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Development of the cost-effective, miniaturized vein imaging system with enhanced noise reduction

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ABSTRACT

Venipuncture is one of common, important processes for diagnosis and treatment of a certain disease. Improper venipuncture can cause medical malpractice and erroneous examination result. Besides, multiple attempts can be required for patients whose veins are not visible, which could be affected by the patient's age, patient's disease, degree of obesity, environmental conditions, and experience of medical practitioners. Here, to overcome these problems, we developed the miniaturized vein imaging system with enhanced noise reduction algorithm based on modified-CLAHE at low cost. The final pseudo colored vein images of a human dorsal hand and a human forearm are clearly visualized with much reduced background noise and enhanced SNR. For more accurate analysis of the developed system performance, we compared the final images with the images processed using several widely used conventional algorithms

Key words : Venipuncture, Vein imaging, NIR, Modified CLAHE

1. INTRODUCTION

In medicine, venipuncture is one of common, important processes for diagnosis and treatment of a certain disease with an analysis of the blood sampling and intravenous injection of therapeutic treatments [1]. It can also be widely used for the blood donation, blood transfusion, hemodialysis, and so on. Improper venipuncture can cause medical malpractice such as swelling, bleeding, or permanent vein damage, and erroneous result of examination even if this procedure is usually performed by medical practitioners, nurses, and medical laboratory scientists [2]. Multiple attempts can be required for patients whose veins are not visible so that multiple pains can happen to them. Especially, it could be affected by the patient's age (the old people and the children), patient's disease (diabesity), degree of obesity, environmental conditions, and experience of medical practitioners. To overcome these problems, the vein viewer technologies were introduced, which are designed to help locate invisible dorsal hand veins as the common site of venipuncture [3,4]. Most of vein imaging approach implement the optical property of the IR light absorption based on the light-tissue interaction. Generally, Arteries contain the oxygenated hemoglobin and veins contain the deoxygenated hemoglobin. Optically, these two types of hemoglobin have different absorption spectra and higher absorption coefficient compared over other components within biological tissues as shown in Fig. 1. The vein pattern image acquired by the IR light illumination appears darker than others because the vein absorbs the IR light better than other tissues [5,6]. There is an optical window of biological tissue, which is a wavelength range of about 700 nm ~ 900 nm. It means that a light in the wavelength range of the optical window can penetrate into biological tissues in more depth [5,7]. Hence, the center wavelength of a NIR light source is commonly selected to be within the range of 700 nm ~ 900 nm. But it's not always appropriate since the system performance can be critically varied by combination of two core component specs of detection sensor and light source.

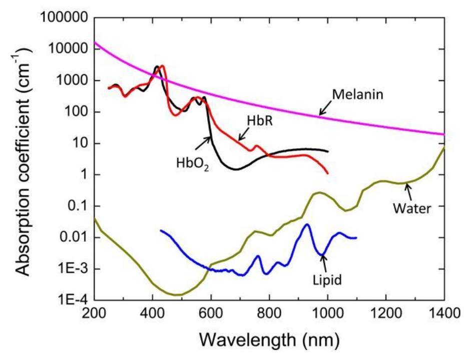

Figure 1: Optical absorption spectrum of biological tissue [8]

In this study, we developed the cost-effective, miniaturized vein imaging system with enhanced noise reduction algorithm based on modified-CLAHE. The system is based on a hand-help typed probe which consists of a commercialized IR CMOS sensor module, two NIR LEDs centered at 940 nm wavelength, and DLP projector. We demonstrated successfully the pseudo colored vein images of a human dorsal hand and a human forearm with much reduced background noise and enhanced SNR.

2. EXPERIMENTAL SET UP

Figure 2 demonstrates a configuration of vein imaging system set up developed in this study. Two NIR (near infrared) LEDs centered at 940nm wavelength are employed as a light source to illuminate on the imaging target tissues such as the back of a hand, arm, and so on. The information coming back from the blood vessels and the surrounding tissues within a human skin can be detected from the IR (infrared) CMOS sensor module after passing through a dichroic filter. The visible light is reflected by the optical property of a dichroic filter while the IR light is passing through. The dichroic filter has an edge wavelength of 757 nm and transmission efficiency of ~ 93% in the range of between 768 nm to 1100 nm so that it can play a critical role as an optical long pass filter. Commercial components of NIR LED and IR CMOS sensor (3280 x 2464 pixels) without IR-CUT filters are used to provide the cost effective miniaturized vein viewer system.

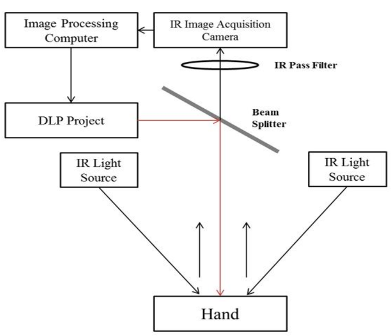

Figure 2: Configuration of Vein imaging System for development of the image process algorithm with optimized mechanical parameters.

The center wavelength of a light source was selected by a specification of IR CMOS sensor sensitivity feature since the image quality based mechanical system performance can be critically varied by combination of two core components. NIR optical long pass filter centered at 720 nm is placed in front of a sensor to enhance the image quality of the vein patterns because the visible light information can be rejected completely. Commercial miniaturized lens is used after calculating the acquired imaging range, a fine focal length, a view angle, and an image display size of DLP (digital light processing using digital micro-mirror device) projector. When IR LED light is incident onto the imaging target, the detected light coming back from the vein region appears relatively dark because of the IR absorption characteristics related to the tissue-light interaction [5]. The acquired images are transferred to the main control processor (Raspberry Pi3 compute tool kit) with 1.2 GHz quad cortex A53 and 400 MHz video core GPU, and finally displayed on a surface of the imaging target area by DLP projector after several image process algorithms. We adjusted slightly mechanical system parameters using 3-D micro-stages to find out the optimized parameters such as working distance, DLP image size, ROI (region of interest) for image process, the number of NIR LED, NIR LED location, illumination angle, and so on. Hence, we can acquire the enhanced image quality and the image display speed can be up to 60 frame / sec.

2.1 Image Processing Approach

The image processing algorithm was developed to visualize clearly the vein patterns of the imaging target area by Matlab. The acquired images are transferred to the computer and the several image processing steps are performed as shown in figure 3. The developed algorithm is based on CLAHE (Contrast limited adaptive histogram equalization) which is one of widely used algorithms in medical imaging field so that the developed processing algorithm is a modified CLAHE approach. Firstly, the ROI (Region of Interest) centered at the vein region can be selected and manually adjusted analyzing the image quality based on unnecessary dark noise level usually located at the side of the acquired image [9]. The ROI located at the center region of the acquired image has the fixed image size with the same number of pixel for all images once the ROI is determined [10]. In the second step, the selected ROI is converted into a gray scale format with appropriate threshold values in the range of 0 to 255, and processed by the histo equalization. The gray scale conversion which can reduce the burden of the data processing compared over the RGB data can be performed.

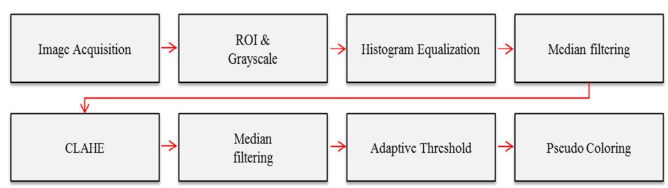

Figure 3: The modified-CLAHE algorithm developed in this study

Use of the simple Histogram Equalization step makes the entire pixel spectrum stretched evenly. As the histogram distribution becomes wider, each pixel value of the image becomes more distinguished as following this formula [11]:

$$h(i) = Gmax/N*H(i)$$

h(i) : Histogram calibration value
Gmax : Maximum brightness value of the image
N : Image size (The number of pixels)
H(i) : Cumulative sum of original image histogram

In the third step, modified-CLAHE combination can be applied to reduce the noise and to enhance the SNR (signal to noise ration) for better image quality, which can be called as a modified CLAHE developed in this study. It is very important to remove the basic background noise before the core processing performance. Median filter is one of nonlinear digital filters widely used to reduce the basic noise in the initial step, which is suitable for reducing Impulse noise with exceptionally different intensity. We used the 5 x 5 median filter for the proper smoothing and noise reducing effects. The core processing engine, CLAHE, is implemented to overcome drawbacks of Histogram equalization (HE) and Adaptive Histogram equalization (AHE) even if HE and AHE are the simply efficient ways to enhance the image contrast in the spatial domain approach. CLAHE has the only control parameter of "clip limit" which enables limiting the maximum value as the following [12]:

$$S' = (1-y)\{(1-x)gA(s)+xgB(s)\}+y\{(1-x)gC(s)+xgD(s))\}$$

It designates the center of the four areas adjacent to the sample points of A, B, C, D. The gA(s), gB(s), gC(s), and gD(s) are the gray level mapping values based on the histogram spectrum. The parameter S is the original intensity of light at the sample point. The parameters of x and y are the horizontal and vertical distances from point A to other sample points. The parameter S' is the light intensity of the sample point changed by calculation. If the value of the clip limit is higher, the image contrast is better. The valid range of the clip limit value is 0 to 1, and we determined the optimized parameter value of 0.2 with the developed system. Each pixel is basically compared to that value in basic thresholding once the threshold value is selected, but the adaptive thresholding has a different threshold value for each pixel. So it has more robust characteristic change of the brightness. The background changes to white and the vein part changes to black through an adaptive thresholding. Additional median filter plays a final role of making the images pass the band pass filter. Hence, this allows to reduce unwanted noise expressed numerically, and we evaluate the processed image data via an actual check. In the final step, the pseudo color codding is applied to visualize the vein patterns remarkably.

3. RESULTS AND DISCUSSION

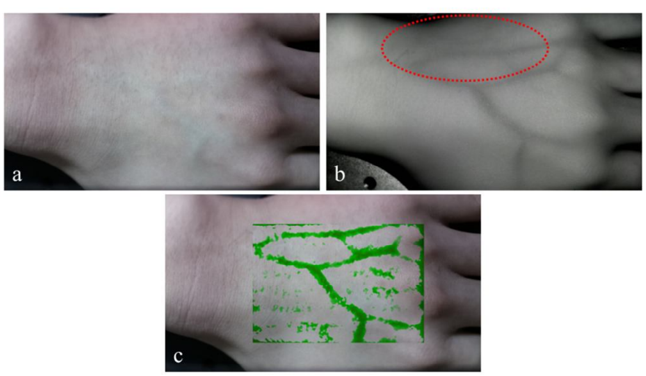

Figure 4: Acquired images of the back of a human hand: visible color image (a), IR image without any software process (b), Vein pattern image using the developed process algorithm of the modified CLAHE (c)

Figure 4 shows the images acquired and processed by the developed system in this study. Figure 4 (a) is the acquired original color image of the back of a human hand, figure 4 (b) and figure 4 (c) are the acquired IR image and the final image resulted from the proposed image process algorithm with modified CLAHE. Acquired IR image detected by IR camera sensor module is converted into a gray scale format with a proper threshold after ROI set up. The ROI located at the center region of the acquired IR image has the fixed image size with the same number of pixels for all images once the ROI is determined manually to enhance the performance of the developed process algorithm as a pre-mask set up. The converted image information is stretched and processed by the histo equalization and the developed modified CLAHE algorithm. The noise minimized final image can be reconstructed with a pseudo color codding and an original color image as shown in Fig. 4 (c). The vein texture of the back of a hand is clearly visualized, especially the vein pattern in the dark region indicated by the red dotted line circle is remarkably shown well compared with the original IR image shown in the Fig. 4 (b).

To evaluate the performance of the developed core process algorithm, we compared the images processed by several conventional process algorithms such as Median, Gaussian, and CLAHE. Figure 5 shows the pseudo colored final images processed using Median [Figure 5 (a)], using Gaussian [Figure 5 (b)], using conventional CLAHE [Figure 5 (c)], and using the developed modified-CLAHE [Figure 5 (d)]. All images are processed by each intrinsic algorithm with the best performance.

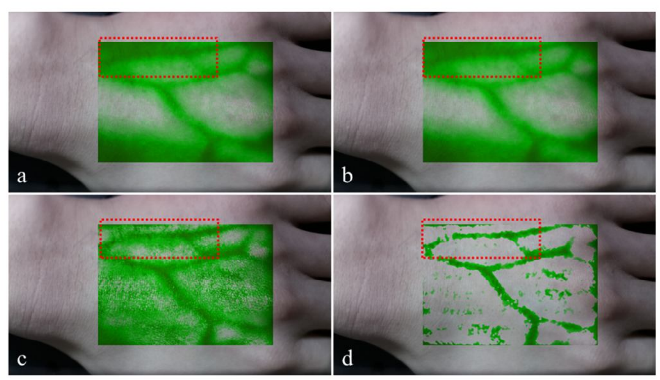

Figure 5: Pseudo colored images processed by several image processing algorithms of Median (a), Gaussian (b), conventional CLAHE (c), and the developed modified-CLAHE (d) to evaluate the performance of modified-CLAHE algorithm developed in this study.

The image processed using a conventional CLAHE shown in Fig. 5 (c) demonstrates the enhanced SNR of the vein pattern compared with the images using Median and Gaussian shown in Figs. 5 (b) and 5 (c). However, it still has a lot of noise so that it's difficult to identify the margin existed between the surrounding background and the vein. The image resulted from the developed modified-CLAHE process shows the powerful background noise reduction compared over the image processed using a conventional CLAHE shown in Fig. 5 (c). Especially, the vein pattern imaging performance is much remarkable in the dark region of the side area indicated by the red dotted line box

Figure 6 (b) shows the final pseudo colored image of the human forearm processed using the developed modified-CLAHE algorithm. We can see a real time display image on the human forearm illuminated by DLP projector as shown in Fig. 6(c). The operation performance of the developed system can be evaluated by comparing the real position and displayed position of the vein pattern of a volunteer's forearm. Hence, we can see clearly the real time displayed vein pattern image positioned exactly on the real vein pattern of the human forearm. Furthermore, for a technical transfer we developed a prototype version of the vein imaging system, 'vein viewer', with technologies of both hardware and software developed in this work as shown in figure 6 (d).

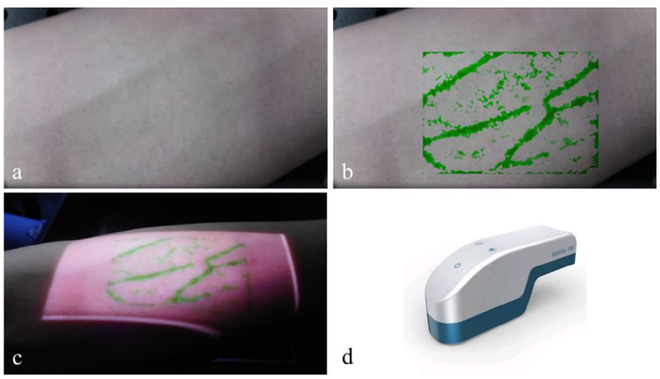

Figure 6: The original color image (a), the final pseudo colored image processed using the developed modified-CLAHE algorithm of the human forearm (b), DLP displayed vein pattern image on the human forearm in a real time, and a picture of a prototype developed in this study.

4. CONCLUSION

We developed the miniaturized vein imaging system with enhanced noise reduction algorithm based on modified-CLAHE at low cost. For more accurate analysis of the developed system performance including both hard- and software, we compared the resulted final image with the images processed using several widely used conventional process algorithms such as Median, Gaussian, and CLAHE. We can clearly see the vein pattern image with reduced background noise and enhanced SNR compared with the images resulted from the several conventional process approaches. We demonstrated also the pseudo colored final vein pattern image of a volunteer's forearm, which is illuminated by DLP projector in a real time display. Furthermore, we successfully developed the prototype version of the vein imaging system for a technical transfer

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