DEVELOPMENT OF A NON-INVASIVE VEIN SCANNER SYSTEM FOR IMPROVED BLOOD COLLECTION IN HEALTHCARE SETTINGS

BY

MAC-ASORE DAVID EDAFE

(19CJ025801)

JUNE 2024

DEVELOPMENT OF A NON-INVASIVE VEIN SCANNER SYSTEM FOR IMPROVED BLOOD COLLECTION IN HEALTHCARE SETTINGS

BY

MAC-ASORE DAVID EDAFE

(19CJ025801)

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL & INFORMATION ENGINEERING, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF ENGINEERING DEGREE (B.Eng) IN COMPUTER ENGINEERING, COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA.

SUPERVISOR

DR. ADEWALE ADEYINKA

JUNE 2024

DECLARATION

I hereby declare that I carried out the work reported in this project in the Department of Electrical and Information Engineering, Covenant University, under the supervision of Dr Adewale Adeyinka. I also solemnly declare that to the best of my knowledge, no part of this report has been submitted here or elsewhere in a previous application for the award of a degree. All sources of knowledge used have been duly acknowledged.

Mac-Asore, David

19CJ025801

CERTIFICATION

This is to certify that the project titled "**DEVELOPMENT OF A NON-INVASIVE VEIN SCANNER FOR IMPROVED BLOOD COLLECTION IN HEALTHCARE SETTINGS**" by Mac-Asore David Edafe, meets the requirements and regulations governing the award of the Bachelor of Engineering Computer Engineering degree of Covenant University and is approved for its contribution to knowledge and literary presentation.

Supervisor 1: Sign: __________________

Name: Dr Adewale Adeyinka Date:

Internal Examiner: Sign: __________________

Name: Date:

Head of Department: Sign: __________________

Name: Dr. Isaac A. Samuel Date:

DEDICATION

I dedicate this project to God Almighty for His grace and wisdom given to me to see this project to its completion. I also dedicate this project to my parents for all their love and support throughout my years of study.

ACKNOWLEDGEMENT

I appreciate God almighty for seeing me through five years of study and guiding me every step of the way.

I am also grateful to my wonderful parents: Dr Kingsley Mac-Asore and Mrs Temilola Mac-Asore, for their loving support, continuous sacrifice, patience, and prayers.

I extend my gratitude to my supervisor, Dr. Adewale Adeyinka for all the help, advice, and mentoring she provided me with while I worked on this project, which helped me complete it on time. Working under her has been a privilege.

I would also like to acknowledge my friends who were a source of constant encouragement while I worked on this project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION AND SYMBOLS

NIR:	Near Infrared
IR:	Infrared
OpenCV:	Open Source Computer Vision Library
VEID:	Vein Entry Indicator Device
DVT:	Deep Vein Thrombosis
CT:	Computed Tomography
MRI:	Magnetic Resonance Imaging
MR:	Magnetic Resonance
ADT:	Active Dynamic Thermography
PPG:	Photoplethysmography
PAD:	Peripheral Artery Disease
LOG:	Laplacian of Gaussian
QR:	Quick Response
LED:	Light Emitting Diode
CLAHE:	Contrast Limited Adaptive Histogram Equalization
JPEG:	Joint Photographic Experts Group
PNG:	Portable Network Graphics
BMP:	Bitmap
TIFF:	Tagged Image File Format

ABSTRACT

The difficulty of intravenous access in patients is an important clinical issue. This project developed a non-invasive vein scanner that leverages near-infrared (NIR) imaging technology to enhance vein visualization, particularly for patients with challenging vein conditions. The system integrates a Raspberry Pi 3B, Raspberry Pi Camera (No Infrared) NoIR, and Infrared (IR) LEDs. Advanced image processing algorithms were employed, including gamma correction, grayscale conversion, Contrast Limited Adaptive Histogram Equalization (CLAHE), median filtering, adaptive thresholding, Otsu thresholding, and morphological transformations. The image processing pipeline was designed to enhance the visibility of veins by improving contrast and reducing noise. The Raspberry Pi controls the camera and processes the captured images in real-time, utilizing OpenCV and Python to implement the algorithms. The IR LEDs illuminate the patient's skin, allowing the camera to capture images that highlight veins beneath the surface. The system was tested on various subjects with different skin tones and vein visibility challenges. The results demonstrated that the NIR imaging technology significantly improved the visibility of veins compared to traditional methods. The gamma correction and CLAHE techniques enhanced the contrast of the vein images, while the median filtering and adaptive thresholding effectively reduced noise and highlighted the vein patterns. The system provided clear and accurate real-time vein images, facilitating easier and more successful vein access procedures. The project achieved significant improvements in the ease and success of vein access procedures, offering a reliable and user-friendly solution for healthcare professionals. This technology has the potential to significantly enhance patient care by assisting physicians, nurses, and surgeons in locating veins more efficiently and accurately.

Keywords: Image Processing, Near-Infrared (NIR) Imaging, Non-Invasive Vein Scanner, Vein Visualization

CHAPTER ONE
INTRODUCTION

1.1 Background Study

Blood collection is a pivotal aspect of modern healthcare. It serves as a vital bridge between patients and accurate diagnoses, effective treatments, and ultimately, improved health outcomes. The accuracy of this process heavily relies on effective vein visualization, as more than 70% of clinical decisions are based on data derived from blood sample [1].

However, traditional methods, primarily dependent on palpation and visual inspection, encounter challenges in efficiently locating veins, particularly in individuals with deep or fragile veins, obesity, or dark skin pigmentation, this can result in increased discomfort, multiple puncture attempts, and potential complications. The Non-Invasive Vein Scanner utilizes non-invasive infrared technology in capturing the real-time venous image on the patient's skin and making sub-surface vessels visible using the reflection of near-infrared light.

The light reflected is captured by a digital video camera, and a microprocessor is used to apply contrast to the image of the veins, which is then projected onto the skin. NIR vein visualization devices have been shown to improve the efficiency of blood collection and reduce patients' discomfort [1].

These devices have been reported to display veins up to 10 mm deep and blood flow up to 15 mm deep. Various models of vein-finder devices include portable handheld and hand-free devices that can be used for all patients, including those with darker skin pigmentation.

However, there are still challenges and limitations that need to be addressed, such as the development of a low-cost, non-contact vein finder prototype that prevents the possible transfer of bacteria or viruses and also utilizes ultrasound in detecting the vein with the better blood flow.

Advancements in image processing are revolutionizing vein visualization, offering improved accuracy and efficiency. Noise reduction algorithms suppress extraneous skin texture and background artifacts, while edge detection techniques enhance vein boundaries, facilitating clearer identification [3].

Image segmentation algorithms, like thresholding and morphological operations, further refine the image by separating veins from non-vascular structures.

Additionally, by integrating ultrasound data, image processing can reveal deeper vasculature, creating comprehensive 3D maps of the underlying vasculature [4]. These advancements bring significant benefits, including reduced failed punctures, shortened procedure times, and enhanced patient comfort.

Ultimately, image processing is shedding light on veins, offering a more precise and efficient approach to vascular access, with profound implications for both healthcare professionals and patients.

1.2 Significance of Study

Blood collection is an essential medical function that is required for many therapeutic and diagnostic procedures. It makes important activities easier, like:

Disease diagnosis: This involves identifying blood borne infections, keeping an eye on current aliments, and evaluating general health.

Blood Transfusions: This involves providing patients who are deficient in blood or have lost blood with additional blood components.

Administration of Treatments: Provision of vital treatments such as immunoglobulin replenishment for immunological deficits.

However, traditional vein localization methods can be uncomfortable and distressing for patients, also Healthcare professionals often face challenges when attempting to locate veins, especially in patients with obesity, pediatric populations, or elderly individuals, inaccurate vein punctures can lead to complications such as hematoma, nerve damage, or infection.

Non-invasive vein scanners have emerged as a promising technology to address the limitations of traditional vein localization methods, this method of vein location leads to improved efficiency where faster vein identification and visualization can expedite blood collection processes, reducing wait time and improving workflow, it also minimizes the risk of needle-related injuries and compilations.

This study aims to contribute to the advancement of non-invasive vein scanner technology by developing a system that:

i. Offers enhanced accuracy and reliability in vein localization and visualization compared to existing solutions.

ii. Provides increased portability and ease of use to facilitate integration into diverse healthcare settings.
iii. Enhances patient comfort and safety by minimizing discomfort and reducing the risk of complications associated with traditional venipuncture.

By addressing these aspects, this study aspires to:

i. Improve the overall patient experience during blood collection procedures.
ii. Optimize workflow efficiency within healthcare facilities.
iii. Contribute to the development of a safer and more patient-centered approach to blood collection in healthcare.

1.3 Problem Statement

In the realm of medical practices, existing vein localization techniques predominantly depend on manual palpation and Trans illumination. However, these methods are often subjective and prone to inaccuracy, presenting significant challenges in accurately locating veins, particularly in individuals with compromised vascular access. The limitations of current techniques contribute to patient discomfort, heightened anxiety levels, and prolonged procedure times.

Addressing these challenges necessitates the exploration and integration of advanced technologies that can revolutionize vein visualization. Emerging technologies such as infrared imaging, near-infrared spectroscopy, and ultrasound offer promising avenues to enhance the precision and efficiency of vein localization. The incorporation of these innovative approaches holds the potential to not only alleviate patient discomfort and anxiety but also streamline medical procedures, ultimately improving the overall quality of healthcare delivery. As we delve into the future of medical interventions, the seamless integration of cutting-edge technologies is poised to redefine the landscape of vein localization, ensuring more accurate, efficient, and patient-friendly outcomes.

1.4 Aims and Objectives

The aim of this project is to develop a non-invasive vein scanner system for improved blood collection in healthcare settings.

The objectives of this project are to:

i. Develop a non-invasive vein scanner system using advanced imaging technologies.

ii. Implement image processing algorithms to generate real-time vein maps.
iii. Develop an interface for displaying vein maps and guiding medical professionals during venipuncture procedures.

1.5 Methodology

This project will employ a mixed-methods approach, combining hardware and software development with clinical evaluation. The research design will consist of the following phases:

i. Develop a portable vein scanner device using NIR imaging technology.
ii. Develop image processing algorithms to extract vein patterns from NIR images and generate real-time vein maps using an image processing library “OpenCv” in python.
iii. Implement an interface for displaying vein maps and guiding medical professionals during venipuncture procedures.

Figure 1.1 presents a visual representation of the non-invasive vein scanner's workflow.

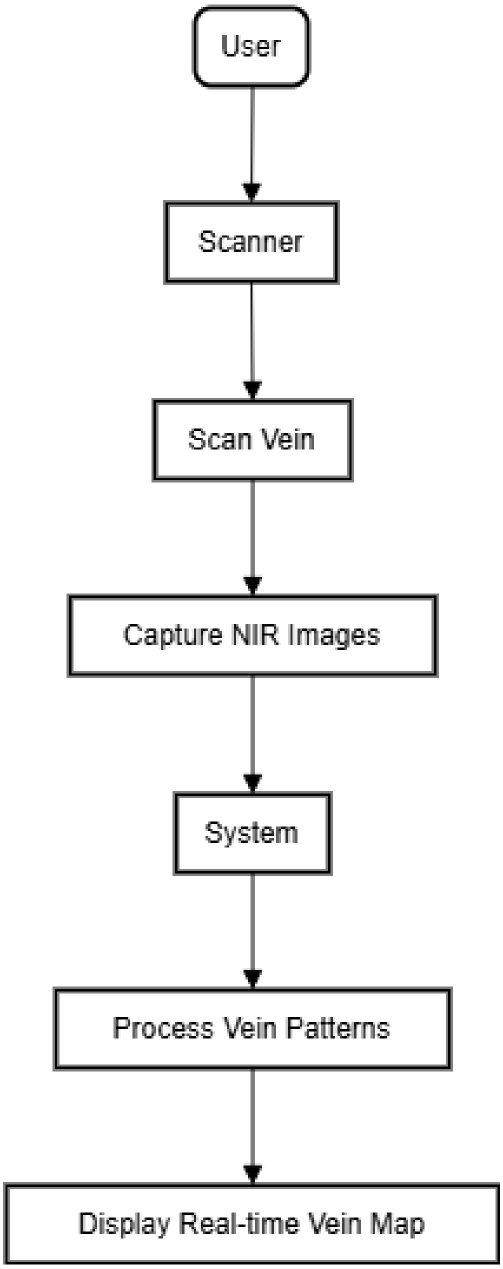

Figure 1. 1: Non Invasive Vein Scanner Flow Diagram

1.6 Scope and Limitation of Study

This project focuses on developing a prototype for a non-invasive vein scanner designed to improve blood collection procedures in healthcare settings.

1.6.1 Scope

i. The project will explore the use of Near-Infrared (NIR) imaging technology for vein visualization.

ii. The project will investigate algorithms for automated vein pattern recognition and localization within the captured NIR images.

Evaluation of the system's performance would be in terms of:

i. Accuracy of vein localization compared to traditional methods.
ii. Ease of use and user experience during scan operation.
iii. Feasibility of integration into existing healthcare workflows.

1.6.2 Limitations

This project will focus on a prototype development stage, not a production-ready device.

i. Testing will be conducted in a controlled environment, and real-world clinical evaluation will be a future consideration.
ii. The project will explore specific vein pattern recognition algorithms. Further research might be needed to optimize performance for diverse patient populations.
iii. The scope excludes integration with specific blood collection equipment, focusing primarily on vein pattern identification and localization.

1.7 Project Report Organization

The project report is organized in the following manner.

Chapter One is the introductory chapter. It will include the background of study of the project, challenges of traditional vein visualization methods and potential of vein scanners, project goals and objectives, the methodology and limitations of the project.

Chapter Two of this project will comprise a comprehensive review of the existing literature on the topic of the project. It will include a brief history and overview on vein localization methods, it will include a review on non-invasive imaging methods, focusing on NIR for vein location, analysis on existing vein scanner system, discussion on image processing for vein pattern recognition and acknowledges challenges. Lastly this chapter includes a thorough analysis of the technical and scholarly literature on research performed on the project topic.

Chapter Three will focus on the approach utilized to execute the project to attain the project's aim, system design & development (Hardware, Software and Integration), hardware components and their functionalities, the software development process, algorithms, and user interface design and also describe how the hardware and software are integrated into a system.

Chapter Four will cover the results obtained from the development, validations, evaluations and testing of the system.

Chapter Five will contain the conclusion of the project. It outlines the challenges faced in accomplishing the project and the contributions that can be made to the project as well as recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

2.2 Brief History and Overview of Vein Localization Methods

Vein localization is significant for successful, safe, and efficient collection of blood. Vein localization refers to the process of identifying the precise location and path of veins beneath the skin's surface. This information is crucial for various medical procedures, particularly those requiring intravenous access.

Accurate vein localization is crucial in blood collection to minimize bleeding and ensure accurate test results. Traditional vein localization techniques such as manual palpation and visual assessment are common, however they have drawbacks when collecting blood. Because veins beneath the skin are typically difficult to see, it can be particularly challenging in infants and elderly persons, as well as in obese patients, people with dark skin, intravenous (IV) drug abusers, people with hypertension, and people who suffer from numerous wounds that limit the number of limbs that may be utilized [5].

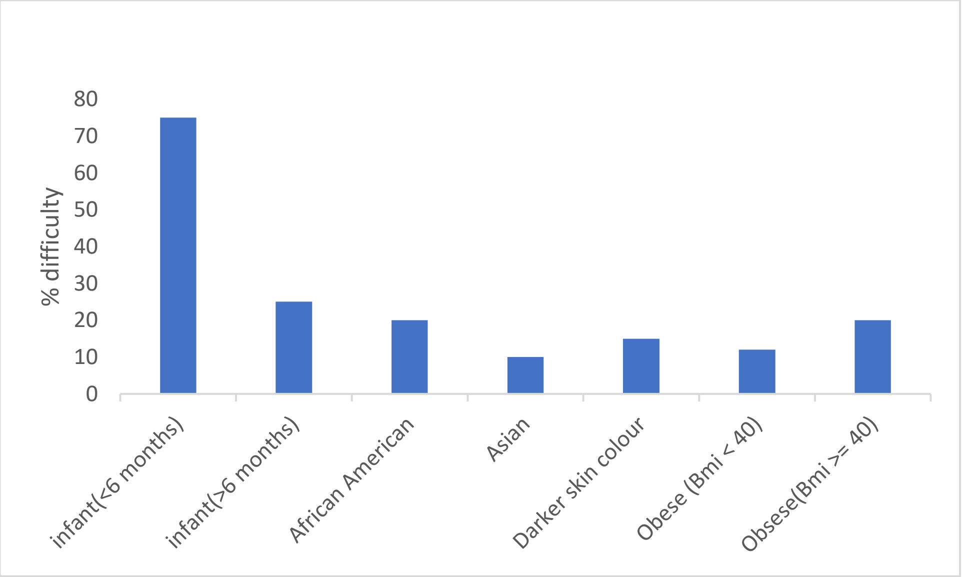

Figure 2. 1: Percentage of Difficult Cases by Demographic Factor

These procedures are not always accurate or efficient. This can result in a prolonged operation and more discomfort for the patient because it may take more than one try to find a vein that works.

Furthermore, if accurate vein localization is not accomplished, there is a chance of missed punctures or nerve damage. Because it might be challenging to find venipuncture sites, more research has been conducted in the advancement of vein localization over time.

To properly localize veins and blood cells, advanced vein localization techniques use near-infrared and ultrasonic technologies. Multispectral imaging systems and the Vein Entry Indicator Device (VEID), which is equipped with a pressure sensor, are examples of technologies that have been developed to further improve vein visualization during procedures. Additionally, the diagnosis and visualization of deep vein thrombosis (DVT) have been transformed by developments in imaging modalities like as CT, MRI, and MR venography. With their ability to provide precise and quick imaging of the venous architecture, these modalities are particularly helpful in complex situations involving central veins or consequences such as pulmonary embolism [6]. Newer methods such as active dynamic thermography (ADT) that use infrared thermal cameras and external cooling methods to provide high contrast vein visualization have also been developed. By using dynamic synthetic pictures to visualize veins in real time, ADT improves the precision and effectiveness of venous access techniques [7]. Regarding bettering procedural success rates, lowering problems related to venous access operations, and increasing patient care, these cutting-edge vein visualization technologies mark a substantial advancement.

2.3 Non-Invasive Imaging Methods for Vein Localization

When performing a number of medical operations, including as blood draws, IV line insertion, and the diagnosis of vascular disorders, the ability to see veins is essential. Fortunately, there are several non-invasive imaging methods that provide efficient and secure methods of visualizing veins without skin punctures. Below is an overview of a few common methods:

i. Transillumination

Transillumination is a non-invasive imaging technique that is commonly used for vein localization. The basis behind transillumination is the differential absorption of light by the veins and the surrounding tissue [8][1], for vein visualization, a handheld transilluminator is put on the skin, and a camera or imaging sensor is placed on the opposite side. Light penetrates the epidermis and tissue, and veins containing deoxygenated hemoglobin absorb more of the incident light than surrounding tissue[1]. This results in the veins appearing as dark lines on the captured image. Transillumination devices, such as the Transilluminator Device, Vein Navigation Device, and VascuLuminator, use this principle to visualize veins, notably in the hand and wrist areas [9]. These devices have been demonstrated to be beneficial in increasing the success rate of venipuncture procedures, especially in problematic circumstances such as pediatric patients or those with poor veins.

However, transillumination technologies do have significant limitations. They often demand a higher light intensity, resulting in increased power consumption and a larger design, as the body part being scanned must be situated between the light source and the camera. [1].

Furthermore, these devices may have difficulties visualizing veins that are placed deeper within the tissue or in areas of thicker skin, such as the arm [9].

ii. Photoplethysmography (Ppg)

Photoplethysmography is a commonly used technique for measuring blood volume changes and assessing peripheral circulation. PPG measures blood volume changes in a microvascular bed of the skin based on optical properties, such as absorption, scattering and transmission properties of human body composition under a specific light wavelength [10]. The method entails illuminating the skin and monitoring variations in light absorption, which are directly related to changes in blood volume [11]. PPG is often used in pulse oximetry to calculate arterial oxygen saturation (SpO2) non-invasively [10]. Additionally, PPG can be utilized to monitor blood volumes and oxygenation changes during intermittent vascular occlusions in the forearm, whether venous or arterial in nature [11]. The PPG signal is composed of a pulsatile component (AC) and a relatively slow varying component (DC). The AC component refers to throbbing arteries and arterioles, whereas the DC reflects the constant absorption of non-pulsatile tissue along the light route, such as venous blood, venoules, and non-pulsatile arterial blood [12]. PPG has been demonstrated to improve the success percentage of venipuncture procedures, especially in tough circumstances such as pediatric patients or persons with poor veins [11]. This approach is appropriate for situations that need free movement, such as perfusion mapping or healing assessments [12].

In terms of limitations, PPG usually provides blood volume information by focusing just on the pulsatile AC PPG component, whereas NIRS excludes the pulsatile nature of arterial blood and expresses changes in blood volume and oxygenation by relative changes in hemoglobin concentrations [10].

Also Interpreting PPG signals for vein localization requires some level of expertise. Factors like skin tone, underlying medical conditions, and sensor placement can influence the signal characteristics.

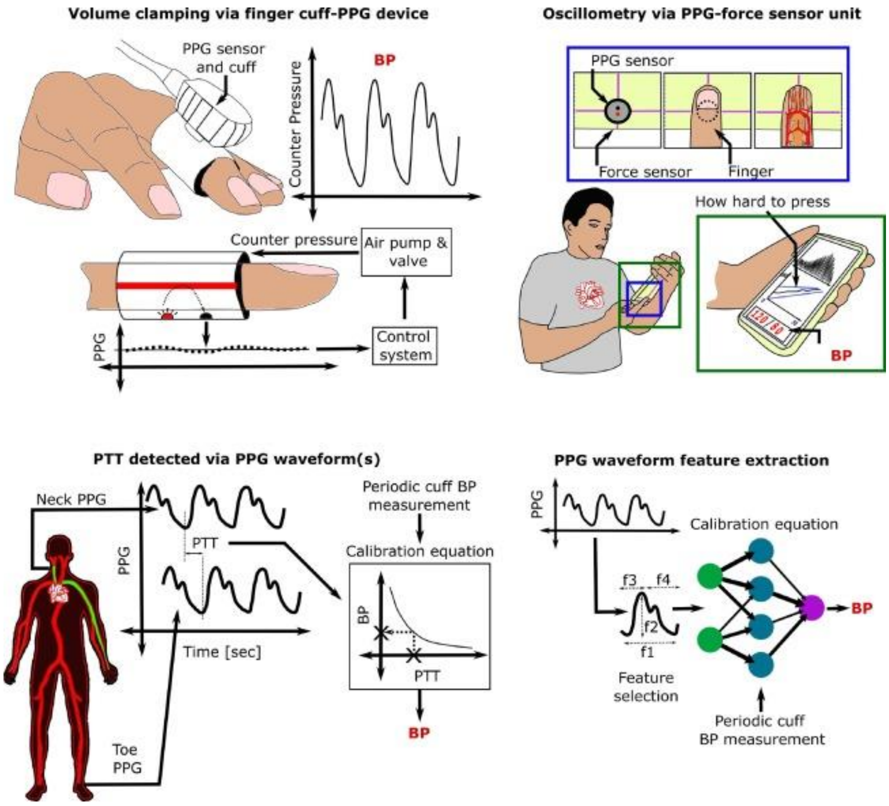

Figure 2. 2: PPG vein localization process with waveform

iii. **Doppler Ultrasound**

Doppler ultrasound uses high-frequency sound waves to create images of blood flow within veins. The Doppler Effect is based on the idea that sound waves change frequency as they contact with moving things, such as blood cells.

The ultrasound transducer detects the shift in frequency and converts the sound waves into electrical data, which are subsequently processed to provide images of blood flow[13]. Doppler ultrasound is frequently used in venous mapping to find blood clots, particularly in the veins of the leg, which is typically referred to as deep vein thrombosis (DVT) [14]. It assesses blood flow in veins and arteries, aiding in the diagnosis of diseases including PAD and DVT [15].

The technique is non-invasive, painless and does not use ionizing radiation, making it a safe and effective method for vein localization [15].

Doppler ultrasound is widely used in various medical settings, including hospitals, clinics and imaging centers, and is performed by trained sonographers or radiologists[15].

iv. Thermal Imaging

Thermal imaging is a non-invasive vein localization method that captures the variations in heat emitted from the body surface, it measures the temperature changes on the skin surface, which are related to blood flow and metabolic changes in the underlying tissues [16]. Thermal imaging can be exceptionally useful in the identification of superficial venous disorders, such as chronic venous insufficiency, as it can detect temperature variations related with blood stasis, inflammatory conditions, and edema[16].

This technique is also used to diagnose deep vein thrombosis (DVT) and peripheral artery disease (PAD)[17].

Thermal imaging can be used to examine the veins and identify changes in blood flow, which can help diagnose venous insufficiency[16]. One significant advantage of thermal imaging is its capacity to identify veins that are difficult to detect using conventional methods, such as the cephalic vein in the forearm[18]. Thermal imaging may disclose the entire vein system, including invisible veins, without any preprocessing by separating the forearm from the surrounding area in thermograms and rebuilding the venous system using directed curvature algorithms[18]. Researchers created an infrared thermal image display system for vein localization that employs a specific infrared amplification lens to improve image quality [19]. A novel fuzzy directional curvature algorithm has been proposed to recognize the entire vein system of the front forearm using infrared thermal imaging [18]. While thermal imaging is a promising technology, it should be noted that it may not be appropriate for delicate, injured, burned, or dark skin. In such situations, near-infrared (NIR) imaging is preferred to visualize veins [20]. NIR imaging can be combined with thermal imaging to provide a more thorough assessment of vein dynamics [20].

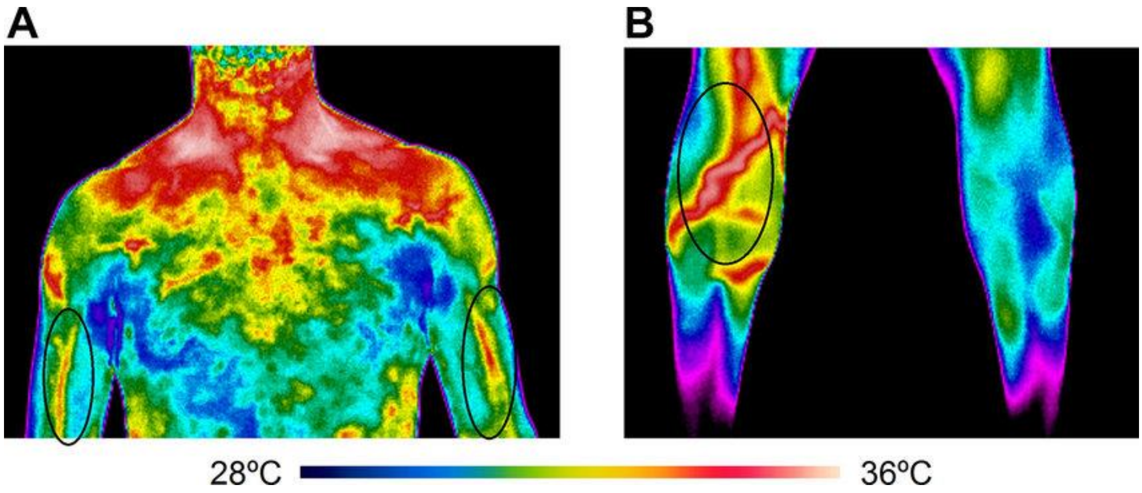

Figure 2. 3: Thernal image showing vein position

v. Near-Infrared (Nir) Imaging

Near-infrared (NIR) imaging has developed as an important tool in the medical profession, providing a non-invasive method of vein location, also a low-cost and efficient solution for various medical applications.

NIR (Near-Infrared) imaging technique uses near-infrared light absorbed by hemoglobin in the blood to reveal veins beneath the skin. NIR light penetrates the skin and is absorbed by hemoglobin, allowing vein vision.

This absorption pattern is caught by a camera or sensor, producing clear pictures of the veins for accurate localization [21].

By utilizing the difference in absorption qualities between bloods and surrounding tissues, NIR imaging promotes vein visualization without the need for invasive operations, assisting medical personnel in procedures like venipuncture and vein therapy.

Advantages of NIR inaging include:

i. **Enhanced Depth Penetration**: NIR light has a longer wavelength than visible light, therefore it can penetrate deeper into tissues. This allows for the viewing of deeper veins that may be hidden by fat or muscle layers, which is a drawback of transillumination procedures employing visible light [22].

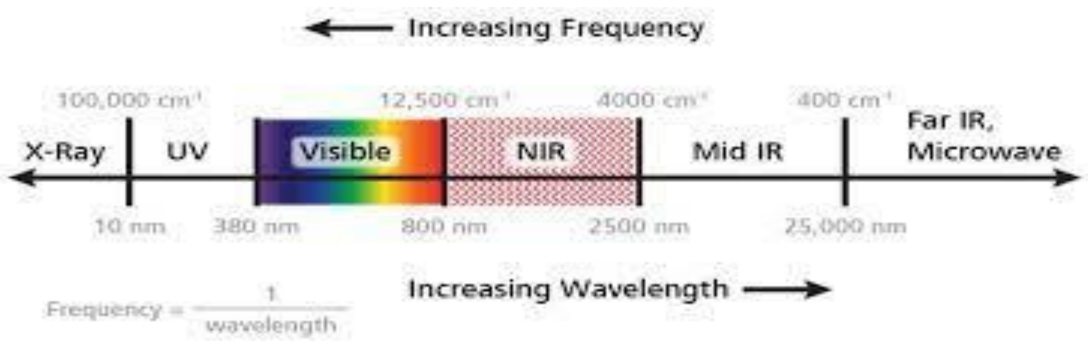

Figure 2. 4: electrimangetic spectrum indicating the wavelength of infrared ligh vs visible light

ii. **Improved Visualization in Challenging Cases:** NIR imaging proves particularly beneficial for:

   i. **Obese Patients:** Obese people have thicker adipose tissue, making transillumination more difficult. NIR light's deeper penetration overcomes this constraint and efficiently reveals underlying veins [5].

   ii. **Skin Tones:** Melanin, a pigment found in skin, absorbs visible light more easily, making vein identification difficult in people with darker skin tones. NIR light has decreased melanin absorption, which improves vein contrast.

iii. **Easy to use**: NIR imaging technology is easy to use, requiring minimal training and expertise.

iv. **High Accuracy**: NIR imaging technology allows for great precision in vein localization, lowering the risk of complications and increasing patient outcomes.

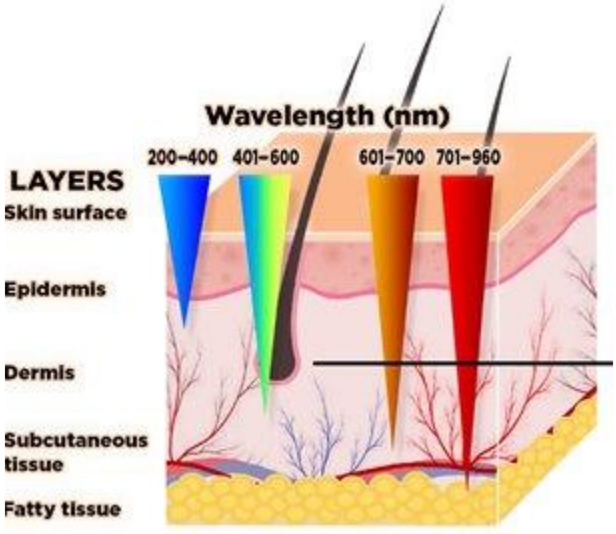

Figure 2. 5: different wavelengths and their possible depth in the skin

NIR technology can locate veins for cannulation, allowing for low-cost venous access for blood sample, therapy, and other medical uses for young and geriatric patients, as well as those with problematic access [23].

Comparison of NIR with other Non-Invasive Methods

Table 2. 1: Comparison of non-invasive methods

Imaging Method	Nir Imaging	Thermal Imaging	Doppler Ultrasound	Photoplethysmography	Transillumination
Principle	Uses near-infrared light absorbed by hemoglobin in blood to visualize veins	Measures temperature changes on skin surface related to blood flow and metabolic changes	Measures direction and speed of blood cells as they move through vessels	Measures blood volume changes in microvascular bed of skin based on optical properties	Non-invasive imaging technique that visualizes veins by differential absorption of light by veins compared to tissue
Advantage	Non-invasive, high accuracy, low-cost, easy to use	Non-invasive, can detect varicose veins and venous return problems, categorizes venous insufficiency stages	Non-invasive, provides detailed information about blood flow and vessel structure	Non-invasive, improves accuracy of blood sampling, real-time monitoring of blood volumes	Non-invasive, aids in vein visualization, effective in challenging cases like pediatric patients
Application	Intravenous cannulation, blood sampling, therapy	Diagnosis of varicose veins, venous return problems, categorization of venous	Diagnosis of deep vein thrombosis, peripheral artery disease, evaluation of	Monitoring blood volumes, oxygenation changes during vascular occlusions, perfusion mapping	Visualizing veins, detecting changes in blood flow, challenging cases like pediatric patients

		insufficiency stages	blood flow in veins and arteries		
Limitation	Poor vein visibility, equipment maintenance	Limited by skin pigmentation, vein visibility, equipment maintenance	Limited by skin pigmentation, vein visibility, equipment maintenance	Limited by skin pigmentation, vein visibility, equipment maintenance	May have difficulty visualizing veins located deeper within tissue or in areas with thicker skin

2.4 Image Processing for Vein Pattern Recognition

Image processing is the process of executing particular operations on an image in order to create an enhanced image or extract necessary information from it. It is a sort of signal processing in which the input is an image and the output can be an image or information that defines the features associated with that image[24]. It comprises a wide range of approaches for extracting useful information from images, improving their quality, and creating new ones. This field is important in a variety of industries, including medical, engineering, entertainment, and cybersecurity.

2.4.1 Principles of Image Processing

The principles for Image processing include the following:

1. **Image Acquisition:**

   The initial stage in image processing is to acquire the image from various sources, such as digital cameras, scanners, or satellite imagery [25]. This step ensures that the image is captured in an appropriate format for subsequent processing.

   Image Acquisition Methods include:

   i. **File Based Import:** This is the most popular way. You utilize software libraries or tools within your image processing environment to load images stored in various formats such as JPEG, PNG, BMP, or TIFF. This images can be from local storage devices like hard drive or ssd, network drives or cloud storage services.

   ii. **Camera Capture:** Sometimes you can use a camera that is connected to your computer to take an image immediately. Libraries frequently offer routines for gaining access to the camera and getting the image data that was taken.

   iii. **Scanner Input:** When working with actual papers or photos, you can scan them to create digital versions that you can import and process.

   Many image processing libraries and frameworks offer functions for image import for example:

   Opencv: `cv2.imread (filename)` loads an image from a file

   Scikit-image (Python): `skimage.io.imread (filename)` loads an image

MATLAB Image Processing Toolbox: `imread (filename)` function reads an image.

2. **Image Representation:**

Following acquisition, the unprocessed image data must be encoded in a way that computers can understand. Two common techniques used for image representation include boundary representation and region representation[25].

i. **Boundary Representation:**

Capturing the edges or outlines of objects in a picture is the main goal of boundary representation. By following the boundaries of the item, it effectively defines its shape. Typical data structures for boundary representation are as follows: **Chains:** A series of joined points that define the edge of an item. **Polygons**: An object's outline composed of a closed series of connected line segments.

Advantages include:

i. **Effective for basic forms:** It is effective to represent simple, well-defined objects with distinct edges using boundary representation.
ii. **Reduced memory needs:** Compared to area representation, it uses less storage space, especially for straightforward structures with thin edges.

Disadvantages include:

i. Restricted to intricate shapes when depicting fine details or holes in complex designs, it can become laborious and less effective. **Topological details:** It doesn't automatically save details about how items relate to one another.

ii. **Region Representation:**

The goal of region representation is to depict an object's inside in a picture. By expressing every pixel that belongs to an object, it defines it. Typical data structures for region representation are as follows:

Pixels List: A list containing every coordinate for every pixel in the object.

Connected Components Labeling: A distinct label is assigned to every connected region of pixels.

Advantages:

i. **Versatility:** Region representation is effective for any complexity of object, even ones with minute details or holes in them.

ii. **Topological information:** It captures the relationships (i.e., which thing is within which other) between objects by nature.

Disadvantages

i. **Greater memory needs**: In comparison to border representation, it may need more storage capacity, particularly for large or complicated objects.

ii. **Computationally costly:** It is possible that processing operations on regions will cost more in terms of computation than actions on boundaries

3. **Image Enhancement:**

By altering a picture's component parts, image enhancement techniques can raise the visual quality of a given image [25]. The goal of this stage is to improve the image's information content, contrast, and clarity. While frequency domain techniques work with the image's orthogonal transformation, spatial domain techniques work directly with pixel values [26].

4. **Image Segmentation:**

The technique of dividing a picture into several areas or components according to predetermined standards is called segmentation.

In order to recognize and extract items of interest, it is an essential stage in the image processing process. Region-based, edge-based, feature-based clustering, thresholding, and model-based approaches are some of the segmentation strategies available [26].

5. **Image Compression:**

Digital image compression lowers the amount of storage space and transmission time needed for photos [25]. It removes superfluous data while keeping the important data intact.

There are two types of compression techniques: lossy, which sacrifices some quality in favor of larger compression ratios, and lossless, which preserves the original image quality.

6. **Image Classification:**

The process of classifying involves giving labels or groups to individual pixels or areas within a picture according to its spectral, spatial, or textural properties.

Among its many uses are object recognition and land cover mapping. There are two types of classification techniques: supervised and unsupervised.

In supervised classification, spectral signatures are created using training samples, and pixels are grouped into classes by the algorithm without human input.

2.4.2 Methods/Algorithms under Image Processing

Some of the methods under Image Processing include:

1. **Noise Reduction:** In image processing, noise reduction techniques are essential for restoring the original image or improving its quality for subsequent tasks.

   Some of the popular noise reduction algorithms are Gaussian filter, median filter, and wavelet denoising.

   i. **Gaussian filter** employs a smoothing method based on the Gaussian distribution (bell curve), a mathematical function. Neighboring pixels are given weights by this filter, with pixels closest to the center having higher weights.

   By effectively blurring the image, this weighted average reduces high-frequency noise components while maintaining low-frequency information like edges.

   Its ability to reduce noise with a Gaussian distribution—a frequent kind of noise in digital images—is one of its advantages.

   On the other hand, noise reduction may result in excessive smoothing, which can blur edges and fine features in addition to noise reduction.

   The Gaussian filter is defined by:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{(-x^2+y^2)/2\sigma^2} \tag{2.1}$$

   Where $\sigma$is the standard deviation of the Gaussian distribution

   ii. **Median filter's** operation focuses on a nearby neighborhood of pixels. It substitutes the neighborhood median value for the value of the central pixel.

   The median filter effectively eliminates outliers (noise) by sorting the brightness of the pixels within the neighborhood and substituting a more representative value from the vicinity.

Although it can still add some smoothing and possibly blur small details, it is well-suited for eliminating salt-and-pepper noise, which manifests as sporadic black-and-white pixels.

$$y[m,n] = median\{x[i,j], (i,j) \in \omega\} \tag{2.2}$$

Where the value ω denotes a user-defined neighborhood centered on the points [m,n] in the picture.

Wavelets are a mathematical technique for expressing signals at multiple scales (frequencies), and they are used in wavelet denoising. The picture is broken down into wavelet coefficients, which stand for various frequency ranges.

Usually, high-frequency components contain noise.

The denoised image is reconstructed by suppressing the wavelet coefficients linked to noise through the application of thresholding techniques.

Because of its multi-scale approach, it can successfully eliminate noise while maintaining edges and fine details, but it's more sophisticated and computationally costly than median and Gaussian filters.

Selecting the right thresholding method and wavelet function can be difficult and take some practice [27].

2. **Edge Detection:** Edge detection basically highlights the important structural components in a picture by drawing lines between areas with differing intensities. Prominent elements like corners, lines, and textures frequently have corresponding edges.

   Motion tracking in videos, content-based image retrieval, and image reduction are all made possible by extracting these elements [27].

   Common Edge Detection include:

   i. **Canny Edge Detector:** This was discovered by john canny in 1986 and it is regarded as the industry standard for edge detection. It uses a multi-stage method that includes thresholding with hysteresis, gradient computation, non-maximum suppression, and noise reduction.

The Canny detector aims for single edge response (avoids redundant detection of the same edge), minimum false positives (non-edges reported as edges), and good edge localization [28].

ii. **Sobel Operator:** This operator computes the approximate gradient magnitude in both the horizontal and vertical axes using a 3x3 mask. Edges are defined as areas where the gradient value is high, signifying notable variations in intensity.

The Sobel operator is quick and effective, however it could be noisy and result in thicker edge responses.

The Sobel Operator is defined as:

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \tag{2.3}$$

$$G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \tag{2.4}$$

Where G_x and G_y are the horizontal and vertical operators, respectively

iii. **Laplacian of Gaussian (LOG):** This method consists of first smoothing the image with a Gaussian filter and then emphasizing the high-frequency elements (edges) with a Laplacian filter.

Although LoG is good at identifying blobs and corners, its second-derivative nature makes it susceptible to noise and may result in multiple edges.

The LoG is defined as:

$$\text{LoG(x,y)} = \frac{\partial^2}{\partial x^2} G(x,y) + \frac{\partial^2}{\partial y^2} G(x,y) \tag{2.5}$$

Where G(x,y) is the Gaussian filter

3. **Image Segmentation:** involves dividing an image into its constituent parts or regions based on certain criteria.

For a variety of uses, including object detection, tracking, and analysis, this method aids in locating and isolating particular items or features within an image. Image segmentation divides the image in such a way so that it becomes very accurate[25]. Some of the methods under image segmentation includes: Thresholding, Edge based detection etc [25].

i. **Thresholding:** The simplest method for segmenting images is known as Thresholding, which converts a grayscale image to a binary image whenever the two points are assigned to pixels[25]. These points are situated both above and below the established boundary point. This method uses a threshold value that is obtained from the original image's histogram. Edge detection is used to determine the values of the histogram. Consequently, the accuracy of the threshold value depends on how effective the edge detection is. When compared to other methods, segmentation with thresholding requires less calculations [25].

$$I(x,y) = \begin{cases} 1 \ \ If\ I(x,y) > T \\ 0\ If\ I(x,y) \leq T \end{cases} \tag{2.6}$$

Where I(x,y) is the intensity value of the pixel at location (x,y) and T is the threshold value

ii. **Edge based Based:** This method is used to identify edges or boundaries in an image. It is not necessary for the edges to be consistent in order to retrieve edge information using this edge detection technique. The process consists of two steps: first, edge data identification, followed by pixel labeling. Interestingly, this method can even extract edges from low contrast regions[25].

$$E(x,y) = \left|\frac{\partial I(x,y)}{\partial x}\right| + \left|\frac{\partial I(x,y)}{\partial y}\right| \tag{2.7}$$

Where E(x,y) is the edge strength at location (x,y), and I(x,y) is the intensity value of the pixel at location (x,y).

2.4.3 The Role of Image Processing in Vein Visualization Systems

The Processing of vein images, which includes removing vein patterns and enhancing vein images for precise vein detection, is a critical component of visual vein systems. For this, a number of techniques, including segmentation, contrast enhancement, and filtering, have been used[29]. Near-infrared imaging can be used to detect veins. Because hemoglobin in the blood absorbs infrared light, veins beneath the skin can be seen[30]. Further methods to improve vein vision have been suggested, including image processing techniques in addition to NIR imaging. A study used a high-boost filter to remove a lowpass filtered image from the original revealed vein patterns. With this technique, low-frequency elements like skin texture are suppressed while high-frequency elements like vein edges are amplified [31].

Numerous image processing techniques have been used, including histogram normalization and morphology. Vein components that are disjointed are joined by morphological dilation, and vein thickness is restored by sharpening following dilation [3]. Normalization and equalization of the histogram improve the contrast between veins, and thresholding eliminates noise from skin creases and fat deposits [3].

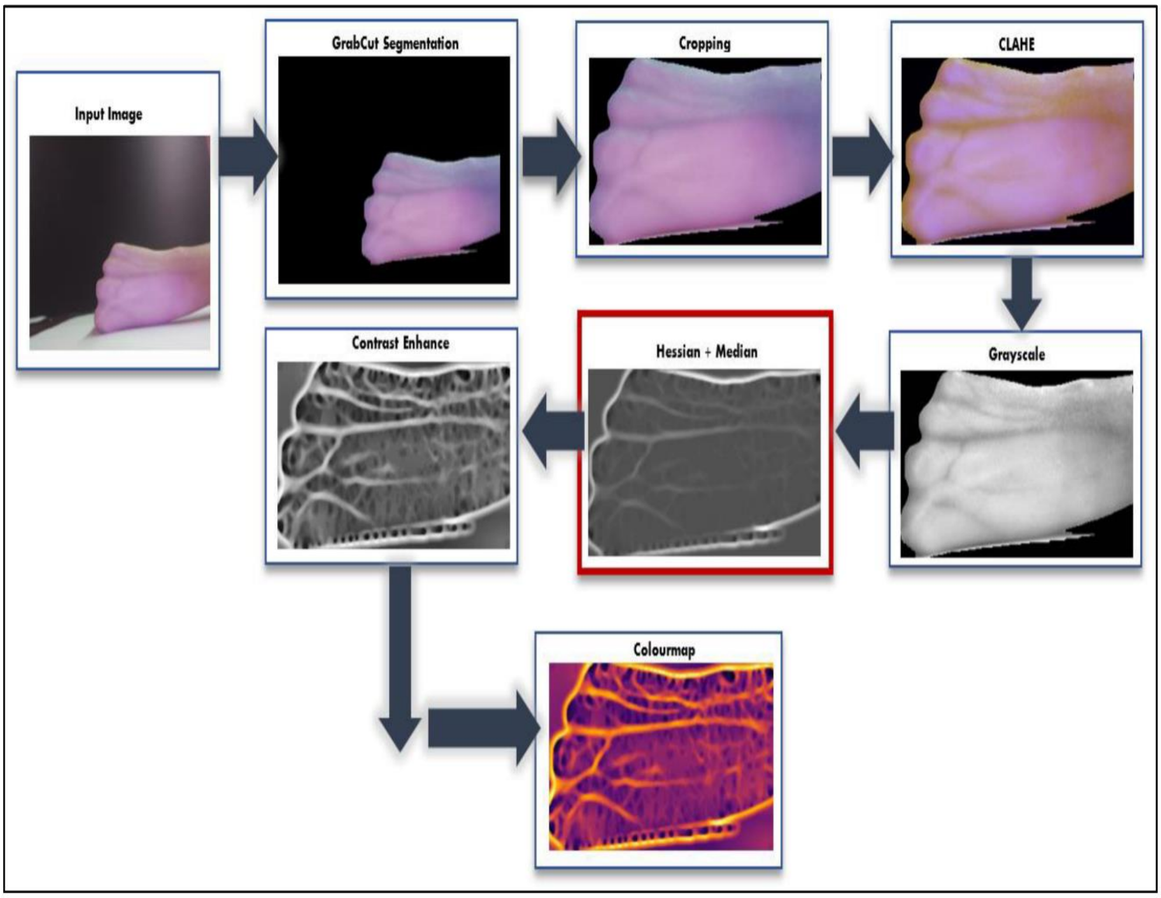

Figure 2. 6: image processing methods for vein pattern accuracy

2.5 Summary of Related Work Done

Using a variety of sensor technologies and imaging techniques, a large number of research studies and works have been done on Nir imaging technologies. A brief summary of some current studies and research on the localization of vein patterns can be seen in the table below.

Table 2. 2: Summary of Related Literature Based on Non Invasive Vein Localization

Paper	Year	Title of Paper/Work	Methodology	Results Obtained	Gap
[32]	2020	Designing and Building the Vein Finder system Utilizing Near-Infrared Technique.	Used an 850 nm 12 W 6-LED array and Raspberry Pi 3 Model B with a NoIR camera board for image acquisition. Processed and displayed the raw data on a monitor.	System could distinguish veins from surrounding tissues based on contrast and brightness differences. Tested on 24 volunteers	Lack of extensive clinical validation across diverse patient populations. In addition, issues like the effect of ambient illumination and the feasibility of utilizing the device in different clinical settings were not fully covered in the study.

[23]	2021	Vein Visualization Using Near Infrared (NIR) Vein Finder Technology in Nursing Care: A Review of the Benefits and Shortcomings.	Examined the advantages and drawbacks of using NIR vein visualization technology in nursing. Also examined a number of studies that involved pediatric patients and NIR equipment.	The amount of time and tries needed for intravenous cannulation in pediatric patients was greatly decreased by NIR equipment.	Requires more studies on the technology's effectiveness across diverse patient populations.
[33]	2021	Verification of technical characteristics and performance of VeinViewer Flex, ICEN IN-G090-2 and AccuVein AV400	Three transillumination devices (AccuVein AV400, ICEN IN-G090-2, and VeinViewer Flex) were evaluated by contrasting their technical specs, picture quality, and functionality in various scenarios.	Devices varied in optimal distance for image quality, number of presented veins, and image dimensions. Performance differences highlighted the need for device-specific	Limited the evaluation's scope to technical features and performance under controlled circumstances.

		transillumination devices		selection based on patient population.	
AccuVein, Inc 2023		AccuVein AV500: Advanced Vein Visualization Technology	Uses near-infrared (NIR) vein visualization with a low power, Class 1 laser to display real-time images of veins on the skin through bright green projection. Features True Center™ technology for accuracy.	Achieved 92% first attempt success rate, 78% reduction in PIV procedure time, and 39% reduction in patient pain. The device is lightweight, handheld, and offers three brightness settings with an inverse mode.	the literature does not thoroughly address the cost-effectiveness and long-term maintenance requirements of the device in comparison to alternative vein visualization technologies
AimVein 2023		AimVein Pro 2.0: High Precision Vein Finder	Utilizes near-infrared light to illuminate veins, with a resolution of 854x480 pixels, 30fps image processing speed,	Increased first stick success by 3.5 times, reduced patient pain by 39%, and provided accurate vein mapping	The literature does not go into great detail about the device's long-term durability and maintenance needs,

			and features seven vein imaging colors, normal and inverse image.	for venipuncture. Includes a battery-saving sleep function and simple operation.	which are essential for its continued usage in hectic clinical settings. Also, there is little data regarding the AimVein Pro 2.0's cost-effectiveness in relation to alternative vein imaging technologies, which may influence its acceptance in healthcare environments where budget is a concern.
[29]	2022	Near Infrared Illumination Optimization for Vein Detection: Hardware and Software Approaches	Evaluation of NIR peak wavelength, LEDs arrangement, presence of diffuser, square LED arrangement	Optimal wavelength for vein visualization found to be 850 nm; square LED arrangement provided	Further optimization needed for deep vein imaging, and integration with advanced image processing techniques

				best light distribution; diffuser showed no significant impact on vein visualization	
[34]	2020	Near-Infrared-to-Visible Vein Imaging via Convolutional Neural Networks and Reinforcement Learning	Used U-Net architecture enhanced with Frangi vesselness filter for NIR vein segmentation. Applied clDice loss function for training the neural network. Used reinforcement learning (RL) for alignment and co-registration of NIR and visible projections	Achieved high accuracy in vein segmentation using the enhanced U-Net. Successful alignment of projected image with real veins using RL Improved catheterization process by 81% and reduced procedure time by 78%	Limited real-world testing and validation in diverse clinical settings. Focus primarily on surface veins, less emphasis on deeper veins.

[35]	2019	Real-time dual-modal vein imaging system	Combined reflectance mode visible spectrum (VIS) images with transmission mode near-infrared (NIR) images using a beam splitter and dual CCD sensors. Applied various image processing techniques including gamma correction, CLAHE, segmentation, and false coloring.	Achieved high-resolution real-time dual-modal imaging with clear vein visibility at depths up to 3 mm. Successfully combined NIR and VIS images to enhance vein localization and visibility.	Limited testing on deeper veins and non-hand regions.
[3]	2022	Design and Implementation of Embedded-Based Vein Image Processing System with Enhanced Denoising Capabilities	Developed an embedded system-based vein image processing system. Used NIR imaging combined with digital hair removal algorithms,	Improved visibility and contrast of veins by removing noise and hair components. Achieved an improvement of	Limited focus on deeper vein imaging. Primarily addressed superficial veins and optimization for embedded systems.

			morphological operations, Telea inpainting, histogram normalization, and equalization. Applied these on an embedded system using OpenCV for image processing.	10.38% in performance over existing systems with body hair removal and 5.04% without hair. Enhanced real-time processing capabilities on an embedded system.	
[36]	2017	Design and Enhance the Vein Recognition Using Near-Infrared Light and Projector	Developed a portable vein visualization device using NIR imaging combined with a projector system. Used a CCD camera, IR bandpass filter, neutral density filter, and image processing algorithms including median filter,	Achieved high-contrast visualization of veins. Real-time projection of vein images onto the skin. Improved venipuncture success rates by enhancing vein visibility. The system was tested on	Limited depth penetration, primarily focused on superficial veins.

			Otsu thresholding, and K-means segmentation.	volunteers and demonstrated effective vein visualization on hands and arms.	
[37]	2015	Nonintrusive Finger-Vein Recognition System Using NIR Image Sensor	Developed a finger-vein recognition system using NIR imaging; analyzed accuracy based on different factors	High accuracy in finger-vein recognition; effectiveness of Gabor filtering	Limited to finger-vein patterns; needs application to other body parts and conditions

2.6 Chapter Summary

This chapter provides a comprehensive review of non-invasive vein visualization technologies, highlighting NIR imaging as a superior method for accurate vein localization. The next chapter will detail the proposed system's design and methodology.

CHAPTER THREE

SYSTEM ANALYSIS AND DESIGN

3.1 Introduction

This chapter offers a comprehensive description of the proposed "Non-invasive Vein Scanner." It explains the various components that were employed in the project's design and their analysis and design. The hardware and software components make up the two primary parts of the system. This chapter explains the various stages involved in implementing the system as well as the design specifications.

3.2 System Architecture

The non-invasive vein scanner is designed as an integrated system that combines imaging, processing, and visualization capabilities. The architecture encompasses several key components, each serving a crucial role in the smooth operation of the system. The system is divided into two main parts: hardware and software. The Software part includes the imaging processing algorithm, control software running on the microcontroller (raspberry pi) and the QR implementation for displaying, while the hardware part includes the micro-controller (raspberry pi) with NoiR camera module, Ir Leds, and power supply unit. Figure 3.1 shows the general structure of the system.

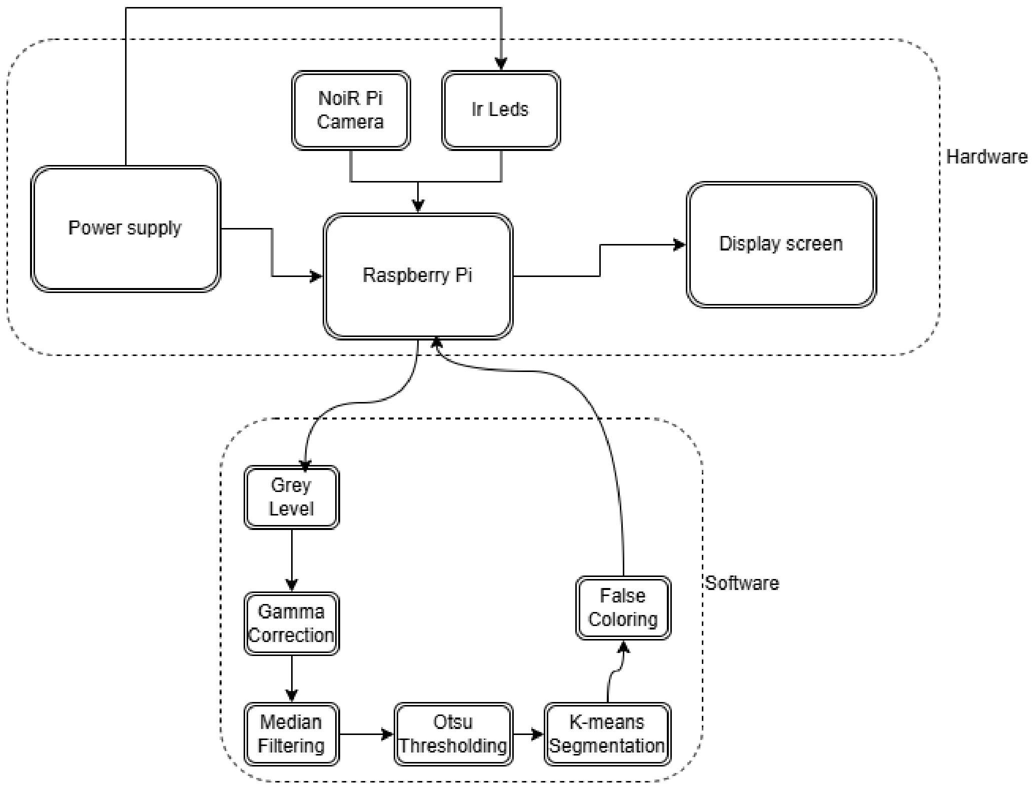

Figure 3. 1: Block Diagram of the System

3.2.3 Functional Requirements

3.2.4 Non-Functional Requirements

3.3 System Hardware Specifications

This section provides an extensive explanation of each individual component that makes up the system's hardware. It provides thorough analysis of the hardware components, outlining each one's specific roles and functionalities within the system and also its circuit diagrams.

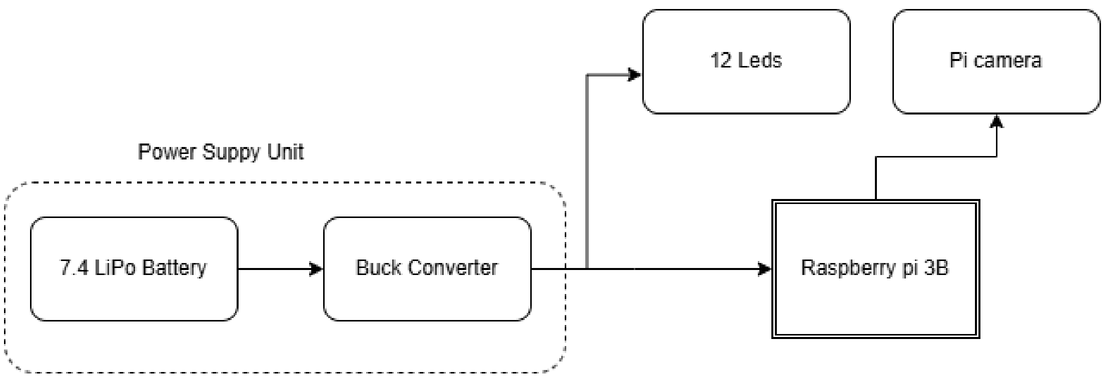

Figure 3. 2: System Hardware Block diagram

3.3.1 Hardware Components

The Hardware of this device consists of a raspberry pi 3B, a 7.4v Battery (Power Unit), a 10k potentiometer, resistors, Buck converter, 12 IR led, Raspberry pi NoiR camera3.

1. **Raspberry pi 3B:** The Raspberry Pi 3 Model B is a single-board computer which features a quad-core Cortex-A53 processor running at 1.2GHz, built-in single-band 2.4 GHz WI-Fi, Bluetooth 4.1, and Ethernet. It has 1GB of RAM, four USB 2.0 ports for connecting peripherals, a full-size HDMI port for connecting displays, a microSD card slot for storage, and 40 GPIO pins for connecting various external devices. The Raspberry Pi is the central processing unit of the system, responsible for running the image processing algorithms and controlling the NIR-sensitive camera, NIR LEDs, and mini projector. It is programmed using Python and uses OpenCV for image processing tasks. The Raspberry Pi 3 Model B can be powered via a micro-USB connection or an external power supply (5V, 2.5A DC). Figure 3.16 depicts a Raspberry Pi 3 Model B.

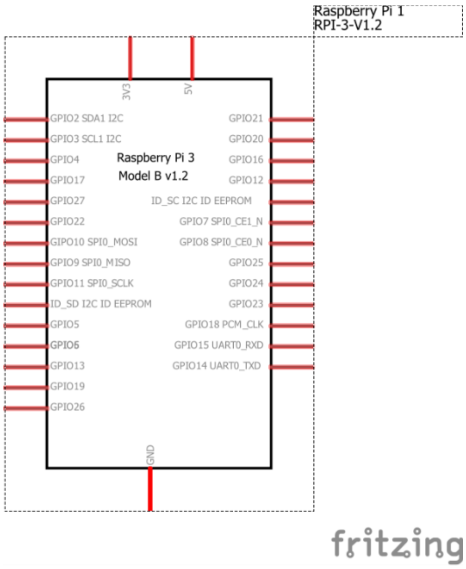

Figure 3. 3: Raspberry pi 3B

2. **Power Supply:** The power supply unit of the system is crucial for ensuring stable and efficient power delivery to all components. The core of this unit is a 7.4V lithium-ion battery, which has been selected for its high energy density and reliability. This battery serves as the primary power source for the entire system,

providing the necessary power for extended operation periods without frequent recharging.

Figure 3. 4: 7.4v battery

3. **Buck Converter:** The buck converter is a key component in electronic power supply systems, offering efficient voltage regulation and power conversion capabilities.

   It plays a crucial role in reducing input voltage to a lower output voltage level while maintaining high efficiency. This process is essential in many modern electronic devices and systems, including the non-invasive vein scanner.

   A buck converter, or step-down converter, reduces a higher input voltage to a lower output voltage while maintaining energy efficiency. It achieves this through precise switching operations involving inductors, capacitors, and transistors, which regulate the flow of electrical energy. This ensures a steady output voltage, even with varying input voltages or loads.

   In the non-invasive vein scanner, the buck converter is crucial for power management. It steps down the 7.4V from the lithium-ion battery to the 5V needed by the Raspberry Pi, providing a stable power supply.

   The efficiency of the buck converter is vital, as it minimizes power loss during conversion, maximizing battery life and operational longevity. This efficiency allows the vein scanner to operate longer on a single charge, improving its usability and reliability in clinical settings.

Figure 3. 5: Buck Converter

4. **Raspberry pi NoiR camera 3:** The NoIR Camera 3, where "NoIR" stands for "No Infrared filter," is capable of capturing images in the visible spectrum as well as the near-infrared spectrum, this makes it particularly useful for applications like vein imaging, where veins are more visible under NIR illumination.

   The camera is equipped with an 8-megapixel Sony IMX219 sensor, which provides high-resolution images and excellent light sensitivity.

   This sensor ensures that even the smallest details of the vein patterns are captured clearly, which is crucial for accurate and reliable vein visualization.

   The camera module connects directly to the Raspberry Pi via the CSI (Camera Serial Interface) connector, allowing for high-speed data transfer and real-time image processing.

   This integration is seamless, leveraging the processing power of the Raspberry Pi to handle the computational tasks required for image enhancement and analysis. The camera's compact size and lightweight design make it easy to integrate into the portable vein scanner system without adding significant bulk or weight.

Figure 3. 6: Raspberry pi camera module 3 NoiR

5. **IR Led:** An IR LED, or Infrared Light Emitting Diode, is a semiconductor device that emits light in the infrared range of the electromagnetic spectrum when an electric current passes through it.

   Unlike standard LEDs that produce visible light, IR LEDs emit light that is invisible to humans but can be detected by specialized sensors, such as those used in night vision equipment and infrared cameras.

   The IR LED was chosen for the non-invasive vein scanner project for several key reasons. First, it operates at an optimal wavelength of 940 nm, which is particularly effective for penetrating human skin and being absorbed by hemoglobin in the blood.

   This property makes veins appear more prominent against the surrounding tissue, enhancing the contrast between veins and other tissues, which is crucial for easier and more accurate vein localization.

   Furthermore, IR LEDs emit light that is not visible to the human eye, ensuring that the illumination does not cause any visual distraction or discomfort to the patient during the imaging process.

   This feature is essential for maintaining patient comfort and cooperation. The energy efficiency of IR LEDs is another significant advantage, as they convert most of the electrical energy into infrared light with minimal heat generation. This efficiency is particularly important for portable, battery-operated devices like the vein scanner, as it helps to conserve battery life and extend operational time.

Figure 3. 7: IR Led

6. **Resistors:** A resistor is a passive electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to limit the current flow, divide voltages, and protect components by dissipating power in the form of heat.

   They are fundamental components in virtually all electronic devices and circuits, helping to control and manage electrical energy effectively.

   In the context of the non-invasive vein scanner project, a 220-ohm resistor was chosen to drop the voltage across the IR LEDs from the potentiometer.

   This specific value of resistance is crucial for ensuring that the LEDs receive the appropriate voltage and current to operate effectively without being damaged.

   The IR LEDs used in this project operate optimally at a certain current level, and the potentiometer allows for adjustment of the voltage supplied to the LEDs.

   By incorporating a 220-ohm resistor, the circuit ensures that the voltage drop is sufficient to maintain the LEDs within their safe operating limits.

   This prevents excessive current from flowing through the LEDs, which could potentially cause overheating or failure.

   Using a 220-ohm resistor helps in fine-tuning the LED brightness and ensures consistent performance. The resistor works by providing a fixed resistance, which, when combined with the adjustable resistance of the potentiometer, creates a voltage divider circuit.

This arrangement allows precise control over the voltage supplied to the LEDs, ensuring they operate efficiently and reliably.

Figure 3. 8: 220 ohms 1/4 watts Resistor

7. **Potentiometer:** A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider.

   It is commonly used for measuring electric potential (voltage) and controlling electrical devices, such as volume controls on audio equipment. In electronic circuits, a potentiometer can adjust signal levels, control circuit elements, and provide variable resistance.

   For the Non-Invasive Vein Scanner a 10k ohm potentiometer was chosen to provide adjustable control over the voltage supplied to the IR LEDs. This specific value of potentiometer is crucial for fine-tuning the brightness of the LEDs, ensuring they operate within their optimal range and provide the necessary illumination for effective vein imaging. The 10k ohm potentiometer works by varying the resistance in the circuit, which in turn adjusts the voltage drop across the IR LEDs.

   By rotating the potentiometer's knob, the user can increase or decrease the resistance, allowing precise control over the voltage supplied to the LEDs. This adjustability is essential for achieving the right balance of brightness and power efficiency, especially in a portable, battery-operated device like the vein scanner.

Figure 3. 9: 10k Potentiometer

3.3.2 Circuit Construction and Calculations

Figure 3.10 below is the full circuit diagram of the Non-Invasive Vein Scanner.

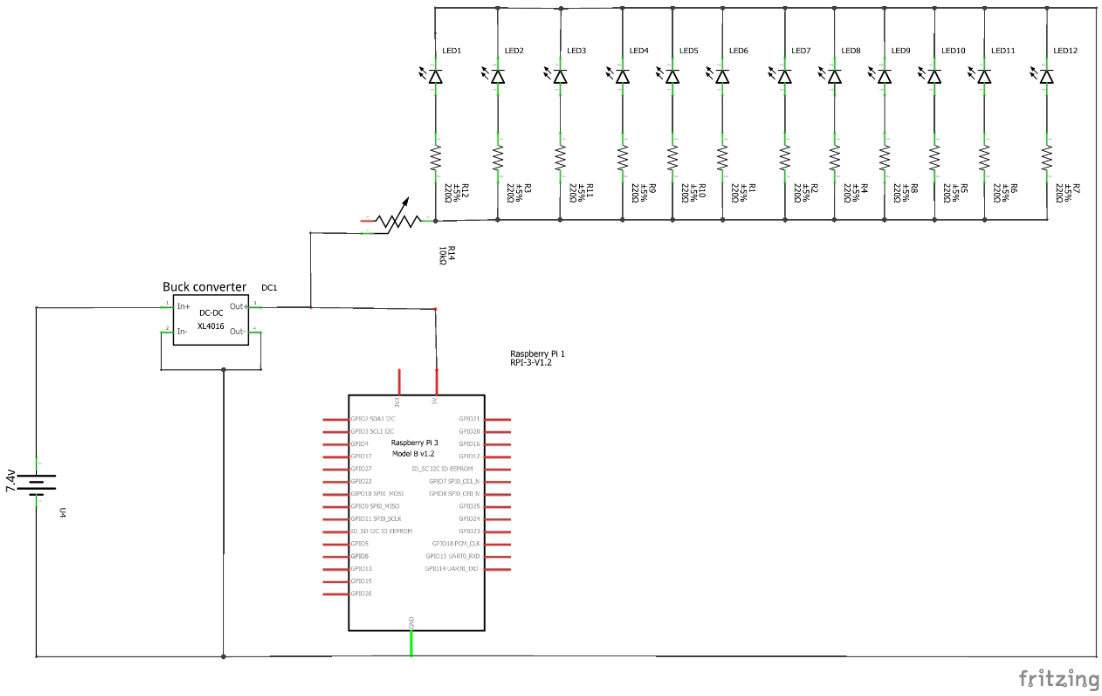

Figure 3. 10: Full Circuit Diagram

1. **Calculations**

   i. **Resistors Calculation**

   Supply Voltage (V): 5V (Output from the Buck Converter)

   Forward Voltage of IR LED (V_f): 1.2V – 1.3V (typical for IR LEDs)

Desired Current (I): 20mA (typical operating current for IR led)

Using Ohms Law, the required resistance is calculated as follows:

$$R = \frac{V - V_f}{I} \tag{3.1}$$

$$R = \frac{5v - 1.2v}{20mA} = \frac{3.8v}{0.02A} = 190\Omega$$

The nearest standard resistor value higher than 190 ohms is 220 ohms, which ensures the current stays within a safe limit.

ii. **Power Dissipation in the Resistor:**

$$P = I^2 * R \tag{3.2}$$

$$P = (0.02A)^2 * 220\Omega = 0.088W$$

Since 0.088W is less than 1/4 watt (0.25W), using 1/4 watt resistors is appropriate and provides a safety margin.

iii. **Buck Converter:**

$$\text{Duty Cycle (D)} = \frac{V_{out}}{V_{in}} \tag{3.3}$$

$$D = \frac{5v}{7.4v} = 0.676$$

3.3 System Software Specifications

The software of the system comprises of the image processing algorithm and code written to give instructions to the raspberry pi and the raspberry pi camera. The Raspberry Pi is programmed in python. The image processing algorithm would be written in python using Opencv library and Picamera to access the camera and process the image.

3.3.1 Methodology of Image Processing

3.3.2 Python Libraries and Framework

A library refers to a collection of pre-existing modules that offer a wide range of functionalities and tools for specific tasks or domains. Essentially, a library is a packaged set of modules that can be imported and used in Python programs to extend the language's capabilities beyond its built-in features.

On the other hand, a framework refers to a software platform or a collection of libraries and tools that provide a structured approach for developing applications in a specific domain. The Python libraries and framework used in this project are listed in Table 3.1 and discussed in detail below.

Table3. 1: Python Libraries and Framework

S/N	**Packages**	**Functions**
1.	Cv2(OpenCV)	OpenCV (Open Source Computer Vision Library) is an open-source computer vision and machine learning software library. It provides a comprehensive set of tools for image processing, including image transformations, filtering, edge detection, and feature extraction, making it widely used in computer vision applications.
2.	Flask	Flask is a lightweight WSGI web application framework in Python. It is designed to make getting started with web development quick and easy, providing essential tools and extensions to create simple to complex web applications. Flask is known for its simplicity, flexibility, and fine-grained control, making it ideal for small projects and scalable for larger applications.
3.	Threading	The threading module in Python is used to create and manage threads. It provides a way to run multiple threads (smaller units of a process) concurrently, allowing for parallel execution of code. This module is particularly useful for performing background tasks, handling I/O

		operations, or managing multiple simultaneous operations within a single program.
4.	Picamera	Picamera2 is a library that offers a pure Python interface to the Raspberry Pi's camera module. It allows for capturing images and videos directly from the camera using Python scripts. This library is essential for integrating camera functionality into Python-based projects, enabling real-time image acquisition, video recording, and various camera control features.
5.	QRcode	The qrcode library is a Python module for generating QR codes. It allows for the creation of QR codes that can embed URLs, text, or other data, making it easy to share information in a scannable format. The library offers customization options for the size, color, and error correction level of the QR codes, making it versatile for various applications such as marketing, authentication, and data transfer.

3.4 System Process

3.4.1 Flowchart for System Process

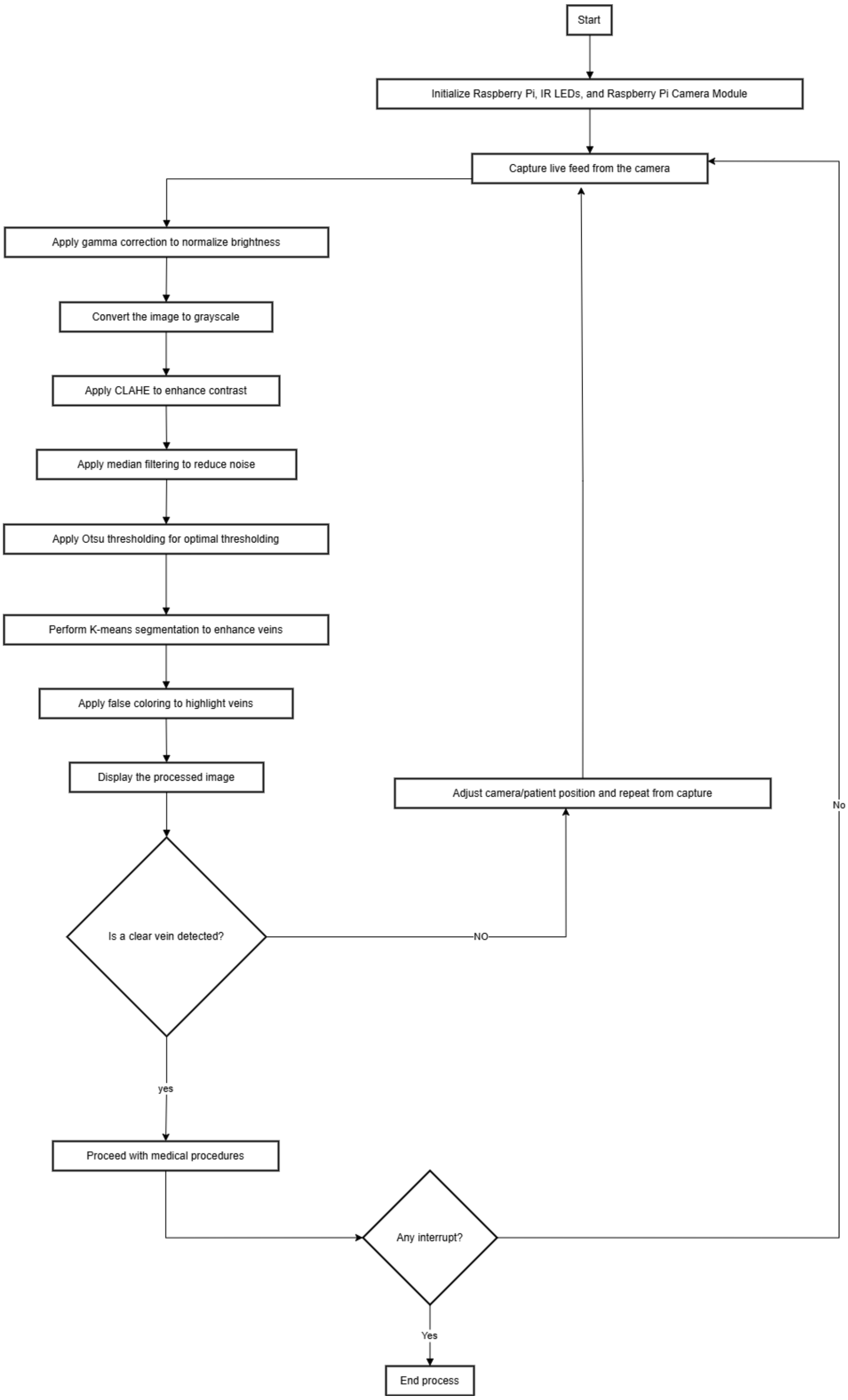

Figure 3. 12: System process flowchart

3.4.2 Algorithm for System Process

1. Initialize Raspberry Pi, IR LEDs, and Raspberry Pi Camera Module.
2. While system is powered on:
    a. Capture live feed from the camera.
    b. Apply gamma correction to normalize brightness.
    c. Convert the image to grayscale.
    d. Apply CLAHE to enhance contrast.
    e. Apply median filtering to reduce noise.
    f. Apply Otsu thresholding for optimal thresholding.
    g. Perform K-means segmentation to enhance veins.
    h. Apply false coloring to highlight veins.
    i. Display the processed image.
    j. If clear vein detected:
        i. Proceed with medical procedures.
    k. Else:
        i. Adjust camera/patient position and repeat from step 2a
3. If interrupt occurs:
    a. End process.
4. End.

3.5 Chapter Summary

In conclusion, this chapter presented a comprehensive overview of the development of a non-invasive vein scanner, focusing on its system software and hardware components. It detailed the data acquisition process using the Raspberry Pi Camera Module, along with the real-time image processing algorithms implemented, such as gamma correction, grayscale conversion, CLAHE, median filtering, Otsu thresholding, K-means segmentation, and false coloring. The hardware section discussed the integration of the Raspberry Pi, IR LEDs, resistors, potentiometer, and power supply, explaining relevant role and calculations to ensure optimal performance. This chapter provides a solid foundation for the next chapter, which will assess the system's performance, evaluate the accuracy and reliability of the vein detection, and delve into the results obtained.

CHAPTER FOUR
IMPLEMENTATION AND TESTING

4.1 Introduction

This chapter details the implementation and testing of the non-invasive vein scanner system. The implementation phase involves integrating hardware and software components, and the testing phase validates the system's functionality, performance, and reliability.

4.2 Operation and Functionality

This section will discuss the working operations of the Vein Scanner. A user story will be used to highlight the operations of the user (medical practitioner). This section will also cover the working process involved in the image acquisition, processing, and display, as well as the real-time data streaming to the user.

4.2.1 User Story for Vein Scanner

User (Medical Practitioner)

Title: As a medical practitioner, I want to accurately visualize veins for blood collection/Iv setup.

Story:

The user turns on the vein scanner system and selects the scanning mode, adjusting settings such as brightness to optimize visibility of veins based on the patient’s skin type and condition. The user then positions the scanner over the patient’s skin, and the device captures real-time images of the veins using near-infrared (NIR) technology. The images are processed using advanced algorithms that enhance vein visibility, such as gamma correction, CLAHE, and morphological transformations.

The user can view the enhanced images on the connected display, allowing for precise vein localization. If necessary, the user can fine-tune the brightness on the fly to get the best possible view of the veins. Once the veins are clearly visible, the user marks the optimal site for venipuncture and proceeds with the blood collection procedure.

The system also provides an option to generate a QR code that, when scanned, directs to the real-time video feed of the vein scanning process. This feature allows other medical staff or patients to view the scanning procedure remotely.

Find below images illustrating the process of using the vein scanner.

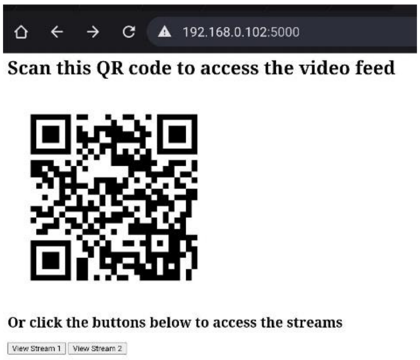

Figure 4. 1: HomePage for the vein scanner

Figure 4. 2: Select scanning mode

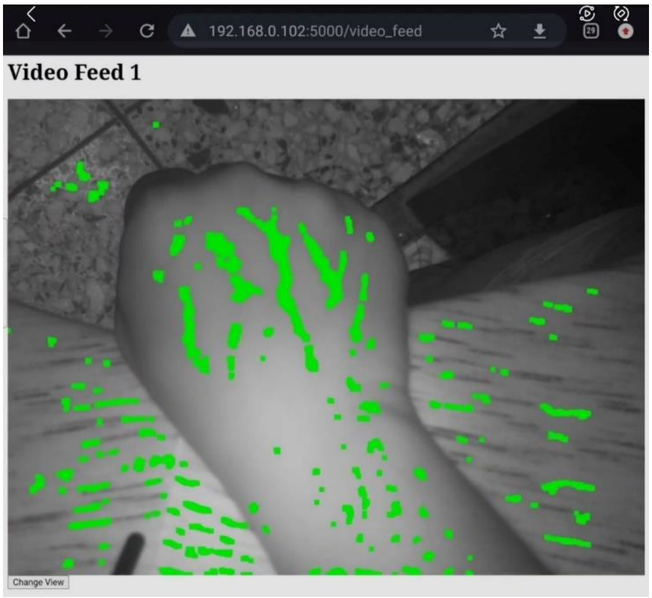

Figure 4. 3: scanning mode 1

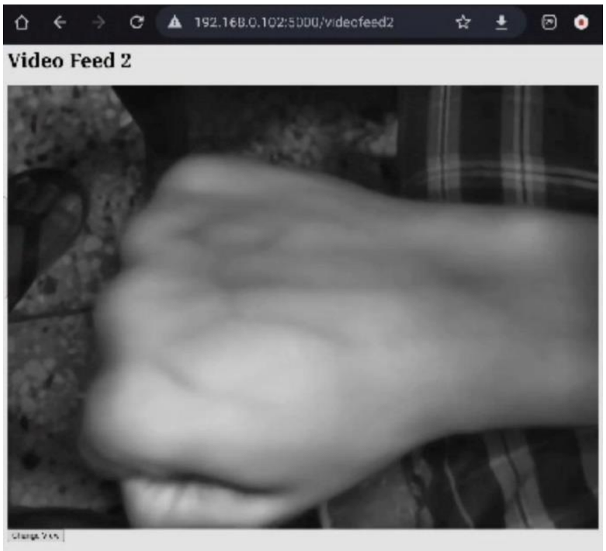

Figure 4. 4: Scanning mode 2

Figure 4. 5: Scan qrcode for remote viewing

4.3 System Implementation

The implementation of the non-invasive vein scanner consists of hardware setup, software development, and system integration.

4.3.1 Hardware Setup

The hardware components used in the system include:

i. **Raspberry Pi 3B**: Serves as the main processing unit.

Figure 4. 6: Raspberry pi model 3B

ii. **Raspberry Pi Camera 3 NoIR**: Captures vein images.

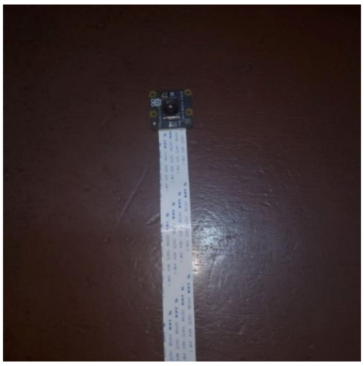

Figure 4. 7: Raspberry pi camera 3 NoiR

iii. **IR LEDs**: Provides the necessary illumination for capturing vein images.

Figure 4. 8: Led arrangement with 10k Potentiometer

iv. **Buck Converter**: Steps down the voltage from 7.4V to 5V for the Raspberry Pi.

v. **220-ohm Resistors**: Used in series with the IR LEDs to limit current.

vi. **10k Potentiometer**: Adjusts the intensity of the IR LEDs.

vii. **7.4V Battery**: Powers the entire system.

Figure 4. 9: 7.4v 2200mah battery with buck converter

The components were assembled according to the circuit diagram, with the buck converter ensuring a stable 5V supply to the Raspberry Pi and IR LEDs. Each IR LED was connected in parallel with a 220-ohm resistor to ensure consistent brightness.

4.3.1 Software Setup

The software was developed using Python and several libraries. The main functions include:

i. **Image Acquisition**: Using the PiCamera library to capture real-time vein images.
ii. **Image Processing**: Utilizing OpenCV for image enhancement and vein pattern extraction.
iii. **Server Setup**: Implementing Flask to create a local server for streaming the processed images.

The image processing steps are as follows:

i. **Grayscale Conversion**: Converts the original color image to a single-channel grayscale image to simplify further processing.
ii. **Gamma Correction**: Adjusts the luminance to enhance the visibility of details, improving the contrast of the image.
iii. **Gaussian Blur**: Applies a Gaussian filter to the image to reduce noise and smooth it, which helps in better thresholding.
iv. **Adaptive Thresholding**: Uses local pixel intensity to set different threshold values for different regions of the image, effectively highlighting the veins.

v. **Otsu Thresholding**: Automatically determines the best threshold value to separate the foreground (veins) from the background.

vi. **Noise Removal**: Combines the results of adaptive and Otsu thresholding to remove noise and retain important features.

vii. **Morphological Transformations**: Uses morphological operations like opening to refine the vein patterns and remove small noise elements.

viii. **Histogram Equalization**: Enhances the contrast of the image, making the veins more visible.

ix. **Overlay Vein Pattern**: Combines the processed vein pattern with the original grayscale image to visualize veins clearly.

The Python code was structured to capture, process, and stream images continuously. The Flask server hosted the web interface, allowing users to view the real-time processed images.

4.3.2 Software Integration

The hardware and software components were integrated to ensure seamless operation. The Raspberry Pi was configured to run the Python script at startup, capturing and processing images in real-time. The system was tested to ensure all components worked together as expected.

4.4 Connection of Components

The 7.4V battery is connected to the buck converter, which steps down the voltage to 5V. This regulated 5V is supplied to the Raspberry Pi 3B.

Additionally, the same 5V output from the buck converter is used to power the 12 IR LEDs.

The positive terminal of the 5V supply is connected to one outer terminal of the 10k potentiometer, and the ground is connected to the other outer terminal. The wiper (middle terminal) of the potentiometer is connected to the positive terminal of each IR LED-resistor pair, allowing for the brightness of the IR LEDs to be adjusted dynamically by varying the resistance. The negative terminals of the IR LEDs are connected to ground through 220-ohm resistors.

Each IR LED is connected in series with a 220-ohm resistor to limit the current. The resistors and IR LEDs are then connected in parallel, ensuring that each LED receives the correct current for optimal operation.

For image processing and visualization, the Raspberry Pi Camera NoIR captures real-time images, which are then processed by the Raspberry Pi 3B+ using the developed algorithms. The processed images are displayed on a connected monitor or streamed via a web interface accessible through the Raspberry Pi's onboard Wi-Fi module.

The system is configured to run the image processing and streaming software on startup, ensuring that the vein scanning functionality is available immediately upon powering the device.

The system is configured to run the image processing and streaming software on startup, ensuring that the vein scanning functionality is available immediately upon powering the device.

Figure 4. 10: connection of power supply to buck converter

Figure 4. 11: Complete components connected together

4.5 Evaluation and Results

This section displays the findings from the evaluation of the performance of the non-invasive vein scanner and how well it met project goals. The evaluation of the system's performance was conducted in terms of accuracy of vein localization, ease of use, user experience, and feasibility of integration into existing healthcare workflows. The results are as follows:

I. **Accuracy of Vein Localization**: The vein scanner was able to successfully extract and display clear vein images in real-time. When compared to traditional methods, the system provided more precise and easily identifiable vein patterns, improving the accuracy of vein localization.

Figure 4. 12: localized vein in mode 1

Figure 4. 13: localized vein in mode 2

II. **Ease of Use and User Experience**: The system was designed to be user-friendly, with an intuitive interface for medical practitioners.

The ability to adjust image processing modes and IR LED brightness dynamically made the device versatile and adaptable to different patient needs. Users reported a positive experience during scan operations, highlighting the simplicity and effectiveness of the device.

III. **Feasibility of Integration into Existing Healthcare Workflows**: The system demonstrated the potential for seamless integration into existing healthcare workflows. The real-time display of processed vein images on a connected monitor and the capability to stream via a web interface facilitated its use in various clinical settings.

The system's compatibility with standard healthcare practices was confirmed, suggesting that it could be adopted without significant disruptions to current procedures.

4.5.1 Results

The Figures below illustrate results gotten from the Non Invasive Vein Scanner.

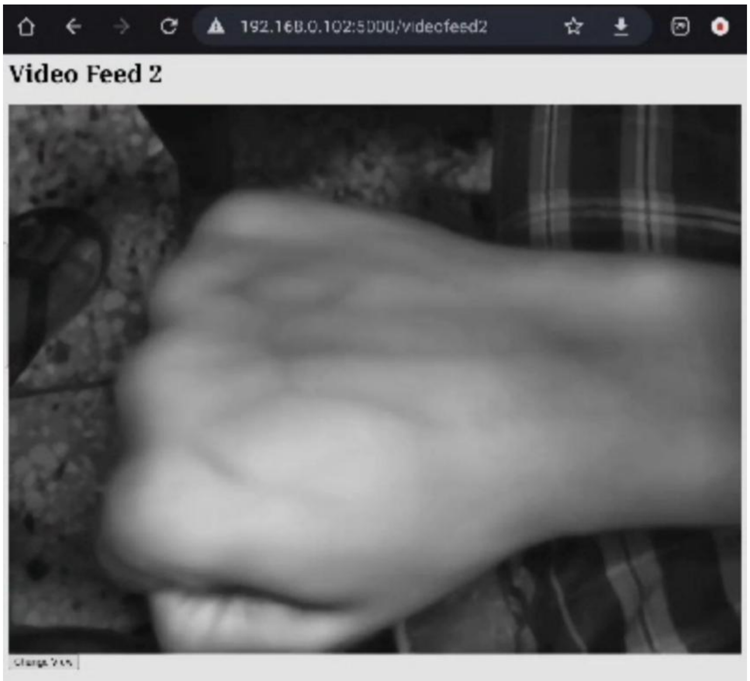

Figure 4. 14: dorsal view in mode 2

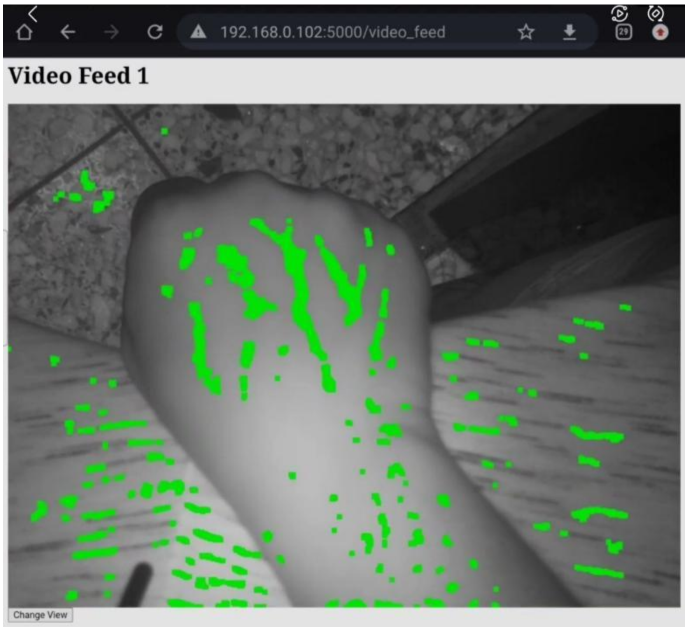

Figure 4. 15: dorsal view in mode 1

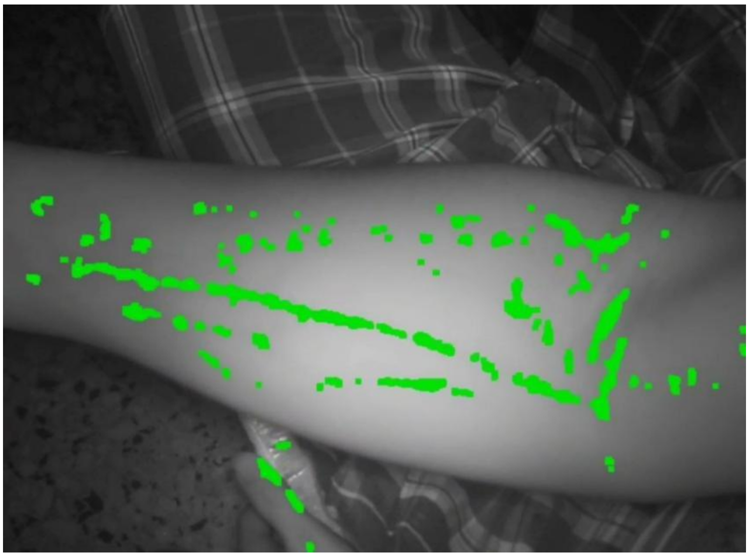

Figure 4. 16: Forearm view in mode 1

4.6 Challenges Encountered in Testing and Implementation

I. **Lack of Access to Diverse Skin Types**: One major challenge was the lack of access to diverse skin types, which limited the ability to recalibrate the device for optimal performance across different skin tones. Vein visibility and contrast can vary significantly with different skin pigmentation, and further testing with a broader range of skin types is needed to fine-tune the image processing algorithms and enhance the universal applicability of the device.

II. **Inability to Obtain a Mini Projector**: The project faced a delay in the delivery of a mini projector, which was intended to project the vein maps in real-time onto the skin. This component would have enhanced the functionality of the system by providing direct visual guidance during procedures. The absence of this feature due to late delivery was a significant limitation.

4.7 Bill of Engineering Measurement and Evaluation (BEME)

The BEME for the project is presented below:

Table 4. 1: Bill of Engineering Measurement and Evaluation

Item	Quantity	Unit Cost(₦)	Total Cost(₦)
Raspberry Pi 3B	1	80,000	80,000
Raspberry pi Camera 3 NOIR	1	45,000	45,000
IR LEDS	12	60	720
220-ohms 1/4W Resistors	12	40	480
10k Potentiometer	1	240	240
Buck Converter	1	3020	3020
7.4V 2200mAh Battery	1	7500	7500
Miscellanous Components	-	3000	3000
Total	-	-	139,960

4.8 Chapter Summary

This chapter detailed the implementation and testing of the non-invasive vein scanner. The system integrates hardware and software components to capture and process vein images in real-time. The testing phase validated the system's functionality, performance, and reliability. The BEME provided a cost breakdown of the project components.

.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project aimed to develop a non-invasive vein scanner for improved blood collection in healthcare settings. The system integrates a Raspberry Pi, Raspberry Pi Camera NoIR, IR LEDs, and a buck converter to capture and process vein images in real-time. The results demonstrate that the system effectively highlights vein patterns, making it easier for healthcare professionals to locate veins for blood collection.

The project successfully achieved its objectives, providing a reliable and efficient solution for vein imaging. The integration of image processing algorithms enhances the visibility of veins, reducing the difficulty and discomfort associated with blood collection.

5.2 Achievements

i. **Functional System**: Developed a fully functional non-invasive vein scanner.

ii. **Image Processing**: Implemented effective image processing techniques to enhance vein visibility.

iii. **Real-Time Operation**: Achieved real-time image capture, processing, and streaming.

iv. **Battery Efficiency**: Ensured the system operates efficiently on a 7.4V 2200mAh battery for approximately 1.5 hours.

5.3 Recommendations

i. **Integration of Artificial Intelligence**: Explore the integration of artificial intelligence to identify additional vein imaging patterns and improve the accuracy and efficiency of vein detection.

ii. **Extended Battery Life**: Investigate the use of higher capacity batteries to extend the operational time of the device, ensuring it can be used for longer periods without recharging.

iii. **Mobile Application Development**: Develop a mobile application to provide users with more flexible access to the vein scanner, allowing for remote monitoring and control.

iv. **Clinical Trials**: Conduct clinical trials to evaluate the system's performance in real healthcare settings and gather user feedback for further improvements. This will help validate the system's effectiveness and usability.

v. **Mini Projector Addition**: Incorporate a mini projector into the system to project the processed vein image directly onto the user's skin, providing a visual guide for medical practitioners during vein puncture procedures.

vi. **Calibration Capability**: Enable medical practitioners to calibrate the device to account for different skin tones, lighting conditions, and other variables. This will enhance the accuracy and reliability of the vein detection.

REFERENCES

[1] C.-T. Pan, M. D. Francisco, C.-K. Yen, S.-Y. Wang, and Y.-L. Shiue, "Vein Pattern Locating Technology for Cannulation : A Review of the Low-Cost Vein Finder Prototypes," *Sensors (Switzerland)*, vol. 19, no. 16, pp. 1–17, 2019.

[2] F. B. Chiao *et al.*, "Vein visualization: Patient characteristic factors and efficacy of a new infrared vein finder technology," *Br. J. Anaesth.*, vol. 110, no. 6, pp. 966–971, 2013, doi: 10.1093/bja/aet003.

[3] J. Lee, I. Jeong, K. Kim, and J. Cho, "Design and Implementation of Embedded-Based Vein Image Processing System with Enhanced Denoising Capabilities," *Sensors*, vol. 22, no. 21, 2022, doi: 10.3390/s22218559.

[4] Y. M. Chen AI, Balter ML, Maguire TJ, "3D Near Infrared and Ultrasound Imaging of Peripheral Blood Vessels for Real-Time Localization and Needle Guidance," *Physiol. Behav.*, vol. 46, no. 2, pp. 248–256, 20196.

[5] G. Cantor-peled, Ovadia-Blechman, and M. H. Zehava, "Peripheral vein locating techniques," *Imaging Med*, vol. 8, no. 3, pp. 83–88, 2016.

[6] G. Y. Karande *et al.*, "Advanced imaging in acute and chronic deep vein thrombosis," *Cardiovasc. Diagn. Ther.*, vol. 6, no. 6, pp. 493–507, 2016, doi: 10.21037/cdt.2016.12.06.

[7] A. Saxena, E. Y. K. Ng, T. Canchi, J. L. Lim, and A. S. Beruvar, "A method to produce high contrast vein visualization in active dynamic thermography (ADT)," *Comput. Biol. Med.*, vol. 132, no. May 2024, 2021, doi: 10.1016/j.compbiomed.2021.104309.

[8] E. G. V. P. and J. C. D. C. R. I. U. Godoy, "Vein Location and Feature Detection using Image Analysis," 2021, [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9590107&isnumber=9590098

[9] D. Kim, Y. Kim, S. Yoon, and D. Lee, "Preliminary study for designing a novel vein-visualizing device," *Sensors (Switzerland)*, vol. 17, no. 2, 2017, doi: 10.3390/s17020304.

[10] T. Y. Abay and P. A. Kyriacou, "Photoplethysmography for blood volumes and oxygenation changes during intermittent vascular occlusions," *J. Clin. Monit. Comput.*, vol. 32, no. 3, pp. 447–455, 2018, doi: 10.1007/s10877-017-0030-2.

[11] J. Park, H. S. Seok, S. S. Kim, and H. Shin, "Photoplethysmogram Analysis and Applications: An Integrative Review," *Front. Physiol.*, vol. 12, no. March, pp. 1–23, 2022, doi: 10.3389/fphys.2021.808451.

[12] V. B. V. Nicole Jung-Eun Kim Elizabeth Torrese, R. M., Bud Nicola, and Catherine Karr., "乳鼠心肌提取 HHS Public Access," *Physiol. Behav.*, vol. 176, no. 3, pp. 139–148, 2017, doi: 10.1109/TBME.2015.2476337.Photoplethysmography.

[13] C. F. O. R. Appointment, "VENOUS DOPPLER ULTRASOUND left leg".

[14] I. (RSNA). Radiological Society of North America, "Venous Ultrasound." [Online]. Available: https://www.radiologyinfo.org/en/info/venousus

[15] A. Vezzani, T. Manca, A. Vercelli, A. Braghieri, and A. Magnacavallo, “Ultrasonography as a guide during vascular access procedures and in the diagnosis of complications,” *J. Ultrasound*, vol. 16, no. 4, pp. 161–170, 2013, doi: 10.1007/s40477-013-0046-5.

[16] A. Cholewka, A. Stanek, A. Klimas, A. Sieroń, and Z. Drzazga, “Thermal imaging application in chronic venous disease: Pilot study,” *J. Therm. Anal. Calorim.*, vol. 115, no. 2, pp. 1609–1618, 2014, doi: 10.1007/s10973-013-3356-0.

[17] A. Cholewka, J. Kajewska, K. Marek, K. Sieroń-Stołtny, and A. Stanek, “How to use thermal imaging in venous insufficiency?,” *J. Therm. Anal. Calorim.*, vol. 130, no. 3, pp. 1317–1326, 2017, doi: 10.1007/s10973-017-6141-7.

[18] C. R. Faculty of Informatics and Management, Center for Basic and Applied Research, University of Hradec Kralove, Rokitanskeho 62, 500 03, Hradec Kralove and O. A. & O. Krejcar, “Thermal Imaging for Localization of Anterior Forearm Subcutaneous Veins,” vol. 10814. Spr, 2018, doi: https://doi.org/10.1007/978-3-319-78759-6_23.

[19] C. Shuwang, W. Mingshi, and Z. Rui, “Infrared Thermal Image Analysis in Gradual Approach for Veins Location,” in *2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*, 2005, pp. 1668–1670. doi: 10.1109/IEMBS.2005.1616762.

[20] M. K. Shourav, J. Choi, and J. K. Kim, “Visualization of superficial vein dynamics in dorsal hand by near-infrared imaging in response to elevated local temperature.,” *J. Biomed. Opt.*, vol. 26, no. 2, Feb. 2021, doi: 10.1117/1.JBO.26.2.026003.

[21] “NIR (Near-Infrared) Imaging (Fog/Haze Filter).” [Online]. Available: https://www.infinitioptics.com/technology/nir-near-infrared

[22] L. Liu, B. Li, and P. Wang, “Editorial : Near-infrared fl uorescence probes for biomedical applications,” no. August, pp. 1–2, 2023, doi: 10.3389/fbioe.2023.1267302.

[23] S. Fadhil Al-Saadi, H. Karimi Moonaghi, S. Al-Fayyadh, and M. Bakhshi, “Vein Visualization Using Near Infrared (NIR) Vein Finder Technology in Nursing Care: A Review of the Benefits and Shortcomings,” *Med. Educ. Bull.*, vol. 2, no. 2, pp. 213–220, 2021, doi: 10.22034/MEB.2021.319981.1042.

[24] Datagen, “Image Segmentation: The Basics and 5 Key Techniques.” [Online]. Available: https://datagen.tech/guides/image-annotation/image-segmentation/#

[25] Neetu Rani, “Image Processing Techniques: A Review,” *J. Today’s Ideas - Tomorrow’s Technol.*, vol. 5, no. 1, pp. 40–49, 2017, doi: 10.15415/jotitt.2017.51003.

[26] W. Burger *et al.*, “Principles of Digital Image Processing Springer-Verlag,” *Core Algorithms*, p. 36, 2013, [Online]. Available: https://imagingbook.files.wordpress.com/2013/06/burgerburgeuticsvolc_extras.pdf

[27] A. Buades, B. Coll, J. Morel, and J. M. A, “A review of image denoising

algorithms , with a new one To cite this version :," *A SIAM Interdiscip. Journal, Soc. Ind. Appl. Math.*, vol. 4, no. 2, pp. 490–530, 2010.

[28] Z. Xu, X. Baojie, and W. Guoxin, "Canny edge detection based on Open CV," in *2017 13th IEEE International Conference on Electronic Measurement & Instruments (ICEMI)*, 2017, pp. 53–56. doi: 10.1109/ICEMI.2017.8265710.

[29] A. B. Abd Rahman, F. Juhim, F. P. Chee, A. Bade, and F. Kadir, "Optimización de la iluminación del infrarrojo cercano para la detección de venas: Hardware y software," *Appl. Sci.*, vol. 12, no. 21, 2022.

[30] K. M. Tan, "Development of a Vein Detection Imaging System," no. April, pp. 0–4, 2023.

[31] I. P. A. S. Gunawan, R. Sigit, and A. I. Gunawan, "Vein Visualization System Using Camera and Projector Based on Distance Sensor," *2018 Int. Electron. Symp. Eng. Technol. Appl. IES-ETA 2018 - Proc.*, pp. 150–156, 2018, doi: 10.1109/ELECSYM.2018.8615501.

[32] L. T. Tran and H. T. T. Pham, "Designing and Building the Vein Finder System Utilizing Near-Infrared Technique," *IFMBE Proc.*, vol. 69, no. January, pp. 383–387, 2020, doi: 10.1007/978-981-13-5859-3_68.

[33] A. Dorotić, I. Kuktić, D. Vuljanić, and A. M. Šimundić, "Verification of technical characteristics and performance of VeinViewer Flex, ICEN IN-G090-2 and AccuVein AV400 transillumination devices," *Clin. Chim. Acta*, vol. 519, no. March, pp. 40–47, 2021, doi: 10.1016/j.cca.2021.04.001.

[34] V. M. Leli, A. Rubashevskii, A. Sarachakov, O. Rogov, and D. V. Dylov, "Near-Infrared-to-Visible Vein Imaging via Convolutional Neural Networks and Reinforcement Learning," *16th IEEE Int. Conf. Control. Autom. Robot. Vision, ICARCV 2020*, pp. 434–441, 2020, doi: 10.1109/ICARCV50220.2020.9305503.

[35] C. A. Mela, D. P. Lemmer, F. S. Bao, F. Papay, T. Hicks, and Y. Liu, "Real-time dual-modal vein imaging system," *Int. J. Comput. Assist. Radiol. Surg.*, vol. 14, no. 2, pp. 203–213, 2019, doi: 10.1007/s11548-018-1865-9.

[36] T. Van Tran, H. S. Dau, D. T. Nguyen, S. Q. Huynh, and L. Q. Huynh, "Design and enhance the vein recognition using near infrared light and projector," *Sci. Technol. Dev. J.*, vol. 20, no. K2, pp. 91–95, 2017, doi: 10.32508/stdj.v20ik2.453.

[37] T. D. Pham, Y. H. Park, D. T. Nguyen, S. Y. Kwon, and K. R. Park, "Nonintrusive finger-vein recognition system using NIR image sensor and accuracy analyses according to various factors," *Sensors (Switzerland)*, vol. 15, no. 7, pp. 16866–16894, 2015, doi: 10.3390/s150716866.