Subcutaneous Veins Detection and Backprojection Method Using Frangi Vesselness Filter

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***Abstract*— Blood vessels detection is a common task performed in numerous medical procedures. During regular medical treatments venipuncture procedures are performed for invasive medication and blood sampling. Near infrared imaging technology can be used to visualize the subcutaneous veins in cases of difficult venous access. In this paper the methods for veins centerline detection and back projection is presented. In order to highlight the suitable veins for venipuncture, the centerline of larger veins are detected and back projected to the original image. The method is applied on the near infrared images of subjects selected from four different classes of skin tone. This can be helpful to medical staff to select suitable vein for venipuncture procedures. The method is based on Frangi vesselness filter for 2D images. The artifacts like hair and small vessel-like structures are removed with morphological operations. The presented method shows consistent performance in terms of vascular structure detection for all skin tone classes.**

***Index Terms*— Subcutaneous Veins; Near Infrared imaging; Frangi vesselness; venipuncture; hessian.**

I. INTRODUCTION

Blood vessel segmentation and localization is a common task performed in several medical procedures. Several modalities are used to acquire the image of human vascular structure in different parts of body. The most common techniques are; computed tomography (CT), magnetic resonance imaging (MRI) and X-Rays (angiograms). These are used to visualize the deeper blood vessels for examination and diagnosis purposes [1, 2]. The application of blood vessel localization and segmentation can be in neurovascular structures detection, retinal blood vessels segmentation, blood vessels extraction in mammograms, limbs, human airways, abdominal aorta, kidneys and liver etc. In general the techniques which are commonly used for blood vessel segmentation can be categorized in to six different categories. These are 1) Pattern recognition techniques, 2) Model Based approaches, 3) Tracking based approach, 4) Artificial Intelligence based approaches, 5) Neural network based approaches and 6) Tube-like structure detection approach [3]. The choice of vessel detection and segmentation techniques depends on the domain of application as well as imaging modality.

The veins which reside closer to the skin surface are known as subcutaneous veins. These veins are used for blood sampling or injecting medication and fluid to the body with syringe or catheter. Intravenous (IV) catheterization is a process of passing catheters to the patient's veins. Medical staff localizes the subcutaneous veins by sight or by feeling the pulse with hand prior to catheter insertion for medication or blood sampling. The physiological characteristics like dark skin tone, presence of hair, scars or burn marks can result in the difficult venous access, increasing the risk of wrong catheterization. More than 2 attempts on average per patient are required for a successful catheterization [4].

Near infrared (NIR) imaging is the most suitable technique for the task of subcutaneous veins localization during routine IV catheterization and syringe injection processes [5]. The hemoglobin (Hb) present in the veins absorbs more light (with higher absorption spectra) as compared to skin tissue resulting veins to appear darker in the NIR images. In the spectral range of near infrared, the light radiations are non-ionizing making it harmless to the patients, even if it is applied multiple times.

Numerous vessel detection methods are based on edge detection phenomenon. But these methods need to have pre enhanced vessel structures in order to overcome the problem of smooth vascular boundaries. The simpler way to detect lines and curvilinear structures in an image can be problematic in terms of efficiency. In this paper a method based on Frangi vesselness filter is presented for subcutaneous veins localization. Frangi et al developed a method which is a type of pattern recognition technique that combines the multiscale approach to the analysis of Hessian matrix for vessel detection [6]. With multiscale approach, the width of vessels to be localized can be chosen in order to reduce the time constrains. The processing time will reduce if the selected range of vessel width through Frangi scaliness is reduced. The presented method includes the formation of NIR images from the hyperspectral images acquired in previous work for the analysis on optimum illumination for different skin tone [7]. Veins centerline is detected and back projected to the NIR images in order to highlight the larger blood vessels, suitable for the IV catheterization. Section II presents the methodology followed in this work. Section III presents results and

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discussions. Conclusion and future work is given in Section IV of this paper.

II. METHODOLOGY

The methodology adopted for the veins detections and back projection of vessel centerline to the original NIR image is explained in this section. A mean NIR image is created from the hyperspectral data and vessels are segmented with Frangi vesselness filter. The image is then binarized and connected components are detected followed by the removal of small vessel-like artifacts based on the parameters like area and eccentricity. To detect the centerline a thinning process is applied on the image and finally the centerline is back projected to the original NIR image in order to highlight the large blood vessels.

The hyperspectral dataset created in the previous research work contains hyperspectral images of 252 subjects from the forearm region. Subjects are divided in to four different classes based on their skin tones. These classes are labeled as fair, light brown, dark brown and dark. The CIE L*a*b value is measured with the help of chromometer. The luminance (L*) value is used to classify the skin tone. The method for veins detection and back projection of centerline was implemented on the images from each of these skin classes. A 2D venous image was extracted from the multidimensional hyperspectral image. In order to ensure the better contrast between veins and skin tissues, the mean of image slices from 800 to 850 nm was computed to create a 2D venous NIR image for each subject [7]. A mean NIR image shown in Fig. 1 can be created from hyperspectral image with Eq.1.

$$\text{Imean} = \frac{\sum_{w=800}^{850} I(x,y,w)}{N} \qquad (1)$$

Where N is the number of slices in optimized range (800-850nm) and w is the wavelength (band) of hyperspectral image I.

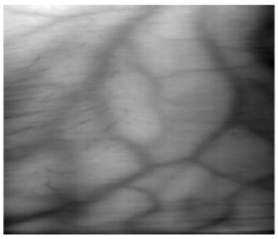

Figure.1: Mean NIR Image of a subject

The mean NIR image is then passed to Frangi vesselness filter to detect the curvilinear structures in the image. This method is based on the Eigen values analysis of Hessian matrix (*H(x,y)*) in order to determine the presence of vessel like structures in the image. Hessian matrix is made continuous by convolving it with 2D Gaussian filter for images. Eq.2 presents the convolution of Gaussian filter with the Hessian of Image '*I*' using convolution property [8].

$$H(x,y) \approx G * \begin{bmatrix} \frac{\partial^2 I}{\partial x^2} & \frac{\partial^2 I}{\partial x \partial y} \\ \frac{\partial^2 I}{\partial y \partial x} & \frac{\partial^2 I}{\partial y^2} \end{bmatrix} = \begin{bmatrix} \frac{\partial^2 G}{\partial x^2} & \frac{\partial^2 G}{\partial x \partial y} \\ \frac{\partial^2 G}{\partial y \partial x} & \frac{\partial^2 G}{\partial y^2} \end{bmatrix} * I(x,y) \qquad (2)$$

The Eigen values and Eigen vectors of H*(x,y)* are calculated to get the information about the contrast and direction at each point of image. The Eigen decomposition generates 2 Eigen values which are: ($|\lambda_1| \leq |\lambda_2|$) and the corresponding 2 Eigen vectors ($\bar{u}_1, \bar{u}_2$). These parameters are analyzed to distinguish the blob-like, tubular or plate-like structure in the image.

Here for a vessel like tubular structure $|\lambda_1| \approx 0$, $|\lambda_1| \ll |\lambda_2|$ and $\bar{u}_1$ points towards the direction of vessel. Frangi vesselness function is defined as :

$$\text{F}(v) = \begin{cases} 0 & \text{if}\, \lambda_2 > 0, \\ e^{-\frac{{R_B}^2}{2\beta^2}} \left(1 - e^{\frac{S^2}{2c^2}}\right) & \text{othewise}, \end{cases} \qquad (3)$$

$$\text{Where } R_B = \frac{|\lambda_1|}{|\lambda_2|}, \qquad S = \sqrt{\lambda_1^2 + \lambda_2^2}$$

The parameter R_B is the measure of eccentricity of the object in 2D image. S is the measure of structureness and is used to get the background area. The contrast in the background is lowest due to the absence of any structure. S is also low for background and high for the region with structures. β and c are thresholds to control the sensitivity of line filter with respect to the parameters R_B and S. The value of β can be set 0.5 while the value of c depends on the gray level intensity of the vessels. This filter is applied to the image in order to get the response value for each pixel. The response values are higher for the pixels belonging to the vessels and vice versa. Fig. 2 shows the results from Frangi filter. Blood vessels are detected and segmented from background, while incorporating some artifacts like hair in the image.

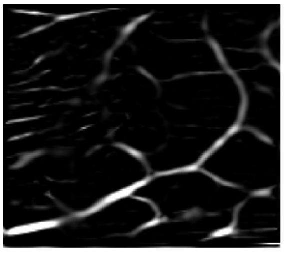

Figure.2: Frangi Vesselness result on a NIR Image of a subject

The images obtained from Frangi filter are binarized to apply binary morphological operations. Binary images are those which contain only 2 levels of intensities and are normally displayed as black and white images. The threshold value T for banalization is found using multilevel thresholding algorithm [9] which is based on Otsu's method for threshold selection [10]. The single minimum value of threshold is selected out of the multiple values provided by the multilevel thresholding algorithm. The reason behind the selection of the minimum threshold is to segment all vessels like structures from the background which appears black in Frangi output images.

$$T = min(multithresh(I, N)) \tag{4}$$

Figure.3: Binary image after Frangi filter resultant image

Connected components are extracted from the binary images in order to apply the morphological operations for image analysis [11]. Two pixels are said to be connected if there exist a path between both of them within a set of pixels in an image. The small vessel-like structures for example; hair, tattoos and smaller vessels are treated as artifacts in the NIR venous image. The reason is to highlight the larger veins only in order to make an easy choice for medical staff for suitable veins. The most suitable vein for venipuncture is the largest in diameter and longitudinal in dimension. The artifacts are removed on the basis of parameters like area and eccentricity. Area is a scalar quantity which defines the number of pixels in the particular region. In this work the threshold value used is 50 pixels to define a large blood vessel in an image with resolution of 170x150. The structures having less than 50 pixels are considered as artifacts and discarded. This number is chosen empirically by performing experimentation on the different images from dataset. Eccentricity is a ratio measure of the foci of the ellipse and its major axis length. It tells how 'un-circular' a curve is. The eccentricity of a circular region is zero and of line is infinite. This measure is used to get larger veins as they appear as curvilinear structures in NIR images. The threshold value chosen is 0.6 empirically in order to filter out structures which have eccentricity measure smaller than this value. Through observations, it is determined that artifacts like hairs, scars usually have eccentricity less than 0.6. Fig.4 shows the clean image after the removal of artifacts defined earlier.

Figure.4: Image after artifacts removal

After the process of artifacts removal and keeping large blood vessels of interest in the image, the process of thinning is applied. The process is used in many applications more often in skeletonization. In this work, we have used this to detect the centerline of veins. After detecting the centerline of large blood vessels, these are projected back to the original NIR image in order to highlight the larger veins. Fig.5 depicts the projected centerlines on the larger veins in a NIR image.

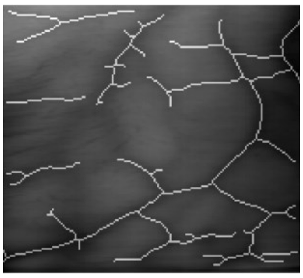

Figure.5: The centerline of large blood vessels are detected and projected back to the original NIR image

III. RESULTS AND DISCUSSIONS

The results of the veins centerline detection and back projection method on the venous images are given in Fig.6. The images of the subjects from four different skin classes are chosen. The method works for all skin classes as can be seen from the results. The segmentation results are highly dependent on the contrast of the NIR image. The images with higher contrast have shown better results in terms of veins segmentation as compared to the lower contrast images. To achieve higher contrast, the optimized illumination for all skin classes explained in the previous work [7] can be used. Similarly other physiological characteristics besides skin tone of subject like the presence of vessel-like structures and veins depth can affect the segmentation results.

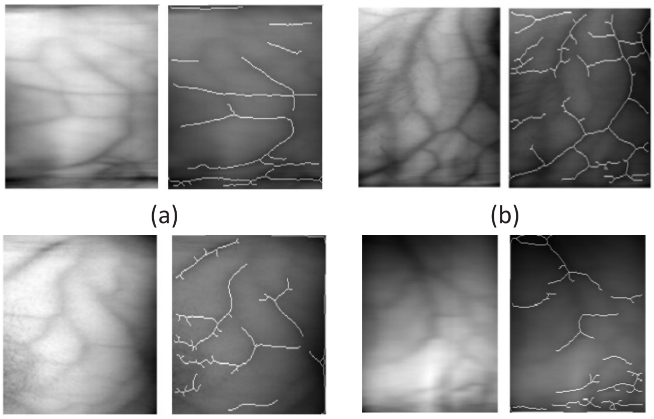
(a) (b)
(c) (d)

Figure.6: The results of veins centerline detection and back projection on NIR images for all four skin classes (a) Fair, (b) Light brown, (c) Dark brown and (d) Dark.

The performance of this method is highly degraded due to presence of large amount of hair on the skin. Hairs appear like curvilinear structures in the image and are detected as vessels. Small hair artifacts can be removed by the application of morphological operation, but if the amount of hair is too large, it's difficult to distinguish between veins and hair. Fig.7.a shows one of the outlier cases, in which the body hairs are detected as veins. Larger hairs combine and appear similar to veins in terms of chosen parameters for veins segmentation i.e. area and eccentricity

Another type of outlier is the image with tattoos similar to curvilinear shape. These tattoos can also appear as vascular structures depending upon their size and shape. In Fig.7.b, an image of subject with a tattoo is presented. The veins localization method applied on this image results in wrong interpretation of tattoo as vascular structure.

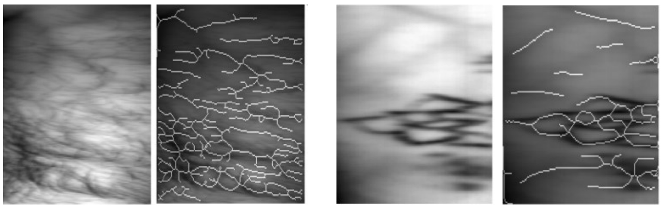
(a) (b)

Figure.7: The results of veins centerline detection and back project on NIR images for outlier cases (a) large amount of hair on skin and (b) veins like tattoo on skin

III. CONCLUSION

Near Infrared imaging is considered to be the most suitable modality to visualize the position of subcutaneous veins. A method to localize the subcutaneous veins from NIR images of four different skin tone subjects is presented in this paper. Veins centerline is detected and back projected to the NIR image in order to highlight the large blood vessels. The images are created from the hyperspectral venous images by selecting the band of 800 to 850nm from NIR spectral range. The mean NIR image is created by taking mean in the defined spectral band. Frangi vesselness filter is used to segment the blood vessels from the background. Small vessel-like artifacts are removed to help finding suitable veins for IV catheterization procedures. This method showed good results on the images of all four skin classes. The main constraint in this method is the processing time. At present this method is not real time. Future work includes the reduction of the processing time of vessel detection method in order to achieve real time or near real time results. Furthermore the enhancement of the method for the cases of outliers is also a challenge at present.

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