ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2010. No. 1(97)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 120 SYSTEM ENGINEERING, COMPUTER TECHNOLOGY
SISTEMŲ INŽINERIJA, KOMPIUTERINĖS TECHNOLOGIJOS

Infrared Imaging System for Analysis of Blood Vessel Structure

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Introduction

Blood vessel imaging and analysis are important tasks for medical and biometric purposes. From the medical point of view human blood vessels give information about health and possible disease or stroke, hence it is important to develop a precise image acquisition system and image processing algorithms. Blood vessel structures can also be used for person identification, for example, palm vein pattern recognition that has become popular in recent years [2]. Human palm veins have a complicated vessel pattern, and are unique among every person. Therefore, it gives a good opportunity to use them for biometric purposes.

Two methods of blood vessel image acquisition in near infrared light will be discussed in this paper. The quality of images acquired by each method will be evaluated to determine the best of the methods used.

Absorption and methods

Most of the popular methods of blood vessel imaging are based on blood infrared (IR) light absorption. To understand the idea of these methods better, properties of IR light absorption in blood vessels is explained next.

Hemoglobin molecule is the primary transporter of oxygen in mammals and many other species. Research shows that hemoglobin in blood leaving the lungs is about 98–99 % saturated with oxygen [1]. It becomes deoxygenated when oxygen is lost at peripheral vessels in the body. Arteries contain oxygenated and veins contain deoxygenated hemoglobin. These two types of hemoglobin have different absorption spectra (Fig. 1).

Deoxygenated hemoglobin absorbs light having a wavelength of about 760 nm within the near-infrared (NIR) area. When capturing an image of a body, vessels will appear darker than the other parts because they absorb IR rays better than the surrounding tissue.

There are two imaging methods for veins that are discussed in this paper: reflection and transmission. There is also an option to use thermal camera to obtain palm vein images [3]. However, such cameras are very expensive, and therefore, they are not discussed here.

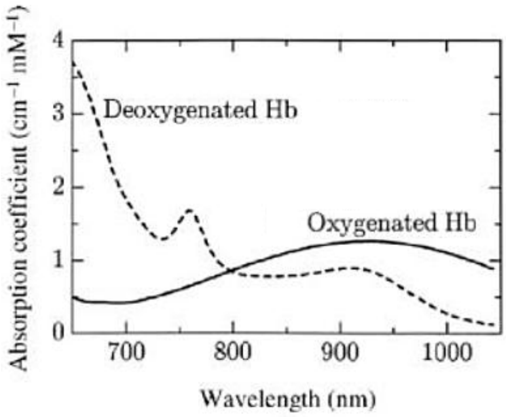

Fig. 1. Absorption spectrum of oxygenated and deoxygenated hemoglobin (Hb) [1]

The reflection method illuminates the target part from the front and the transmission method – from the back, the side, or the surface around the target [2].

In the reflection method palm can be illuminated with IR LEDs, the reflected light filtered with IR filter and the image captured by low-cost charge-couple device (CCD) camera. In transmission method the setup remains the same, except that IR light source is located on the opposite side of the palm. Both imaging methods are evaluated and compared.

Image acquisition system

PC based image acquisition system was developed for experiments. It consists of low cost CCD camera module with good NIR sensitivity [4], IR LED sockets matrix with fast and easy LED replacement option, frosted glass to diffuse emitted IR rays evenly, IR pass filter with 760nm or 850nm transmission wavelength to filter the visible light spectrum, a palm fixing stand and an image acquisition USB module to transfer captured images to PC. Reflection method based system scheme is illustrated in Fig. 2, where: a – camera, b – LED matrix, c – frosted glass, d – IR band pass filter.

Pictures were taken in NIR spectrum. For every experiment ten pictures of palm have been captured.

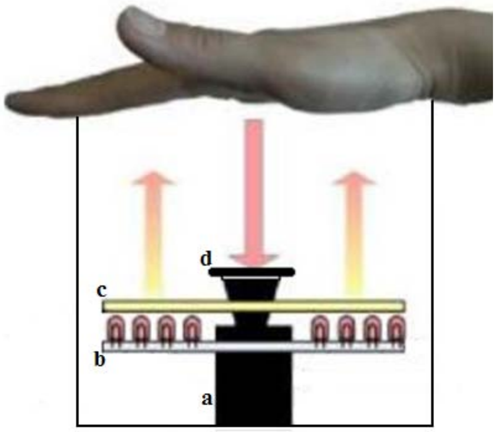

Fig. 2. Image acquisition system setup

Experiments

In the first experiment seven narrow-band IR LEDs with different wavelengths were used. The images for each of the wavelengths from 760–940 nm were acquired using the reflection method. To gain more information about illumination properties of blood vessels no IR filters were used in this experiment.

In the second experiment only two different wavelengths of IR LEDs 760nm and 850nm were used with optical IR filters, to compare the influence of daylight on image quality.

In the next step the reflection and transmission methods were compared. For this experiment the frosted glass and IR LEDs from the camera base platform were not used. Wide spectrum IR light emitter was used to illuminate the palm from the rear side and then the IR images were captured using IR filters (760 or 850nm).

Captured images were analyzed in MATLAB to find the best wavelength, filter and method to capture a blood vessel structure. The image processing and evaluation principles will be explained in the next paragraph.

Evaluation method

There are several ways to evaluate image quality. For example, it can be evaluated by a histogram. This approach gives information about the image contrast and intensity dynamic range. However, it will be hard to specify whether these parameters refer to the palm veins (signal), or to the other objects (noise). Therefore, it is not informative to compare described image acquisition methods by a histogram. It is preferable to obtain information about signal and noise separately.

Image quality might also be evaluated by a signal-to-noise (S/N) ratio. In our case, the standard estimated S/N value is also uninformative, because it includes all noise. However, noise should be divided into significant and insignificant, and the second one ignored.

Image processing usually includes filtration and threshold operations, before the recognition stage. Image filtration attenuates details different from vessels (i.e. image background and noise), and is usually followed by the threshold operation to eliminate them. Those details might be considered as insignificant noise because they are below the threshold level and do not enter the recognition stage. Significant noise contains objects that look similar to blood vessels on the captured image. These include skin wrinkles for the reflection method, and bones for the transmission method.

Insignificant noise should be ignored in evaluation. This would also comply with the purpose of the experiment: to find the optimal IR wavelength, which will display vessels better than the other significant objects.

Therefore, a different approach was developed.

Instead of calculating signal and noise energy as S/N approach does, we work with objects count: n_S (for signal) and n_N (for significant noise).

The main task of the image acquisition system is to capture an image with more vessels, and less noise. Therefore, these two parameters describe the effectiveness of such a system:

1. Purity value:

$$P = \frac{n_S}{n_S + n_N}; \qquad (1)$$

2. Detected vessels count: n_S.

The importance of these parameters for biometric recognition will be explained using an example in Fig. 6.

It is complicated to compare image acquisition methods, by using two parameters simultaneously; therefore we calculate their product and call it “effectiveness index”:

$$E_{ff}(T) = P \cdot n_S = \frac{n_S^2}{n_S + n_N}. \qquad (2)$$

Note, the amount of detected signals and significant noise objects depend on the chosen threshold level T.

For each image, the effectiveness index is observed at different threshold levels, and its maximum is the criteria of evaluation.

Evaluation process

Evaluation process will be demonstrated on the 8-bit image, shown in Fig. 3. Vessels and the other structures are hardly noticeable, because they are only few intensity quantization levels darker than the surrounding background (which will be demonstrated in Fig. 6).

Evaluation process starts with the matched filtering at different mask angles. After examining the parameters of palm vein cross section [6], the appropriate matched filter masks are generated

$$H(u,v) = -\exp\left(-\frac{x'^2}{2\sigma^2}\right) - m, \qquad (3)$$

$$x' = u\cos\varphi + v\sin\varphi, \qquad (4)$$

where H – generated matched filter mask with coordinates u, v; σ – a standard deviation of Gaussian curve; m – mean value of the filter mask; φ ($0 \leq \varphi \leq \pi$) – mask rotation angle. The matched filter will have its peak response only when it is aligned in the same angle with vessel. So the filter needs to be rotated by all possible angles, to obtain more detailed filtration result. Matched filter mask was normalized for the peak response value to be equal with the vessel's effective intensity depth (comparing to the surrounding background intensity level). The result of the matched filtering is shown in Fig. 4. As you can see, image details, including vessels and significant noise are extracted, unlike with the background and insignificant noise. Threshold operation is applied next to eliminate weak responses (insignificant noise). In the experiment it was 20% of the maximum response value. Hereafter, only the signal and significant noise are left (Fig. 5).

Fig. 3. Captured palm image

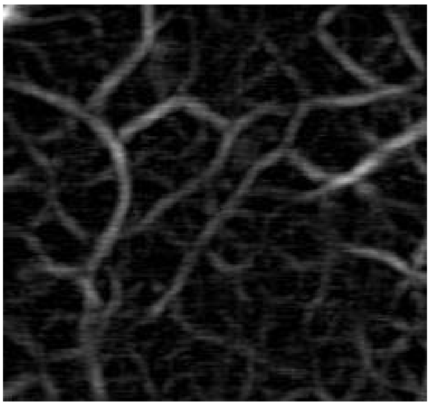

Fig. 4. Image after matched filtering

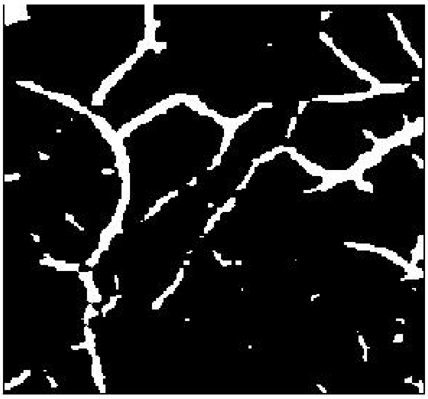

Fig. 5. Segments after thresholding (example)

Now program divides an image into segments by finding line fragments, and the maximum response within each segment is saved. For each segment, this is the maximum threshold value necessary for detecting it – at higher threshold levels segment is not available. Semi-manually segments were divided into vessel and non-vessel ones, and counted at each threshold level. The result is the diagram, similar to Fig. 6, where X-axis represents the threshold T used (also equal to the effective vessel depth, measured in intensity quantization levels); in the first graph Y-axis shows objects count: grey represents vessel segments n_S, black – noise segments n_N; the second graph shows the effectiveness index E_{ff}. At lower threshold levels the count of noise objects increases dramatically and the effectiveness index falls. Further Fig. 6 is used to describe how these parameters relate to biometry.

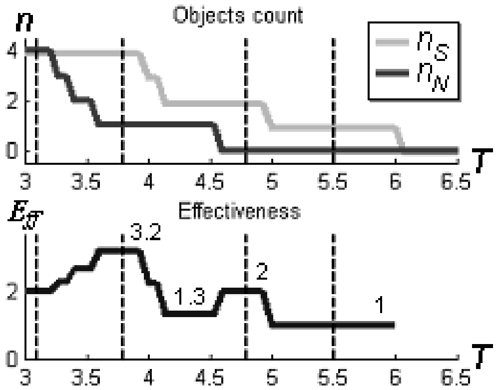

Fig. 6. Segments count and the effectiveness index at different threshold levels (example)

Let's assume that a threshold level is set to 5.5. Then only 1 clear object is found, that is a vessel. Purity is 100% because of noise object absence. However, it is very hard to recognize the person by only one vessel, and the false results are expected. Therefore the effectiveness is low. With the threshold level at 4.8 the effectiveness index is greater, because purity remains 100%, yet we have 2 clear objects. At the threshold level of 4.5 effectiveness index decreases, because the non-vessel objects are considered as noise. Maximum effectiveness index 3.2 is achieved at the threshold level 3.8, when there are 4 vessels and only 1 noise object. Purity is 80%. This is better for recognition and fewer false results can be expected. Similarly, we search for maximum possible effectiveness index for all the acquired images.

For the images with less expressed vessels, the maximum effectiveness index would be lower and the opposite – greater effectiveness index means strongly expressed vessels, comparing to the other image noise. The next chapter will compare both image acquisition methods.

Experimental results

The experimental results (Fig.7.) shown that the image acquisition in infrared light with the transmission method gives better effectiveness index than the reflection method. The standard deviation of effectiveness index lies within the interval between 0.212 and 0.358. System based on the transmission method will be bigger and will consume more power because of the wide infrared spectrum illuminator. If such system is needed, things like power consumption and dimensions must be taken into account. For blood vessel imaging it is preferable to use the transmission method, but it is limited to the parts of a human body where the light can't be illuminated through and the picture captured from the other side.

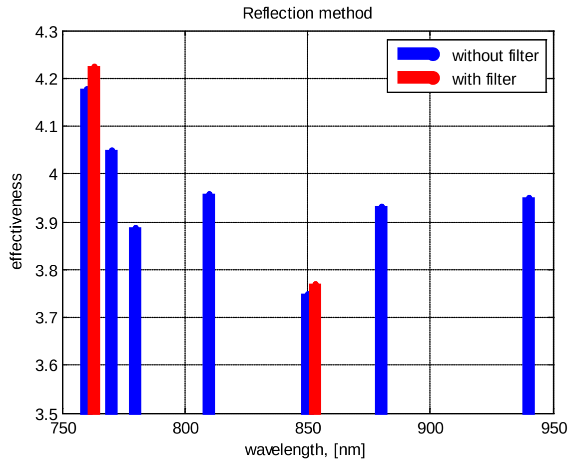

Fig. 7. Experimental results of reflection method

Table 1. Transmission method results

λ, nm	No filter	760	850
Effectiveness index	4,51	4,21	4,63

If the system is used for person identification by its biometric properties, then the reflection method would be the right choice, because smaller and non contact system can be designed. If we use blood vessels for human identification, palm print relief can be used as an extra parameter for analysis.

Conclusions

This paper has introduced an effective approach to acquire infrared images of human palm vein patterns. According experiments have been done to evaluate all methods and compare results. Filtered image quality is evaluated in order to find the best infrared wavelength for palm vein pattern imaging. After calculating the effectiveness index in images, it was shown that the best image quality is with the reflection method when using 760nm IR LEDs with optical filter. It confirms the theory mentioned in the first paragraph (Fig. 1).

Experiments with transmission method gave better results than the reflection method. However, with 760nm filter results were almost same as with the reflection method. The best results with transmission method were acquired with 850 nm filter. Usage of IR optical filter slightly improved the quality of images.

Future plans involve development of biometric person identification system based on the reflection method and image processing algorithm developed before [5].

References

1. **Swarbrick J., Boylan C. J.** Encyclopedia of Pharmaceutical Technology: Volume 19 – Blood Substitutes: Hemoglobin–based Oxygen Carriers to Tablet Evaluation Using Near–Infrared Spectroscopy, Informa Health Care, 1999. – 500 p.
2. **Ratha N. K., Govindaraju V.** Advances in Biometrics: Sensors, Algorithms and Systems. – Springer, 2007. – 508 p.
3. **Fan K. C., Lin C. L.** The Using of Thermal Images of Palm–dorsa Vein–patterns for Biometric Verification // IEEE ICPR, IEEE Computer Society Press, Los Alamitos, 2004. – P. 450–453.
4. Videology B&W Board Camera 21D389 datasheet. http://www.videology.com/media/products/data sheet/20D389/PDS–20D386–20D389.pdf
5. **Greitans M., Pudzs M., Fuksis R.** Object Analysis in Images Using Complex 2D Matched Filters // The IEEE Region 8 EUROCON 2009 Conference. – Saint–Petersburg, Russia, 2009. – P. 1392–1397.
6. **Chaudhuri S., Hatterjee S., Katz N., Nelson M., Goldbaum M.** Detection of Blood Vessels in Retinal Images Using Two–Dimensional Matched Filters // IEEE Transactions on Medical Imaging. – September, 1989. – Vol. 8, No. 3. – P. 263–269.

Received 2009 10 27

R. Fuksis, M. Greitans, O. Nikisins, M. Pudzs. Infrared Imaging System for Analysis of Blood Vessel Structure // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 1(97). – P. 45–48.

In this paper we discuss two basic systems for analysis of blood vessels for biometric purposes. The infrared palm images that contain information about blood vessel structure are taken using 7 different near infrared wavelengths. Ten images for each wavelength have been captured and analyzed. Image quality was determined by image processing and evaluation algorithms and after that IR imaging methods are compared by the implementation and the calculated effectiveness index. Ill. 7, bibl. 6, tabl. 1 (in English; abstracts in English, Russian and Lithuanian).

Р. Фуксис, М. Грейтанс, О. Никисинс, М. Пудз. Инфракрасная система для анализа кровеносных сосудов // Электроника и электротехника. – Каунас: Технология, 2010. – № 1(97). – С. 45–48.

В работе рассматриваются системы анализа кровеносных сосудов, используемые для биометрических целей. Инфракрасные снимки ладони руки, содержащие информацию о структуре кровеносных сосудов, получены двумя разными способами при семи разных длинах волн инфракрасного излучения. Для каждой длины волны проанализированы десять снимков. Качество всех полученных снимков оценено специальным алгоритмом, после чего методы получения снимков сравнены между собой по реализации и по подсчитанному индексу эффективности. Ил. 7, библ. 6, табл. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Fuksis, M. Greitans, O. Nikisins, M. Pudzs. Kraujagyslių struktūros tyrimas taikant infraraudonųjų spindulių vaizdų sistemą // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 1(97). – P. 45–48.

Išnagrinėtos dvi kraujagyslių analizės pagal biometrinius parametrus sistemos. Kraujagyslių analizė atlikta tiriant infraraudonaisiais spinduliais gautus delno vaizdus. Delno vaizdai gauti taikant du skirtingus metodus ir septynių skirtingų ilgių infraraudonųjų spindulių bangas. Tiriant kiekvieno ilgio banga padaryta po 10 vaizdų. Gauti vaizdai įvertinti taikant specialų apdorojimo ir įvertinimo algoritmą. Pagal gautus vaizdus palyginti infraraudonųjų spindulių vaizdų gavimo metodai ir apskaičiuotas efektyvumo indeksas. Il. 7, bibl. 6, lent. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).