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Melanveer: Vein Detection Technology to Improve Health Services

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Abstract

Background: Intravenous (IV) procedures face challenges due to low nurse proficiency (50.8%) in Indonesian and difficulties in vein visualization, especially in patients with darker skin tones. *Objectives*: To develop an affordable, portable vein detection device, "Melanveer," capable of accurate visualization for all skin types. *Materials and Methods*: Melanveer uses near-infrared (NIR) light and Contrast Limited Adaptive Histogram Equalization (CLAHE) for real-time vein visualization. The prototype, made with 3D-printed components, was tested on 20 patients with varying skin tones (Very white to light white skin, Fair to light brown skin, and Dark to very dark brown skin). *Results:* Melanveer demonstrated 94% accuracy in vein detection, improved efficiency for medical staff, and enhanced patient comfort during IV procedures. *Conclusions*: Melanveer offers an innovative, cost-effective, and portable solution for accurate vein detection, addressing challenges in IV procedures and improving healthcare outcomes.

Keywords

CLAHE; Intravenous; Infrared Light; Melanveer; Vein Visualization

1. Introduction

As a healthcare institution providing comprehensive services, hospitals must prioritize patient safety in every aspect of care provided (Larasati and Dhamanti, 2021). Nearly all patients undergoing hospital treatment require intravenous (IV) infusion or injection procedures (Sari, Kurniawan, and Kurniawan, 2021). However, 50.8% of nurses are reported to have low proficiency in performing IV procedures, particularly in infusion placement (Heru et al., 2021; Patidar, 2022). This increases the risk of malpractice, often leading to patient complaints due to discomfort experienced during IV procedures. Repeated infusion attempts on a patient's hand, caused by difficulties in locating veins, can result in various complications such as pain, swelling, or even phlebitis, as shown in Figure 1. It may also cause trauma, leading patients to experience anxiety or fear of future IV procedures due to unpleasant experiences.

Figure 1. Patient injury due to repeated infusion attempts

Various solutions have been developed to assist medical personnel in facilitating IV infusion or injection procedures (Sari, Kurniawan, and Kurniawan, 2021). These efforts aim to improve the success rate of IV placement on the first attempt, minimizing the need for repeated injections (Perdana, Manggala, and Karina, 2020). This led to the development of the Vein Finder, a device capable of visualizing vein pathways (Ahzani and Rahman, 2020). The current Vein Finder visualization technology uses a projector that emits infrared light and projects it onto the patient's skin surface (Francisco et al., 2021). However, this technology has limitations, particularly in its effectiveness for patients with darker skin tones. The primary factor affecting vein detection in darker-skinned patients is the high melanin content (Suryani, 2020). In these patients, the contrast between the veins and skin is less pronounced compared to lighter-skinned individuals (Hamza, Skidanov, and Podlipnov, 2023). Additionally, the Vein Finder device is priced at over IDR 50,000,000, according to the E-Catalog developed by the Government Procurement Policy Agency (LKPP), making it unaffordable for many healthcare institutions aiming to enhance performance and service quality (Pan et al., 2019).

In response, research and development efforts have focused on creating a new vein detection technology, 'Melanveer,' which employs high-frequency near-infrared (NIR) light to visualize veins at a more affordable cost. Melanveer operates by utilizing hemoglobin in the blood, which absorbs light emitted by infrared rays, enabling the formation of vein pathways on the skin surface (Syafiq and Nasution, 2016). The image processing stage employs the Contrast Limited Adaptive Histogram Equalization (CLAHE) method, a technique designed to adaptively enhance image contrast (Stimper et al., 2019). With Melanveer, medical personnel are expected to achieve greater accuracy and efficiency in IV procedures, while patients, particularly those with darker skin tones, will experience increased comfort during IV procedures.

2. Materials and Methods

2.1. Types of research

The development process of Melanveer involves several stages, from design to user implementation. These stages include an analysis of the needs of potential users through interviews with nurses and other medical professionals. This is followed by concept modeling, where a three-dimensional product design is created using Computer-Aided Design (CAD) software. The design, once validated, is printed using 3D printing technology. The next stage involves the assembly of electrical components and the physical assembly of the product. For the software, image processing is performed using the CLAHE method. The product undergoes two testing phases: functional testing and direct testing with potential users. The final stage is an evaluation of the test results to improve the product before mass production. The patients used by researchers were 20 patients with inclusion criteria Healthy patients or volunteers aged ≥18 years, a variety of skin colors based on Fitzpatrick Skin Type I-VI (Very white to light white skin, Fair to light brown skin, and Dark to very dark brown skinrfa), patients who need peripheral venous access procedures, and are willing to follow all research procedures (informed consent). While the exclusion criteria are patients with skin conditions that interfere with vein detection, extreme blood circulation disorders, and severe coagulation disorders.

2.2. Research methods

The initial stage of development begins with an in-depth literature review to gather data from user needs analysis, determined through interviews with nurses. The results of these interviews are translated into device specifications that must be met: the device must be portable for easy mobility, usable by a single user, provide real-time visualization, and detect all skin types. The established specifications are then used to create an initial model using Fusion 360 software, covering both the physical structure design and ergonomic considerations for the user. Melanveer is printed using a 3D printer with Polylactic Acid (PLA) material. The selection of appropriate materials is crucial to ensure the device's performance and safety. PLA is chosen as the primary material for printing the body cover due to its environmentally friendly properties and its compatibility with medical applications (He et al., 2022).

After printing, the assembly of electrical components follows, which includes the infrared camera, monitor, Raspberry Pi Compute Module 4 (CM 4), and 18650 battery. Supporting components such as the 3S BMS, LM2596 step-down regulator, battery indicator, DC jack, and push button are also assembled according to their functions. The assembly process requires high precision to ensure both structural and functional integrity. Therefore, the integrity of each component is represented in the block diagram in Figure 2.

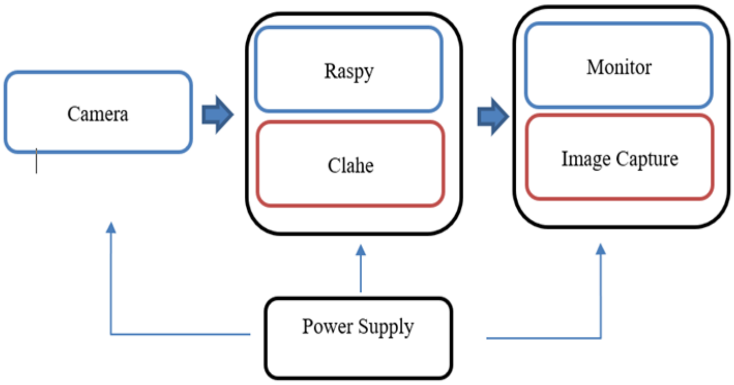

Figure 2. Block diagram of the system design

Each block represents the main function of each component, and the relationships between these blocks reflect the flow of data and control within the system. By following this diagram, it can be ensured that each component contributes effectively to achieving the system's overall goals. The 18650 battery serves as the power source with a capacity of 3.7V 3350 mAh, consisting of six batteries arranged in a 3-series 2-parallel configuration to meet the required capacity for each component, such as the Raspberry Pi CM 4 and the camera. The LM2596 step-down regulator is used to reduce the total battery voltage to 5V for the monitor, while all components can be powered on and off using a single push button. The camera captures the infrared light reflected by the object and sends it to the Raspberry Pi CM 4 for image processing using the CLAHE method. The CLAHE method is used to enhance image contrast and improve the visualization of venous blood vessels, allowing the veins to be displayed on the monitor screen (Yakno, Mohamad-Saleh, and Ibrahim, 2021). After component assembly, the next stage is the physical assembly of the product, which includes installing the 3D printed body cover and camera body, along with the camera stand containing all the electrical components, thus forming a complete device.

After the component assembly phase, the next step is the physical assembly of the product, which includes attaching the 3D-printed body cover, and camera body, and assembling the camera pole with all the electrical components inside, forming a complete, unified device. The Melanveer product operates based on digital image processing principles, enabling the visualization of veins efficiently. The process works as follows:

When the push button is pressed, the power from the battery is split into two paths: one directly to the Raspberry Pi Compute Module 4 at 12V, and the other through the LM2596 step-down to reduce the voltage to 5V for the monitor. The Raspberry Pi CM 4, as the main processor, powers the infrared camera with a 940 nm wavelength and captures images of infrared radiation emitted by objects, capable of penetrating the skin to a depth of 10mm. The camera captures images that are processed by the Raspberry Pi using CLAHE, which enhances image contrast by dividing the image to clarify the visualization of veins. The monitor displays the processed image of the veins in real-time. This monitor uses AMOLED technology and features a touch screen.

The Melanveer product undergoes a series of tests to evaluate its accuracy, effectiveness, and reliability. Testing is conducted using two methods: direct trials with potential users to assess the vein detection capability compared to conventional methods, and functional testing to ensure the device works according to specifications. Functional testing includes load testing, charging tests, durability tests, and image quality tests. Load testing ensures that the battery can power all components simultaneously, including the monitor, infrared camera, and Raspberry Pi CM 4, and that all components can be turned on and off using one push button. Charging tests assess whether the battery can be recharged for reuse after depletion. Durability tests measure how long the battery lasts when continuously powering the device. After ensuring the battery is fully charged, the device is powered on, and its operating time is recorded until the device shuts down or shows a performance decline. Image quality tests are conducted directly with users, such as nurses and other medical professionals, as validators, and data is collected from multiple samples.

Once testing is complete, the next step is an evaluation based on the data obtained from the tests to identify any weaknesses or shortcomings in the product. Evaluation from functional testing is a technical evaluation, where the product is assessed for its compliance with established quality standards, such as ISO and IEC standards. Additionally, user satisfaction is evaluated, considering ease of use, time efficiency, and the device's effectiveness in improving medical personnel performance. Based on the evaluation, improvements are made to enhance the product's quality in terms of functionality, technical aspects, and performance before it is ready for mass production.

3. Results and Discussion

3.1. Results

The results of interviews with potential users emphasized the importance of designing the device to be portable so it can be easily moved to various locations and operated by a single person. Based on this feedback, the Melanveer product was designed with a camera support stand to allow operation by one user. The product has dimensions of 38 cm in length, 37 cm in width, and 5 cm in height, consists of several parts, including a handrest that serves as a place to position the patient's hand. The handrest is made of soft and thick padding, ensuring the patient’s comfort during intravenous procedures. The body cover functions as a protective casing for all the internal components of the Melanveer device. The monitor screen displays real-time visualization of venous blood vessel pathways, making it easier for users to locate veins, thus improving time efficiency. The camera body is made to hold the camera, which is connected to the support stand. The camera stand is made of flexible goose neck material, allowing the camera to move flexibly. The three-dimensional design concept was created according to the standards and needs of potential users and then printed using a 3D printer with PLA material. PLA is a lightweight material with strong rigidity compared to other materials and is safe for use in medical devices (Luo, 2023). Figure 3 shows the result of the assembly of the electrical components, including the body cover, which consists of the handrest, monitor screen, camera body, and camera stand.

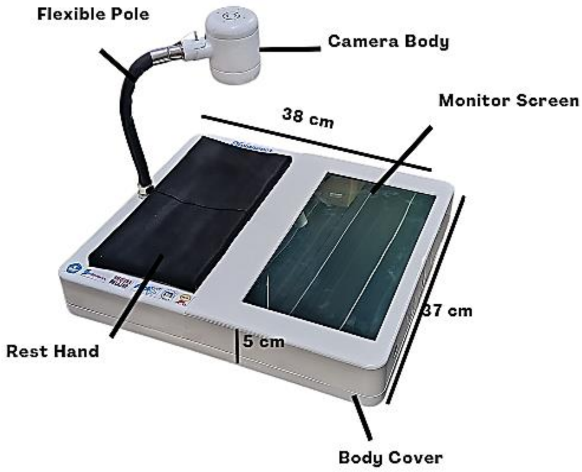

Figure 3. 3D printing result

The Contrast Limited Adaptive Histogram Equalization (CLAHE) method is used to enhance the visualization of venous blood vessels. In this visualization, the veins appear darker compared to the surrounding tissue, which makes it much easier to identify the venous pathways. The contrast difference between the veins and surrounding tissue is clearly displayed, providing a sharp image of the venous structure, as shown in Figure 4. This demonstrates Melanveer's capability to produce high-precision images, aiding in medical procedures such as intravenous injections.

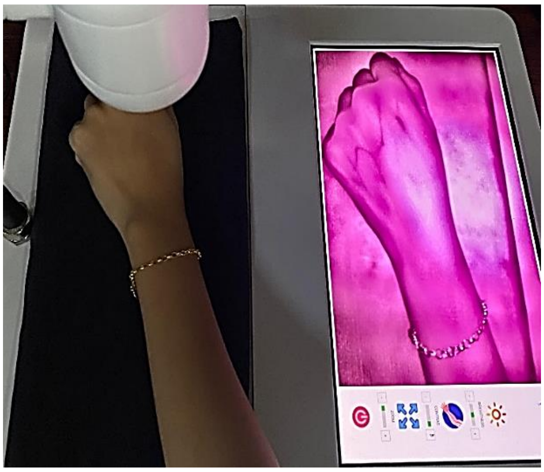

Figure 4. Visualization of venous blood vessels

Functional testing was performed to evaluate the system's performance using the 3S2P battery configuration to meet the power requirements of various components. First, a load test was conducted by measuring the current and voltage generated during system operation. The results showed that this configuration could power the 5V monitor with a 3A current, the 12V Raspberry Pi CM 4 requiring 3A, and the camera requiring 0.2A at 5V. Next, a charging test was performed to measure the system's ability to receive charging current. The results showed that the system could accept voltage up to 12.25V, indicating that the system has a good tolerance to voltage fluctuations. Finally, a durability test was conducted with a fully charged battery. This test showed that the system could operate for up to 3 hours, meeting the power requirements for the device.

Functional testing was also conducted to ensure that the product operates efficiently according to the expected specifications. This testing was carried out at PT. Zenith Almart Precisindo and a Certificate of Analysis was obtained as proof of the validity of the test results. The functional tests cover various aspects according to applicable international standards, as shown in the following Table 1.

Table 1. Melanveer control analysis results at PT. Zenith Allmart Precisindo.

Test	Result	Standard Value	Standard Reference
Accuracy	90%	85%-95%	ISO-14971:2019
Infrared Intensity	3.6 Lm	0.5 - 5 Lm	ISO-20373
Skin Thermal Temperature	26,8° C	<40 ° C	ISO-14971
Main Voltage	12.10V	12 ± 10 %	IEC 60601-1-1-2015
Enclosure Leakage Current	1 μA	100 μA	IEC 60601-1-1-2015
NIR Wavelength	940 nm	700- 1400 nm	IEC 60825-1

The results of these tests indicate that the tested product has met the required safety and performance standards and is ready to be applied in medical environments that demand high accuracy and reliability.
The Melanveer product was tested using two methods: direct testing on patients to evaluate its effectiveness and accuracy in detecting venous blood vessels, and functional testing to ensure that all components operate according to the established standards. Direct testing was conducted on 20 samples with varying skin types. The Fitzpatrick Scale, which consists of six types, was used to classify skin tones, as shown in Figure 5 (Santiago et al., 2023). Each sample's skin tone was determined and compared against the scale, resulting in the sample data presented in Figure 6.

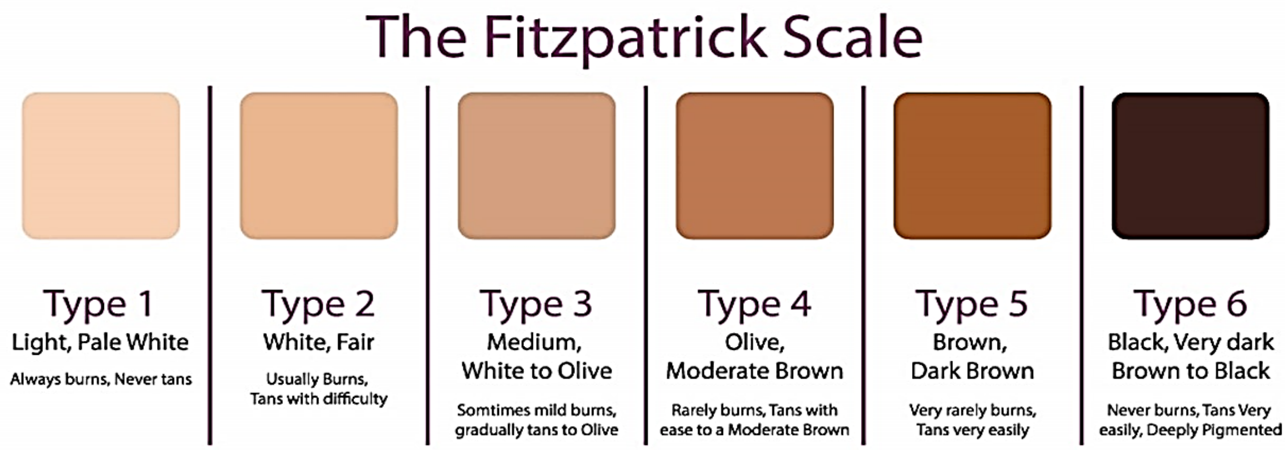

Figure 5. Numerical classification of human skin tones

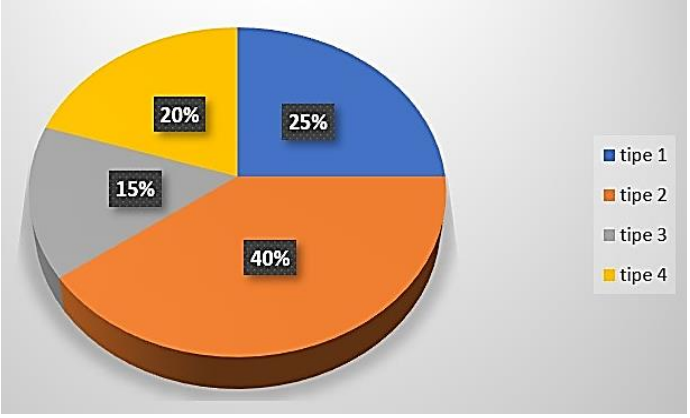

Figure 6. Skin tone determination results for samples

The direct testing of Melanveer on patients was supervised by Ekaningtyas Haryatni, Amd.Keb, a midwife at a local public health center. This test aimed to compare the effectiveness of Melanveer with the traditional palpation technique for detecting venous blood vessels commonly used by midwives.

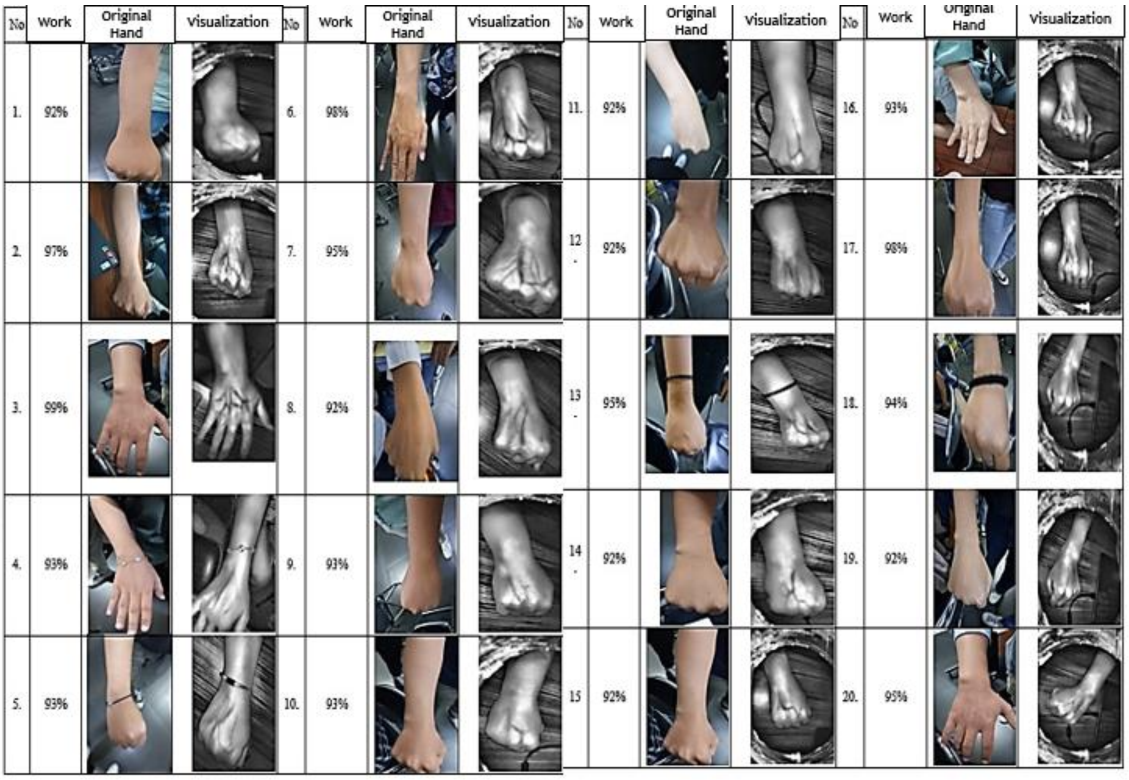

Figure 7. Results of direct testing

Testing was conducted on the same 20 patient samples used in the earlier trials, focusing on the back of the hand, where veins are commonly accessed for intravenous procedures. Results from the 20 samples, which varied in skin tone and hand size, are illustrated in Figure 7.

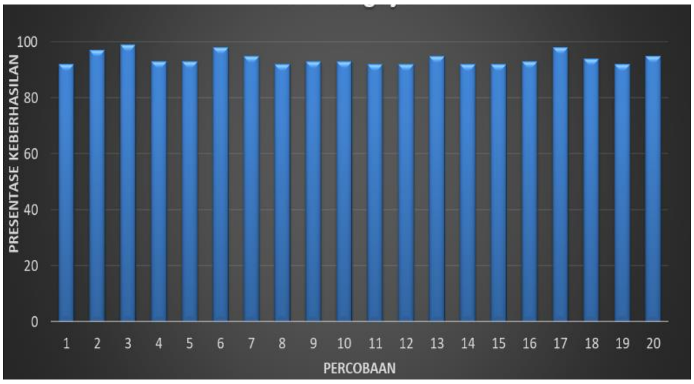

Figure 8. Accuracy testing results for melanveer

During the trial, the midwife counted the number of veins detected by touch on the patient's hand and compared it to the number of veins visualized on the Melanveer monitor. As shown in Figure 8, the trial results for each sample indicate that Melanveer achieved a 94% accuracy in detecting venous blood vessels. This demonstrates the device's high level of accuracy and effectiveness in visualizing venous blood vessels. The veins detected were primarily the largest veins suitable for intravenous injection procedures.

Figure 9. Device validation by medical professionals

Figure 9 illustrates that the device was also tested and validated by two general practitioners, both of whom confirmed that Melanveer performed well, particularly on the back of the hand. The veins visible on the back of the hand were the dorsal veins, which are commonly used for infusion procedures. Additionally, two nurses validated the device, both stating that Melanveer successfully detected venous blood vessels with an accuracy exceeding 90%.

4. Conclusions

Melanveer is a portable vein detection device based on Near-Infrared (NIR) technology equipped with the CLAHE image processing method, with detection accuracy reaching 94% and production costs below Rp10,000,000. This device is able to display real-time visualization of veins, including in patients with dark skin tones, and has been proven effective without causing complaints from medical personnel. With its ergonomic design, affordable price, and reliable performance, Melanveer is an innovative solution that improves the quality of intravenous procedures, reduces the risk of medical errors, and increases patient comfort, while being a superior alternative to similar devices on the market.

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Conflicts of Interest: There are no research conflicts

Author Contributions: IA: Conceptualization, Methodology, Hardware, Writing-Original draft preparation. AM: Software, Data curation, Writing and Editing. SH: Visualization, Design, Investigation, Writing and Editing. WAP: Supervision, Validation, Reviewing and Editing.

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