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DEVELOPMENT OF A PORTABLE VEIN VISUALIZATION DEVICE BASED ON NIR IMAGING AND RASPBERRY PI

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Article Info

Abstract

The use of venous blood for diagnostic tests is a common yet critical procedure in medical practice. However, locating suitable veins for cannulation or phlebotomy remains a significant challenge, especially in patients with factors like obesity, dark skin tone, or age-related venous changes, leading to high pre-analytical error rates and patient discomfort. This paper proposes a low-cost, non-invasive vein detection system utilizing Near-Infrared (NIR) illumination and real-time image processing. The system employs an infrared dome camera with an NIR LED ring to capture subcutaneous vein patterns. The captured video stream is processed on a Raspberry Pi using Contrast Limited Adaptive Histogram Equalization (CLAHE) to enhance vein contrast against the surrounding tissue. The processed image is then displayed on an LCD screen, providing a clear, real-time map of the patient's vasculature. Experimental results demonstrate that the system effectively visualizes veins that are not visible to the naked eye, offering a portable and affordable solution to improve the success rate of first-attempt venipuncture, thereby reducing patient pain and associated complications.

Keywords:
Vein Detection, Near-Infrared (NIR) Imaging, Image Processing, CLAHE, Raspberry Pi, Phlebotomy.

1. INTRODUCTION

Venipuncture is one of the most frequent procedures in clinical settings, essential for blood donation, transfusion, and intravenous therapy.[1] Despite its routine nature, the process of locating a suitable vein is often difficult, particularly in pediatric, geriatric, obese, and dark-skinned patients.[2] Failed first attempts not only cause patient pain and anxiety but also contribute significantly to pre-analytical errors, which account for 46% to 77% of laboratory mistakes **[Table 1]**.[3]

Existing solutions like ultrasound are effective but often expensive and not readily available in all settings.[4] This work addresses the need for a cost-effective and accessible alternative. We present a vein detection system based on the principle that deoxygenated hemoglobin in veins absorbs NIR light (740-940 nm) more than the surrounding tissues, creating a contrast that can be captured by an IR-sensitive camera. By applying real-time image processing techniques, this contrast is enhanced to produce a clear venous map. The primary motivation is to provide medical practitioners with a simple, portable tool to improve procedural accuracy, minimize patient discomfort, and enhance overall healthcare efficiency.

Table 1. Statistical report on pre-analytical errors (2010–2017)

Study	Pre-Analytical Error (%)
West J et al., 2017	up to 68.20
Najat D, 2017	up to 70.00
Salinas M et al., 2015	60.00 to 70.00
Patra S, 2013	46.00 to 68.20
Hammerling J, 2012	46.00 to 68.20
Lippi G et al., 2011	60.00 to 70.00
Goswami B et al., 2010	77.10

2. Methodology

The proposed system was designed and implemented using a structured approach involving specific hardware components and a dedicated software processing pipeline. The hardware setup centered around an imaging unit consisting of a dome camera equipped with an integrated ring of Near-Infrared (NIR) Light Emitting Diodes (LEDs), emitting light at a wavelength of approximately 850 nm. This wavelength was selected for its ability to penetrate human tissue up to a depth of about 5 mm while being absorbed by the deoxygenated hemoglobin in veins.[5] To ensure optimal image quality, an IR band-pass filter was employed over the LEDs to isolate the NIR spectrum and eliminate interference from ambient visible light. The processing unit of the system was a Raspberry Pi single-board computer, chosen for its computational capability, compact size, and portability, which are essential for a handheld medical device.[6] The final output was displayed in real-time on a 7-inch AVT LCD screen, providing an immediate visual map of the vasculature.

The core functionality of the system was driven by its software and image processing workflow. The process began with the IR camera capturing a live video feed of the skin area illuminated by the NIR LEDs. This raw video feed was then processed on the Raspberry Pi. The key image processing technique employed was Contrast Limited Adaptive Histogram Equalization (CLAHE), which was applied to each frame of the video stream. CLAHE works by enhancing the local contrast of the image, effectively making the darker vein structures, which absorb more NIR light, more distinguishable from the lighter surrounding tissues that reflect it.[7] This method was specifically chosen over standard histogram equalization for its ability to improve contrast without over-amplifying noise, leading to a clearer and more reliable visualization of the venous pattern.[8] The overall workflow, from NIR illumination to the final display on the LCD, provided a seamless and real-time aid for venipuncture.

3. Results and Discussion

The system's performance was evaluated by comparing images of a subject's wrist under different conditions. The initial capture without IR illumination showed no visible subcutaneous veins, as expected, since a standard camera lens cannot detect the NIR spectrum without dedicated hardware **[Figure 1a]**. However, with the activation of the NIR LED ring, the system successfully produced a real-time image where the venous patterns were clearly delineated as dark, contrasting lines against a lighter background **[Figure 1b]**. This successful visualization empirically confirms the underlying working principle that deoxygenated hemoglobin in veins has a higher absorption coefficient for NIR light at the 850 nm wavelength compared to the surrounding dermal and subdermal tissues. The application of the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm was then demonstrated to be highly effective in enhancing this inherent contrast, making the vein patterns prominent and easily distinguishable for the operator.

These findings are supported by the literature, which indicates that NIR imaging is a robust diagnostic modality largely unaffected by skin pigmentation. This represents a significant advantage over traditional visual and tactile methods, which are known to struggle with patients having high Body Mass Index (BMI) or darker skin tones, classified as Fitzpatrick skin types IV- VI **[Table 2]**. By providing a direct visual map of the subcutaneous vasculature, the proposed system directly addresses several key risk factors for difficult cannulation identified in clinical studies, including patient dehydration, pediatric or geriatric age, and poor venous condition. The primary strength of this work lies in its cost-effectiveness and portability, achieved through the integration of a Raspberry Pi and a modified standard IR camera. This design philosophy makes the technology a viable and accessible tool for improving procedural accuracy in primary care clinics and resource-limited settings, where expensive alternatives like ultrasound may not be readily available.

Table 2. Skin Tone

Skin Type	Description
I	Very light complexion
II	Light complexion
III	Medium complexion
IV	Darker complexion
V	Dark complexion
VI	Black complexion

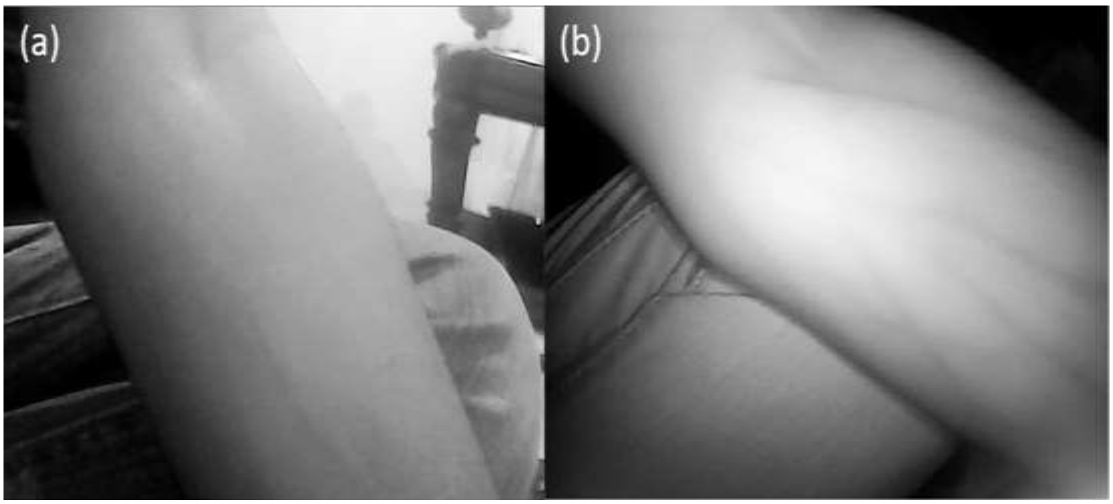

Figure 1 A visual comparison of vein visibility (a) without and (b) with Near-Infrared (NIR) illumination, demonstrating the enhanced contrast of subcutaneous veins under NIR light.

4. Conclusion

This study successfully designed and implemented a low-cost, non-invasive vein detection system. By leveraging NIR illumination and real-time CLAHE-based image processing on a Raspberry Pi, the system provides a clear and immediate visualization of subcutaneous veins. The proposed solution has the potential to significantly improve the success rate of venipuncture on the first attempt, thereby reducing patient pain, pre-analytical errors, and procedure time. Future work will focus on clinical trials to quantitatively assess the improvement in first-stick success rates and further refine the image processing algorithms for even greater clarity and depth perception.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. No financial or personal relationships with other people or organizations have inappropriately influenced the work reported in this manuscript.

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