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Optimized Vein Pattern Recognition for Biometric Applications– a Modern Approach

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***Abstract* – Recently, a stagnant or decreasing influence of the vein pattern as a biometric parameter has been observed, even though – by assessing the features of the model: universality, permanence, collectability or performance – the technology is superior to other traditional biometric parameters. The problems are mainly related to the lack of access to clear and robust images of the vein pattern for the development of processing algorithms. This paper aims to contribute to the implementation of biometric applications using optical vein scanning by optimizing a crucial part of the biometric platform: the hardware scanning device. As an evolution of the previous research, experimental devices have been implemented for the robust optical scanning of the vein patterns in the back of the hand and an optimized, modern approach to the modular structure of the acquisition system will be presented. Experiments have shown that the resulting scans are resilient to illumination problems or position modifications of the scanned hands.**

I. INTRODUCTION

As opposed to other traditional biometric parameters – fingerprints, voice, signature or the iris model, the features of human blood vessels as a biometric identification trait are significantly less explored. The optical acquisition is not optimized [1], the systems are mainly used indoors [2] and the scans are performed under strict constraints and conditions usually impossible to replicate. There are many advantages of using vein patterns as a biometric parameter- in comparison with other existing biometric technologies- such as higher authentication accuracy and better usability [3].

Unfortunately, the novelty of the methods employed and the low technological barrier for entry in the vein acquisition field has created an important set of problems: *the scanning technology is not standardized, the algorithms are often optimized for a reduced number of samples and the methods and techniques employed in the identification of hand vein patterns proposed in various papers can not be replicated due to lack of access to the original scans.*

These problems and limitations are easy to detect in reference papers such as [4] that determines the vein pattern models under illumination from multiple sources and wavelengths, [5] with variable threshold windows or other examples revealed in [6][7][8][9] where the acquired images suffer from lack of uniform lighting or the algorithms cannot be reproduced by other authors in their respective detection systems.

These problems are difficult to solve since the domain has not reached a level of maturity specific to other biometric methods. This paper offers several solutions for the hardware scanning system that can increase the accuracy of the vein pattern scanning and offer a stable set of modules that can be implemented in any vein detection application.

II. VEIN SCANNING BACKGROUND

The visual scanning of veins in the back of the hand is a process of digital reproduction of the model created by the Basilic veins, present in the surface of the hand, namely the upper part of the back of the hand. Cephalic veins - the group of veins attached with the wrist of the hand -can also be prime candidates for scanning. The acquisition is possible due to the behavior of deoxidized hemoglobin that absorbs near infrared radiation under a narrow optical window as depicted in figure 1.

Under these conditions, systems can detect veins but not arteries and the increased absorbance of veins creates a good contrast between the vessels and the surrounding tissue. It can also be noted that water in the tissues does not carry a significant influence at these wavelengths. The radiation penetration is low (0.5...2mm) due to tissue scattering and absorption before radiation reaches the veins and the hand has an increased specular reflection [10]. This makes acquisition difficult since the amount of radiation has to be carefully controlled to not overexpose the image or underexpose the vein pattern. Vein pattern detection shares several similarities with fingerprint scanning [11] since the vein pattern of the human hand can be seen in the same way as fingerprint and palm print, as a collection of ridges and bifurcation points. The main difference consists of the number of said intersection points that is greatly reduced in the model of the veins, especially in the back of the hand. This forces the acquisition system to take as many veins as possible into account for a valid discrimination between individuals.

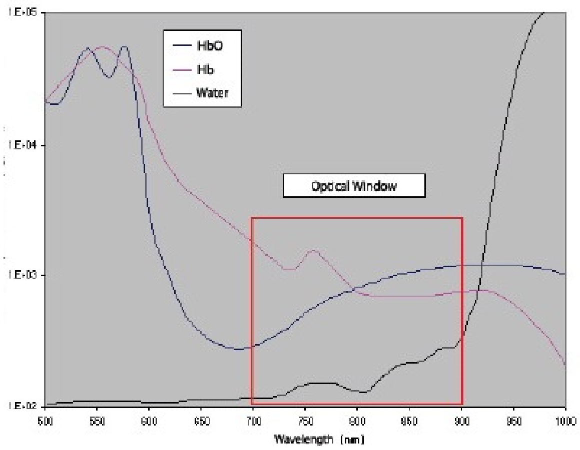

Fig. 1. Optical window used for detecting the vein pattern. [12]

The constrains of the blood vessels can be used as an input in the detection algorithms and there are important aspects regarding the nature and shape of the hand vein model:

- Veins can not be unconnected. A visible vein that has no connection to the general model is usually discarded
- Major dorsal metacarpal veins follow the general direction of the hand
- It is impossible for a vein to reconnect to itself (and not to anything else- vein patterns can sometimes have redundant paths, a process visible in varicose veins)
- All lower veins should converge to three points, each point connecting two fingers [13]
- the vein model can not exceed the dimensions of the assigned shape of the hand

These factors allow the algorithms to only select good vein candidates. While the accuracy of the model is preserved, in many cases the amount of usable veins is decreased and the number of crossing and ending points becomes insufficient for a good separation between probes. Predictive algorithms can be employed in order to restore a broken vein path but software limitations prevent a successful reconstruction when the hardware system fails to acquire an adequate scan of the vein model.

Figure 2 shows similar numbers of feature points but the scanned hands belong to different individuals

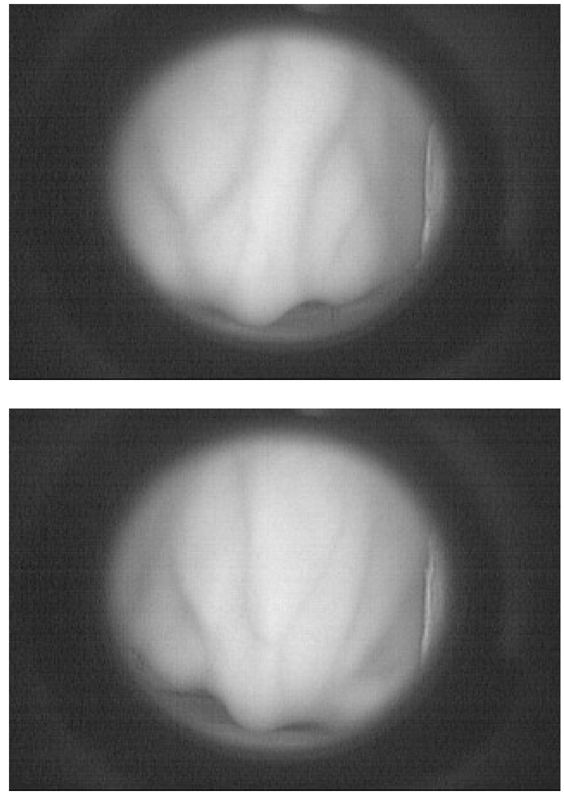

Fig. 2. Matching low number of feature points in different individuals

The quality of acquired images strongly depends on three factors:

- Imaging device quality and responsivity to the desired wavelength, ability to control exposure, shutter speed and ISO.
- Lighting system quality, uniformity, adjustability to environment changes and specificity for the vein model
- Sample placement, controlled or unconstrained, each with their own array of difficulties having a significant impact on the repeatability of measurements.

III. OPTIMIZED HARDWARE MODULES FOR VEIN PATTERN RECOGNITION

Previous research by the authors [12], [14], [15] has suggested the use of circular polarizing filters to reduce unwanted reflections, diffusing filters for preventing illumination hotspots and narrow bandpass filters on the camera to match the spectral emission of the radiation sources. While these key points have been backed up by numerous experiments, the conclusion of the authors is that - due to the nature of the blood vessel absorption parameters- a vein detection system is unable to provide a stable, full model scan using low quality cameras.

Most of the papers described in the introductive chapter and some of the authors' own research points toward using inexpensive webcams with IR-cut filters removed. This represents a low-cost solution but unfortunately it is also a low–quality one. Webcams lack the required dynamic range for providing a good contrast between veins and the surrounding tissue; they have difficulties in low-light conditions and exhibit too much noise on the resulting image. In addition, the manual controls of such cameras are usually lacking, with automatic exposure and a slow rolling shutter.

Fortunately, recent years have brought low-cost, improved quality cameras that negate many of the disadvantages of using general purpose webcams. The researching leading to this paper has mainly focused on integrating the PI NoIR camera into a vein pattern processing chain. The PI NoIr camera is a 5MP camera with full manual controls and no infrared cut filter developed by the Raspberry Pi Foundation, creators of an inexpensive but very powerful System on a Chip micro-computer [16]. Figure 3 shows the PI NoIR camera and the normal PI camera (with infrared filter attached).

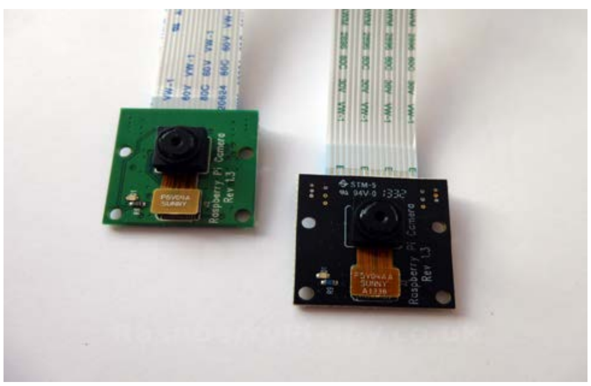

Fig. 3. Near-Infrared PI NoIR camera and the normal PI camera [16]

The PI NoIR is used together with a Raspberry PI computer for all the necessary image preparations before the image is relayed to the processing computer. The lighting system has been upgraded from previous research with the use of reverse pointing neutral white LEDs. In order to provide the necessary amount of illumination and to prevent hotspots or overexposure, the inside of the device is coated in an 11% reflectivity material and the LEDs are directed in the opposite direction of the camera. This insures a stable illumination and the lighting control is also performed by the Raspberry PI onboard computer.

One of the most difficult tasks in acquiring a valid vein pattern scan is related to the position, orientation and exertion of the hand being scanned. Most setups, including the ones visible in the reference list, force the user in a constrained hand placement, usually with the fist clenched onto a piece of a fixed module. While this simplifies orientation and position determination, it adds several issues due to the varying force of the clenching or the direction of the effort towards the support module. In addition, this method negates one of the basic advantages of vein pattern scanning: no hygiene concerns. In a free movement scenario, position of the hand can be inferred by analyzing the contour and shape of the image but the orientation of the sample, especially pitch and roll with respect to the camera axis is a difficult task.

Several experiments have been performed using laser-projected grids and photogrammetry techniques. While these methods, together with hand orientation calibration using inertial sensors are able to provide accurate results, the authors have chosen a dual-camera depth system that is able to analyze the rotation and position of the hands and also finger placement and curvature. The camera system chosen is a LEAP Motion device that comes with a very robust algorithm set and modules for hand and finger detection but other solutions exist.

Again, advances in modern depth scanning have allowed for very low-cost stereopsis cameras to be available for the general population and for this research, the advantages of such a system negate the need for more complex systems such as time of flight sensors or structured light scanners. Figure 4 depicts a snapshot of the recognized finger and hand orientation using the Leap Motion camera.

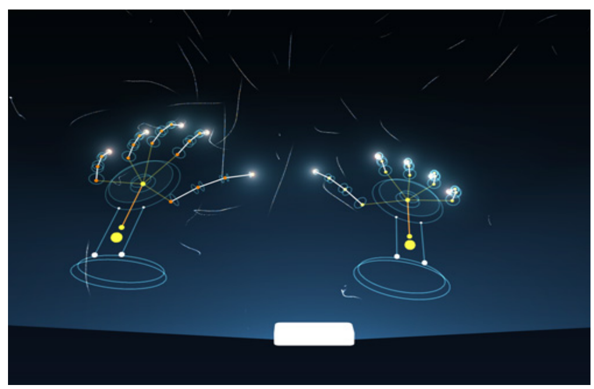

Fig. 4. LEAP MOTION hand detection algorithm [17]

Since LEAP MOTION camera and PI NoIR camera are sensitive to the same wavelength of radiation, the same illumination system can be used for position and orientation determination and for the actual scanning.

In order to achieve the best possible image snapshot of the vein pattern, the following detection schema for a non constrained hand scan is proposed:

- The LED matrix only has a few items illuminating
- The background is captured and stored (reacquiring happens when background changes by more than 5%) [15]

- Camera focal point is selected at 20cm, at this setting the camera depth of field allows for a +/- 5 cm position variation while in focus.
- Camera is set with low manual exposure, low ISO
- Camera waits for motion (difference from background)
- Camera determines hand presence [15]
- LEAP camera performs orientation resolving.
- All LEDs are lit, LEAP in standby.
- Camera shutter speed increases to 1/200 seconds
- The user is instructed to hold the hand stable
- The vein pattern is continuosly acquired for the duration of ½ seconds storing only the frame with the highest focus to prevent motion blur.
- The vein pattern position is fused with the hand orientation from LEAP camera and mapped on a planar surface.

This scanning algorithm takes into account the strengths and quality of the dual camera setup in order to provide an accurate depiction of the vein pattern.

IV. RESULTS AND LIMITATIONS

An experimental setup has been devised where a very common hardware device –as depicted in [12]- is paired side by side with the new vein pattern acquisition system. The images acquired with the proposed model have been down-sampled to 320x240 pixels to perfectly match the resolution of the old system. 162 images were acquired using both systems from multiple individuals and contain both left and right hand vein patterns. For this data analysis, the user hands have been mechanically constrained to eliminate the influence of position and rotation.

In order to analyze and correctly compare the sets of resulting images, a modified image contrast coefficient defined in [14] and applied to image quality classification in [18] is used. Through analysis of the pixel intensity transitions between adjacent pixels in multiple parts of the image, the four vein image quality classes described in [18] have been employed to assess image quality changes between the systems used in this experimental setup.

The levels of contrast between veins and the surrounding tissue are gathered using averaged local kernel windows from identical parts of the image belonging to the two systems and directly compared.

Figure 5 shows the raw and normalized contrast coefficient for two sets of captured vein images. Blue and orange data sets are two relevant images scanned with the classic system and red and green bars are the same vein structures gathered with the proposed system.

It can be observed that the contrast increases substantially (19...27%) for lower grade images (class 1 and 2) and to a lesser extent (<11%) for class 3 and above images. It can also be inferred that – due to the more uniform lighting- the influence of over and underexposed parts of the image present using the webcam – based solution is significantly reduced.

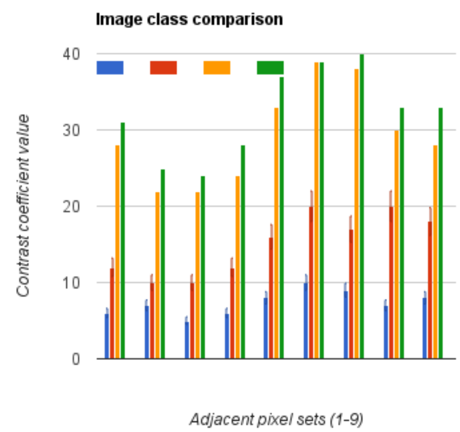

Fig. 5. Image quality comparison based on a contrast variation coefficient

This first set of experiments has shown that the combination of neutral, uniform illumination with the increased sensor quality of the Pi NoIR camera is capable of augmenting the quality of the acquired images by an entire class for low contrast vein patterns. This effect can be easily observed in figure 6, where the high contrast of the vein pattern image allows for complete extraction of the features from the vein model.

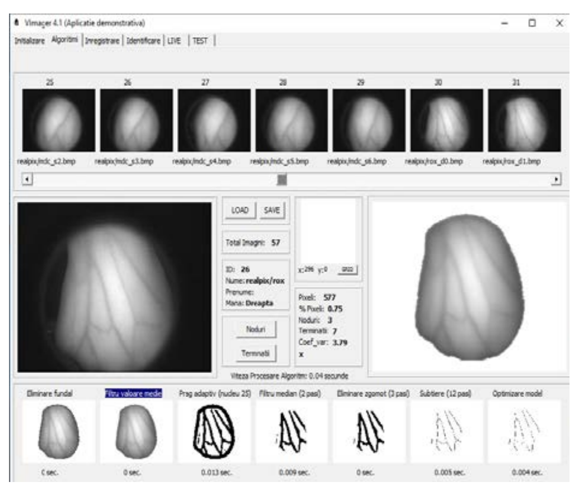

Fig. 6. Vein extraction algorithm stages on a vein scan with the proposed system - VImager front panel

The second set of experiments uses the proposed system in an uncontrolled setup where the user hand is not constrained and the rotation and position is calculated using sensor fusion between the stereo camera and the normal camera images. Vein scans of 67 individuals slowly moving the hand on a single plane below the sensors are compared with the constrained images belonging to the same users. Subsequently the contrast variation is computed for both images and a new experimental setup is performed using free hand position images. For this experiment, the burst mode of the Pi NoIR camera is used where, due to the optimal illumination level, 14 pictures per second can be gathered by the system. The detection steps described in the last chapter are applied and the resulting images is remapped on the X-Y plane and compared with the original constrained image. Experiments have shown comparable results for hand angles lower than 15 degrees from the horizontal plane in any direction and increasingly worse results for higher angles due to the extremity veins occlusion in the camera field of view. Using an inertial glove system with a calibrated accuracy of 1.2 degrees, 67 users were asked to repeatedly move their hand under the sensor system in an uncontrolled/free motion scenario. This set of experiments has revealed that users generally (>87%) insert their hand at an angle lower than 15 degrees. While a larger sample base is required for a full ergonomics analysis, the experimental results sustain the viability of such a vein scanning system.

V. CONCLUSIONS

Advances in the field of biometric vein detection can benefit from higher quality hardware modules specifically tailored for this type of application that increase dramatically the accuracy of the image scanning. Software algorithms alone are usually unable to reconstruct a damaged vein image due to hardware limits. This paper has shown a possible vein detection system using an infrared sensitive high-quality, low-cost camera coupled with an inexpensive but very capable stereo camera system combined in a single vein detection device with variable illumination and unconstrained sample position. The ability to control exposure, shutter speed and especially ISO values allows for a custom, streamlined acquisition system that increases the quality of the scanned images. Coupled with the depth map generated by the stereo camera, such a system allows for faster and more accurate vein pattern extraction algorithms. Using this modern approach, difficult biometric problems such as hand position and orientation analysis can be solved by this system with no user constraints or multispectral lighting setup.

Future efforts will be directed towards suggesting a standard modular setup for vein pattern recognition that can improve the quality of feature extraction and will act as a basis for algorithm implementation.

VI. ACKNOWLEDGEMENT

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