred. The reason for this choice is the general availability of the hand. A sketch of an actual vein detection system is shown in figure 1.

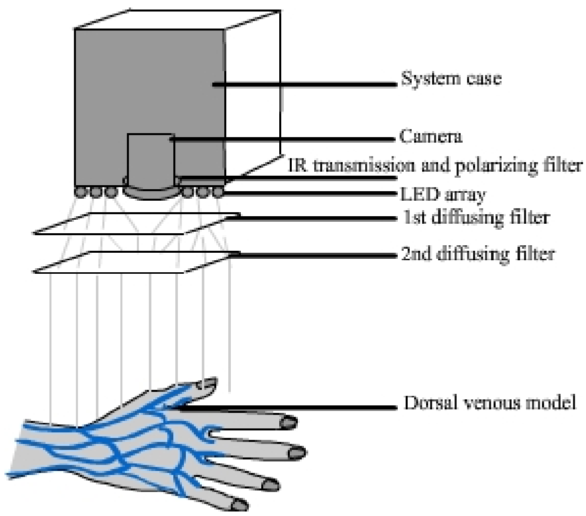


Figure 1. A basic hardware vein detection system (sketch)

The infrared radiation is absorbed in a different way in various types of tissue. In order to achieve visual penetration through the respective tissue, lighting should be performed under a very tight optical window namely 740nm up to 760nm (inside the near infrared part of the electromagnetic radiation spectrum).

Because of the optical properties of the human tissue, a near-IR vein scanning device cannot penetrate very deep under the skin therefore the device will recognize the superficial veins and rarely the deep veins. Good candidates for the scanning procedure are the dorsal metacarpal veins and the general dorsal venous network.

A statistical maximum penetration distance is 3mm and this poses some limitations on the quantity and quality of the extracted vein pattern. Two basic optical coefficients are involved in this absorption process:

- absorption coefficient $\propto_a$
- scattering coefficient $\propto_s$.

The absorption coefficient $\propto_a$ determines how far light can travel before loosing its intensity while still in its original path, and, the scattering coefficient $\propto_s$ determines how far light can travel before losing its original phase and changes direction.

Taking these optical properties into account it is obvious that the lighting source should be uniform throughout the region of interest, the degree of illumination should be kept constant for different acquisitions and the contrast of the resulting image should be sharp enough to reduce the need for complex post processing image algorithms.

II. Hardware setup and design

As mentioned in the introduction, the hardware setup has a crucial role in the acquisition of vein images. Two aspects can be underlined here:

-the actual camera used for taking the snapshot has only one important parameter, the response to near infrared radiation. Spatial resolution and frame rate are of lower importance since for the acquisition of a vein pattern a still image is required and the details are easily seen even at a lower resolution

-the design of the lighting system is one of the most important aspects of the image acquisition process. A good lighting system will provide accurate contrast between the veins and the surrounding tissue while keeping the illuminations errors to a minimum.

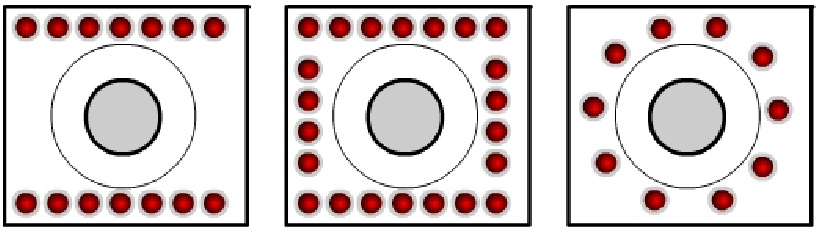
In our research we have experimented with various lighting systems including natural sunlight, filtered tungsten lamps and near IR LED arrays [4]. While sunlight and tungsten lamps offer a more constant illumination throughout the region of interest, a LED array is preferred due to the high contrast it provides. The drawback of such a system is the lack of uniformity of the light source. This can be easily fixed by adding layers of holographic diffusers in front of the LEDs to achieve constant illumination. The diffuser will scatter the light from the LEDs and in the meantime diminish the radiation intensity. High power light sources have an undesirable effect by decreasing the contrast due to the high quantity of radiation emitted, therefore, using multiple layers of diffusers the lighting will be constant and the intensity will be optimal.

At the first glance, since diffusers will be used, the configuration of the array seems less important. Yet, we have found out that various matrix arrangements of the LEDs will modify the distribution of the radiation intensity even if multiple layers of light scattering materials are used. This is mainly due to the fact that this system is using a reflection/absorption method and the camera has to be placed on the same side as the light source. Different configurations are used nowadays, either for simplicity or for accuracy of the scan.

These configuration include:

- 2D single or double arrays, used in order to simplify the light source, lower contrast but cheap and easy to implement
- Rectangular sources, good definition, especially when used in conjunction with multiple diffuser sheets
- Concentric LED arrays, a method which seems accurate enough even if less diffusing is used, good intensity distribution but slightly harder to design and implement

A graphical representation of these arrays is presented in figure 2.

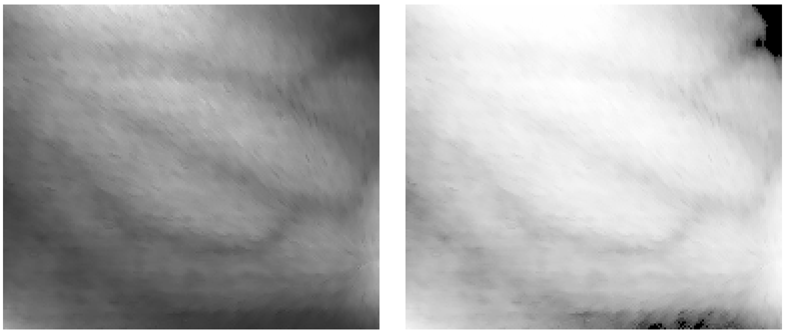


a b c

Figure 2. Various near infrared LED arrays used in vein pattern acquisitions
a) double line b) rectangular c) concentric array

Polarizing filters used in front of the illumination source and camera will help with the reduction of specular reflection of the skin thus increasing even more the contrast of the resulting image. Since the method uses the absorption of infrared radiation into the veins, the reflection of the incident radiation from the surface of the hand is mainly a cause of image errors.

Our experiments have shown that in the absence of other infrared sources, even a single 28 mW near IR LED shining on the back of the hand will overexpose the image. In order to produce better results, a short tweaking of the infrared light source is required but this will not guarantee the best results. The skin is a highly reflective medium and therefore the use of polarizing filters will prevent unwanted radiation from reaching the camera when the polarizing angles are chosen correctly. This eliminates the need to compensate reflection using a software algorithm and it offers far superior results as shown in figure 3



a b

Figure 3. Image enhancement using polarizing filters
a) specular reflection almost removed b) without polarizing filters

While all the presented array configurations offer a good contrast in the region of interest, our experiments have shown that the double or even triple concentric LED array works best in terms of radiation distribution and uniformity. In addition, this system can be easily scaled to accept different LEDs for different radiations. One example would be the combination of near IR and UV light sources in order to test more parameters concerning the vein pattern.

In order to further increase the uniformity of the image, a distribution pattern of the incident radiation must be calculated. We have used a blank sheet made of polycarbonate with a very high absorbtion rate at the employed wavelength. A compensation algorithm was created to alter the pixel values of the resulting image in concordance with the actual distribution so that the image will not be affected by variations of the array position.

III. Feature extraction algorithms

When using a correct hardware setup, the need of a complex algorithm is reduced. If there is a sharp contrast between the veins and the surrounding tissue, the vein pattern can be easily extracted and the relevant data saved for future use. However, infrared radiation does not penetrate all kinds of tissue in the same manner and therefore images taken from various subjects may vary significantly in terms of clarity of the vein model and in some severe cases the resulting image may have connectivity problems, several regions could be blurred or even impossible to detect. A “smart” algorithm should be able to compensate these problems and in our research we have experimented several algorithms with similar results in the end.

The basic processing algorithm and different variations of the standard approach can be described using the following steps:

A region of interest is established and the camera is focused in this area. The region is illuminated using near infrared radiation. In some particular cases the amount of radiation must be compensated with the environment lighting if natural or artificial infrared light sources are present

An image of the vein pattern is acquired with a CCD camera the result being a greyscale image with almost black lines representing the veins that absorbed the near infrared radiation. The degree of accuracy is given by may factors including the depth of the vein model beneath the skin, the flow of hemoglobin and the thickness of the veins.

Without further processing, the image is similar to what is depicted in figure 4. The vein model can be easily seen but the image is not clear enough for machine vision and pattern recognition purposes.

Figure 4. Raw image of a human vein pattern collected from the back of the hand

As it can be seen in the figure above, hair is sometimes an obstacle especially when acquiring images from male subjects. The back of the hand is the area many producers of vein scanners prefer and therefore the algorithm has to take this into account since it can lead to false representations of the vein pattern.

Consecutive contrast operations in conjunction with a low-pass Gaussian filter are used to enhance the image of the vein model then a threshold is applied thus creating a binary image outlining the vein pattern. The threshold cannot be applied statically, since the images will differ due to the depth of the vein pattern for different subjects. The best approach is to use an adaptive threshold calculated in different parts of the image.

The resulting image suffers more transformations. A thinning algorithm is applied and all lines are converted into 1 pixel-width lines in order to compensate for the effects of aging, temporary vessel constriction or dilation, and other medical factors that can modify the width of the veins. This is also necessary if the measurement data has been collected at various timestamps and the vein pattern has modified in size (usually a global increase of the pattern).

One of the most important problems of a feature extraction algorithm is the preservation of the connectivity of the vein model since a regular edge detection technique is not optimized for finding vein structures. Several sub-algorithms can be used to find the lines of the model, either by the same technique used in fingerprints (ridge finding) or by following the connectivity of each line. Different algorithms will differ in terms of complexity and therefore the needed computational resources will vary.

A representation of a proposed algorithm is shown in figure 5.

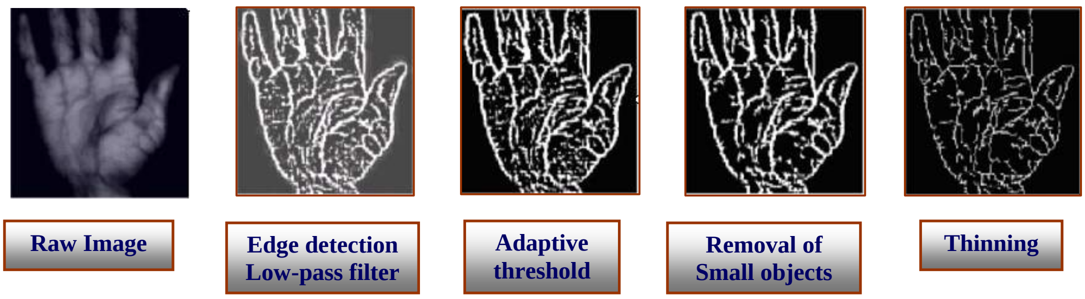


Figure 5. Proposed steps for a vein model feature extraction algorithm

Various processing algorithms are then used in order to determine the number of intersections, relative angles, length of the vein segments and other relevant data according to the degree of complexity set by the desired application

IV. Conclusion

Our research has focused on improving the two essential parts of a vein scanning device: the hardware lighting system and the feature extraction algorithms. Our previous work included the actual implementation of such a device and we were able to test different configurations. While there is no conclusive proof that there is an absolute system, different applications will require different approaches because complexity will always be a definitive issue.

The experiments have shown that a double or triple concentric LED array as a light source provides a very good uniformity of the radiation even with a reduced number of diffusers. The system is scalable and it can accommodate various wavelengths in order to use the device for an in depth scanning of the human veins.

The presented algorithm has managed to correctly identify the vein pattern from different images but as any algorithm, it's always subject to improvement. Our future work will focus on a low resource adaptive algorithm suitable for standalone vein readers.

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