Vein Visualization System Using Camera and Projector Based on Distance Sensor

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***Abstract*—The location of the veins of every person is different, some are visible with the naked eye and some are invisible. This is due to the location of the veins deep below the skin, usually due to excessive fat covered. Many papers that have the topic to solve this difficulty mostly perform only image processing without back-projection. In this paper, we propose a method for improving vein image enhancement using high boost filter and preliminary study about back projection by using the intersection between camera view and projector view. Vein data acquired by NIR reflection method. The obtained vein image enhanced by using a high-boost filter. To deal with the post-segmentation noise, we use a combination of morphology and contour area. Based on these combinations, the accuracy of vein detection is 84.62%. The result of the preliminary study about back-projection is already able to project the vein image and the future work is focused on adjusting the projection in term of distance change between device and object.**

Keywords—vein pattern; NIR; back-projection; intravenous access; image processing; high boost filter; contour area;

I. INTRODUCTION

The location of the veins of every person is different, some are visible with the naked eye and some are invisible. This is due to the location of the veins deep below the skin, usually due to excessive fat covered. Difficulty in determining the location of these veins causes intravenous access procedures to be longer and cause the process of intravenous therapy (administration of fluids, parenteral nutrition or drugs into the veins in a certain amount of time funds) cannot be done quickly.

Vein Viewer, also known as Vein Contrast Enhancer (VCE), is a tool in the medical scope that used to view the veins by applying the principle of the absorbed infrared light by the blood. Research on the first attempt to perform vascular action showed that with conventional methods and patients with easy level, has a success rate of 80%, while for the category of patients with hard level, the success rate only reaches 25% (5 of 20 patients). However, with the Vein Viewer device, the success rate for the category of patients with hard level increased to 58.3% (14 of 24 patients) [1]. Currently there are some vein viewer products such as VeinViewer, AccuVein, and VascuLuminator which have an important role but the price is still too expensive [2].

Based on previous studies that discussed vein image processing to facilitate intravenous access, most only did processing without real time projection. For vein image processing equipped with real time back projection has been developed by Zeman [3] with construction techniques using hot mirror. This technique requires very precise mechanical design and complex construction. In 2013, Dai [4] also developed a technique to facilitate real time projection. In his research, Dai only use camera and projector without hot mirror. Camera and projector are placed in the same axis. In addition, there are also study that do back projection in 2016 with the same technique with Dai but by using two cameras to get depth of vein image [5]. The research about back projection that was mentioned before only test the projection at a fix certain distance without observing on different distance.

This paper proposes a method for improving vein image enhancement using high boost filter and preliminary study about back projection by using the intersection between camera view and projector view and adjust the projection based on distance sensor.

II. THEORY

A. Intravenous Access

Intravenous cannulation is a technique in which the cannula is placed inside a blood vessel to provide venous access. Intravenous access allows blood sampling, as well as administration of fluids, medications, parenteral nutrition, chemotherapy, and products commonly called intravenous therapy [6].

In practice, the medical officer seeking vein patient to perform intravenous access process. Veins are sometimes difficult to see by naked eye because of fat accumulation factors or skin color factors. These difficulties cause delays in providing first aid to the patient

B. Infrared Spectrum Absorbtion

Blood consists of two different types of hemoglobin namely Oxyhemoglobin hemoglobin binding oxygen ($HbO2$) and deoxyhemoglobin or non-binding oxygen hemoglobin (Hb). In the arteries, the $HbO2$ content is very high in excess of 95% whereas in the veins there are only about 50% so there is Hb in a lot of percentage in the veins. These two different types of hemoglobin exhibit different spectrum absorptions that are usually represented in molar extinction coefficient. The differences in absorption shown in Fig. 1.

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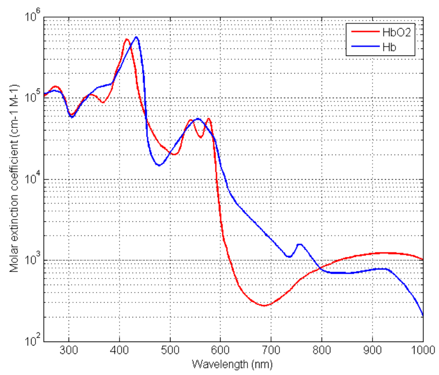


Fig. 1. Infrared spectrum absorption [7]

Based on Prahl's research [7] that shown image in Fig. 1 then the near infrared ray (NIR) which has a light spectrum of about 700nm can be used to obtain vein image.

III. System Architecture

The following in Fig 2. represent the system architecture that has been developed to implement the purpose of this research.

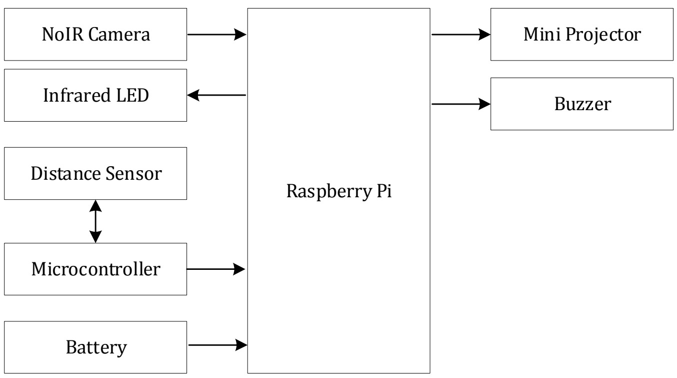


Fig. 2. System Design

There are two inputs in this system. The first one is no-NoIR camera (a camera without IR cut filter) that serves to get vein image and the second one is distance sensor that serves to get the distance between the camera and the object. In the processing side, there is a microcontroller as a distance data processing from distance sensor and Raspberry Pi as vein image processor. In the output side, there is an infrared LED that serves to illuminate the object to be observed, a mini projector to display the result of processing on the object and buzzer as an alarm or indicator when the projection reaches the best focus.

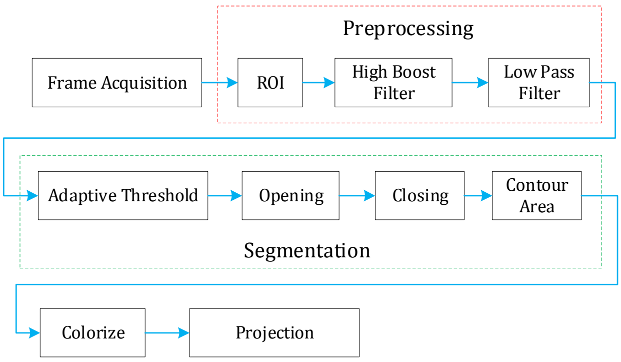


Fig. 3. Image processing algorithm

To perform preprocessing on the image that has been obtained, here are some steps that must be done. First is to determine the coordinate area of the image to be processed by setting the region of interest (ROI). The obtained image has a low information about vein vessel. To clarify the difference between the veins and the skin, the image enhancement such as histogram equalization and high boost filter need to be performed. By performing image enhancement, the veins will become darker and the skin will become brighter.

Once the difference between the skin and the veins looks clear, the next step is performing the segmentation process to obtain the vein pattern. Vein image converted into a binary image using adaptive thresholding. The result of adaptive thresholding is not perfectly getting the vein pattern because there is some point of noise. To remove some small parts that are not categorized as a vein pattern, we perform the morphology opening process. However, the morphology opening process causes some pattern loss. We need to restore it and then morphology closing process is performed to solve the problem. Since the two morphological process cannot be maximized to remove noise, then we use the contour area to determine the noise area and perform the elimination process to obtain a clean vein image and ready to projected. Before the back-projection process is performed, the clear vein image colorized to yellow to avoid feedback rays from white lights.

IV. Analysis and Implementation

The implementation and analysis of system begin with vein image acquisition, implementation of vein image processing, and the last is performing back-projection to the skin.

A. Implementation of the vein image acquisition

In the process of venous data acquisition, there are two techniques that are often used are reflected NIR and penetration NIR[8]. In this study used the reflected NIR method with two NIR LEDs as light sources with placement as show in Fig 4.

In the process of acquisition of this vein image, there is one additional parameter that is the distance between the camera with the skin surface using HC-SR04 that shown in Fig. 5. This distance value will be used as a parameter on the back-projection method.

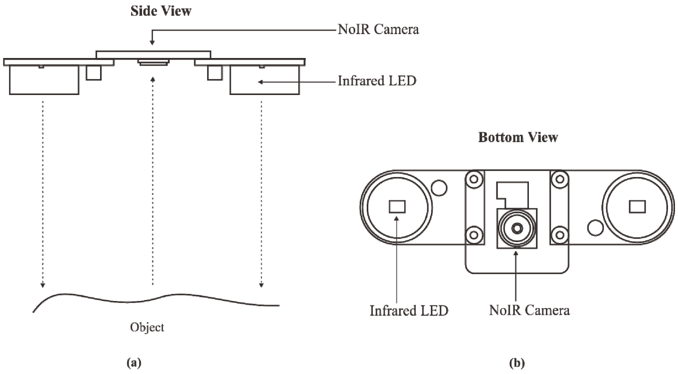


Fig. 4. (a) Vein image acquisition method in side view, (b) vein image acquisition method in bottom view show the placement of camera and 2 pieces IR LED

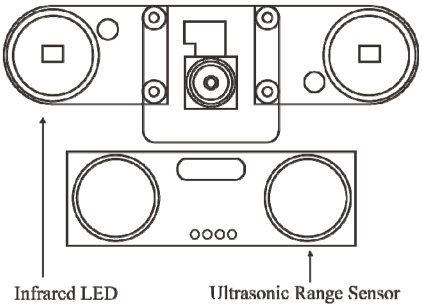


Fig. 5. Placement of ultrasonic range sensor from bottom view is close to camera and infrared LED

By using the technique in Fig. 5, we obtained the following picture shown below:

Fig. 6. Image taken with IR LED = ON

Whereas if only use the camera without infrared LEDs, we obtained the following results:

Fig. 7. Image taken with IR LED = OFF

Based on these results then the infrared LED has an important function to obtain the vein pattern. The stronger intensity of infrared LED, cause the vein pattern is seen more clearly.

B. Implementation of vein image processing

Implementation of image processing in this research is divided into two stages: preprocessing and segmentation. Preprocessing aims to create a clean image and strengthen the difference between the vein pattern and the skin. Furthermore, the segmentation process aims to take the pattern of the veins and remove the parts that are not vein.

The images obtained by the camera are determined to be 640 x 480-pixel to avoid heavy computation because it uses a single board computer. In this case, the ROI is placed on the center of the frame because it has relevance to the projection method that will be developed in this research.

Fig. 8.Original image with size 640*480 pixel

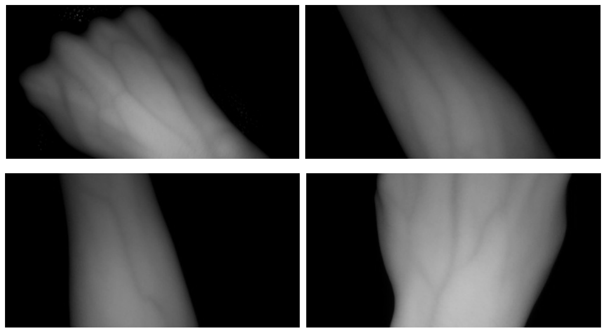


Fig. 9.ROI image after grayscale process on 4 different samples

The results obtained by NIR cameras still do not provide clear information about the difference between the veins and the skin. Because of this, some studies use histogram equalization to clarify vein images [9], [10]. However, in this case it would be more appropriate to use contrast limited adaptive histogram equalization (CLAHE). Since this method is local so it will not be affected by background conditions. There is a problem where the result of CLAHE causes the appearance of dark parts that make the segmentation process even more difficult. To deal with the problem, we propose to use a method that is able to clarify the veins without causing the appearance of dark parts. This method is called high-boost filter where the working principle is by subtracting the original image with the original image that has been given a lowpass filter and expressed in the following equation:

$$G_{(m,n)} = A.F_{(m,n)} - lowpass(F_{(m,n)}) \quad (1)$$

$$G_{(m,n)} = (A-1).F_{(m,n)} + [F_{(m,n)} - lowpass(F_{(m,n)})] \quad (2)$$

$$G_{(m,n)} = (A-1).F_{(m,n)} + highpass(F_{(m,n)}) \quad (3)$$

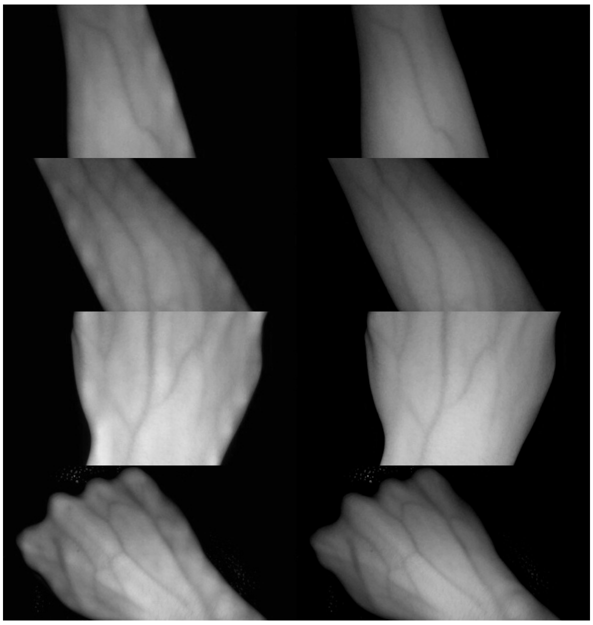


Fig. 10. Result of CLAHE (left side) and high boost filter with a=1.1 (right side) on 4 different samples

Because the result of the histogram equalization process and the high boost filter also amplify the noise, the vein image needs to be filtered so that the segmentation process becomes easier. Based on Habib's research [11], they used the median filter after grayscale process while in this study using gaussian filter with kernel size 7 x 7 to reduce noise. To know better filter results can be analyzed with peak signal to noise ratio (PSNR). The PSNR method computes the peak signal-to-noise ratio, in decibels, between two images. This ratio is often used as a quality measurement between the original and the compressed or reconstructed image.

$$MSE = \frac{\sum_{M,N}[I_1(m,n)-(m,n)]^2}{M*N} \quad (4)$$

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right) \quad (5)$$

The result is the image filtered with median filter has a PSNR of 41.5 dB, while the image filtered with the Gaussian filter has a PSNR of 42.6 dB. Both of these results have a PSNR value that is not much different but the Gaussian filter is chosen because having a faster computation time.

The next process is vein image segmentation by using adaptive thresholding. Parameters that we used is the block size is set to 11 and in determining the threshold value, we prefer to use mean neighbor rather than Gaussian. Can be seen from Fig. 11, on this system the use of Gaussian type threshold value is less suitable because it causes many parts of the veins pattern disconnected. While the use of mean threshold value is more suitable because the vein part is only slightly disconnected.

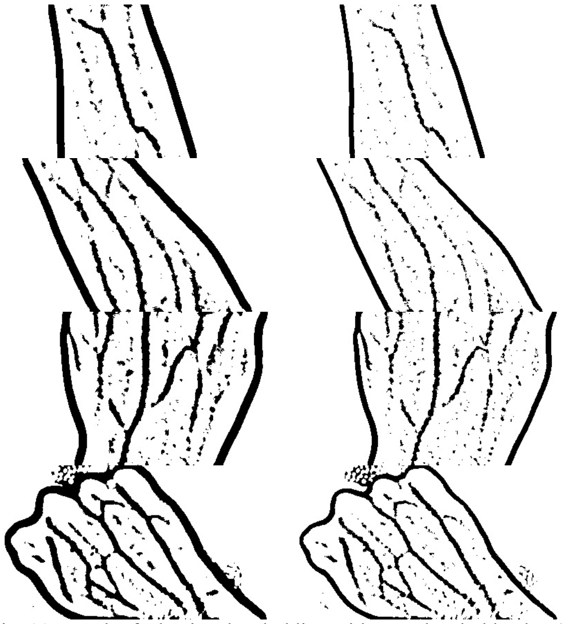


Fig. 11. Result of adaptive thresholding with men threshold value (left side) and gaussian threshold value (right side) on 4 different samples

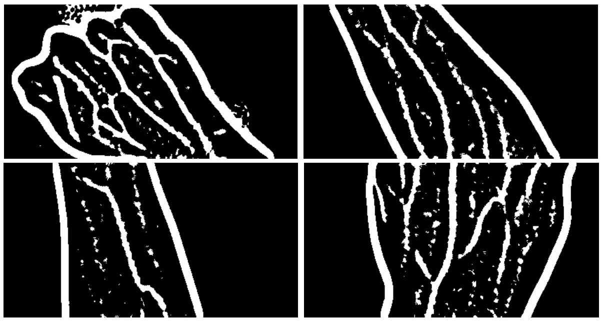


Fig. 12. Result of inverse of adaptive thresholding on 4 different samples

The results of the adaptive thresholding as shown in Fig. 12 are still not good because still contain noise. Based on Kim's research [8], they used morphology closing after thresholding process. In this case, to remove the noise we attempt to use morphology opening. This process in addition to removing the noise also causes the loss of some vein patterns and to restore the vein pattern can be solved by morphology closing. The result is as follows:

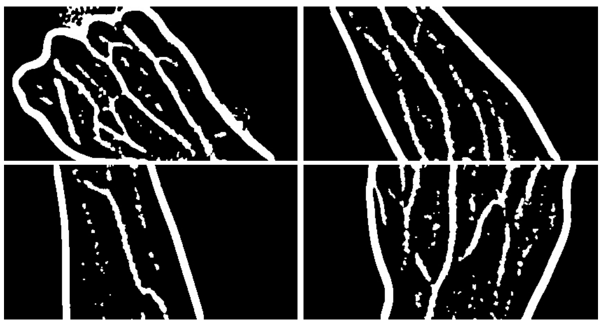


Fig. 13. Result of morphology opening with structuring element size = 2*2

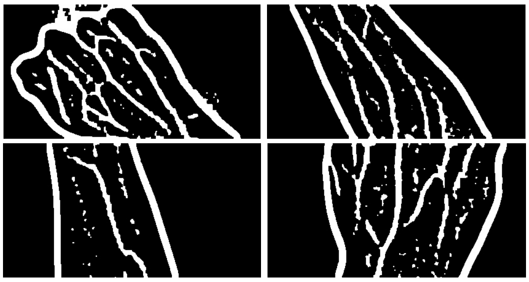


Fig. 14. Result of morphology closing with structuring element size 4*4

Fig. 14 is the result of morphology operation, can be seen the noise still remains. We can't force morphology anymore, it can eliminate the vein pattern. To solve this problem, we attempt to look for contours of each shape in the image. After the contours are obtained then we calculate the area for each shape. From Fig. 15 can be seen that veins have a large area, and the noise have a small area.

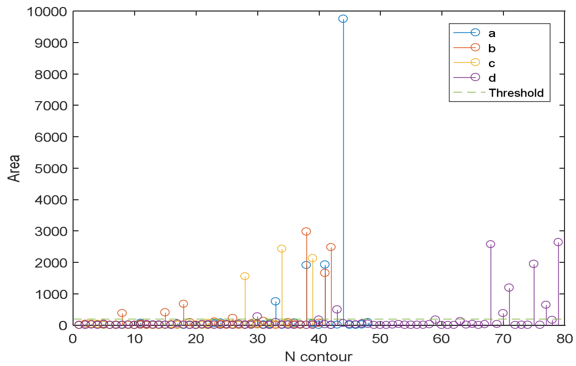


Fig. 15. Contour on sample images

As presented in Fig. 15, the sample images have 80 contours and there is one that has the largest area of 9751 pixels. This huge area indicates the edge of the hand. Then to clarify other contour parts can be seen in the figure below.

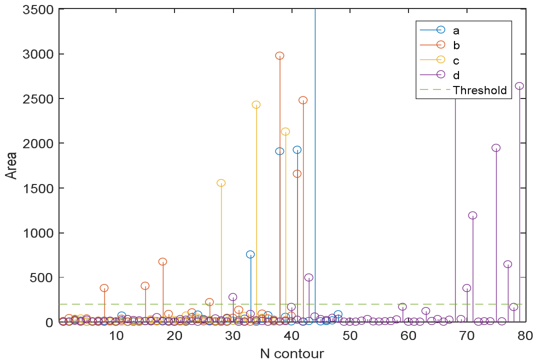


Fig. 16. Contour on sample images zoomed

Based on Fig. 16, it can be seen that the noise has a low contour area. We attempt to set the threshold value to 200 and eliminate all the shape under the threshold value. The results can be seen in Fig. 17 where only the vein pattern and the edges of the hand are left on the image.

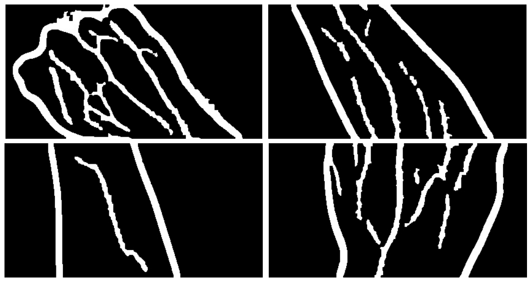


Fig. 17. Result of element having contour > 200

To test the performance of the segmentation process, the result of the high boost filter in Fig. 10 were used as a reference for vein pattern. The result of the final segmentation as presented in Fig. 17 are converted into edge image with yellow lines. Reference images placed as background while the converted segmentation placed as foreground.

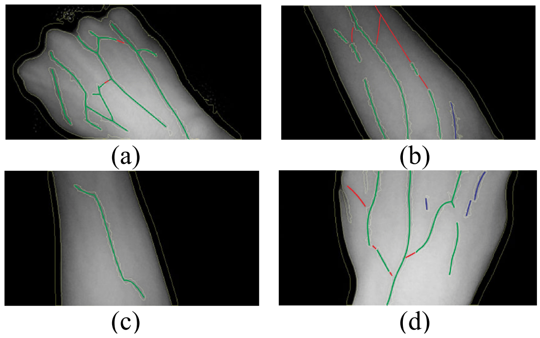


Fig. 18. Result of vein pattern identification

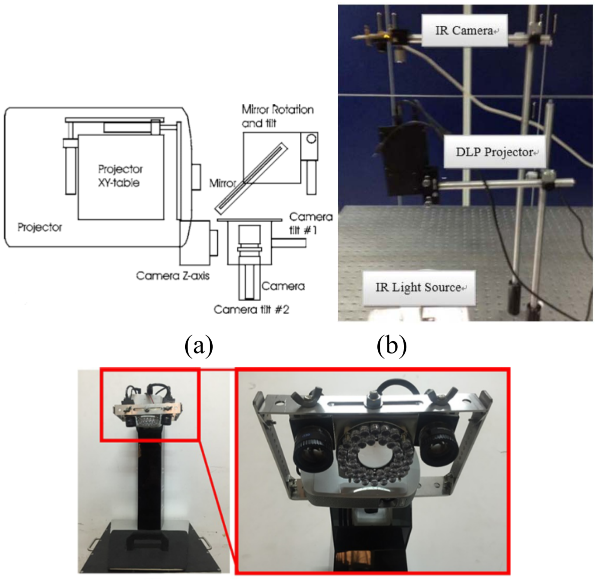
As seen in Fig. 18, to identify the vein pattern, we draw a curve in accordance with the results on the high boost filter. If there are vein flanked by segmentation lines then we draw the line following the vein pattern with green color as true positive (TP). If there is a vein pattern whereas not flanked by segmentation line then we draw a red line following the vein pattern as false negative (FN). If there is a segmentation line while there is no vein pattern on that location then we draw a blue line as false positive (FP). The line is calculated by macro editor and the result is obtained in millimeters shown in Table 1.

TABLE 1. Measured Vein Vessel Length

Img.	Total length (mm)	TP (mm)	FN (mm)	FP (mm)	Sensit -ivity (%)	Accura -cy (%)
a	407.4+8.5	407.4	8.5	0	97.95	97.95
b	262.3+107.2	262.3	107.2	31.2	70.99	65.46
c	10.4	10.4	0	0	100	100
d	237.1+27	237.1	27	51.7	89.78	75.07

C. *Preliminary study about vein image projection*

The back-projection process aims to re-project the enhanced vein image. Products that are currently available on the market are not mentioned in detail the techniques used for back-projection, but there is a patent [12] which explains that the back-projection method is similar to the previous research conducted by Zeman [3] that shown in Fig. 19a. Camera and projector placed in different axis and using hot mirror to separate visible light and infrared light. This method needs complex and precise construction. Different method proposed by Dai [4] are explained in Fig. 19b to improvise method that have been developed by Zeman. The concept of Dai's research is the placement of the camera, projector and IR LED source in the same axis to remove the hot mirror. To perform the method, placement of each component is in a different location and it needs a large space. In addition, similar back-projection method proposed by Ai [5] using dual camera system shown in Fig. 19c. This method able to obtain the vein depth, but the projection result is similar to the single camera system and need huge computation time even already using a personal computer to process the image.



(c)

Fig. 19. (a) Back-Projection method proposed by Zeman [3], (b) Proposed method by Dai [4], (c) Proposed method by Ai [5]

Projection methods that previously explained only perform back-projection at a certain distance without observing the results at different distances. If the projection location has been set at a certain distance, then the correct projection will only occur when the distance is precise to the distance during calibration.

This research is a preliminary study to develop a back-projection method which only use mini projector, IR pass filter and distance sensor. The expected achievement in this step is to obtain a projection of the vein image that can self-adjusting when there is a distance change between device and object so that the specific distance between device and object during visualization is not necessary.

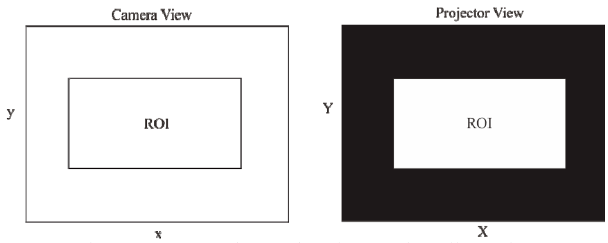


Fig. 20. Camera View and Projector View Illustration

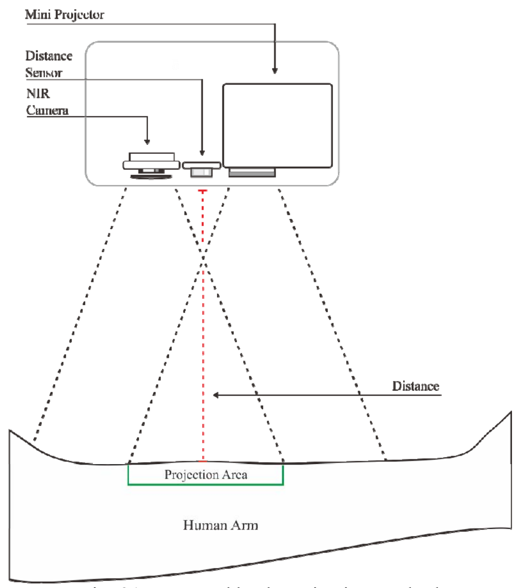


Fig. 21. Proposed back-projection method

Based on the Fig. 21, we design the placement of each component is on the same axis to reduce space between the component. To perform back-projection, we propose a method by utilizing the intersection between camera view and projector view. When the distance is changed, the projection will not be correct so in this research we develop a projection method using intersection technique and equipped with the distance sensor as a parameter to adjust the projection.

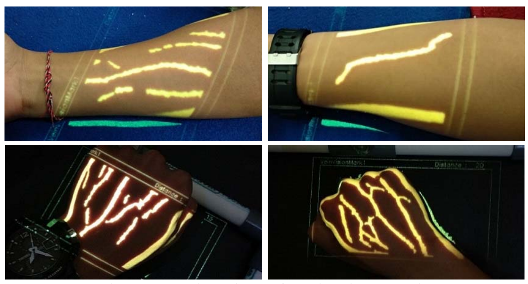


Fig. 22. Estimation of projection result.

Based on the illustration in Fig 20, to synchronize camera view with projector view, we need to perform calibration to get the formulation. Fig. 22 show the proposed method able to project the vein image to the skin but still in an offline system. The problem we found in developing this projection method is that the projector angle and the camera angle should be the same. In addition, we also have to equalize the image scale to real size object.

V. CONCLUSION

The acquisition of vein images is determined by the IR LED. In the preprocessing stage the high boost filter method is very important in strengthening the difference between the veins and the skin. To deal with noise, gaussian filter giving a good result with 42.6 dB PSNR value. In the process of segmentation, adaptive thresholding with mean neighbor threshold value is better than gaussian threshold value. By using combination of morphology and contour area, the final result of segmentation in this research got 84.62% accuracy and 89.66% sensitivity. The result of the preliminary study about back-projection show that the vein image already able to be projected by using the proposed method but still in an offline system and the future work is focused on adjusting the projection in term of distance change between device and object.

ACKNOWLEDGMENT

The authors would like to thank all the members of the SVG (signal, vision and graphics) laboratories for their support and guidance in this research.

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