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A Low-Cost Vein Pattern Detector for Clinical Diagnostics and Non-Intrusive Medical Monitoring

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Abstract- The vein pattern detector (VPD) stands as a revolutionary invention in the healthcare industry, evolving into a critical tool especially for healthcare-workers (HCW)s. In general, the studies have employed near-infrared (NIR) light reflection to create a vein mapping. Currently, this technology has not been widely adopted despite its potential benefits because of factors like its high-cost and restricted accessibility. Due to such reasons, phlebotomists consequently experience complications with instantly distinguishing veins, resulting in pre-analytical errors and triggering more discomfort for the patient. To address such challenges, this study aimed on developing a prototype system for detecting vein, with particular emphasis on affordability and portability. The study yielded significant outcomes in assessing subjects across varying categories ranging from underweight to obese subjects. By addressing constraints of the cost, the results highlighted the system's potential to diagnose the vein effectively, making it widely accessible especially for facilities with limited financial resources.

Keywords- Infrared (IR), LED (Light Emitting Diode); Cannulation; Venipuncture; Near-Infrared Imaging; Vein Detection; Clinical Diagnosis;

I. Introduction

Precision medicine is strongly reliant on the critical role of medical laboratory diagnostics in patient treatment. Advances in this subject are critical for improving healthcare quality, particularly in duties such as biological specimen requisitioning, collecting, and management. These enhancements contribute greatly to obtaining greater standards in personalized treatment[1]. This includes blood samples, which are a common type of biological specimen. These methods are crucial to the pre-analytical step[2]. Previous research identified pre-analytical errors as the most frequently observed challenges, with the largest error rates occurring in the clinical laboratory context, particularly during specimen collection through phlebotomy, also known as venipuncture. These issues compromised the integrity of biological samples designed to accurately reflect in vivo biological condition, resulting in unreliable diagnostic data[3]. According to research findings, over 90% of hospitalized patients may require peripheral cannulation for intravenous therapy, and performing over one billion venipunctures annually has become a key prerequisite for executing most diagnostic procedures[4]. Venipuncture is the process of drawing blood by putting a needle into the vein's wall. This intrusive procedure can create anguish, suffering, and can provoke strong reactions, particularly in children, adults, or those with mental illnesses, making it a difficult process for some patients[5]. Nonetheless, a considerable proportion of patients experience difficulties with venipuncture, necessitating at least two to ten attempts by attending nurses to successfully insert the needle[6]. Furthermore, thrombosis can be caused due to a failed venipuncture in vein [4]. Additionally, venipuncture side effects might include hematoma development or even nerve damage, particularly to the lateral antebrachial cutaneous nerve (LACN), which could result in conditions like complex regional pain syndrome (CRPS) or "causalgia" [5, 7].

In current scenario, transilluminating devices have been introduced as a technical innovation using near IR [8-10] to envisage veins superficial in the superficial region. This process involves the absorption of light by hemoglobin, resulting in the formation of an image on the skin surface[5]. The use of trans-illuminating devices for imaging allows for a more in-depth picture beneath the skin by utilizing an ideal wavelength range to enhance the contrast between the images of the skin and veins[11]. Unfortunately, the current vein viewers are prohibitively expensive, especially for low-income nations, with costs ranging from $1000 to more than $4000 [12-16] (see Table 1). Furthermore, currently accessible healthcare equipment and research solutions in the commercial market use modern technologies to improve vein visibility. However, their accessibility is restrained by high expenditures and operational equipment that is governed by static, difficult, and restricted conditions[17-18]. This essential tool, crucial for preventing dangerous consequences, is nevertheless underutilized in healthcare facilities and clinics.

As a result, the ultimate goal of this research was to develop an affordable and low-cost vein pattern detector that would be easily accessible by practitioners, clinics, and low-income healthcare facilities, thereby improving the quality of life for people of all income levels. As a result, this study is based on the concept of non-invasive NIR imaging in real time, in which NIR rays are recorded by an NIR camera and the results are displayed on an LCD screen.

Table 1 Exploring the Diverse Landscape of Vein Viewer Technologies: Market Survey

Distributor/ Manufacturer	**Price in USD ($)**	**Reference**
Korrida Medical Systems, India (www.korrida.in)	1370	[13]
Portable Vein finder, Y-Med Pharmaceutical Co. Ltd	1691	[14]
AccuVein AV300	4530	[15]
IISM, VPism-C Phlebology	3323	[16]
Vein Viewer Flex, Christimed	4531–8000	[19]
Vein locator, Wuxi Belson Medical Company Ltd	5035	[20]
Vensitehandfree system, VuTek Scientific	4627	[21]

II. MATERIALS AND METHOD

2.1 Hardware

2.1.1 NIR LEDs

The wavelength range between 800 to 850 nm has been reported todeliver the best possible performance for vein imaging[22]. Consequently, our study employed 830 nm IR LEDs (TSHG8400, Vishay Semiconductor, US) with a 5 mm package form (T-1 3/4) and a half intensity angle of 22°, as illustrated in Fig. 1. Initially, the synergistic influence was assessed with various arrangement at 15 cm, including rectangular (Fig. 2c), one-sided (Fig. 2b), and coaxial configurations, as illustrated in Fig. 2. The green arrow indicates the enhanced synergistic output. In contrast, the red arrow suggested reduced output. Following the comprehensive analysis, the coaxial arrangement (Fig. 2a) emerged as the most advantageous compared to the other two arrangements. This inclination was ascribed to its capacity to guarantee a uniform radiation dispersion, thereby concentrating it within a specific compact area.

Therefore, this study employed a total of 32 NIR LEDs, each emitting light at the peak wavelength of 830 nm, were synergistically arranged in a coaxial manner. This arrangement was strategically chosen to achieve optimal contrast between surrounding tissue and the veins, elevating the accuracy of detection. Moreover, the coaxial arrangement minimized the illumination errors, ensuring alignment with the skin. This specific design further played a pivotal role in image acquisition processes following to vein detection. Specifically, since veins absorb IR light selectively, NIR LEDs were used to detect deoxygenated blood. The NIR camera then received these reflections from the reflected light source. This technique was essential for accurately and effectively collecting vein images within the study's scientific context.

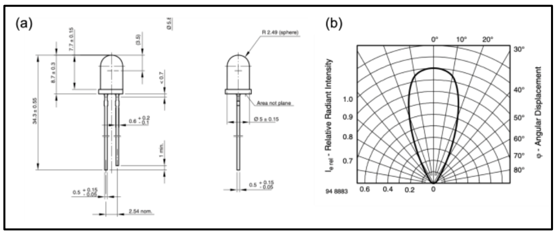

Fig. 1 Illustrates the (a) Package size, (b) Angular Displacement of IR LEDs

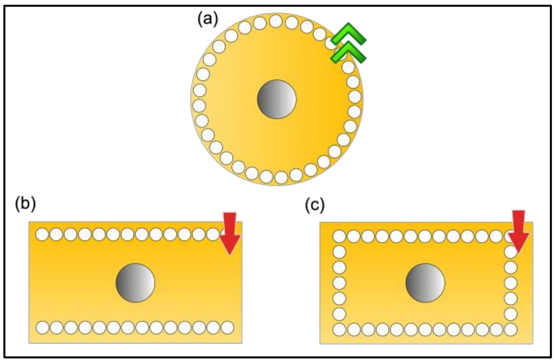

Fig. 2 Illustration of optimizing synergy through different arrangements. (a) Coaxial arrangement, (b) One-side arrangement, and (c) Rectangular arrangement.

2.2.2 NIR Camera

As depicted in Fig. 3, the NIR camera (C429-L36, China) played an essential role in capturing photos or real-time images for the imaging purpose. Equipped with a 3.6 mm lens, the camera proved essential for its ability to detect NIR radiation effectively employing a CCD. With its compact design, the NIR camera was strategically placed within a central hole in the upper section of the hardware (see Fig. 5). This placement was carefully chosen for focusing precisely on a particular region, predominantly to capture real-time images of subjects' veins.

Notably, this particular camera operated 80 mA and 5 V, enhancing efficiency and sustainability. The compact size of 32 x 32 mm allowed for ease of integration and minimized spatial requirements. With the camera centrally located, the design facilitated accurate focusing on a specific area, optimizing the vein detection process. The camera could discern veins, excluding arteries, due to the specific absorption characteristics of infrared radiation in blood vessels. By employing IR radiations at particular wavelengths for various body parts, the system enabled the examination of vein patterns in almost any part of the body. After capturing the real-time image of the subject's veins, the data was seamlessly transferred to an LCD for immediate display, facilitating further analysis and diagnostic interpretation.

2.2.3 Selection of LCD Panel

A low-cost 3.5" TFT LCD (as shown in Fig. 3), specifically designed for CCTV applications, was integrated into the experimental setup. This LCD was chosen for its compatibility with the NIR camera, which ensured a smooth and precise connection between the two components. As shown in Fig.3, the LCD functioned as a critical interface for displaying information gathered by the NIR camera in real time. The LCD functionality facilitated the immediate presentation of a real-time, precise image depicting the patient's blood pattern. To enhance the visibility and clarity of an image, the contrast and brightness settings of the displayed image was adjusted conveniently using the LCD function panel. This integration between the NIR camera and the compatible LCD contributed to efficient data visualization and analysis during vein detection.

Fig. 3 3.5" TFT LCD Panel

2.2.4 Image Processing

In executing the image processing procedure, once the image was retrieved (as illustrated in Fig. 4), a series of preprocessing steps were implemented to enrich image quality and facilitate successive vein segmentation. The inherent speckle noise in the IR images was successfully alleviated by applying a median filter. The median filter was particularly effective in reducing the speckle noise, which is a common issue in IR imaging, thereby preserving the edges of the veins while removing unwanted noise. Following this, the enhancement of the vein region within the preprocessed images was accomplished through several techniques. The application of a digital image negative helped in highlighting the vein structures by inverting the pixel values, making the veins stand out against the background. Contrast stretching further improved the differentiation between the veins and the surrounding tissue by expanding the range of intensity values. Thresholding was used to create a binary image that distinctly separated the vein regions from the background based on intensity values. Finally, adaptive histogram equalization was employed to enhance the contrast of the images adaptively, based on the local regions' intensity distribution, which improved the visibility of the veins across varying lighting conditions and image qualities. This collaborative approach effectively optimized the vein structure's discrepancy, enhancing visibility and contributing to the subsequent validation phase. These preprocessing steps were crucial in preparing the images for accurate vein segmentation and detection, ensuring that the vein patterns were clear and distinguishable.

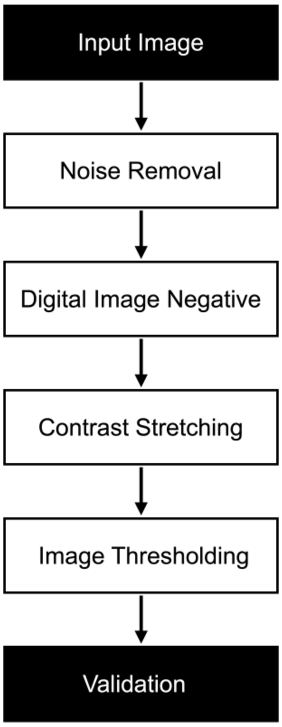

Fig. 4 Flow chart of Image Processing

2.3 Configuration of Hardware and Overall System

The VPD depicted in Fig. 5 is characterized by a coaxial configuration of IR LEDs, coupled with the strategic positioning of the LCD and circuitry compartment. Notably, the system exhibited optimal functionality up to a maximum distance of 30 cm. The prototype, boasting a lightweight design of less than 1.2 kg, offered portability for versatile use across various settings. The system's economic viability was accentuated by its unremarkable cost, with the working prototype costing about ~ $83. This low-cost prototype combined practicality with cost-effectiveness, offering a promising solution for vein visualization in diverse medical or clinical scenarios. The coaxial arrangement of IR LEDs and the compact design contributed to its versatility and ease of transport, aligning with the demands of modern healthcare applications. The diaphanous breakdown of component costs in Table 2 further facilitated scalability, fostering accessibility in implementing this vein viewing technology.

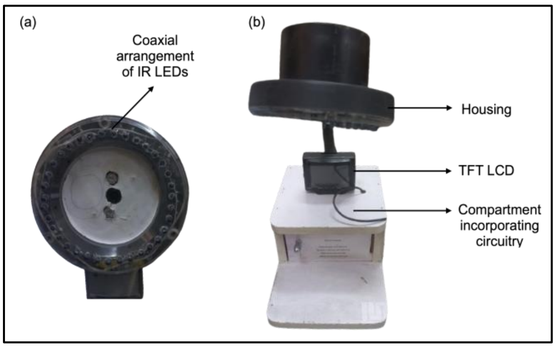

Fig. 5 VPD setup (a) Coaxial arrangement, (b) Overall hardware.

Table 2 Breakdown of the Approximate Cost

Hardware/ Component	Pricing in USD
IR LEDs	$ 10
CCD Camera	$ 14
Microcontroller	$ 5
AV converter	$ 4
Projector	$ 15
Power Supply and Wiring	$ 10
TFT LCD	$ 15
Fabrication	$ 10
Total Estimated Cost	**$ 83**

2.4 Testing and Assessment

The VPD system was evaluated with participants who gave informed consent. Before beginning the testing phase, the participants' Body Mass Index (BMI) was determined, emphasizing the significant importance of BMI in healthcare. As part of the testing procedure, this preliminary stage sought to consider and account for the participants' varied BMIs. This emphasis on BMI was supported by Kam J and Taylor D[23], who highlighted the increased challenges in patient management, particularly during procedures such as cannulation and venipuncture, when BMI falls within the obese or morbidly obese range.

BMI is a valuable metric for indicating whether an individual fall underweight, has average weight, is overweight, or is obese. The classification of BMI values is shown in Table 3.

Table 3 Classification of BMI Values [24]

	BMI
Underweight	Below 18.5
Normal	18.5 – 24.9
Overweight	25.0 – 29.9
Obesity	30 and above

More importantly, the study conducted by Dhakshayani M and Yacin S. [25]emphasized that age played a critical role in influencing vein access challenges. Elderly individuals face difficulties due to changes in vein structure, characterized by thinness and fragility due to decreased elasticity. Conversely, pediatric populations posed challenges due to smaller peripheral veins with higher subcutaneous fat content and increased susceptibility to vasoconstriction.

Hence, we implemented a systematic categorization methodology to methodically observe subjects within distinct age groups and weight parameters. Our targeted cohorts encompassed underweight individuals below the age of ten, individuals within the normal weight range (above 20 and below 30 years), individuals classified as overweight (aged between 30 and 40 years), and those categorized as obese (aged above 50 years). This deliberate stratification facilitated a comprehensive exploration and analysis of the influence of age and diverse weight categories on the efficacy of our vein detection system. By adopting such a structured approach, we sought to derive nuanced insights that could contribute to a more profound understanding of the system's performance across a spectrum of demographic factors.

III. Result and Discussion

Light is crucial in modern medicine for diagnostics and treatments such as ultraviolet (UV) and IR. Recent technological advancements have demonstrated that UV light is a promising tool for eradicating pathogens[26-28], while IR light is used for thermography to detect inflammation and vascular issues and widely for vein detection. This study explored the development of low cost VPD technology using IR light source. By utilizing IR light, the research aimed to create a more accurate and non-invasive method for detecting vein patterns.

In contrast to the challenges outlined in Dhakshayani M.'s 2015 study[25], which emphasized the difficulties in assessing veins in elderly individuals, our investigation produced significant outcomes. The results from our study showed that vein patterns were clearly visible, effectively overcoming the previously stated challenge. Notably, our prototype demonstrated efficacy in vein assessment without the limitations associated with direct skin contact, as reported in certain prior prototypes[29]. Our system exhibited successful vein visualization within the optimal range of 15 – 30 cm, showcasing its potential for reliable and non-intrusive vein detection.

It was imperative to recognize that researchers worldwide have suggested and developed vein detectors, as evidenced by current literature. However, several contributors needed to offer more details about prototypes turning into commercial products. The restricted disclosure about the commercialization of their generated prototypes may be due to their ongoing patenting processes, waiting for medical certifications, and validating their works.

While the current research contributes to the basic understanding of the topic, our method sought to overcome these drawbacks by enhancing the hardware architecture using readily accessible, low-cost, commercially available components, optimizing the experimental design, and carrying out evaluations on broader aspects. By doing this, we aim to develop inexpensive, equally efficient vein recognition systems and, eventually, enhance suitability for use in medical settings.

This VPD has several potential applications beyond its primary focus, significantly enhancing healthcare delivery in various settings. In emergency medical services (EMS)[30], the VPD would be able to aid in rapid and precise vein location, crucial for administering lifesaving medications and fluids under challenging conditions like low light or patient distress[31]. In home healthcare, the VPD would be able assist caregivers and patients in managing chronic conditions requiring regular intravenous treatments, reducing the need for hospital visits and improving patient comfort and autonomy. Additionally, VPD can be employed in clinics particularly in the middle- or low-income state of the country where resources are very limited.

The study has some encouraging findings, but it also has some drawbacks. First off, various skin tones may not benefit from the NIR-based imaging technology equally[32], especially for the people having dark tone of the skin[33]. It is recommended to explore further with particular emphasis on the people with range of skin colors.

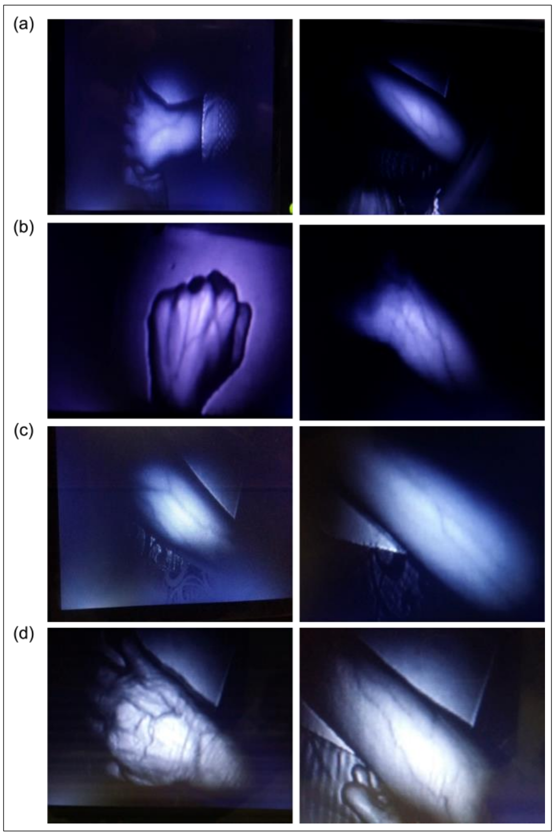

Fig. 6 Vein Pattern Detection: (a) Underweight Subject, (b) Normal Subject, (c) Overweight Subject, and (d) Obese Subject

IV. CONCLUSION

Finally, our in-depth examination of VPD showed its undeniable significance in the medical field, giving professionals essential knowledge regarding vein patterns for a variety of applications. Despite their obvious benefits, the cost of existing vein detection devices prevents healthcare facilities from being utilized in a broader aspect. In light of this, the creation of an affordable VPD prototype with a low cost of around $85, positioned it as a game-changer for healthcare institutions, clinics, practitioners, and even homes with little resources. From a wide range of BMI, our prototype resulted effectively in visualizing the patterns of the veins. Furthermore, the device's intuitive layout ensured its easy integration into a range of medical settings. In a nutshell this study not only offered an alternative method to counter the barriers in regards of budget constraints, but it also opens the door for a more advanced, inclusive, and accessible method of vein analysis and recognition.

Conflict of Interest
None declared

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Declaration of Competing Interest

The authors have no competing interests to declare that are relevant to the content of this article.

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