A low cost Finger Vein Authentication System, using Maximum Curvature Points

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***Abstract* – Finger vein patterns have been proposed as a suitable biometric feature for authentication applications. Systems using this feature are generally low cost, accurate and easy to use. Such a system is described in this work. Infrared light is used to capture an image of a finger and a pattern recognition algorithm extracts the vein patterns. For robust and precise extraction of the depicted veins, a method of calculating local maximum curvatures in cross-sectional profiles of a vein image was used. The authentication algorithm has been evaluated with images acquired from the device built, as well as with images from a 400 fingers database. The false acceptance and false rejection rates obtained were promising.**

Keywords-finger vein; low cost authentication system; biometric

I. INTRODUCTION

Personal identification is applied in a variety of systems for functions such as: logins for personal computers, area access control, cash machines and numerous others. The main idea behind the use of the biometric techniques for personal identification is to create a system as safe as possible, which will eliminate the chances of theft, loss and deception. Several biometric characteristics have been proposed as criteria for authentication systems over time, for instance: fingerprints, voice, face, or even iris. Each one of these alternatives has its own advantages and disadvantages. The criterion proposed by this study is the finger veins' pattern. This choice was based on the fact that the use of the veins' patterns offers four important advantages: high accuracy, high security, low cost and easy usage. A more detailed comparison between authentication systems based on different biometric characteristics is shown in Table 1 that follows:

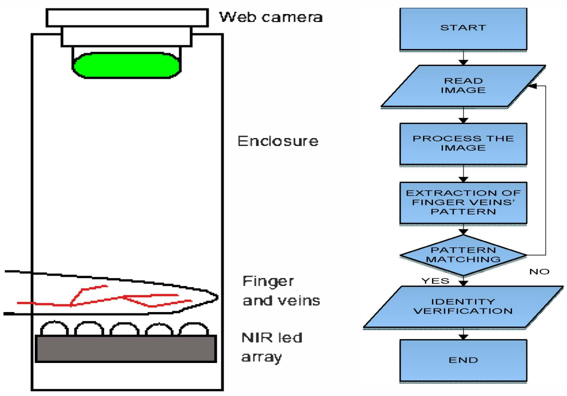
Table 1: Comparison between authentication systems

	IRIS	VOICE	FACE	FINGERPRINTS	VEINS
Low cost		●	●	●	●
Accurate	●			●	●
Easy to use		●	●	●	●
Secure	●				●

In the system proposed, infrared light is transmitted from an array of five near infrared LEDs, connected in series and driven by a common 9V battery with a 1K resistor to control current. The finger is positioned right above the LEDs (touching them) while a low cost web-camera captures the image as shown in Fig.1a. The use of infrared light is essential, as the blood absorbs it; therefore finger vein patterns are perceived in the image as shadows. In order to keep the cost low, a $5 web-camera is used from which the installed infrared filter is removed to let the NIR light pass, while visible light is obstructed from a piece of black photographic film that is put in place. Since the camera is low-end, great attention is needed for focusing. After experimentation, the camera used has been positioned 14cm above the led array to produce the best possible result. Special care is also required to ensure that the finger pictured should be positioned exactly above the led array since small moves to the sides of the array may cause problem to the pattern recognition algorithm.

In Fig.1b the flowchart of the method is depicted: Initially, the image captured in the way mentioned above, is loaded in order to be processed in a certain way which assures that only the useful information is exploited. Subsequently, the extraction of the finger veins' pattern takes place, which is the most important and challenging part of the algorithm. Finally, the clear veins' pattern obtained from the previous stages is used in order to verify the identity.

During the last years, numerous methods have been proposed, in order to achieve personal identification via finger veins' patterns. Some of the



(a) finger vein capturing device (b) flowchart

Figure 1: Flowchart of the proposed method.

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most notable between them are: Personalized Feature Selection by Xiaoming Xi et al [1], Personalized Best Bit Map by Gongping Yang et al [2], Local Line Binary Pattern by Bakhtiar Affendi Rosdi et al [3] and Maximum Curvature approach by Miura [4]. After comparison between them, the latest has been selected for being robust to fluctuations in vein width and brightness. It is advantageous due to the fact that this method emphasizes only the center lines of veins by checking the curvature of the image profiles. In details, the center lines are detected by searching for positions where the curvatures of a cross-sectional profile of a vein image are locally maximal.

II. ALGORITHM

The algorithm proposed consists of three parts:

1) Preprocessing stage
2) Training stage
3) Patterns Matching

In Preprocessing stage, several characteristics of the image are modified so that useful information is exploited. One of the first problems that had to be faced is the fact that the images used, included unwanted areas which needed to be removed. In order to do so, the images are cropped so that information is taken mostly from the finger region. Some other obstacles that had to be overcome were: on the one hand the big amounts of noise that the images include and on the other hand the fact that most of them are blurred. To deal with those difficulties: firstly, the image contrast is adjusted, in order to increase the difference between veins and their background (so that vein patterns extraction is facilitated). Also, the existing and unwanted noise is suppressed by filtering the image with appropriate masks, a process called smoothing.

The Training stage itself consists of three individual steps.
[Step A] Extraction of the center positions of veins.
[Step B] Connection of the center positions.
[Step C] Labeling the image.

[Step A] The main idea behind the method proposed is the exploitation of the fact that the cross-sectional profile of a finger around a vein appears like a dent, because the vein is darker than the surrounding area, as shown in Fig.2. The curvature of the profiles of the veins are appeared to be large, therefore the center position of the veins can be obtained by calculating local maximum curvatures in cross-sectional profiles.

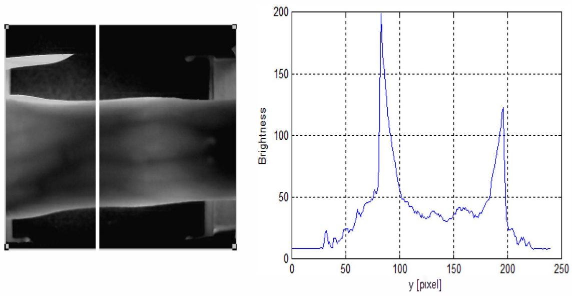
Given I is an image and $I(x,y)$ is the intensity of pixel (x,y). $P_i(z)$ is defined as a cross-sectional profile acquired from $I(x,y)$ at any direction and position where z is a position in profile. To relate a position $P_i(z)$ to that of $I(x,y)$, a mapping function T_{rs} is defined as $I(x,y)=T_{rs}(P_i(z))$.

The curvature $k(z)$ can be represented as:

$$k(z)=\frac{d^2P_i(z)/dz^2}{\{1+(dP_i(z)/dz)^2\}^{\frac{3}{2}}} \quad (1)$$

Where $k(z)$ can be either positive or negative. In case $k(z)>0$ the profile $P_i(z)$ is a dent (concave). So, the local maximums of $k(z)$ are calculated, because they indicate the center positions of the veins. These positions are defined as z'_i where i=0,1,…N-1 where N is the number of local maximum points in the profile. Subsequently, in order to make vein patterns extraction robust against vein width fluctuation, only positions of the centerlines of veins are emphasized. A score is assigned to each position, a bigger score indicates that the dent is deeper or wider. A score, $S_{cr}(z)$ is defined: $S_{cr}(z'_i)=k(z'_i) * W_r(i)$, where $W_r(i)$ is the width of the region where the curvature is positive and one of the z'_i is located. So, a bigger $W_r(i)$ which represents a larger vein's width, also indicates a bigger probability that a vein is spotted. Finally, all the scores are assigned to a plane V, which is a result of the emphasis of the veins. That is: $V(x'_i, y'_i) = V(x'_i, y'_i) + S_{cr}(z'_i)$, where (x'_i, y'_i) represents the points defined by $I(x'_i, y'_i)= T_{rs}(P_i(z'_i))$. In order the vein pattern spreading in the entire image to be obtained; all the profiles are analyzed in four directions: horizontal, vertical, main oblique and secondary oblique. Thus, all the center positions of the veins are detected by calculating the local maximum curvatures.

[Step B] To connect the center of the veins, one neighboring pixel on the left side and one on the right side of the pixel (x,y) is checked. If (x,y) has a small value while its neighboring pixels have larger ones, then the value of (x,y) is increased (so that the appearance of a gap is avoided). If (x,y) has a large value while its neighboring pixels have smaller ones, the value of (x,y) is decreased (so that the noise at (x,y) is eliminated). To achieve all these $C_{d1}(x,y) = \text{median}\{V(x-1,y), V(x,y), V(x+1,y)\}$, and C_{d1}, C_{d2}, C_{d3}, C_{d4} the four directions in which the profile is



(a) vertical cross sectional profile

(b) brightness of pixels along the vertical line

Figure 2: Cross-sectional profile of veins.

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analyzed. Finally, an image called *vein_pattern(x,y)* is obtained by selecting the maximum of C_{d1}, C_{d2}, C_{d3}, C_{d4} for each pixel of the image, as shown in Fig.3 .

[Step C] The *vein_pattern* is now binarized by using a threshold. Pixels with values smaller than the threshold are labeled as parts of background, while those with values greater or equal to the threshold are labeled as parts of the vein region. Otsu's Method was used in order to choose the threshold's value. After experimenting with different values near the one provided by Otsu's Method, it was revealed that a smaller threshold and specifically one third of the original Otsu's value, was an ideal choice which provided a final image with sufficient information about the vein patterns.

Finally, in Patterns Matching stage the clear vein patterns produced by the previous stages are used in order to compare the two images they represent (the original and the query one respectively). Given *f* is the vein pattern produced by the processing of the original image and *w* is the vein pattern produced by the processing of the query image. Firstly, FFT is used to convert *f, w* into frequency domain as *F, W* respectively. Secondly, the complex conjugate of *W* is calculated and represented as *W**. Afterwards, *F* is multiplied with *W** and their product is converted to time domain with the IFFT. The process described above is the calculation of correlation in frequency domain [5]. The outcome of this process is an image *result(x,y)*. The maximum value of *result(x,y)* is the maximum number of matched pixels of the two images *f* and *w*.

In order to check if the two patterns are matched, two ratios S_r (similarity ratio) and D_r (difference ratio) are defined as it follows:

$$S_r = \frac{\max(result)}{number\ of\ white\ pixels\ in\ original} * 100\%, \quad (2)$$

$$D_r = \frac{|\text{white pixels in original} - \text{white pixels in query}|}{number\ of\ white\ pixels\ in\ original} * 100\% \quad (3)$$

If S_r>50% and D_r<25% the two images are considered to be matched and the identity is

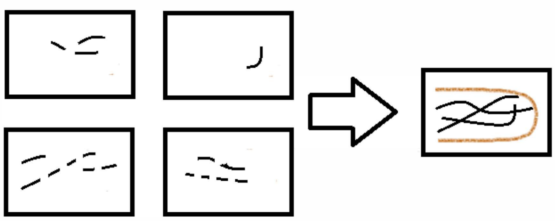

Figure 3: Obtain the vein pattern by combining four directional vein images.

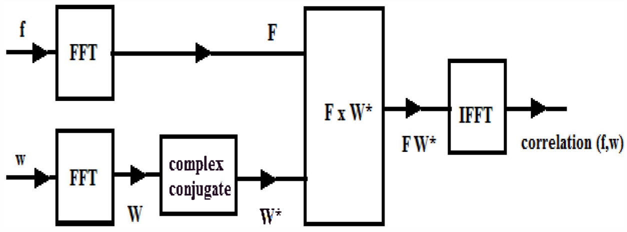

Figure 4: Correlation in frequency domain.

authenticated. The process described above is shown in Fig.4.

III. EXPERIMENTS

During the experimental procedure a test base was created by randomly drafting images from a mixed database. The database consists of some images that were taken by the proposed system, augmented with those of a preexisting finger veins' database [6]. The final test base consists of two hundred folders, each one of them including two different images of one person's finger. Four hundred different comparisons were conducted. In details, the first two hundred comparisons were between the two images included in each of the one hundred files. The rest of them, were between images from different folders therefore, between different individuals' fingers. In Fig.5 which consists of images captured by our device, a comparison between two different shoots of the same person's finger and two different images of different persons' fingers, are shown in the left and right column respectively.

The results obtained from the comparisons are the following: two out of the two hundred comparisons faulty rejected a query image, while no falsified image was (faulty) accepted, in any of the rest two hundred comparisons. Therefore, the percentages were calculated as follows: FRR (false rejection rate) =1% and FAR (false acceptance rate) =0%.

Another worth mentioning piece of information is the time required for each stage of the proposed algorithm. In details, the time needed during the training and the matching stages are approximately: 0.85 and 0.45 seconds respectively.In other words, the total time needed to read an initial RGB finger vein image, extract the veins' pattern from it and finally compare it with another given vein pattern is 1.30 seconds. The experimental procedure as a whole took place in a desktop with Windows 7 Ultimate operating system, 4 gigabytes RAM and processor Intel® Core ™ i7-2600 CPU. Matlab R2014b was used for the image processing algorithms and Yawcam software for image capturing (any simple web camera, still image capture application can do the job).

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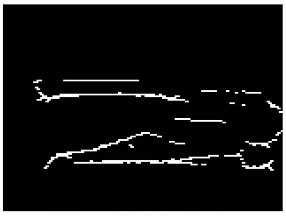
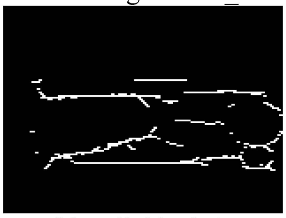
(a) Individual_1 middlefinger shoot_1

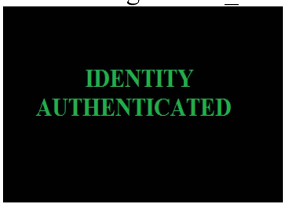


(d) Individual_1 middlefinger shoot_1

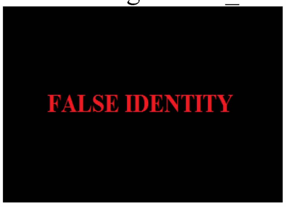


(b) Individual_1 middlefinger shoot_2

(e) Individual_2 middlefinger shoot_1



(c) result of comparison between a and b



(f) result of comparison between d and e

Figure 5: Comparison results of the proposed algorithm, using images captured from the device.

IV. DISCUSSION

It is essential, to underline the fact that the results obtained by the proposed algorithm show that the system is highly secure. On the one hand, the use of the finger vein patterns itself, as criterion for personal identification, does not permit any technical attempt of forgery. While, on the other hand, the zero percentage of the FAR shows that the system would not be deceived by the use of an individual's finger which is different from the original one.

However, an FRR value of 1% has been calculated. Practically, this percentage originates from the fact that in the two hundred comparisons which were supposed to accept the given query image, two images were faulty rejected. The main reason for these rejections is the fact that in both cases the finger was either bent or twisted in a way that some details differentiated between the two images. Such placement issues could be avoided if the capturing device did not allow for the finger to be misplaced.

Table 2: Comparative Summary of relative work

Reference	Methodology	Database	Performance
Rosdi, Shing [4]	Local Line Binary Pattern	51 users	FAR=1.78% FRR=1.78%
Tang, Huang [7]	A Person Retrieval Solution	1200 users	FAR=1.5% FRR=1.5%
This study	Maximum Curvature	200 users	FAR=0% FRR=1.00%

The results of the proposed method are quite satisfying, as they appear to have smaller error rates than other conventional methods as is shown in Table 2 above. For example, the Local Line Binary Pattern [4] provides equal values for FAR and FRR (1.78%). Another less efficient approach is the one proposed in Person Retrieval Solution Using Finger Vein Patterns [7] where FAR=FRR=1.5%. Both of the above mentioned error rates seem to be at least 1.5% and 0.5% lower than the FAR and FRR obtained by the proposed method respectively.

V. CONCLUSION

The usage of biometric characteristics as criteria for personal authentication systems is rapidly adopted in many technologically advanced countries. Therefore, the need to achieve personal identification in a secure, robust and low cost way is a clear demand of our times. As this study shows, the method proposed is in position to satisfactorily fulfil this need. Nevertheless, there are still aspects to be optimized and therefore further research is ongoing. Given, the results of this study our future goals will be focused in creating a bigger and more trustworthy database than the one used, which is the main reason why our capturing device was developed.

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