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Multi-Mode Biometrics for Law Enforcement Operations

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Abstract - Fingerprinting is the most extensively used biometrics supported by biggest database compared to other biometrics, such as retina imaging, face or voice recognition and others. However fingerprinting image could be distorted by pressure of the finger against the scanner, therefore needs to be contactless. Most important, distances between ridges on a finger depend on physical conditions (health) of an individual. That is when map of blood vessels in a finger is very helpful and supportive information. In addition, police criminal investigators do find some time not standalone fingerprint but images of few fingers or even image of a palm. In current study, we report a new design and test results of contactless line scan hardware, which produces images of single nail-to-nail finger, four fingers together, and image of human palm. The major focus of the study is development of high-resolution images of blood vessels and the new algorithm based on linear filtering neighborhood analysis, which generates a well-defined and interconnected blood vessel map. The new position of IR light sources provides a good and mostly uniform contrast between the veins and surrounding tissues. This configuration is different from the conventional positioning, where all three objects are aligned along vertical axis, that is, the source of light positioned above the tested finger, and the camera is located below the finger. The new experimental imaging configuration and blood vessel tracking algorithm could be combined with contactless fingerprinting to reinforce biometric personal identification.

Keywords: Contactless fingerprinting, Vein recognition, Line scan, Linear filtering, Image processing.

1. Introduction

Widely used and most extensive biometrics system is based on registration and analysis of fingerprints [1]. Increased security requirements relevant to the worldwide war against terrorism and cybercrime has recently prompted the improvement of biometric systems used by law enforcement officers in identification of individuals at border crossings, airports, and government building access points [2]. A group of law enforcement officers working for criminal police and the Federal Bureau of Investigation (FBI) established an extended requirements list for the biometric recognition [3-5]. These requirements are based on several field operation considerations that needed to be addressed. First, often criminals leave not only images of individual fingers, but traces of several fingers together and/or images of their palms at a crime scene [6-8]. Second, rapid personal identification is especially complicated when an officer stops an individual on the highway or busy street [9]. In current research, we created mobile multimode biometric system, which can be successfully used in above-mentioned scenarios and maybe more. It should be emphasized again that although fingerprinting is one of the oldest and most reliable means of biometric identification, there is a list of drawbacks and limitations of fingerprinting. That is why combination of contactless fingerprints with a map of blood vessels in examined finger appears to be more reliable instrument for recognition of an individual.

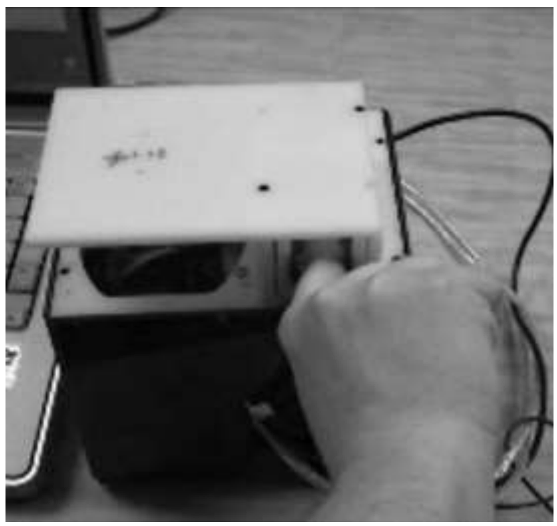
Fingerprint image acquisition is considered the most critical step of an automated fingerprint authentication system as it determines the final fingerprint image quality and therefore the rate of success of fingerprint recognition. Not long ago, the rolled ink technique was widely used to obtain fingerprints. The wet ink method was used to create most of the fingerprint library in United States and other countries. The basic idea behind each capture approach is to measure the physical difference between the ridges and the valleys of stored in library fingerprint of an individual and freshly taken image of a fingerprint. All the proposed technology can be grouped into two major families: solid state readers (capacitive sensors, for example) and optical readers.

We demonstrate recently [10], that under the pressure due to the finger's own weight, fingerprint ridge spacing can be distorted by about 20%. Forceful contact of the finger against the scanner produces even more distortion [11].

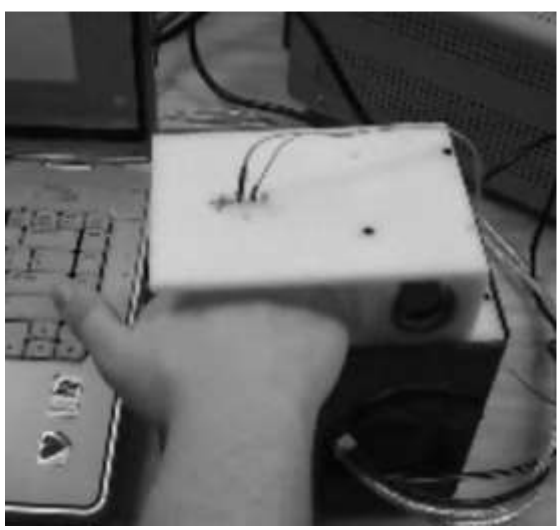
One of the critical elements of fingerprinting is the FBI standard to record nail-to-nail image of a fingerprint, that is almost 180° view of a finger. In our recent work [5], automatic contactless system controlled the move of a camera about 180° around stationary position finger. With the clockwise rotation of the camera the finger was illuminated by the visible light. The recording was very fast, taking 1.5 second. During immediately following anticlockwise rotation the finger was illuminated by IR light registering map of blood vessels. Unfortunately, work condition of law enforcement officers in the field, i.e., on a highway, was not served well by a system with moving optics. Alignment of that optical system was distorted by moves of the equipment. That is why we redesigned it and presented a new multimode biometrics system with no moving optical parts [12-13].

2. Mobile hardware for contactless multi-mode biometric identification

In current study we describe mobile systems for contactless, multi-mode biometric line scanning, which include imaging of a palm, imaging of four fingers together, images of nail-to-nail fingerprint and blood vessels. Fig. 1 presents operation of the multi-mode biometric hardware. Fig. 1(a) shows the position of a finger for imaging of a fingerprint. If an image of a flat part of the finger is needed, the finger is stationary. If a nail-to-nail fingerprint should be taken, then examined finger is rotated about 180°. The small portable hardware does not have moving optical parts. Fig. 1(b) shows the position of human arm when images of palm or four fingers together need to be recorded or recognized.



(a)



(b)

Fig. 1: a) Taking nail-to-nail finger scan b) Taking palm scan.

Fig. 2 presents the internal view of a design of a contactless capture of a fingerprint and a map of blood vessels. The first modality is a nail-to-nail fingerprint captured using the radial line-scan hardware. The second modality is a blood vessel image, which is recorded via transmitted infrared (IR) light using the same radial-scan imaging hardware used for a fingerprint capture. The developed radial line scan technique and the selected frame allows for this device to fit in a volume which makes it a portable device (15 cm x 13 cm x 17 cm). To satisfy the requirements of the criminal police and FBI, our system carries area scanning camera, which allows to take a full view of a palm or a full view of four fingers together. The area scanning camera provides, as an option, the image of upper part of a palm together with four fingers (see Fig. 3). Fig. 4 shows a contactless crisp image of a nail-to-nail fingerprint. The system can satisfy any FBI requirements, that is 600 x 600 pixels or 1000 x 1000 pixels resolution. Unfortunately, the same line-scan method did not produce high-quality imaging of blood vessels in the finger - this drawback is attributed to limits of selected lenses. Below we will discuss some small editions to our multi-mode biometric hardware, which allows to produce high-quality medical grade images of blood vessels in a finger.

IR Imaging is being used as a biometric method for many security applications [14-16] including identification of individuals. Though this concept is relatively new, much research has been done and continues progressing on the topic [17- 20], and state-of-the-art technology still focuses on the image capturing and image processing techniques.

Images of blood vessels are generated by absorption of infrared light in a finger followed by standard processing steps [21-22]. Most experimental steps consist of capturing the image of the

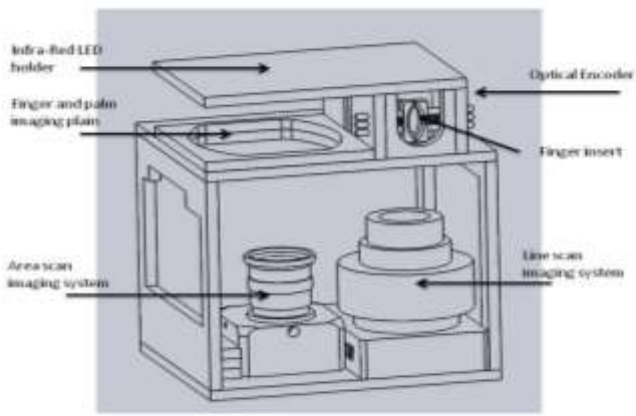


Fig. 2: Optical system arrangement for multi - modal fingerprinting with stationary optics.

veins, noise reduction processing, then digitizing the image, to a point where a blood vessels map can be extracted. The most important, as mentioned, is the method of noise reduction, pre-processing of the image, and then usage of localized thresholding algorithm to extract the veins impressions. For example, similar approach was used in [22] for extracting vessel map from the palms of the hand, but not a finger. High accuracy of imaging of blood vessels requires showing the main vessels with all small brunches visible in each finger. Some studies used complex algorithms that relate curvelets and the local interconnection structure of the neural network to process images [23], but even then, the attained images are noisy leading to “clumped” digitized images.

Though the processing mentioned above leads to a binarized image of the finger veins, a lot of the vein map has been clustered in the final product due to the addition (instead of reduction) of noise in the early steps of processing the image [23]. Finger veins themselves are very complex maps with multiple nodes and branches. Therefore, our method focuses more on improving the overall quality of the image itself before trying to extract information from the image. The more uniform the illumination of an image is, the more accurate it will come out when processed.

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Fig. 3: Image of partial palm with fingers.

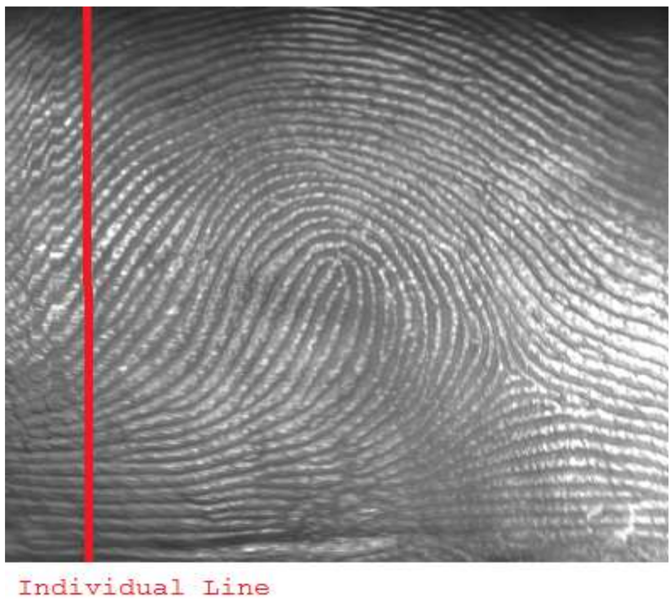

Fig. 4: Line-scan generated fingerprint image. The vertical line denotes a single line that was taken by the line-scanner.

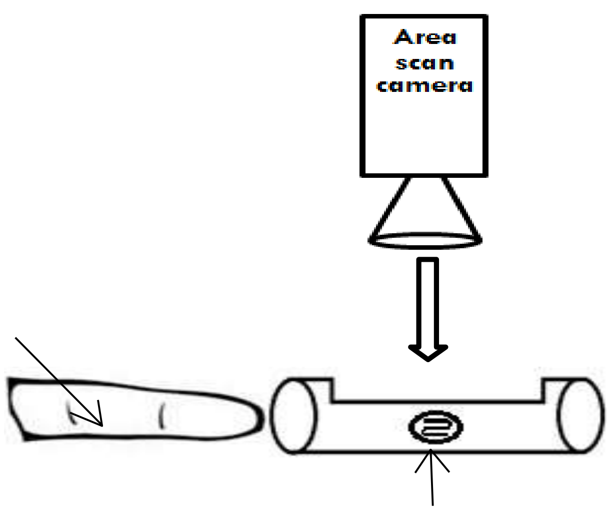

Fig. 5: Cylinder with two open sides to use two IR LED’s.

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Different experimental setups have been tried, where the IR light source is behind a human finger , at certain angles below the finger, or on the sides of a human finger [21]. We tried similar geometry (see Fig.2) without much success. It is important to note that the method by which the image is captured may be one of the most significant steps in finger vein extraction. The IR light must penetrate and scatter well enough throughout the finger to show the intricacies of each vein map in each finger. In the case of a human finger, much research has been done with IR blood vessels capturing, processing, and extraction [21-23]. Majority of conducted research like [21-23] tend to use IR lights placed underneath a finger or at angle to the finger. However, the images that are taken from such setups tend to be noisy and not uniform.

Using two sources of near-infrared (NIR), 970 nm wavelength, which is well absorbed by human hand [24], we changed the positions of light sources and the position of the light detector. Fig. 5 presents the holder with opening for illumination of a finger from opposite two sides by IR light emitting diodes system, which provides good and mostly uniform contrast between the veins and surrounding tissues. This configuration is different from conventional positioning, where all three objects are aligned along vertical axis, that is, the source of light positioned above the tested finger, and the camera is located below the finger.

Illuminating the finger not from the bottom, but from both sides takes away impact of absorption through finger thickness. This way the uniformity of image is acceptable even for very thick finger tissues. The IR sensitive camera takes the snapshots from the top of a finger. This hardware setup has a very important role in the acquisition of vein images providing more uniform background and better contrast. Moreover, hardware configuration might affect some recognition algorithms, for example, such approaches as Local Directional Code method [25] are much more sensitive to changes in positioning IR sources. This is because varying position of the source (for example, when operating on several different IR machines) will affect the illumination concentration on the image of a finger, therefore affecting the local derivatives in those areas. This is an advantage of linear filtering approach, which is much less affected by such hardware variables.

3. Contactless blood vessel mapping

Use of blood vessels as recognition feature instead of fingerprinting reduces the stigma of criminality of people registering their fingers. Hitachi Co from Japan and Kronos Co from the United States, among others, are engaged in mass production of perimeter access devices based on blood vessel recognition. Government institutions and commercial companies use these devices, however there is no statistical data published about the accuracy of recognition of blood vessels. The statistics is well recorded with commercial equipment based on fingerprinting, where rate of success is about 87 – 92 %. A few years ago, our group at University of Massachusetts Lowell manufactured a line- scan hardware, where imaging of fingerprints was combined with mapping of blood vessels in a finger. We found that accuracy of recognition of the fingerprints was near 100 %, yet accuracy of blood vessel recognition was questionable. The field of blood vessels imaging is important for medical diagnosis as well. For example, the disease leading to breakage of blood vessels in a finger requires urgent treatment for cases of genetic or pharmacological conditions. The diagnosis of Raynaud's (blocking of blood capillary) and other syndromes, as well as the accuracy of pulse oximetry require high quality images of blood vessels in the finger. The necessity to have very accurate trace of every single blood vessel in the field of biometrics led to our development of new experimental set up and a new linear filtering neighborhood analysis - based algorithm, which generates well-defined and interconnected blood vessel map line scan hardware, where imaging of fingerprints was combined with mapping of blood vessels in a finger. Analyzing previously published blood vessel images, algorithms of noise reduction, general processing of these images are missing well defined lines of blood vessels. Lack of contrast and sharpness of blood vessel lines was not compensated by processing techniques. That motivated us to enhance infrared imaging of the blood vessels, apply different algorithms and, finally, auto-trace and colorize the blood vessel map. Collection of statistics in biometric recognition, or accuracy of medical diagnosis based on our images was not the goal of this study. We offer a method to generate high- quality map of blood vessels in human finger with hope that the method would be useful for many applications.

4. Linear filtering algorithm

The algorithm works with 8-bit grayscale images where each individual pixel has a value in a range from zero (darkest) to 255 (lightest). Pre-processing routine consists of lightly blurring an image of interest in order to minimize irregularities in pixel values. Additionally, it is always suggested to define a mask for the area of interest in order to ignore any artefact acquisitions from background.

This algorithm compares the value of each individual pixel to an average value of the pixels in its n-by-n neighborhood (calculating the dimension “n” is described in the later paragraph). Figures 6, 7, and 8 give an intuition to why this relationship is important in vessel recognition process. These figures are topological representations of the original image where the height (z-axis) of each point is an 8-bit grayscale value of a pixel that is located at those coordinates. Red squares in Figures 7 and 8 represent the borders of the neighborhood of a base pixel, and the altitude of where the square is positioned represents the average value of all pixels within that neighborhood. If the altitude of the base pixel is lower than the altitude of its neighborhood square, then the pixel is marked as a trough. The marked pixels then constitute blood vessel mapping, refer to Figure 9 that shows a raw result of the algorithm. This approach allows assessing each pixel’s position with reference to the values of all other pixels in its neighborhood, which dynamically changes from pixel to pixel, thus naturally separating relatively dark regions from relatively light regions. The raw result then morphologically filtered based on the size of autonomous morphological objects on the picture (white “islands” in Figure 9). Afterwards a skeleton of the dark regions is acquired, where some spur lines are eliminated.

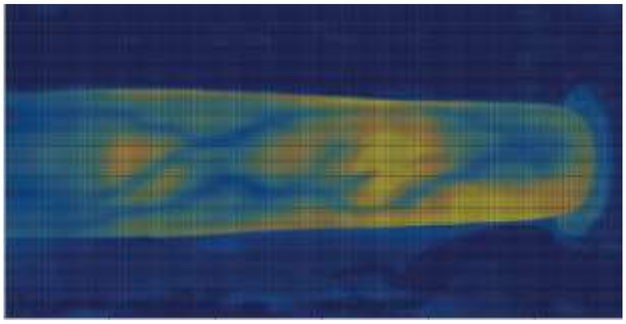


Fig. 6: Top view on the topological representation of a grayscale image.

The area of a neighborhood is automatized with reference to the area of a finger. It was empirically determined to be optimal at 0.25% of the area of a finger. Operating on such a tiny fraction of the image at once allows the algorithm to be more sensitive to changes on a local level.

Additionally, if the area of a neighborhood is bigger than the localized feature of the image, the algorithm’s decision-making accuracy will be lowered which will therefore cause higher artefacts

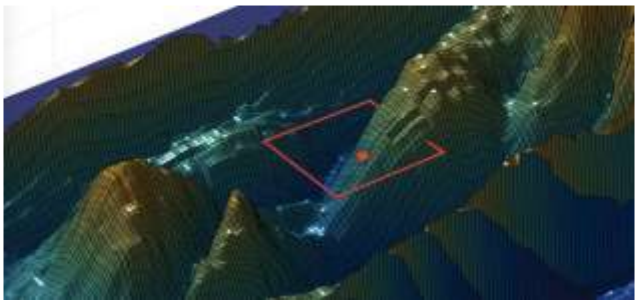


Fig. 7: Isotropic view on the topological representation of a grayscale image.

occurrence rate. Note that the vein regions in the challenging bright areas of the picture were picked up correctly by the proposed algorithm. A fingernail overshadows blood vein information on a front half of a fingertip phalanx and thus it is recommended to mask that area out.

The advantage of this algorithm when compared to [7] is that it operates on morphological shapes extracted from the picture instead of the gradient field. Operation on the morph shapes allows a human operator to work with the results live (e.g. medical applications). The results are easily interpretable by a person in case if such inspection, or verification is needed, unlike the results of the gradient field method.

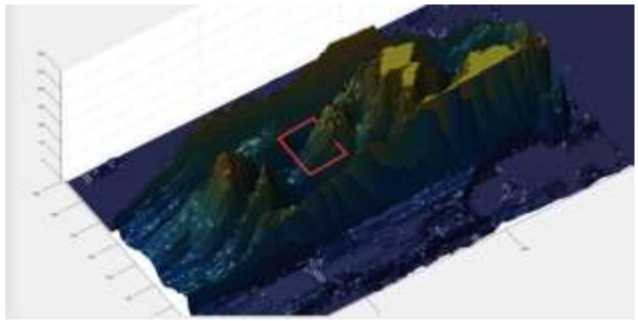
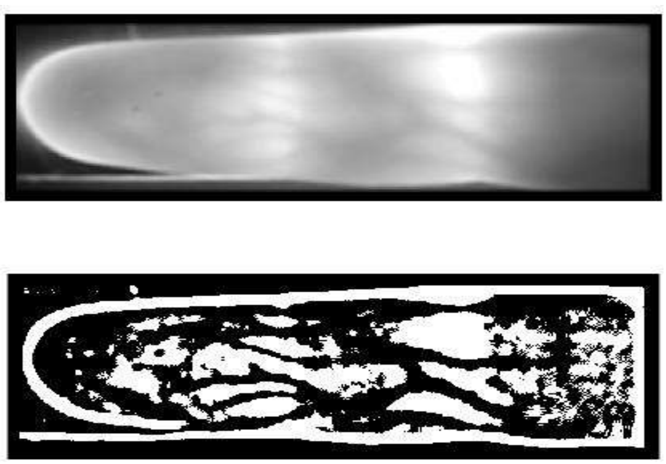


Fig. 8: Illustration of a dynamic base pixel and its neighborhood.

The advantage of this algorithm when compared to [27] is its ability to detect and preserve interconnections of blood vessel regions and the result being less noisy. Interconnectedness of different regions on the image is an important factor for both differentiating blood vessels from non-vessel regions and further recognition process. It is a common practice to eliminate artefacts and noise based on the information of their shape, size, and whether they are located autonomously or connected to a larger region of its kind. Therefore, higher connectivity of generic dark regions helps to make decisions that are more reliable in vessel recognition. Lower noise level of the final vein track line positively affects the accuracy of recognition.



a)

b)

Fig. 9: a) Original picture acquired using the experimental setup
b) Binarized image of a finger using linear filtering algorithm.

Applying the algorithm to the images with uniform distribution of light (this condition is provided in our experiments) gives better results in tracking of the blood vessels. Figures 10 and 11 are a demonstration of a good tracking. For the images with non-uniform absorption of light the algorithm might miss some segments of a blood vessel. We would like to emphasize that uniformity of light absorption is the critical factor, much more important than quality of the contrast of the image. Yet, the novel algorithm produces much better tracking results on any randomly selected finger images from available libraries.

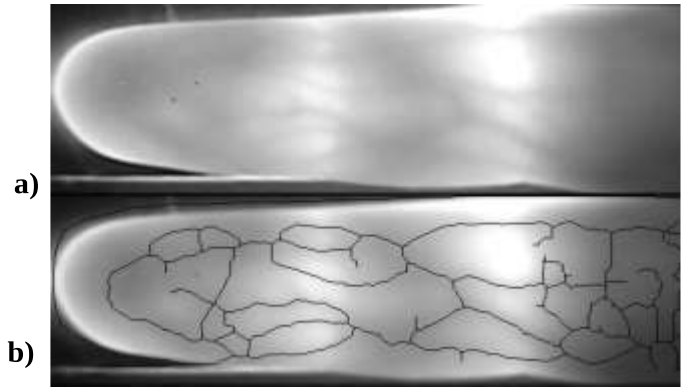


Fig. 10: a) Processed vessel-map image b) Binarized image of a finger using linear filtering algorithm.

We also observed that in conventional configuration of the experiment, where the light source, the finger and IR camera are aligned, in the areas shadowed by the nail and by thick bones, the tracking algorithm produces less accurate tracking. Therefore, we recommend to users of conventional alignment set up of vein tracking to do tracking only in the area of the middle phalanx of fingers. All the above are strong indication that the best testing of blood vessel map should follow configuration described in Figure 5, where uniform absorption of light is produced. One possible improvement that can be done is if the brightness of the IR exposure varied during the scanning motion. This variation could be done in two runs such that the first run detects the relative brightness of different regions of the finger, while the second run is done with higher IR exposure at darker IR image regions from the first run and lower exposure at lighter regions. This way the entire finger is illuminated relatively uniformly which might improve the recognition quality.

Lines of blood vessels in human hand or fingers are often overshadowed by the contrast of nearby layers of human tissue. Disappearing images of certain segments of blood vessels make the work of tracking the blood vessels very difficult and complicated. When that overshadowing happens, the loss of clear map of blood vessels makes it impossible to use vein recognition in identification of individuals.

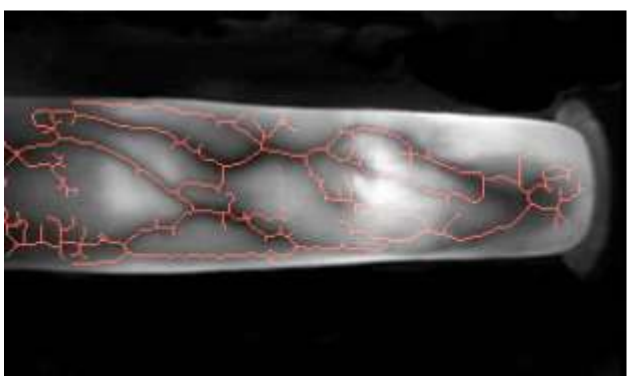


Fig. 11: Processed vessel-map image (colorization is optional).

Colorizing of the blood vessel map is helpful by itself, however the most important outcome of our algorithm is highly accurate tracking of blood vessel line with variable thickness, as the red mark follows with high precision the center of a given generic dark region. There are two factors that did allow us to trace the uninterrupted blood vessel lines. Uniform intensity of light coming from two sides of a finger created more uniform illumination and better absorption of light by oxygenated hemoglobin in a blood vessel. Additionally, the use of a linear filtering algorithm combined with colorization did allow to separate the images of lines of veins from dark contrast of some nearby layers of biological tissues. Our algorithm demonstrated much better tracking of blood vessels compared to blood vessel maps demonstrated in [26] or even maps produced by commercial equipment of Hitachi [26]. It is known, that fingerprinting is associated with a certain stigma and many people are rejecting this procedure because it is mostly used for identification of criminal. Yet the mapping of blood vessels carries reliable and standalone method for biometric identification. Combination of contactless fingerprinting with our novel mapping of blood vessels strengthens recognition, removing known deficiencies and limitations of these two methods, when they are used separately. Most important result of this study is ability to trace every blood vessel in a low noise continuous track lining (see the red color lines in Fig. 11).

5. Practical results

Let us briefly summarize the abilities and drawbacks of our multimode biometric system. The new biometric system is mobile and capable to produce high quality contactless nail-to-nail fingerprint images of a single finger, four fingers together, the entire palm or combination of partial palm with fingerprints, but not high-quality blood vessel images in the finger. Designing a small attachment to the mobile system we significantly improved the quality of blood vessel map in a finger. For this purpose, the novel algorithm was developed by us and is described below. However, list of physical and medical limitation of fingerprinting and mapping of blood vessels map in finger, as well as accuracy of identification procedures and hardware used should be analyzed [27-29]. Let us assume that at some point all individual fingerprints images are produced by contactless methods:

a) it is important to remember that with age (arthritis, joint inflexibility) real fingerprint changes; fingerprints are diluted (the contrast of fridges is very weak) for the individual who performs hard physical job.
b) in most cases contactless images of the fingerprint (taken at the airport or border crossing) could be only compared with widely distributed wet ink - based library; at police station contactless fingerprint images are compared with images (left with strong pressure say at window frame) of fingers at the crime scene.
c) It is important to remember that with age and dependence on medical conditions the blood vessel map could be modified.
d) contactless mapping of blood vessels in the finger although enhances the identification in combination with fingerprints however doesn't have a library for comparison.

6. Conclusions

With support of the United States Department of Justice researchers of Advanced Electronic Technology Center at UMass designed and tested several different stationary machines for both, contactless fingerprinting and mapping of blood vessels in fingers. During few years of biometric research supported by the government contract we designed novel imaging algorithms [29] and addressed practical issues of comparison of partial fingerprints, comparison of wet ink library with novel non-distorted fingerprinting [28]. However, the most challenging was design and testing of mobile multi - mode biometric systems. The operation complexity of these systems was challenged by special requirements of the Federal Bureau of Investigation (FBI) and unique aspects of police detective work at crime scenes. Not less challenging were tests required by the United States Government Institute of Standards [30-31, where real fingers were replaced by aluminum cylinders with integrated grid of lines distant one every from the other at 20 micrometers. We intentionally omitted discussion of micrometer scale patterns, as this is the separate issue.

We succeeded to create a mobile biometrics system, which contains hardware producing both contactless fingerprinting and mapping of blood vessels, generates nail to nail image of the fingerprint as well as image of four fingers together and/or a palm.

Absorption of infrared light by human tissue depend on many factors, to name the most important, presence of water in finger flesh and then blood vessels. That is why sharp, with good contrast image of blood vessels in the finger is very difficult to get, unlike images of fingerprint pattern. Presence of micro vessels, changing distance of blood vessel from the top of the finger, as the vessel goes in depth, all these factors require a special image processing algorithm, which was successfully developed. Applying the algorithm to the images with uniform distribution of light (this condition is provided in our experiments) gives better results in tracking of the blood vessels. Figures 10 and 11 are a demonstration of a good tracking. For the images with non-uniform absorption of light the algorithm might miss some segments of a blood vessel. We would like to emphasize that uniformity of light absorption is the critical factor, much more important than quality of the contrast of the image. Yet, the novel algorithm produces much better tracking results on any randomly selected finger images from available libraries.

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