An Efficient Method for Subcutaneous Veins Localization Using Near Infrared Imaging

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***Abstract*- In the majority of the medical treatments, intravenous catheterization is the most important phase in which skilled medical practitioners locate the best vein and perform catheterization process for medication or blood sampling. Due to the different physiological characteristics, mainly darker skin tone, scars or dehydrated condition of patients, medical staff stumbles in localization of veins. This paper proposes an enhanced method which intends to overcome the difficulty faced by medical staff in veins localization for intravenous catheterization. Using the Near Infrared imaging and image processing algorithms a novel approach for veins visualization is proposed. In order to have complete insight of veins location in the subcutaneous layer of skin a method to estimate the depth of veins using Monte Carlo simulations is presented. The complete system will increase guidance towards medical practitioners to facilitate the insertion of catheter or syringe into the veins.**

Keywords: Intravenous, catheterization, multispectral, NIR, PCA

I. INTRODUCTION

Current medical treatments mostly depend on invasive medications or blood sampling through venipuncture and intravenous (IV) catheterization process. These tasks are carried out by trained medical staffs who locate the veins either by sight or in difficult cases by merely feelings of fingers. Due to many physiological differences including skin tone, veins depth, scars, presence of hair etc, the medical staff often faces difficulties and stumbles in veins localization. Therefore, it either increases the number of attempts and/or results in skin bruising or veins damage. Studies reported that 2.18 venipuncture attempts are required on average per patient who needs IV medication [1]. The patients (especially infants) suffer a lot of pain due to the multiple attempts for catheter insertion. A very serious consequence of unsuccessful attempt for venipuncture is the delivery of medication to the tissues surrounding the IV catheter. This may result in infiltration and extravasations which may lead to surgical intervention [2].

There are few devices and techniques like Computed Tomography (CT) scan, Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI) and Ultrasound that can be used for veins localization. However these techniques are expensive, bulky and take longer time to perform. Hence these methods are not suitable for subcutaneous veins localization in daily clinical practices.

For the normal catheterization/ blood sampling process; it is required to localize the subcutaneous veins present in hypodermis which is the third layer of skin.

This paper proposed a novel technique which is meant for localization of subcutaneous veins in a cost effective, efficient and ergonomic approach. Based on near infrared (NIR) technology, the system will be able to overcome the skin tone problem. The method for veins depth estimation based on Monte Carlo simulations and tissue phantoms is also described. A multispectral dataset has been created by acquiring the lower arm images of 80 subjects having different physiological characteristics mainly skin tone. Through principal component analysis (PCA) technique, multispectral images have been analyzed. With the application of PCA on high dimensional multispectral images, dimensionality is reduced and high contrast images are created with first component of PCA. The optimum wavelength combination within the NIR range used to illuminate the targeted area of skin. In this way proposed method is suitable for patients with different physiological characteristics. This optimum wavelength is determined by experimentation on multispectral data. Veins detection algorithms are being tested to enhance and display the blood vessels. The depth of veins will be approximated by a method using the Monte Carlo Simulations.

Rest of paper is organized as follows: In Section II, current state of the art for the veins localization techniques is presented. Section III presents the veins detection and depth estimation methods. The initial results are being presented in Section IV of this paper.

II. STATE OF THE ART

In literature there are mainly three different techniques for subcutaneous veins localization namely Transillumination, Photoacoustic and Near Infrared Imaging technique.

A. Transillumination Technique: This technique uses a single wavelength from visible range of the electromagnetic spectrum to illuminate the targeted area of the skin. A direct contact of the device to the patient's skin is needed.
Veinlite (TransLite LLC, Sugar Land, TX) [3], Venoscope (Venoscope, Lafayette, LA), Wee Sight (Children's Medical Ventures, Monroeville, PA) and Vein Locator (Sharn Inc., Tampa, FL) are devices using transillumination technique to localize the subcutaneous veins and can be used in IV

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catheterization process. The major drawback of transillumination technique is the need of direct contact with the skin of patient which may lead to spread of viruses and bacteria from patient to patient. Hence they require the costly process of cleaning and disinfection before every use. The single visible wavelength used in these devices may not be suitable for the veins localization process all the times due to limitation in penetration depth in the skin tissues [4-6].

B. Photoacoustic technique: This technique uses light and ultrasound waves to obtain the real time high resolution image of the blood vessels. The images obtained from this technique provide information on depth and diameter but not about the position, shape and orientation. This technique is very sensitive to the spread chaos waves, which is a phenomenon that tends to generate echo signal and thus significantly reduce the signal to noise ratio (SNR) [7-9]. The systems using this technique are complex and larger. The operating cost is also high due to the application of ultrasonic gel to reduce environmental noise.

C. NIR imaging technique: NIR Imaging system works on the principle of light propagation i.e. absorption, reflection and scattering. In the low absorption window (see Fig.1) light penetrates deeper inside the skin tissues. Subcutaneous veins lies in the third layer of skin hypodermis, on an average depth of 2-4mm depending on the physical characteristics of a person and the location of skin present on the body. For example the skin on the back is much thicker as compared to the skin on the forearm.On the basis of absorption and reflectance spectra of skin tissues and De-oxygenated hemoglobin (Hb) present in veins, skin tissues can be separated from the veins. Consequently, in the resulting images veins appear darker compared to skin tissues due to high absorption of Hb in NIR range.

NIR imaging has vast applications in biomedical field and has several advantages over the other radiological methods used for medical spectroscopy. The radiations are non-ionizing therefore can be applied several times on patients without any harmful effects to subject on which it is applied. NIR imaging is very cost effective; hence systems using this technique can be used in majority of hospitals and clinics. Through optical methods skin tissues can be differentiated from veins based on their respective reflection, absorption and scattering coefficients. The noninvasive capability of this technique leads to its widely acceptance in the field of biomedical applications. All these advantages make the NIR technique as most suitable technique for subcutaneous veins localization.

A few devices have been reported till now which use NIR imaging techniques for subcutaneous veins localization. The most well-known is VeinViewer by Luminetx Corp [11-12]. This device uses the wavelength of 740 nm and digital NIR sensitive camera to capture the image. A image processing algorithm is used to approximate the position of veins and a binary image is retro-projected on to the surface of the skin using green light. This device works well for normal patients, but suffers to improve the quality in medical care in the patients having different physiological characteristics like dark skin tone, hair, scars on the skin etc.

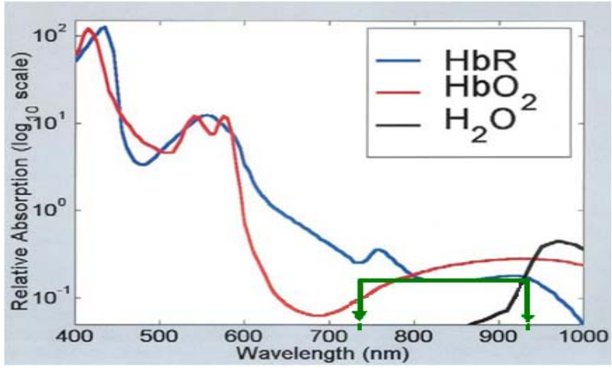

Figure 1: Absorption factors of primary absorbers: Hemoglobin, Oxygenated Hemoglobin and Water [10]. Green arrows highlight the low absorption window.

This problem arises due to the use of single wavelength in the device to illuminate the targeted area of skin. Determining the width of veins is the most important step in choosing the best vein for catheterization process. Using VeinViewer it is impossible to define an accurate measurement of the width of veins. The reflectance values measured at the surface are correlated to the depth of the veins [13]. The ratio of reflected and absorbed light is increasing with deeper depth. At a certain point the intensity variation between veins and skin area becomes minimal. If this situation occurs, image processing algorithm used in this device will not be able to detect the veins. Accordingly this device is not suitable for veins localization of a patient having deeper veins.

A latest device called Veebot (Veebot LLC) is recently introduced by a team of researchers which reportedly can localize the vein with an accuracy of 83%. This robotic device uses NIR imaging to localize the veins and ultrasound to confirm the blood flow in the selected vein [14]. The shortcoming in this device is that it does not provide information about the depth of veins. Furthermore cleaning process after every use is necessary to prevent infections to spread from one patient to other.

This paper proposes the novel method for subcutaneous veins localization, based on NIR imaging.

III. VEINS DETECTION AND DEPTH ESTIMATION

Veins detection and the depth estimation are two important steps in our proposed technique.

A. Veins detection

Veins are like curvilinear structures present in the third layer of skin known as hypodermis. Using NIR camera with NIR illumination we acquire the image of fore arm of subjects. In these acquired images veins appear darker as compared to the due to higher absorption as compared skin tissue to skin with the acquisition system, we have to classify veins from the other skin tissues. There are several methods in literature to detect the curvilinear structure from the given biomedical images. Out of these, matched filters based method is widely used to detect the curvilinear structures [15-17]. Currently we are investigating the state of the art Frangi's vessel detection algorithm, to detect the centerline of veins to choose the proper, wide enough vein that matches the catheter to be inserted [18, 19]. This algorithm is based on differential geometrical properties (Hessian) of the image. This algorithm has the low computational complexity and almost similar performance as compared to other standard comparable vessel enhancement algorithms.

B. Depth estimation

Depth plays important role in the visibility and localization of veins. Patients having deep veins due to the presence of high fats in the body have veins non-visibility problem. In order to ensure the accurate catheterization the visualization of veins is not enough; information about the depth of veins have to be provided. Veins depth estimation method using Monte Carlo simulations and tissue phantoms is proposed by measuring diffused reflectance, absorption and transmission factors. In next section the initial results of Monte Carlo Multilayered media (mcml) simulations are presented. Human skin has three main layers namely: epidermis, dermis and hypodermis. The veins which are used for medication and blood sampling in daily clinical practices are located in the third layer of skin, i.e. Hypodermis. The layered structure of skin is modeled by the simulations and by measuring the reflectance, absorption and transmission parameters, and the depth of veins can be estimated. Tissue phantoms will be built using materials that have similar optical properties of skin and veins (de-oxygenated hemoglobin). These phantoms can be used to validate the results from Monte Carlo simulations for veins depth estimation.

IV. INITIAL EXPERIMENTS AND RESULTS

The simulation of light propagation in tissues is performed using publically available mcml code [20, 21]. Three layers of skin have been simulated featuring the parameters given in Table.1. The depth of third layer was increased by the factor of 0.01 cm in each of 18 simulations. The number photons used in simulations were 250, 00,000. Currently in the chosen layers for simulation the third layer is presumed to contain the blood vessels. The parameters for simulation were chosen to represent the optical properties of human skin layers at 800nm wavelength [22, 23]. An average thickness for each layer has been chosen for experimental purpose to highlight the changes in factors like diffused reflection, absorption and transmission fraction with depth variation. The simulation results are depicted in Fig.2.

Table.1: MCML SIMULATION PARAMETERS

Layer No	Refract-ive index (n)	Absorption coefficient (μa- cm^{-1})	Scattering coefficient (μs-cm^{-1})	Anisotropy factor (g)	Thickn-ess (mm)
1	1.34	4.0	90	0.85	0.2
2	1.40	0.8	100	0.85	3.0
3	1.44	1.36	90	0.8	0.1-1.8

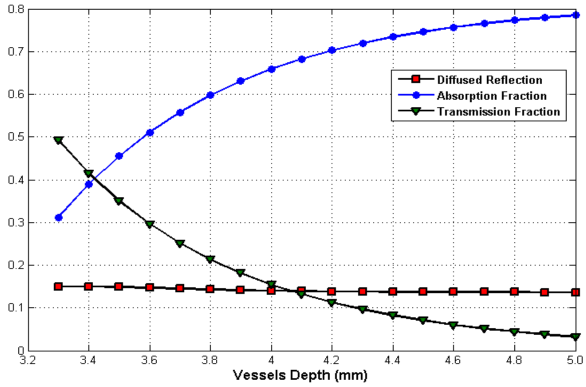

Figure 2: Results from Monte Carlo simulations (18 runs). Thickness of third layer (including blood vessels) is incremented from 0.1 to 1.8 mm, making range of the depth of vessels from 3.2 to 5 mm.

By measuring the factors of diffused reflection, absorption and transmission fractions; the depth of veins present in the subcutaneous layer of skin can estimated with a proper mathematical model. In future work, the experiments will be reproduced on tissue phantoms which include veins in its layered structure in order to assess the accuracy of the estimation.

With Specim® multispectral camera, a data base of lower arm images of 80 subjects having different skin tone has been created. This camera provides multispectral images with the spectral range from 382 to 1055nm with spectral resolution of less than 2nm. That includes the whole visible spectrum and NIR range. For Illumination halogen projector lamp has been used. This projector provides a stable illumination ranging from 350 to 2500nm range. The multispectral images obtained with this setup are in the form of cubes, having high dimensionality. These multispectral images are then analyzed using PCA, a technique to identify patterns and to reduce dimensionality. Fig. 3 exhibits the results of PCA for four subjects having different skin tone. Resulting images are obtained by reconstructing the cube with the first principle component, which contain the highest energy. Hence the dimensionality of multispectral images is reduced, tissue/veins contrast is enhanced and veins can be visualized in the resulting images. Examining the Eigen vectors obtained from PCA, we can define the suitable range of wavelengths for each of the skin type.

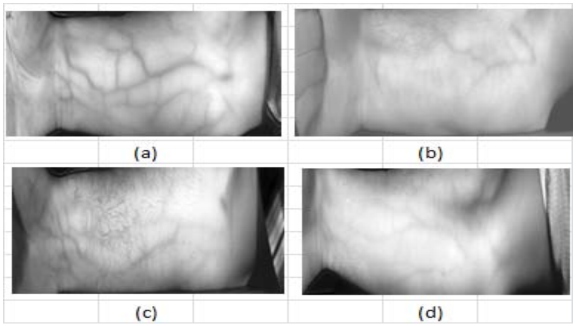

Figure 3: Results from PCA applied on multispectral image of 4 subjects having different skin tone. (a) Fair, (b) Light brown, (c) Dark brown and (d) Dark

The optimum combination of wavelengths will be investigated for subjects having different skin tone in order to design low cost and compact illumination for the image acquisition system.

V. CONCLUSION

This paper introduced a novel technique for subcutaneous veins localization based on NIR imaging. The approach is to illuminate the scene with optimized wavelength combination, and capture the image using NIR sensitive camera. Depth information of veins will be provided in order to avoid incorrect catheterization. Through Monte Carlo simulations we presented a method for the estimation of veins depth by measuring the parameters of simulated light. The analysis of multispectral images using PCA has been performed, and the results are presented as enhanced contrast between veins and the skin tissues with lower dimensionality. In future work we are investigating multispectral images, to select the optimum wavelengths combination where we get maximum reflectance contrast for each skin tone.

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