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Prototype Design for Wearable Veins Localization System Using Near Infrared Imaging Technique

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Abstract—**Advance biomedical engineering technologies are continuously changing the medical practices to improve medical care of patients nowadays. In this paper, we describe the concept used to prototype a device for needle insertion navigation during intravenous catheterization process via Near Infrared (NIR) imaging technique. A vein locator prototype using the NIR imaging technique and augmented reality (AR) technology have been developed in this work which is meant to be used in the process of intravenous catheterization. The challenges faced during the development of this prototype included the calibration of composite images in the see-through display. In this prototype, the Vuzix STAR 1200XL eyewear system has been used as the head mounted display and the imaging video is input by IR CCD camera. Additional, We select the optimum illumination by using NIR LED with wavelength of 830nm and 850nm in prototyping to obtain the best contrast NIR venous image for different types of skin tone.**

Keywords—Vein Locator Device, Near Infrared (NIR) Imaging, Subcutaneous Vein Localization.

I. INTRODUCTION

In hospital, the patient groups of obese, geriatric, and pediatric are the main challenges faced by medical personnel especially nurses in venipuncture process. Obese patients who are having the thicker layer of subcutaneous fat and the pediatric patients who are having small veins, are the common challenges for nurses to locate the subcutaneous veins by using only human's eye. On the other hand, the anxiety of patient is another factor that can lead to failure in venipuncture attempts and causing more unnecessary needle insertion. This condition may increase more again the difficulty for nurses to locate the subcutaneous veins and consequently lead to the risk of vein damage.

The proposed veins locator device of this work is to assist medical personnel in overcoming such tough circumstance of unseen subcutaneous veins during their job, by providing the virtual visualization of subcutaneous veins. This wearable device assists medical personnel especially nurses to upgrade their performance during intravenous catheterization process by providing the visible virtual subcutaneous veins image. The NIR illumination used in this prototype is from the electromagnetic spectrum's range around 740nm to 940nm. In this range, the light is capable to penetrate about 5mm deep into the skin tissue [1]. In contrast to the skin tissues, veins appear dark in the NIR images. This phenomena is due to the factor of higher light absorption coefficient and lower backscatter light coefficient in deoxygenated hemoglobin of blood inside the subcutaneous veins [2].

In most of the hospital and clinic treatments, intravenous catheterization mostly applies to subcutaneous veins which locate in the hypodermis skin layer. This hypodermis skin layer lay beneath about 5mm deep into lower forearm tissue and thus NIR light at wavelength range about 740nm to 940nm are suitable to be applied due to its property of 5mm deep penetration and also non-ionizing to the skin tissue [3]. Therefore, the clinician can use this non-ionizing NIR imaging for multiple times in medical treatments without risk. Additional, we use NIR LED with wavelength of 830nm and 850nm in prototying to obtain the best quality NIR venous image for different types of skin tone [4]. As a result, subcutaneous vein localization by using NIR imaging has become possible with the auxiliary of simple image processing technique and augmented reality (AR) technology in Head Mount Device (HMD).

By using both AR technology and NIR imaging technique, this wearable HMD system superimposes the real world environment on virtual view in order to interpret the real world object with NIR spectroscopy view. In other words, this HMD system will create a virtual image and overlay onto real-world object to form a composite view in the HMD see-through lenses. This AR's composite view has the functionality to enhance a user's perception and interaction with the real-world by superimposing the virtual imaging onto the real-world object to assist user view in the see-through lenses. In simple word, virtual imaging is the counterpart of real-world and it provides the augmented view that assists human's eye to see certain objects under NIR spectrum band range such as subcutaneous veins. By the augmented view of NIR spectrum band, human can view the subcutaneous veins which are lying in the hypodermis skin layer through the NIR virtual imaging in this wearable see-through HMD.

There are two types of AR's HMD, which are known as transparent HMD of optical see-through and video mix HMD of video see-through [5]. In video see-through, it immerses the user in the virtual world but isolate user view from real-world environment. Whereas in optical see-through, it immerses user in real-world environment by augmented of virtual world and this enable user interact with real-world by its composite view. Perception in optical see-through is then higher compare to video see-through and thus we chose optical see-through in this vein locator device prototyping. In optical see-through, various techniques have existed but generally it can be classified into two main groups, that are curve mirror based and light guide based. In our prototype, we use the Vuzix STAR 1200XL with curve mirror based as shown in Fig. 1 as the wearable vein localization system. This wearable system displays the composite view and provide the subcutaneous veins image to user in the see-through lenses.

Fig. 1. Vuzix STAR 1200XL (Optical see-through HMD).

Other than that, Vuzix STAR 1200XL is also capable to track the real-world environment with its 1080p HD camera and a head tracker as shown in Fig. 2 for the purpose to enhance user's awareness on the head movement and positioning data. The combination design of HD camera and head tracker enable user to determine real-time viewing orientation and this feature enhances the precise view of reality environment.

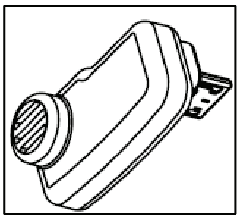

Fig. 2. Head Tracker.

In the normal visible light spectrum environment, human eye is not capable to view the NIR imaging. Therefore, original HD camera without visible light blocking filter had replaced with the NIR-based CCD camera in order to capture the NIR imaging video. This bullet type CCD camera is mounted on top of LED bar as shown in Fig. 3 (right) to capture the imaging video of the illuminated objects.

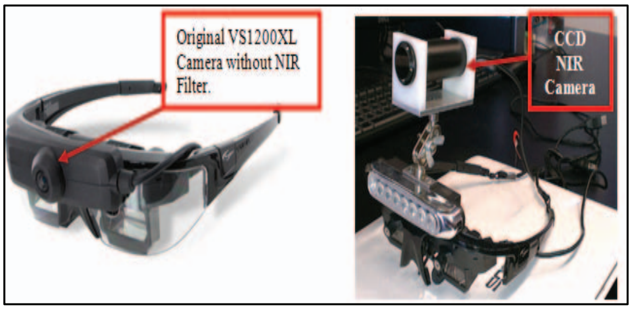

Fig.3. Original Vuzix STAR 1200XL visible light camera (left) and TVL 420 NIR-based CCD camera (right).

The distinctiveness of this wearable HMD is the capability to view the real-world under NIR band of electromagnetic spectrum. From the demonstration in the transparent lenses display, Fig. 4 shows the differentiation of virtual image between visible light (left) and NIR light (right). This comparison indicates a substantial fact that the NIR illumination is capable to display the subcutaneous veins whereby the visible light illumination is not.

Fig. 4. Virtual imaging in visible light (left) and virtual image in NIR light (right).

II. CHALLENGES

In the Vuzix STAR 1200XL wearable system design, the virtual screen is displaying at 3 meters away from eye view as shown in Fig. 5 (right). This feature intrinsic the drawbacks of unequal size and irregular position composite image in the see-through lenses. Once the size and position of virtual NIR imaging are imperfectly overlay to the real-world image, it will then display the incorrect imaging information which the virtual image is variance to the real-world image as shown in Fig. 5 (left). In such condition, the composite image becomes more complicated to be calibrated by using image processing method. The real time image calibration require complicated algorithm and heavy processing unit and this will consume more time and energy.

Fig. 5. Size and position of virtual image are not calibrated with the real world image (left) and virtual screen display 3m apart from eye view (right).

III. METHODOLOGY

The vein localization system primarily consists of five parts: (1) Vuzix STAR 1200XL set, (2) A software module of MATLAB for image processing, (3) NIR LED at 850nm, (4) White cloth diffuser, and (5) A IR CCD camera. With the parts mentioned above, the vein localization system configured as in Fig. 6 below:

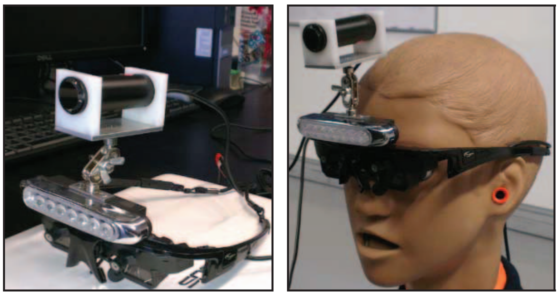

Fig.6. Vuzix STAR 1200XL HMD with IR CCD camera on top of LED bar (left) and Vein locator prototype wear on phantom (right).

First, we removed the original visible light camera from Vuzix STAR 1200XL eyewear and replaced with an IR CCD camera. In order to firm the position of CCD camera, a camera mount had been customized to lock the bullet type CCD camera on top of the LED bar as shown in Fig. 7 (left). Second, we attached the LED bar on top of the eyewear's glass frame. In this step, white cloth diffusers were used to diffuse the light in order to have the smooth illumination for the targeted sites as shown in Fig. 9 (right). Here, we can see the NIR light is sharper when there is no white cloth diffuser applied as highlighted in Fig. 9 (left) compare to NIR light with white cloth diffuser applied. Third, an adjustable kit to join the CCD NIR camera to LED bar had been customized and located in between of camera and LED bar as seen in Fig. 7.

Fig. 7. Adjustable camera mount (left) and its adjustable kit which is able to fine tune the CCD camera coordinate (right).

For vein locator device demonstration, the wearable system is connected to processing unit in order to output the virtual imaging in the HMD's display lenses by simple MATLAB code as depicted in Fig. 8. Subsequently, we found the virtual image is not overlay perfectly in the real-world. According to this non-calibrated image problem, we apply the MATLAB's zooming code in order to adjust the imaging video size and fit with the size of real-world object.

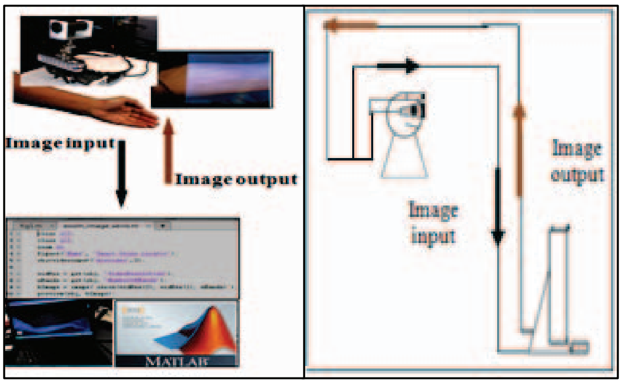

Fig. 8. Clip art image of proposed vein locator device system (left) and a diagram of vein locator device system configuration (right).

After then, we design an NIR LED bar to place on top of the wearable HMD's frame as shown in Fig. 9. During the demonstration, we found that the direct NIR illumination producing high quantities of radiation and this cause imaging video becoming sharpen and consequently lead to poor vein contrast. To overcome this problem, we had covered the LED bar with white cloth diffuser for the purpose to reduce the direct radiation from LED to the real-world object.

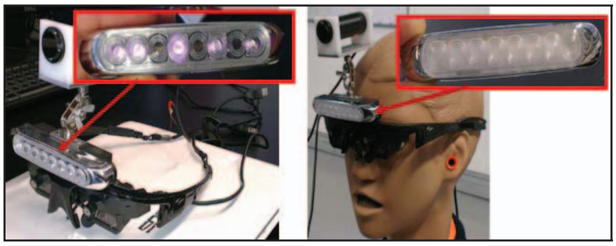

Fig. 9. NIR LED bar without cover of white cloth (left) and NIR LED bar with cover of white cloth (right).

IV. RESULTS AND ANALYSIS

The demonstrations have been done by using the experiment setup as described in the previous section. From the experimental result, the size and position of the virtual image is not calibrated to the real-world images as shown in Fig. 10 (left). In order to equalize the image's size, we adjust the virtual image by MATLAB's zooming feature until it is equal size with the real-world image. Next, for the problem of non-calibrated image position, an adjustable camera mount has been designed to align the IR CCD camera. This adjustable camera mounts enable user to align the IR CCD camera until the virtual image's position is equally lying onto the real-world image as shown in Fig. 10 (right). Accordingly, the demonstration of this prototype had resulted a perfect superimposed composite image by implementing the action of virtual image's size alignment and its mechanical position calibration. During the adjustment of camera mount, IR CCD camera must be aligned manually according to only one target reference so that both of the images are overlapping in the same spatial plane as shown in the Fig. 10 (right).

Fig. 10. Non-calibrated composite image (left) and calibrated composite image (right).

Our target is to have a perfect superimposed composite image in the lenses display. Therefore, we had equalized both the Epipolar line's length of the IR CCD camera (L2) and eye view (L1) as shown in Fig. 11 by adjusting the camera mount base on a target reference. Once the L1 is perfectly equal to L2, both the 2D projection of view point will overlay to each other entirely. The non-calibrated composite image encountered in the see-through lenses is due to the factor of intrinsic Epipolar geometry which occurred when the length of L1 and L2 are not equal as shown in Fig. 12. When these two cameras view a 3D scene from two distinct positions, the 3D points and 2D projection images will lead to constraints between the image points. Hence, this Epipolar geometry varies the position of virtual image to the real-world image in the composite image and we see two identical images are displayed in a different position in the see-through lenses.

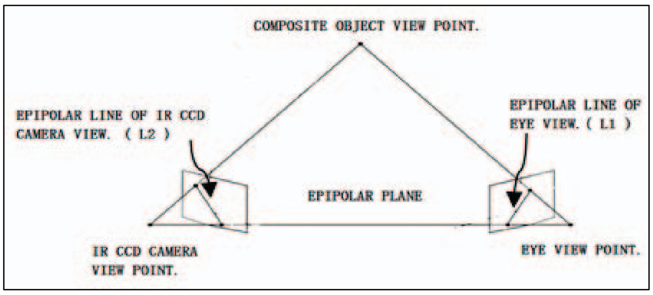

Fig. 11. Epipolar geometry in Vuzix STAR 1200XL see-through lenses where the L1 is equal to L2.

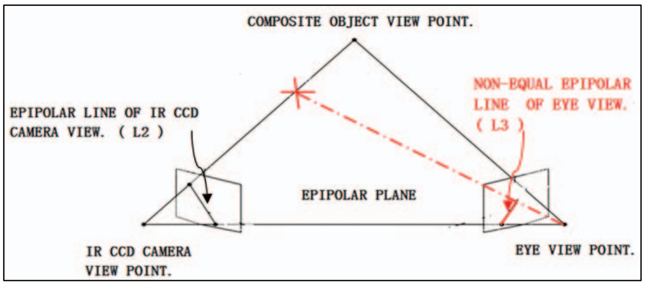

Fig. 12. Epipolar geometry in Vuzix STAR 1200XL see-through lenses where the L3 is not equal to L2.

From the results displayed in computer screen and see-through lenses, we can see that the appearance venous image is sharper as seen in Fig. 13 (left) compare to the right side image in Fig. 13. Regarding on this concern, the white cloth diffuser had been used to cover the LED for the purpose to reduce the amount of NIR light emitted to target site. The image displays became smoother when the white cloth diffusers were applied as shown in Fig. 13 (right). As seen in the results displayed in Fig.13, the contrast of venous image is higher after applied the white cloth diffusers. Meanwhile, the venous are more visible in the higher contrast of NIR image.

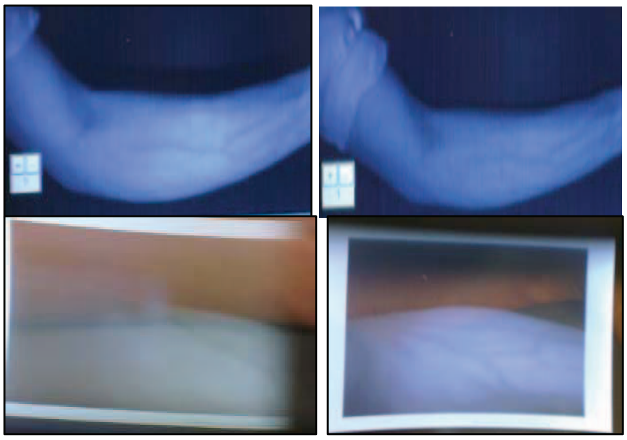

Fig.13. Imaging display on the computer screen: Virtual NIR imaging before white cloth diffuser applied (left) and Virtual NIR imaging after white cloth diffuser applied (right).

V. CONCLUSION

This research work has performed the initial design of a wearable vein locator device by using optical see-through HMD and NIR imaging technique. The AR technology used in this vein locator device had demonstrated the potential to improve medical personnel especially nurses in their daily job performance by the augmented view of NIR virtual image. Future work of this prototyping will focus on auto image calibration by using image processing technique.

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