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Impact of NIR wavelength lighting in image acquisition on finger vein biometric system effectiveness

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ABSTRACT

Finger vein biometric systems become increasingly more popular because they offer higher security comparing to other authentication solutions with respect to positive persons experience. Those systems operate on near infrared light (NIR) in wavelength range from around 700 to 1000 nm, however dedicated research to determine impact of NIR lighting on biometric system effectiveness has not been conducted and presented in the literature ever before. In this paper the study of correlation between wavelengths in NIR spectra and effectiveness of person identification in a biometric system is presented. To achieve that goal, a new model of image acquisition system allowing change of light wavelengths has been created and NIR finger vein dataset containing 11 556 images was established. Furthermore, this model was used to perform experimental work and proof that some NIR wavelengths better suit for vein patterns acquisition, allowing to increase the recognition effectiveness of finger vein biometric systems.

1. Introduction

With a rapid growth of electronic-commerce products, there is an increasing need to efficiently identify humans and protect information security. Biometric identifiers, unique to each of us, can be used to verify one's identity. Nowadays, automated recognition of individuals based on their biological and behavioral characteristics, is rapidly becoming a common practice. Because of inherent association with a specific individual, biometrics can be layered with other tools to form more secure, automated identity authentication solutions.

Biometric systems are essentially pattern recognition systems. In recent years biometric patterns have received significant research attention and several investigations on diverse biometric characteristics such as face, fingerprint, iris, online signature or voice have been conducted. Biometric recognition using hand vascular patterns is emerging as a touch-less and spoof-resistant hand based means to identify individuals or to verify their identity. Vascular biometric systems use information about the blood vessel structures inside the hand area (finger, palm or wrist) and overcome problems of latent prints or unnoticed acquisition on distance and liveness detection issues.

Vein imaging requires near-infrared (NIR) light for the complex vascular structures residing inside the hand to become visible. Vein structures are subcutaneous and hidden, thus they do not leave traces, which could be used against individuals and cannot be seen by naked eye. NIR imaging constitutes an aliveness detection of the user, since blood must be circulating in order for the veins patterns to be captured. Owing to these properties, compared with other modalities such as fingerprints and face, they are more robust against spoofing and external conditions. Moreover, they cannot be captured without the subject's consent. In this context, the hand veins, in particular finger veins because of their size, have emerged as a promising new biometric modality, in particular for banking transactional applications, where hygienic, contact-free sensors without guidance for the hand or finger can be deployed.

Available in the references description of devices for vascular pattern images acquisition used infrared light of wavelength in the range from approximately 700 to 1000 nm [1–3]. However, the authors of these solutions did not explain why the specific wavelength was selected. There are also some commercial devices in which the applied wavelength was not revealed as they constitute producer know how. A survey of references does not answer the question which wavelength of NIR light is the best for a proper operation of hand vascular biometric system. It causes motivation for our research in this area that concentrates on finger vein recognition.

The main goal of this research to prove the hypothesis: considering the irregularity in radiation absorption by hemoglobin

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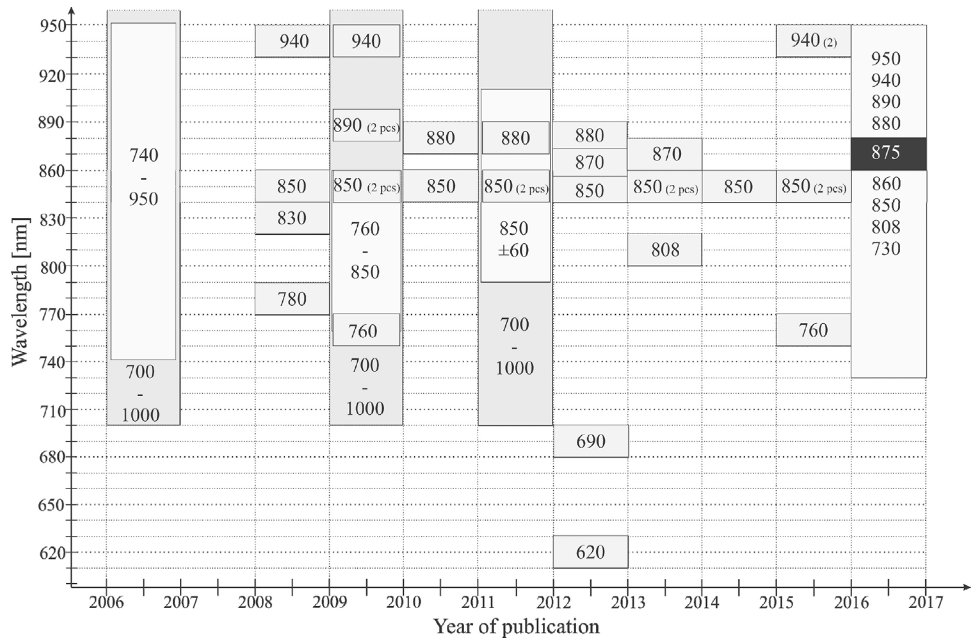

Fig. 1. State of the art of used wavelengths in research prototype devices [12].

and other tissues, some part of wavelengths in the range of near infrared spectrum are more capable for biometric samples acquisitioning than others. Samples for those wavelengths demonstrate better visibility of vascular system, and in consequence induce the increase of effectiveness of personal identification in a biometric systems. To verify this hypothesis finger vein patterns database is needed. It is not possible to use the available datasets (a. o. [4–6]) because there are no images of the same fingers in light of different wavelengths. Thus, a finger vein pattern database for person's identification which contains images obtained for a different NIR wavelength must be created. A new model of the finger vein biometric system was prepared for appropriate images acquisition and image processing procedures. It allows to perform experiments for the proposed hypothesis verification.

2. Finger vein pattern imaging

The vein patterns are not visible for human eyes however, they can be recorded by sensors of camera which is sensitive to NIR light. The light of wavelength between 700 and 1000 nm penetrates human tissues and gets to the surface of a vascular system. Effective penetration depth for NIR wavelengths, is practically 10 times greater than for wavelengths of visible light. Distinctive tissues of finger absorb differently near infrared spectrum. Due to a greater radiation absorption by hemoglobin deoxygenated and oxygenated comparing to other tissues, the vascular system is observed in the image as areas less overexposed (dark shadow lines). Veins are mainly recorded in the image because the vein system on hand fingers is placed closer to the surface of skin and has bigger diameter comparing to arteries.

From formal perspective, acquisition process of finger vein images includes positioning of a finger between the matrix of NIR diodes and the camera. Generally, the images are either obtained by light transmission, where the light shines through the finger, or by light reflection by these objects. Transmission with top or side illumination is typically used for obtaining vascular patterns from fingers. Normally, reflection is used for palms and dorsal hand but it can be also used for fingers.

Available in the literature solutions of vascular pattern images acquisition utilize lighting in the range of full NIR spectrum. In Fig. 1 presented the references and wavelengths used in constructions of prototype devices gathering biometrical samples and year of publications. On the basis of presented data, we can notice that first devices use wavelengths of almost full NIR spectrum, in years 2006–2015 the majority of finger vein acquisition systems use wavelength of 850 nm. In some of the papers, the NIR wavelengths are not specifically mentioned and only point out the subranges of NIR spectrum (e.g. like specified in Fig. 1. for 2006). It also concerns the multi-band illumination systems like described in Refs. [7–9]. Specified for 2016 wavelengths are authors' contribution in the research of optimal wavelength(s) for the finger veins acquisition and processing purposes. The 875 nm wavelength has been highlighted as suggested for the vascular NIR imaging. Justification of the choice with details testing routines and results of the research are presented accordingly in Sections 4 and 5.

3. Finger vein imaging device

Created model of the finger vein biometry system consists of an image acquisition system and a computer. There are three main blocks in the image acquisition instrumentation (Fig. 2), namely matrix of NIR diodes, camera, and Arduino microcontroller. The matrix of diodes is replaceable to achieve image acquisition in light of 9 different wavelengths: 730 nm, 808 nm, 850 nm, 860 nm, 875 nm, 880 nm, 890 nm, 940 nm, 950 nm. Created system applies the method of light transmission, where lighting elements (LED diodes) and camera matrix are situated in different sides of a finger. In this method there was obtained much more clear patterns of vascular system than from the method of light reflection (Fig. 3).

For imaging in near infrared light spectrum the Pi NoIR camera [10] is a good solution because it is dedicated to the used by Raspberry Pi platform. However, it can be any NIR camera with preferable resolution of 640 by 480 pixels and an 8-bit dynamic range or also some models of webcams which allow to remove optical filter absorbing all wavelengths beyond visible light.

The Raspberry Pi platform is a computational-decision unit which controls all external peripherals of system whereas Arduino microcontroller is used for controlling diode light intensity and camera parameters. The system applies two techniques for the improvement of the image quality. The first based on automatic

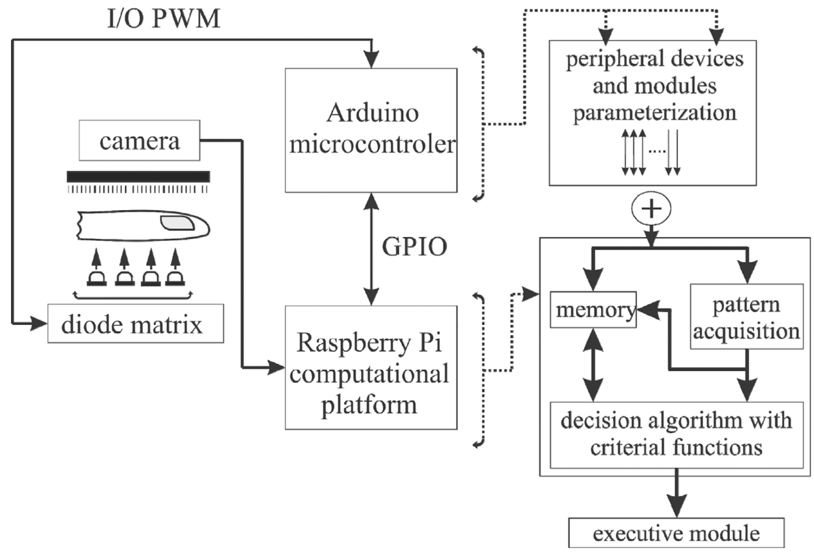

Fig. 2. The general diagram of imaging device.

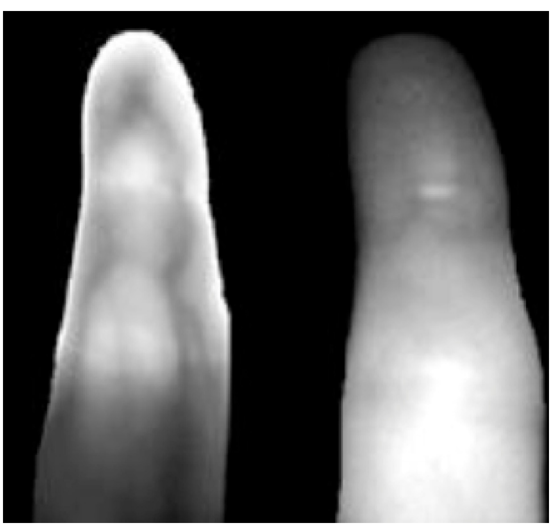

Fig. 3. Imaging techniques: a) light transmission, b) light reflection.

adjustment of diode light intensity. The process is performed iteratively in a feedback loop, wherein the quality of the obtained images is estimated in real-time. Therefore, the selection of a proper quality metric is crucial for the overall efficiency of the acquisition system. The distance transformation approach was used for image quality estimation which provides best results comparing to other methods tested in Ref. [11]. The second technique uses several low dynamic range (LDR) images acquired for different diode light intensities and next forms one high dynamic range (HDR) image. Both techniques can be started independently and user of system decides which one should be used. The software of Raspberry Pi platform performs also algorithmic tasks for image pre-processing, including noise removal, reshaping the histograms, scaling, sharpening, etc.

To present why application of the above techniques is important. Figs. 4–6 present some examples of acquired images. Finger veins obtained in light of 9 different NIR wavelengths is shown in Fig. 4. It can be seen that a degree of vein pattern visibility depends on wavelength. Fig. 5 demonstrates the improvement of the image quality by the second technique described above. There are ten LDR images captured for different light intensities and their transformation to HDR image (first from right) using OpenCV package. First finger from left is invisible due to a low illumination level of NIR diodes. The images of fingers in Fig. 6 come from one of experiments [11] which were performed to test the feedback loop applied in the system for automatic improvement of the image quality. Every second image from the entire series of 20 acquisitions (obtained for 20 levels of backlight intensities) is shown. The algorithm based on distance transformation properly indicates that image number 10 (fifth from right) is the best of this series.

The image from acquisition system is next transferred to the computational-decision unit where software-based processing takes place. Above all, the image must be normalized and region of interest (ROI) is determined. Next, the vein pattern is extracted from the image by the use of segmentation algorithms that leads to mathematical description of a pattern by feature vector. This process significantly decrease data dimension and is crucial for time reduction of classification procedure. All essential component blocks for finger vein identification are shown in Fig. 7.

Described image acquisition system was used to create the GustoDB® database [12] consisting of 11 556 unique finger vein patterns, taken in 3 series from 107 persons (male and female) in age between 19 and 80 years old. All persons are of European origin. Acquisition was performed for light of 9 different wavelengths (730 nm, 808 nm, 850 nm, 860 nm, 875 nm, 880 nm, 890 nm, 940 nm, 950 nm), for 3 fingers (forefinger, middle finger, ring finger) of left and right hand. Each pattern was captured twice for top and bottom side of a finger.

4. Experimental procedure

The database of finger vein patterns and computer software for image processing were used to verify hypothesis if is it possible to determine wavelength of NIR light for which effectiveness of personal identification in a biometric systems is better than for other wavelengths.

All patterns from database were divided into training set and testing set. As mentioned above, the vein pattern of each finger was captured 3 times so two of them were assigned to training set and one to testing set. The pattern assignment to both sets are performed randomly. Next, a special matrix was formed in which testing patterns relate to rows and training patterns relate to columns, thus a matrix has 642 rows and 1284 columns (there are 6 finger patterns for each of 107 persons in the base). A feature vector was extracted from all of patterns and then a matching ratio is cal-

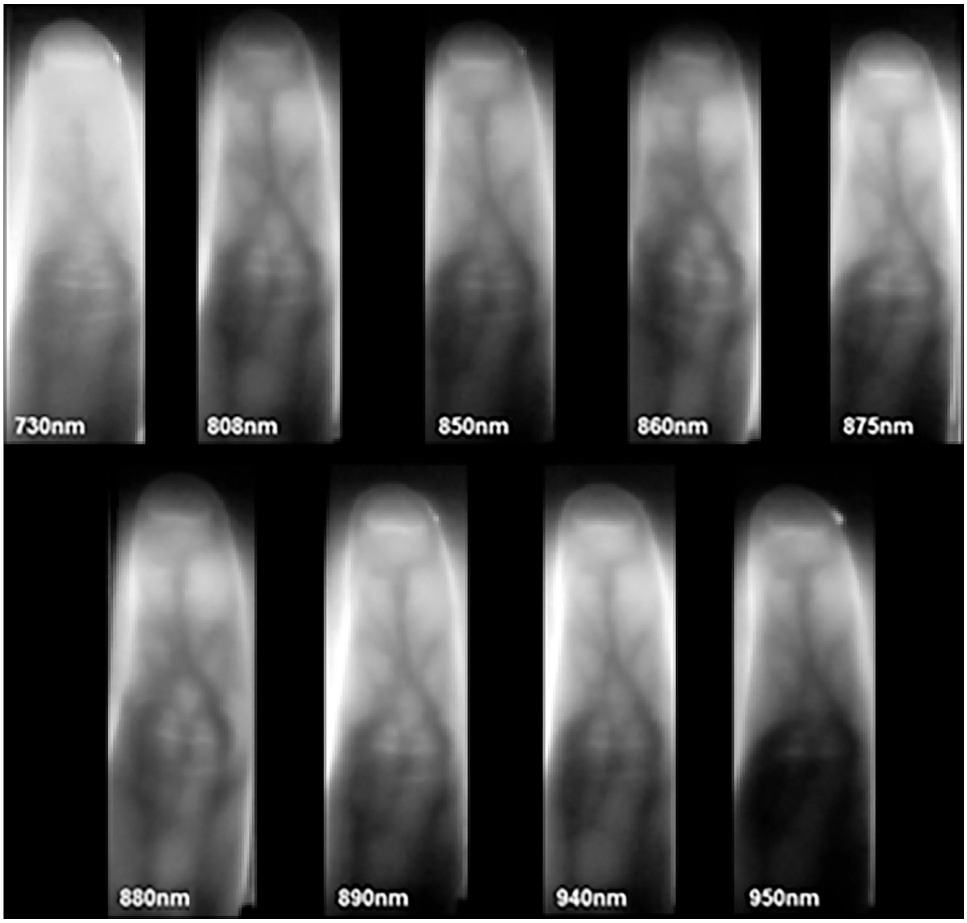

Fig. 4. NIR images obtained for different wavelength.

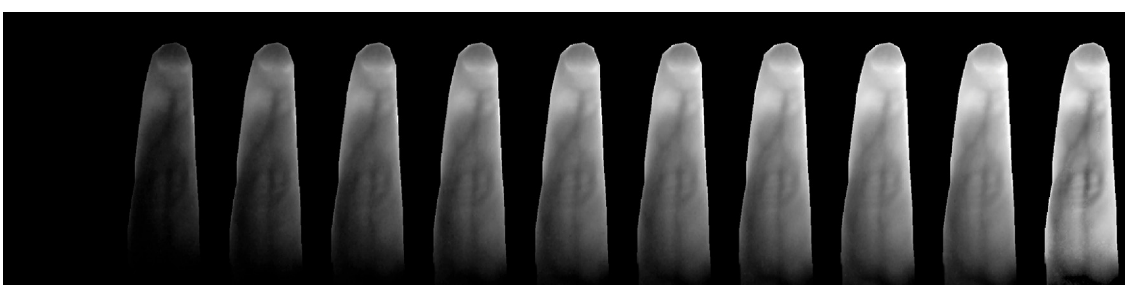

Fig. 5. Ten finger vein LDR images and their transform to HDR image (first from right).

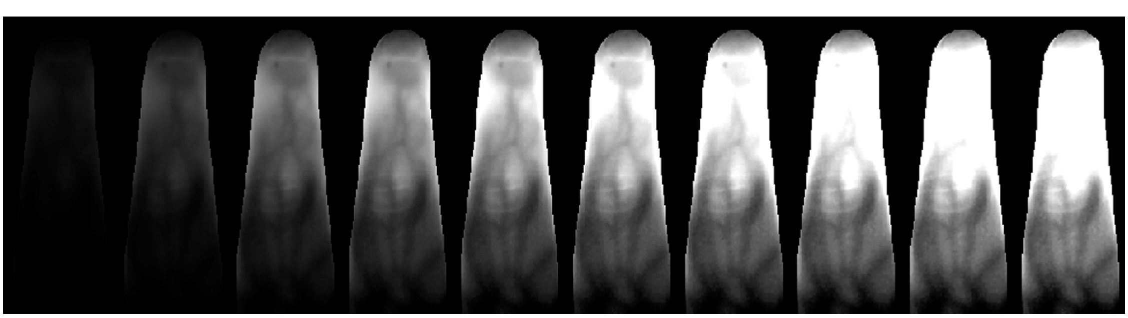

Fig. 6. NIR images obtained for different diodes brightness's.

culated for each element of matrix using five methods of matching techniques, namely Miura match [13], Xiao match [14], modified Hausdorff distance (MHD) [15], matched pixel ratio (MPR) [14] and Hamming distance (HD) [16]. The maximum values of matching ratio was found in all rows which allow to evaluate classification process because the correct decision is *a priori* known.

Table 1
Results of image classification based on Miura match technique.

Average *MaxACC* [%] for Miura match												
	Bottom side of fingers						Top side of fingers					
Wavelength [nm]	DT	PGPC	MC	NAT	RDLT	WD	DT	PGPC	MC	NAT	RDLT	WD
730	83.4	70.2	84.1	68.9	72.8	86.8	84.4	74.1	81.7	70.5	67.9	86.6
808	86.5	86.5	90.3	87.7	89.0	97.4	85.6	93.5	92.6	89.1	88.7	94.3
850	88.8	85.0	84.4	83.8	84.4	95.0	87.6	90.3	90.3	85.4	87.2	93.8
860	91.8	90.6	93.7	92.5	94.3	97.5	87.4	89.1	90.9	83.9	87.8	92.6
875	96.2	92.4	94.9	92.4	95.5	**99.4**	92.6	94.8	93.9	89.2	91.8	96.1
880	88.3	84.6	89.5	87.0	89.5	93.8	91.2	90.8	91.7	88.2	87.7	**96.5**
890	91.8	93.7	91.2	89.9	91.2	98.7	88.6	89.1	90.8	88.6	88.6	93.0
940	90.9	83.5	92.1	87.2	89.0	95.7	83.8	86.3	88.0	83.8	84.2	93.6
950	88.4	85.2	83.9	74.8	73.5	93.5	86.6	82.7	84.8	79.2	79.2	92.6

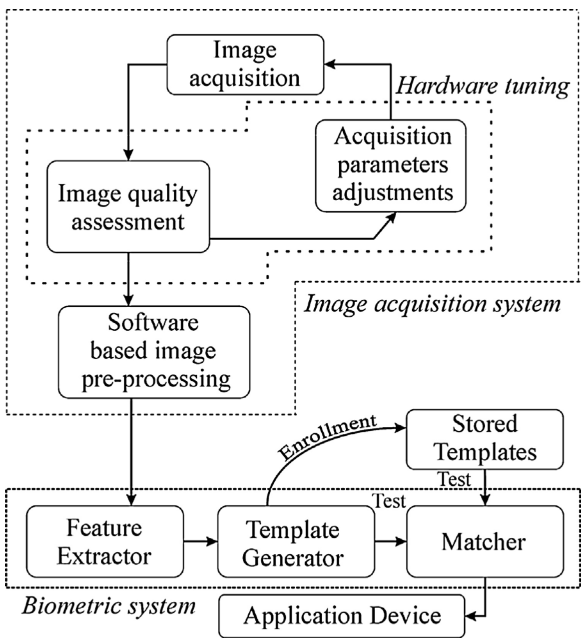

Fig. 7. The block diagram of finger vein biometry system.

Described procedure was repeated for 9 wavelengths of NIR light and for 8 methods of segmentation: Niblack image adaptive thresholding (NAT) [17], repeated dark line tracking (RDLT) [18], maximum curvature points in image profiles (MC) [19], wide line detector (WD) [20], position-gray-profile-curve (PGPC) [21], method based on distance transformation (DT) [12], local binary pattern (LBP) [22] and local derivative pattern (LDP) [23]. However, HD matching was used only with LBP and LDP segmentation methods.

The performance of classification (effectiveness of identification) was measured by accuracy ratio (*ACC*) defined as:

$$ACC = \frac{TP + TN}{TP + TN + FP + FN}$$

where four statistical numbers are used: *TP* – true positive, *TN* – true negative (both for correct person's identification) and *FP* – false positive, *FN* – false negative (both in case of error during the identification).

5. Results

All experiments were performed 500 times for different randomly assigned patterns to training and testing sets and separately for top and bottom side of fingers. The best results achieved are presented within Table 1 where average values of maximum *ACC* (*MaxACC*) for Miura match technique are printed and in more condensed way in Fig. 8 where best outcomes for each applied segmentation method are bolded. Other configurations came out worse so detailed results were omitted and are not presented within this paper. They can be found in Ref. [12] were other quality measures for biometric system evaluation are also presented.

The experiments show that in all cases the wavelength of light has the influence on identification effectiveness. The best efficiency of the biometric systems equals 99.4% (Table 1). It is achieved for bottom side of fingers by light of a wavelength of 875 nm, wide line detector as a segmentation method and Miura match or matched pixel ratio methods used for matching process. A counterpart of this result for top side is evidently worse than for bottom (equals 96.5%) and is obtained for a wavelength of 880 nm (Fig. 8). In most instances to be analyzed the highest values of *MaxACC* are coincided with bottom side of fingers and wide line detector. Comparable, however few percentages lower accuracy coefficients achieved for all non-binary based segmentation techniques. The cases of LBP and LDP segmentation methods together with classification based on Hamming distance came out the worst comparing to other matching modes. Maximum *MaxACC* coefficient for this group (equals 57.6%) achieved for the bottom sight of a finger and a wavelength of 730 nm.

6. Conclusions

Finger vein authentication is a new biometric method used for personal identity verification. It utilizes the vein patterns inside human fingers. This unique aspect allows its adoption by majority of institutions requiring high level of security. In Poland, finger vein products have enjoyed great success in the banking sector, where majority of institutions (top commercial and cooperative banks) have adopted or are adopting within pilots biometric solutions. Since biometric identifiers are unique to individuals, they are more reliable in verifying identity than other techniques such knowledge-based or token-based identification systems. Conducted research has practical applications in security clearance which provides a certain level of assurance as to an individual's suitability to have trusted access to its sensitive applications.

In the paper the vein biometric system is presented. It component, the imaging device, allows to change the wavelength of NIR light and automatically adjust image quality. The system was applied to create GustoDB® patterns database containing 11 556 unique finger vein images, taken from 107 persons and captured for 9 different wavelengths of NIR light. Next, the patterns from database were used to perform experiments which demonstrate the relationship between wavelength of NIR light and effectiveness of personal identification.

This research shows that the highest performance of finger the vein biometric system is achieved for a wavelength in the range from 875 to 890 nm depending on the configuration of used methods and matching strategies. It proves that it is possible to

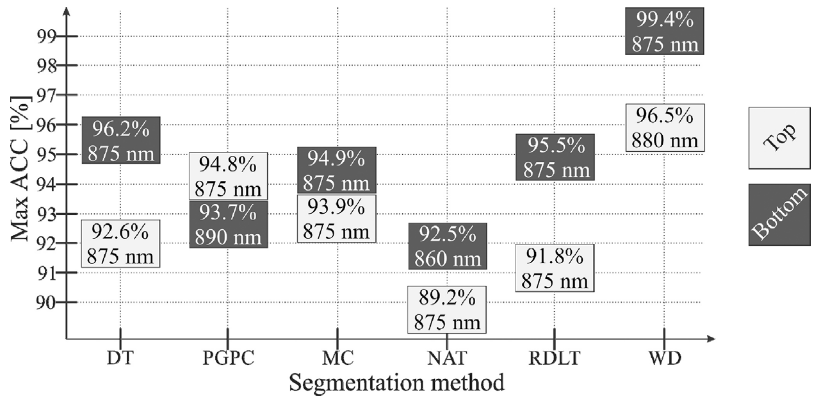

Fig. 8. Outline of the best results achieved for each segmentation method, Miura match technique.

determine wavelength of NIR light for which effectiveness of personal identification in a biometric systems is better than for other wavelengths. Furthermore, it revealed that by careful selection of acquisition parameters (NIR wavelength), segmentation methods and matching strategies it was possible to achieve higher level of biometric system accuracy what directly influence the probability that the biometry system correctly match the input patterns and provide access only to the genuine individuals.

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