

Near-Infrared Mobile Imaging Systems for e-Health

Lighting the Veins

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Abstract—The evaluation of the methods used in image processing techniques with new perspectives has enabled the development of applications to address a wide range of usage areas. One of these perspectives brought to image processing is spectroscopy. Spectroscopy is a method based on obtaining information about the molecular structure of a substance as a result of its interaction with electromagnetic radiation (light photons). In this study, the interaction of haemoglobin in the blood vein structure with near-infrared light photons is utilized. With this interaction, superficial veins can be detected. The results obtained in this study are used to create a system which presents e-health measurements to the user through virtual environment. The system is created in the form of a mobile e-health application via smart devices or tablets. The data obtained by the near-infrared camera is passed through various image processing filters and stages as the software part of the study. In this way, vein structures are obtained. New images will be taken from the same veins of the user at certain time periods. The images taken at different periods will provide information to the user whether these veins have any problems with blood flow. This information will also be shared with the doctor. This procedure is aimed to create a pre-diagnosis data with the calculated mobile measurements.

Keywords - *image processing; near-infrared light; spectroscopy; e-health; virtual pre-diagnosis environment.*

I. INTRODUCTION

As a result of rapidly increasing technological developments, it is revealed that multipurpose systems which can work anywhere any time are extremely necessary. Now, not only desktop computers, but also mobile phones or tablets that we always carry with us as a part of our lives, offer a wide range of applications. Although the most common usage areas of these applications are telephone communication and photo functions, there are also applications covering various fields, such as calculation, notepad, calendar planner, office applications, step counters, and health measurements. Among these applications, health applications are often used for mobile measurement. For example, there are applications which include the measurement of heart rate, the calculation of calorie intake or the daily intake of water, allowing health measurements to be taken.

In terms of wearable devices, specialized devices, such as blood pressure meters or step wristbands, can also be used to make such measurements. Instead of being purchased

separately, such devices can be purchased as an integrated system in a single device which is always preferred by the user.

Health measurements taken via electronic devices are usually carried out by means of customized sensors located on the device. These sensors can take measurements from the outside world by means of motion, vibration, temperature, speed, or position detection. There are also special devices operating with infrared light, which are frequently used in hospitals. These devices are connected to the fingers to monitor the heartbeat.

Vascular access, commonly used in blood tests in hospitals, is an invasive process for the patients. It is among the most common applications used in the field of health. In order to perform this process with less pain for the patient, health personnel should open the vascular system, at the first attempt [1]. This depends both on the experience of the health personnel in this process and some of the characteristics of the patient. Characteristics, such as ethnicity (skin color) or adipose tissue may vary from person to person. These characteristics lead to difficulties in detecting the vein to be opened, while increasing the number of trials and giving more pain to the patient. Facilitating vein detection may result in less painful vascular access. To this point, various devices have been developed commercially and are currently being used in hospitals. However, these devices using Near-InfraRed (NIR) light are not suitable for daily use, as they are only intended for a particular purpose (heart rate measurement or vascular access detection) and are very expensive devices.

Among the commercial devices operating with NIR light, which are currently used in hospitals, VeinViewer, which has two different versions: Veinviewer Vision (the smaller one) and Veinviewer Flex (portable), is used to detect veins in vascular access. The device reflects the superficial vein image obtained with the use of NIR light on the patient's skin, so that the anatomical location of the veins remains the same. AccuVein AV300 is an easy-to-use and a hand-held device used for locating and visualizing superficial veins [9][10][22].

Currently used commercial devices capture the image of the vein with the infrared Charge Coupled Device (CCD) camera. The captured image is processed and reflected back (as NIR vein image) to the skin surface onto which the camera focuses [14].

The main method for vein visualization with infrared light used to obtain images in this study is basically similar to the methods used by commercial devices. However, the study differs from these devices in terms of processing the images and determining the blood flow changes in the veins from the processed images. After processing the images, only the Region Of Interest (ROI) in black-and-white colour format can be seen in the NIR image. The vein shapes obtained from the images will be compared with the vein images taken from the same tissue region of the same person in different periods (weeks or months, depending on the disease to be followed). This way, it is aimed to examine whether the blood flow in the veins within the image has changed or not. At this point, the comparison process will be determined by calculating the differences between these veins (more precisely, haemoglobin in the blood) in the next image taken. If any decrease in the lines representing the blood flow within the veins in the images is to be detected, then an obstruction in the vein will be conveyed to the doctor as a preliminary diagnostic data.

NIR devices which are successful in providing visualization in vascular access, often have high costs. Therefore, they are only used for limited applications (vascular access, vascular visualization) for specific targets in private treatment centers [24][25].

Plastic surgeons and dermatologists applying neurotoxins (Botox, Dysport) and fillers can perform more sensitive injections with AccuVein, which is a vein illuminator device. In addition, complications that may occur after the surgery/application (especially bruises, for aesthetic reasons) can be reduced with these devices [23].

Along with advancing imaging technologies, various vein imaging systems involving the use of NIR light have also been developed for different uses. These systems are able to perform identification procedures, from the palm veins or finger veins by performing vein imaging. Specialized ophthalmoscope systems which use NIR light to detect diseases of the eye veins are also available [2].

In this study, which is prepared within the scope of an ongoing PhD thesis, how to design a NIR vein imaging system that can be used as a mobile e-health application is discussed in terms of hardware and software. Also, the features of the cameras and Light Emitting Diodes (LEDs) that can be used to design such a system have been specified. The software steps that should be passed during the processing of the NIR images obtained by using these cameras have been explained in general. In Section 2, literature review about the use of NIR light is given. In Section 3, the basics of NIR imaging are discussed and their hardware characteristics are explained. In Section 4, the software processing stages of the NIR images to be obtained by using the hardware part of the developed system are mentioned. In Section 5, the steps of developing an

exemplary NIR imaging system are discussed. Finally, the overall summary of the study is given in Section 6.

In Section 2, the literature review related to the studies involving the usage of NIR light is examined.

II. LITERATURE REVIEW

In the majority of studies involving the use of NIR imaging, vein imaging has been addressed for vascular access or safety. Ai et al. [3] combined images from the vein imaging system with augmented reality environment and aimed to reduce the time of intravenous injection. In this way, they determined that they could increase the ejection success rate and the efficiency by the system they developed. Chaio et al. [4] stated that they could provide better clinical care in vein discovery by using VueTek Scientific Veinsite in their superficial vein visualization. They examined how patient characteristics (ethnicity, age, or adipose tissue) affect the vein visibility by the system they developed. Fernandez and Armada [5] emphasized that the guide system they developed for catheter insertion can be used as a robotic guide system in the future. With their proposed multisensory systems, they identified the surrounding veins and paired them on a three-dimensional reconstructed surface. As a result, a complete representation of the vein region was obtained. Asrar et al. [6] compared three different cameras having different light characteristics (using visible light, infrared light and NIR light) for vein recognition to be used in vascular access. As a result, they stated that the most effective results from these cameras were obtained by NIR camera. Zhong et al. [7] examined smartphone security for authentication and developed the veinDeep system. In this system, vein images that uniquely identify the person were obtained by using an infrared depth sensor. They also underlined that, for authentication security, the disadvantages of fingerprints leaving marks on the surface or the human face being easily registered in the public area are not present in vein patterns. Bazrafkan et al. [8] obtained the vein structure map that they used in the authentication system they developed, by using the vein structure in the middle part of the finger. According to their results, they found that image acquisition and fusion methods provided by the system, which can be easily integrated into handheld devices, are suitable for vein imaging. Şeker and Engin [1] created two separate phantoms, liquid and solid, that will mimic human blood and skin. They used plastic tubes instead of the veins through which the liquid phantom would pass. In this way, they developed a system that can be used in vein network analysis with NIR imaging. The advantages of the system they developed include the utilization of non-ionizing radiation, providing a cost-effective design and providing algorithmic simplicity. Elnasir and Shamsuddin [9] reported that, with the help of the palm vein recognition system, which uses NIR light with a wavelength of 850 nm, penetration up to 3.57 mm depth in the palm area was observed. According to the results of the experiments, they stated that the system they designed gave 99.74% recognition rate and 100% verification rate. Shotri et al. [10] argued that a camera hardware capable of detecting NIR light could be developed by configuring an ordinary webcam

to develop a more cost-effective vein imaging system. In addition, the noise on the image due to the use of a webcam with a low imaging capability has been improved by the noise reduction algorithm.

In Section 3, the fundamentals of NIR imaging are discussed and their hardware characteristics are explained.

III. NEAR-INFRARED IMAGING

Light is an electromagnetic radiation including different wavelengths and frequency ranges, which carries energy in the form of photon particles. The diagram formed of these different ranges of the light is known as the electromagnetic spectrum. In this spectrum, "the visible region" that the human eye can detect is the region having wavelength range of about 380-770 nm. The wavelengths of the electromagnetic spectrum covering 380 nm and below are ultraviolet and X-Ray; 770 nm and above are infrared and radio waves [11].

The electromagnetic spectrum region in the wavelengths range of 700-900 nm is defined as the NIR optical window because it is located near the visible region [12][13].

When light energy strikes a matter, the matter exhibits different interactions with respect to the molecules that make it up. As a result of examining these interactions, the method of obtaining information about the molecules that make up the substance is called spectroscopy [11].

The spectroscopy method which provides information from the substance was the basis for imaging of blood veins.

The radiation in the NIR optical window is scattered by direct penetration into the lower layers by tissues, such as skin and adipose layer with low absorption coefficient. On the other hand, blood mostly absorbs these NIR photons due to its haemoglobin molecules. NIR photons are absorbed slightly by oxygenated haemoglobin in arteries and strongly absorbed by deoxygenated haemoglobin [1][12][15].

NIR spectroscopy, in other words, the visualization of blood veins with the use of NIR radiation, requires cameras that have different characteristics than ordinary cameras used in daily life. NIR systems use cameras with infrared-pass filters (which allow these rays to reach the camera lens) instead of the filter that blocks NIR rays in ordinary cameras [14].

The improved work is designed with an external infrared camera integrated into a mobile device (smartphone or tablet). The built-in cameras in all smart devices currently available on the market, designed for daily use, have a filter that allows visible light to pass through, but prevents the passage of NIR light. However, the method of vascular imaging to be used in this study is based on the detection of NIR light. From this point of view, there are two methods for the user to get a NIR image with his/her mobile device. Either in a professional manner, it should be carefully interfered with the mobile device camera (NIR light blocking filter should be removed and replaced with NIR light passing filter), or an external camera should be integrated to a mobile device via USB support. In the study, a USB-powered NIR camera integrated into the mobile device was used. With this NIR camera, the users have the ability to take their own images and send them to the server computer with a mobile

application prepared with Android Studio [20] within the scope of the study. The images transferred to the server computer were processed with the MATLAB [21] program and the vein images consisting of black and white colors were recorded. The parts representing the veins in these recorded images were examined. The results (investigating if the pixel values representing the blood vein have changed or not in the next image) obtained by processing these images, which the user will periodically capture and transfer to the server, will be sent to the doctor as preliminary diagnostic data and to the user for information purposes via the server.

From the hardware perspective, in the NIR imaging process, the tissue to be imaged is illuminated by a NIR LED (700-900nm) or laser light. The skin layer passes most of these light photons towards the lower layers, whereas the haemoglobin in the veins absorb it. Therefore, in the NIR image taken by the camera, parts of the reflected photons appear light-colored. The other dark parts represent the veins. [1]

Lingyu and Leedman [15] found that the optimal infrared image was at 800 nm wavelength. They obtained hand dorsum, palm and wrist images using NIR LEDs having this wavelength. Bazrafkan et al. [8] used 10 NIR LEDs with 940 nm wavelength in their studies. Şeker and Engin [1] worked with 875-940 nm NIR LED which they placed in a ring form. Shetri et al. [10] stated that, in order to develop a cost-effective vein imaging system, the best illumination can be provided with an IR sensitive webcam in the middle and concentric LED placement around it. Seymen et al. [16], in order to make the veins more prominent, they suggested making the participants carry 3 kg weighted bags, squeeze elastic ball for 1 minute and put ice on the hands before hand photographs were taken. In this way, they aimed to facilitate vein detection in needle and laser applications.

In Section 4, the software processing parts of the NIR images to be obtained by using the hardware part of the developed system are mentioned.

IV. PROCESSING NEAR-INFRARED IMAGES

Digital image processing is based on the processing and modification of digital images in electronic media by various ways [17].

The processing of an image basically takes 5 steps; (1) The image is transferred to digital media with a hardware, such as camera or scanner that can record in desired format (NIR image, thermal image, etc.), (2) Defects caused by camera or ambient lighting on the raw image transferred to digital media are eliminated by pre-processing (noise removal, contrast enhancement, etc.), (3) In the pre-corrected image, the parts of the target area of interest (defined as ROI) are separated from the rest of the image, (4) Identification of the parts that have formed specific patterns (corner, curve, etc.) on the ROI, (5) Making inferences on the identified patterns by various methods (machine learning, data mining, etc.) [18]. Bazrafkan et al. [8] determined that the vein image was best obtained from the second region in their NIR finger images, by developing a biometric authentication system with a finger vein map. In order to obtain the vein details, first the High Pass Filter in the frequency domain was used

and then the median filter was applied. Finally, vein structures were extracted with the Gabor filter. Zhong et al. [7] obtained vein patterns from the NIR image with the adaptive threshold filter and eliminated the background with the depth threshold filter. They created references as key points from the vein patterns they obtained, and compared these reference points with test vein patterns and calculated similarity score. Francis et al. [19] performed the software part of the system developed for the detection of blood veins in the forearm in 9 steps; (1) Conversion of the NIR image to a gray-level image, (2) Noise elimination with median filter, (3) Gaussian filter for smoothing, (4) Adjusting the intensity of images with Contrast Limited Adaptive Histogram Equalization (CLAHE), (5) Detection of vein edges with the Gabor filter, (6) Separation of veins and other tissues by Otsu's thresholding method, (7) Sharpening of vein shapes by morphological procedures, (8) Obtaining the ROI, (9) Enhancing the vein image for real-time application.

In Section 5, the steps of developing an exemplary NIR imaging system are discussed.

V. APPLICATION

The ongoing doctoral dissertation which includes a NIR vein imaging system, consists of two parts as hardware and software, as shown in Figure 1.

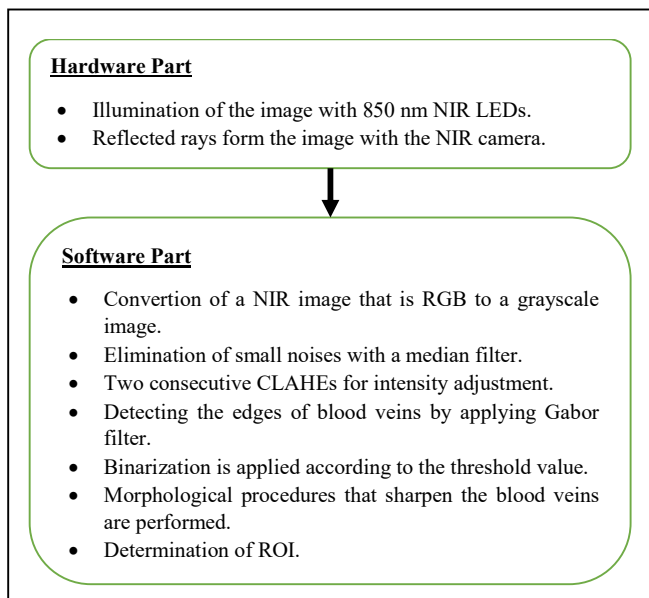


Figure 1. Hardware and software parts of the study, and their contents.

In the hardware part, the tissue to be imaged is illuminated by NIR LEDs having a wavelength of 850 nm. When NIR photons pass through adipose and skin tissue, haemoglobin in the blood absorbs them when they penetrate intravenously. The back-reflected photons are detected by the NIR camera to produce a NIR image of the illuminated portion of the tissue.

In the software part, the steps in Francis et al. [19] work are used. In this section, firstly the Red-Green-Blue (RGB) image obtained in three-dimensional format is rendered two-

dimensional (including 0 and 1) as grayscale. Secondly, salt and pepper type small noises are eliminated by applying the median filter. In the third step, in order to adjust intensity, CLAHE algorithm is utilized twice in a row and the contrast of the grayscale image is enhanced. With a re-application of the median filter, the small noise that may occur in this stage is also eliminated. In the fourth step, by applying Gabor filter, the edges of blood veins are detected. In the step five, with the binarization process used, the grayscale image is converted to include only black and white images according to the threshold value, and the blood vein and the surrounding tissue can be extracted from each other. In the sixth step, morphological processes (line-shaped shapes show vein structures better) are applied as pixel insertion or deletion in order to make the blood veins more specific and to show their shapes more sharply. In the last step, the ROI part, which will be studied in more detail on the vein image, is separated from the other sections by considering pixel coordinates.

In this study, the raw NIR image of the forearm with ROI extraction is given in Figure 2. Unlike the working steps of Francis et al.[19], first the ROI was determined and then the image processing part was applied. In Figure 3, the NIR image passing through the filter stages is depicted. The image that has been converted to the black-and-white colour format through the image processing stages is given in Figure 4. The image given in Figure 4 obtained at the stage of vein extraction of the study will be further improved in terms of image processing within the scope of future studies, and the vein structures will be made less discontinuous and more distinctive.



Figure 2. Raw NIR image with ROI extraction.



Figure 3. NIR image passed through filter stages.



Figure 4. NIR image in black and white format.

In Section 6, an overall summary of the study is given.

VI. CONCLUSION AND FUTURE WORK

In commercially or academically developed vein imaging systems, NIR imaging technique is generally used. In terms of user health, the NIR imaging technique is mostly preferred since it does not give harmful beams to the user as in the X-ray or tomography. Moreover, since it is very easy to obtain or create NIR cameras (it is possible to obtain a NIR camera by removing the IR-Cut filter that blocks NIR rays in the ordinary webcam and replacing it with the IR-Pass filter), it is possible to come across numerous studies in the literature with vein imaging systems using such cameras. Most studies on vein imaging are the basis for security systems using vein pattern recognition infrastructure. In this study, which is currently being developed within the scope of a PhD thesis, the hardware and software steps used to develop a vein imaging system to be used for mobile measurements via smart devices are described. In the hardware part, the wavelength range of the NIR technique and the NIR device to be used is specified, and it is explained that the acquired images are generated by the spectroscopy technique. In the software part, in the guidance of a study in the literature which software filters and image processing parts should be applied in order to make the vein images extracted from NIR images more specific is explained and the obtained preliminary examples of the processed images are given.

Within the scope of future studies, the developed system will be used to monitor patients who may have suspected vascular occlusion. Periodically, NIR images can be obtained from patients anytime anywhere by using NIR camera which is integrated with a mobile device (via smartphone or tablet) and personal vein databases will be created in this way. Following the processing of the images and the steps in the software part, the doctor will be notified of any vascular occlusion, and, this way, preliminary information is presented to the doctor and possible delays in treatment are avoided. The blood flow changes detected in the images along with the blood flow rates and numerical values after calculation will be reported both to the doctor and the user via server by e-mail.

REFERENCES

- [1] K. Seker and M. Engin, "Deep tissue near-infrared imaging for vascular network analysis", *Journal of Innovative Optical Health Sciences*, *Journal of Innovative Optical Health Sciences*, 10 (3), pp. 1650051.1-12, 2016.
- [2] K. Yılmaz, "The design of a new portable ophthalmoscope and utilization of the device for diagnosis and identification", *Doctoral Dissertation*, Ege University, The Graduate School of Natural and Applied Sciences, 2014.
- [3] D. Ai et. al., "Augmented reality based real-time subcutaneous vein imaging system", *Biomedical Optics Express*, 7 (7), pp. 2565-2585, 2016.
- [4] F. B. Chiao et. al., "Vein visualization: Patient characteristic factors and efficacy of a new infrared vein finder technology", *British journal of anaesthesia*, 110 (6), pp. 966-971, 2013.
- [5] R. Fernández and M. Armada, "Multisensory system for the detection and localization of peripheral subcutaneous veins", *Sensors*, 17 (4), pp. 897,1-16, 2017.
- [6] M. Asrar, A. Al-Habaibeh, and M. Houda, "Innovative algorithm to evaluate the capabilities of visual, near infrared, and infrared technologies for the detection of veins for intravenous cannulation", *Applied Optics*, 55 (34), pp. D67-D75, 2016.
- [7] H. Zhong, S. S. Kanhere, and C. T. Chou, "VeinDeep: Smartphone unlock using vein patterns", In *Pervasive Computing and Communications (PerCom)*, IEEE International Conference on, pp. 2-10. IEEE, March 2017.
- [8] S. Bazrafkan, T. Nedelcu, C. Costache, and P. Corcoran, "Finger vein biometric: Smartphone footprint prototype with vein map extraction using computational imaging techniques", In *Consumer Electronics (ICCE)*, 2016 IEEE International Conference on, pp. 512-513. IEEE, January 2016.
- [9] S. Elnasir and S. M. Shamsuddin, "Palm vein recognition based on 2D-discrete wavelet transform and linear discrimination analysis", *Int. J. Advance Soft Compu. Appl*, 6 (3), pp. 43-59, 2014.
- [10] A. Shrotri, S. C. Rethrekar, M. H. Patil, and S. N. Kore, "IR-webcam imaging and vascular pattern analysis towards hand vein authentication", In *Computer and Automation Engineering (ICCAE)*, 2010 The 2nd International Conference on, 5, pp. 876-880. IEEE, February 2010.
- [11] Introduction to spectroscopy. [Online]. Available from: <https://edu.rsc.org/download?ac=11384> [retrieved: 03, 2020]
- [12] H. Rao, P. Zhang, and C. Sun, "Contrast enhancement for the infrared vein image of leg based on the optical angular spectrum theory", *Signal, Image and Video Processing*, 11 (3), pp. 423-429, 2017.
- [13] S. Crisan, "A novel perspective on hand vein patterns for biometric recognition: Problems, challenges, and implementations", In *Biometric Security and Privacy*, pp. 21-49. Springer International Publishing, 2017.
- [14] S. Sawant, Turn webcam to IR sensitive camera. [Online]. Available from: <http://www.instructables.com/id/turn-webcam-to-IR-sensitive-camera/> [retrieved: 03, 2020]
- [15] W. Lingyu and G. Leedham, "Near-and far-infrared imaging for vein pattern biometrics", In *Video and Signal Based Surveillance, AVSS'06*. IEEE International Conference on, pp. 52-52. IEEE, November 2006.
- [16] V. Seymen, Ö. F. Boyraz, Ö. Çetin, and M. Z. Yıldız, "Hand-vein pattern detection from infrared images", *2nd International Symposium on Innovative Technologies in Engineering and Science (ISITES)*, Karabük, pp. 722-729, 2014.
- [17] O. Marques, *Practical image and video processing using MATLAB*: John Wiley & Sons, 2011.
- [18] A. McAndrew, An introduction to digital image processing with Matlab: Notes for SCM2511 image processing 1, School of Computer Science and Mathematics, Victoria University of Technology, 2004 [Online]. Available from: <http://www.math.hkbu.edu.hk/~zeng/Teaching/math3615/ls.pdf> [retrieved: 03, 2020]
- [19] M. Francis, A. Jose, and K. K. Avinash, "A novel technique for forearm blood vein detection and enhancement", *Biomedical Research*, 28 (7), pp. 2913-2919, 2017.
- [20] Android Studio Official Website. [Online]. Available from: <https://developer.android.com/studio> [retrieved: 03, 2020]
- [21] MATLAB Official Website. [Online]. Available from: <https://www.mathworks.com/> [retrieved: 03, 2020]