UNIVERSIDAD DE INVESTIGACION DE TECNOLOGIA EXPERIMENTAL YACHAY

ESCUELA DE CIENCIAS BIOLÓGICAS E INGENIERÍA

TÍTULO: Live Vein Viewer for Patients with Hard-to-Find-Veins

Trabajo de integración curricular presentado como requisito para la obtención del título de Ingeniero Biomédico

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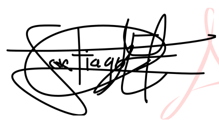

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Dedicatoria

Dedico este trabajo a todas aquellas personas que al imaginar crear un dispositivo no se atreven a hacerlo. Este proyecto es un ejemplo claro de que se puede hacer mucho, con poco material. Con esto espero impulsar el desarrollo de nuevas tecnologías y dispositivos en el Ecuador, a que todos los jóvenes que se encuentran cursando una carrera que implique creatividad, nunca se dejen apagar, siempre habrá una solución para lograrlo y sacar adelante cualquier proyecto.

Manuel Santiago Espinosa Caro

Agradecimiento

Agradezco a todas las personas que se vieron involucradas en la realización de este proyecto, por más mínima que haya sido su ayuda, sin ellas no lo habría logrado. Con esto incluyo a mi tutora, PhD Graciela Salum, quien me apoyó en todo momento hasta la culminación de mi proyecto.

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Manuel Santiago Espinosa Caro

ABSTRACT

The use of infrared radiation for medical imaging is becoming more and more relevant. Nowadays, there are several technologies that facilitate common processes in a hospital such as venipuncture. There are several conditions in patients that can cause problems when performing any venipuncture procedure. Patients with dehydration, patients who have undergone chemotherapy, and patients with obesity or overweight. The latter being the ones with the highest index in the case of Ecuador for patients to have hard to find veins.

Starting from the fact that overweight and obesity are a problem in Ecuador, and that facilitating any common process is an advantage for the comfort, costs, and precision of the procedure. This research is aimed at the creation and development of a device capable of visualizing the veins on the back of the hand. Using infrared technology and analyzing the best and available sensors in the Ecuadorian market to lower production costs.

Starting with a normal webcam as a base and after making some modifications to its filter, creating an infrared light source, and developing a series of algorithms in conjunction with a user interface for image processing. It was possible to arrive at a prototype capable of differentiating between the veins and the tissue that surrounds them on the back of the hand. The results of this device are promising in terms of the precision and the advantages that it provides during the venipuncture process compared to the same procedure, but without the use of a similar device.

Key words

Infrared radiation, vein pattern, image processing, obesity, overweight, optical window.

RESUMEN

El uso de la radiación infrarroja para la imagen médica cada vez es más relevante. Hoy en día existen varias tecnologías que facilitan los procesos comunes en un hospital tales como la venopunción. Existen varias condiciones en los pacientes que pueden generar problemas al momento de realizar cualquier procedimiento de venopunción. Pacientes con deshidratación, pacientes que han pasado por quimioterapia, y pacientes con obesidad o sobrepeso. Siendo los últimos dos los de mayor índice en el caso de Ecuador para pacientes con venas difíciles de encontrar.

Partiendo del hecho de que el sobrepeso y la obesidad son un problema en Ecuador, y de que facilitar cualquier proceso común es una ventaja para la comodidad, costos, y precisión del procedimiento. Esta investigación va dirigida a la creación y desarrollo de un dispositivo capaz de visualizar las venas del dorso de la mano. Utilizando la tecnología infrarroja y analizando los mejores y disponibles sensores en el mercado ecuatoriano para abaratar los costos de producción.

Iniciando con una webcam normal como base y tras hacerle algunas modificaciones a su filtro, creando una fuente de iluminación infrarroja, y desarrollando una serie de algoritmos en conjunto con una interfaz de usuario para el procesamiento de la imagen. Se logró llegar a un prototipo capaz de diferenciar entre las venas y el tejido que las rodea en el dorso de la mano. Los resultados de este dispositivo son prometedores en términos de la precisión y de las ventajas que el mismo otorga durante el proceso de venopunción en comparación con el mismo procedimiento, pero sin el uso de un dispositivo parecido.

PALABRAS CLAVES

Radiación infrarroja, patrón de venas, proceso de imágenes, obesidad, sobrepeso, ventana óptica

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1. INTRODUCTION AND JUSTIFICATION

The use of several attempts for intravenous cannulation increases the suffering of patients and could cause damage to veins and neighboring tissues. Therefore, it is vital to set up the route of the peripheral vein effectively on the first attempt. Blood test, vaccination, fluid injection or any other process that needs venipuncture are common procedures for millions of people daily. These processes should be easy for patients and doctors. However, most of the times there are complications that becomes the process difficult. It is important to get an accurate location of the veins to avoid lots of tries and pain caused by the doctor injecting in the wrong place to the patient. This difficulty is presented when the process is performed not using a device to get vein pattern before the injection [1].

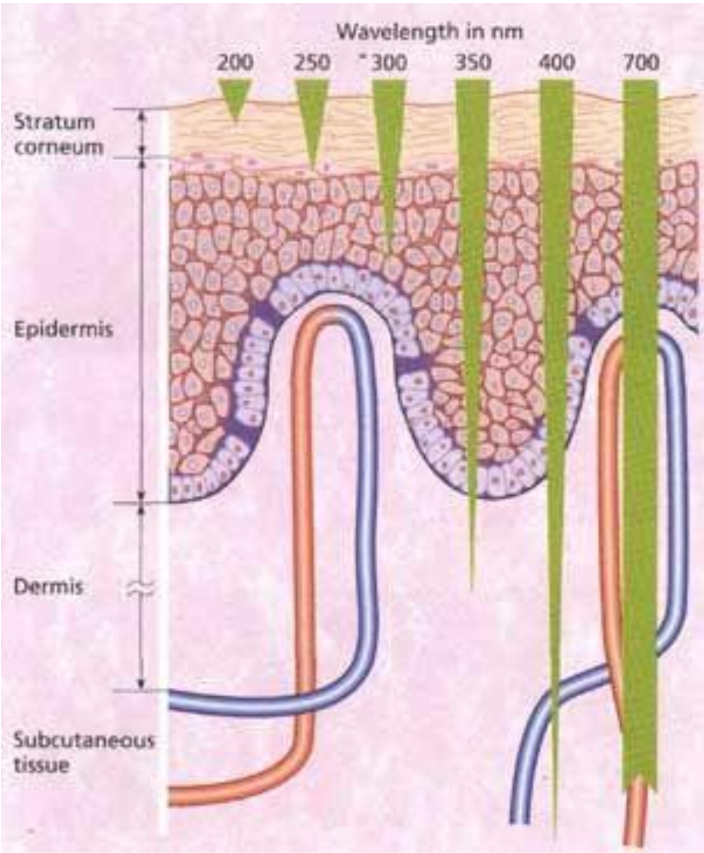


Figure 1. Behavior of different wavelength penetrating the human skin [2].

Light can differently penetrate the skin depending on the wavelength (Fig. 1). According to how much the light can penetrate the skin there are three main divisions or groups. Wavelength of 200-400 nm can only penetrate the epidermis skin layer, light with a wavelength of 400-600 nm can penetrate the dermis layer of the skin, whereas light with a wavelength of 600-700 nm can penetrate the skin subcutaneous tissue. The corresponding radiation that belongs to most penetrating light is the near infrared (IR) radiation, which is used for the vein localization system developed in this project [3].

1.1 Infrared radiation (IR)

Infrared radiation is a type of electromagnetic radiation. In the electromagnetic spectrum (Fig. 2), it is located above the visible light, which means that its wavelength is greater in comparison with visible light [4]. It is not possible by the human eye to see the infrared radiation, but when using technologies capable of see the radiation the medical applications become important.

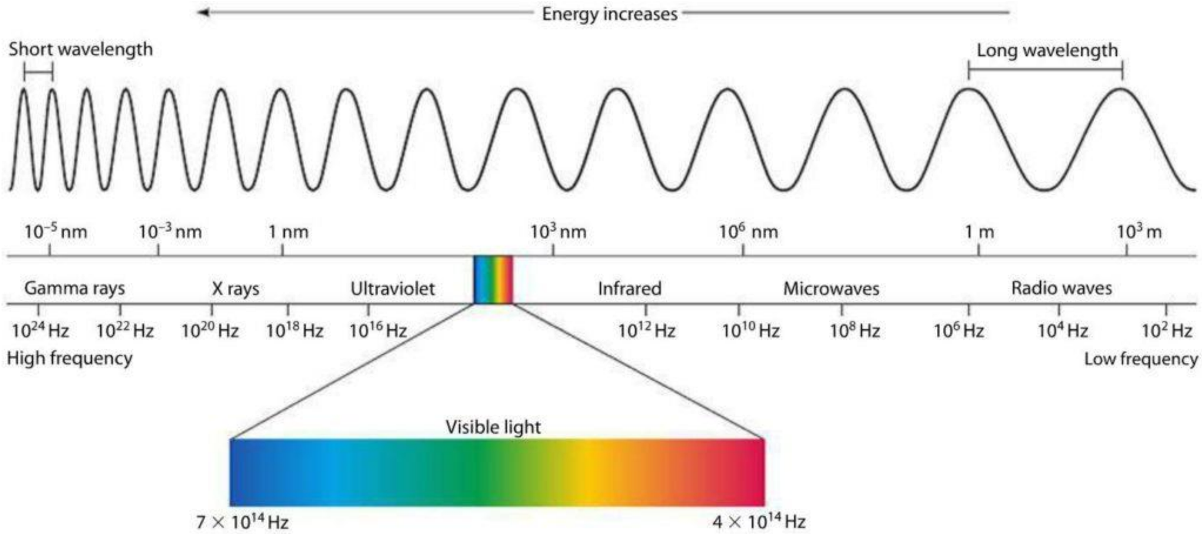


Figure 2. Electromagnetic Spectrum [4].

The red blood cells circulating on the bloodstream are made up mainly of hemoglobin, which carries oxygen from lungs using arteries and carbon dioxide from tissues using the veins to the lungs again [5]. The recognition with infrared radiation over the veins is simple, the deoxidized hemoglobin absorbs infrared light, in that way, the veins become visible on the camera [5]. Furthermore, arteries are impossible to see with this system because of the specific absorption rates of infrared radiation in blood vessels and oxidized hemoglobin become transparent on the camera [6].

It is possible to analyze almost any part of the body with this technique, but the hand is a better option because the veins are more likely to be visible under infrared light and the camera due to the proximity to the surface of the skin [6].

Figure 3. Veins (blue) and arteries (red) of the posterior part of the hand [7].

The IR radiation is divided in three ranges; near IR, middle IR, and far IR. Near Infrared Radiation (NIR) goes from 780nm to 1100nm wavelength and is the preferred range for the application needed on this project because it shows better characteristics for absorption by the red blood cells [8].

1.2 Optical window and tissue absorption rates

The near-infrared window or optical window involves the range of wavelengths from 650nm to 1350nm where the light is capable of penetrates in tissue with the largest depth possible [9]. The best absorption rate of light for blood is produced at short wavelengths, while the best absorption for water occurs at long wavelengths. This is the reason why it is possible to identify veins using near infrared radiation, because in the veins the blood is constantly circulating.

In the composition of blood there are two types of hemoglobin: oxyhemoglobin (HbO_2), and deoxyhemoglobin (Hb). The difference is that HbO_2 is bound to oxygen, but Hb is not bound. This difference is reflected in the absorption spectra (Fig. 4). In the case of HbO_2, the highest absorption occurs at 400 and 600 nm, then there is a significant decrease in absorption. On the other hand, the Hb has two peaks, like the HbO_2 but the decay is not as hard as the oxygenated hemoglobin. The absorption decreases gradually, and it is what the infrared device will recognize the most when using for localizing the veins [10].

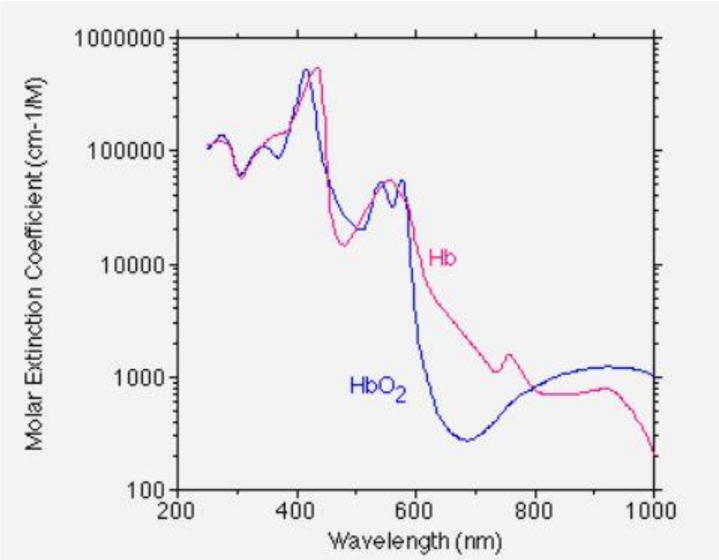


Figure 4. Molar extinction coefficients of oxyhemoglobin and deoxyhemoglobin [10].

Each type of tissue has a different absorption rate for IR radiation. However, the largest penetration in the tissue treated in this study occurs between 740nm to 800nm, which is a short-range optical window. There are two types of veins present in the upper limbs: superficial and deep veins. Furthermore, none NIR device or light source can penetrate enough to reach deep veins due to optical properties of the human body, and thus it will not recognize the deep veins [11].

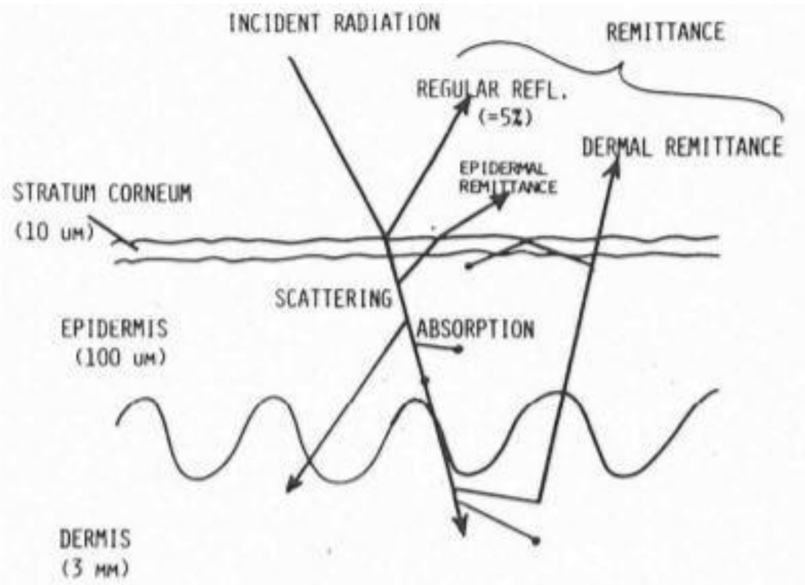


Figure 5. Schematic representation of optical phenomenon on skin [12].

The optical coefficients involved in this application are absorption and scattering coefficients (see Fig. 5). They determine the distance that light can penetrate before losing its intensity and the distance that light penetrates before losing its phase and changes direction [13]. Furthermore, scattering becomes a problem for acquiring any image of deep veins under the skin.

Considering the optical properties of human skin, the veins could be recognized on an IR image, and after the application of some algorithms, the vascularization of the object under study will be shown clearly.

1.3 Types of sensors

Charged Coupled Device (CCD) are sensors used in digital cameras and video cameras to record still images and videos [14]. Complementary Metal Oxide Semiconductor (CMOS) used for analog circuits such as image sensors and integrated circuits [15].

CCD and CMOS sensors are pixelated metal oxide semiconductors. They accumulate signal charge in each pixel proportional to the local illumination intensity, serving a spatial sampling function.

On a CCD sensor (Fig. 6), the camera printed circuit board is responsible for the major part of the functions. CCD transfers each pixel's charge packet sequentially to a general converter, which transforms the photons to voltage and sends it off-chip.

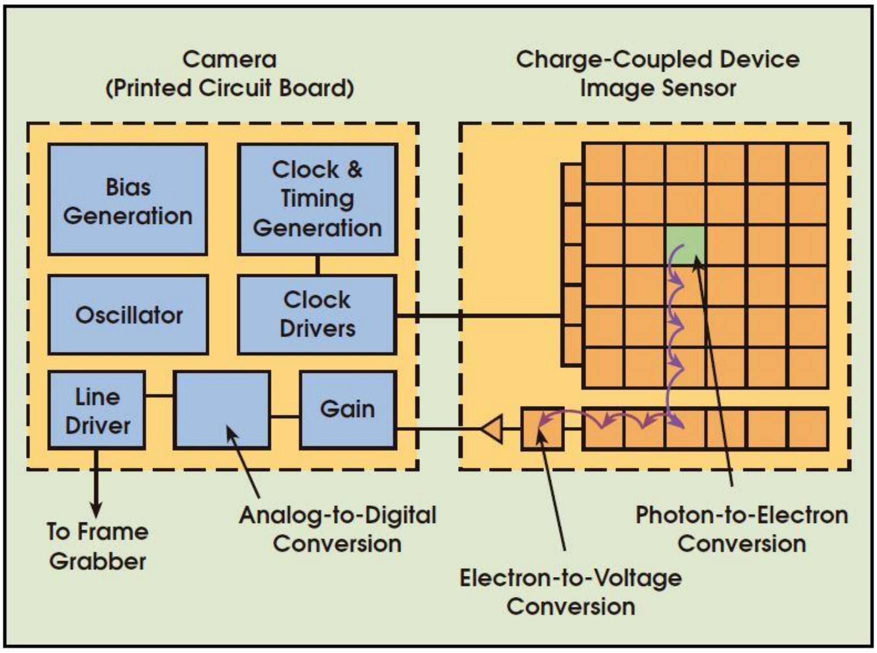


Figure 6. CCD sensor working principle [16].

On the other hand, a CMOS imager converts photons to voltage at the pixel, and the chip contains most of the functions (Fig. 7). This is translated into a sensor capable of giving better results in rugged environments, such as low light conditions inside buildings (hospitals, clinics, laboratories, etc.) or any other place where to use the vein locator system [16].

There are some advantages of CMOS sensors over the CCD's:

- The responsivity, which is how much signal is delivered by the sensor per unit of optical energy, is better in CMOS imagers because transistors are easy to place on the sensor.
- The speed is significantly higher in CMOS due to all the camera functions being on the image sensor.
- The windowing is a unique characteristic of CMOS technology which allows to track objects efficiently in a specific area of the image.
- Anti-Blooming is the ability to reduce localized overexposure and not affect the rest of the image.
- Reliability, CMOS sensors are more durable in any harsh environments because of its rough construction and less leads and solder joints.

However, there are also disadvantages of CMOS:

- The dynamic range is a lot better on CCD which allows better quality images avoiding noise caused by low light situations.
- Uniformity, in CCDs imagers is better, the consistency of response from pixels when capturing images at the same illumination conditions.
- Shuttering, the ability to start and stop exposure. CCDs expose all pixels of the array at the same time, avoiding distortion of resulting images. In higher-performance applications, such as medical, it is important to eliminate distortion by object movement.

All the advantages and disadvantages mentioned before, become the CMOS sensor as the best option for the purpose of this project, allowing to use it in any difficult condition that could happen on any medical facilities. Furthermore, CMOS sensors tend to be smaller because all the components are integrated inside the sensor. However, it is difficult to get a CMOS sensor in Ecuador, and the price is reasonably higher than cameras with CCD imagers in the country [16].

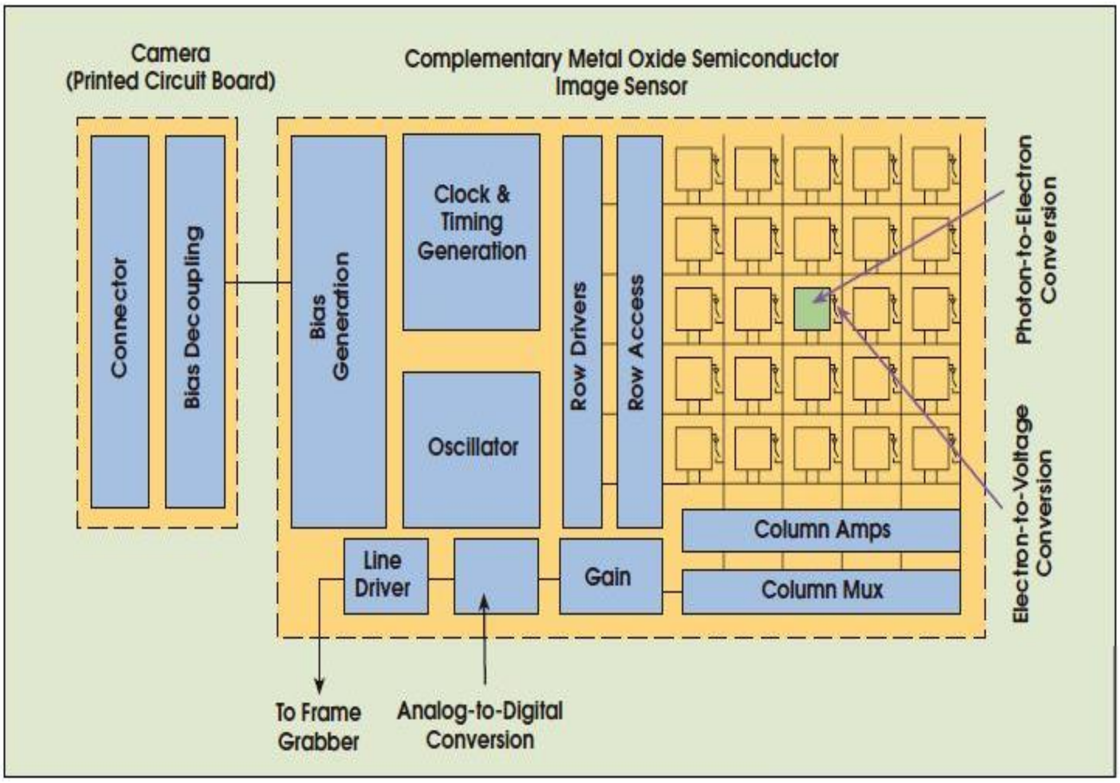


Figure 7. CMOS sensor working principle [16].

1.4 Image acquisition

Charge Coupled Device (CCD) is an integrated circuit that contains a determined number of linked or coupled capacitors. Under the control of an internal circuit, each capacitor transfers its electric charge to one or some capacitors located beside the printed circuit. The CCD is the sensor with small photoelectric cells that register the image. Right there, the image is processed by the camera and written in the memory card, or in this case, in the selected folder for storing all images [14].

The resolution capacity or image detailing depends on the number of photoelectric cells of the CCD. This number is expressed in pixels. The greater number of pixels, the clearer the image in relation with its size. The image acquisition is performed by a modified webcam with CCD sensor [14].

However, it is necessary that the chosen webcam has easy access to the sensor and is separated from its original infrared filter. The webcam has been modified to recognize only infrared radiation through the elimination of the original filter and replacing it by a new one with a band pass for 850nm wavelength, which blocks almost all the visible light. After this modification, the image that the CCD sensor is acquiring is almost grayscale.

Figure 8. Illustration of the filters and sensor in a real camera.

Figure 8 is a better representation of where the sensor and the filters are in a camera. The blue like circles in the image represents the filter(s), in the case a more basic webcam, it will have only one filter. Behind all the filters, there is a rectangular chip, this chip is the CCD sensor. Which needs to be separated from the filters.

For completing the image acquisition, the IR illumination was fundamental. Illumination that is not possible to see with the human eye. So, for testing if the infrared LEDs are lightning, it is necessary to use a camera. Only cameras will recognize the IR radiation. For this,18 infrared LEDs have been placed in a matrix to achieve a proper and uniform illumination over the object to be analyzed. Once the camera is focusing on the area to study and LEDS are turned on, the image is acquired by snapshotting in the native software for the webcam and stored in an specific folder with the images, which will be used as a database.

1.5 Image processing

Digital image processing refers to process digital images using a digital computer through an algorithm. There is also analog image processing, but the digital is much better because it admits a lot more algorithms to be implemented and avoid common problems such as the increasing noise and distortion during the processing [17].

Digital image processing applied on medical devices is important to reconstruct systems present in the human body, which are impossible to see by eyes.

This image processing is the final stage of the device. In this case, five different algorithms are implemented to achieve the desired result of the final image; background removal, Contrast Limited Adaptive Histogram Equalization (CLAHE), inverse, binarization, and erosion.

Each algorithm makes different changes over the original image, and there is the possibility to change parameters inside the algorithm according to the type of image we are processing to get best result.

After implementing all the algorithms on a python scrip. It was necessary to create a friendly way for non-experienced people to process the image. For this, a simple user interface (UI) where the interactions between the machine and the human occurs.

Furthermore, a database is created for storing all the images of any patient. This will organize and collect all the images for being accessed electronically at any moment from a computer system.

2. PROBLEM STATEMENT

Improper localization of veins during venipuncture procedures is the major problem that doctors, and nurses are facing. This project consists of the development of a biomedical device aimed to create a live vein viewer for patients with Hard to Find Veins (HTFV).

According to the 2015 National Survey for Health and Nutrition (Fig. 9), it is reported that in Ecuador 29.9% of children between 5 to 11 years old are overweight and obese, for teenagers from 12 to 19 years old is 26%, and this figure increases to 62.8% in adults (from 19 to 59 years old) [18].

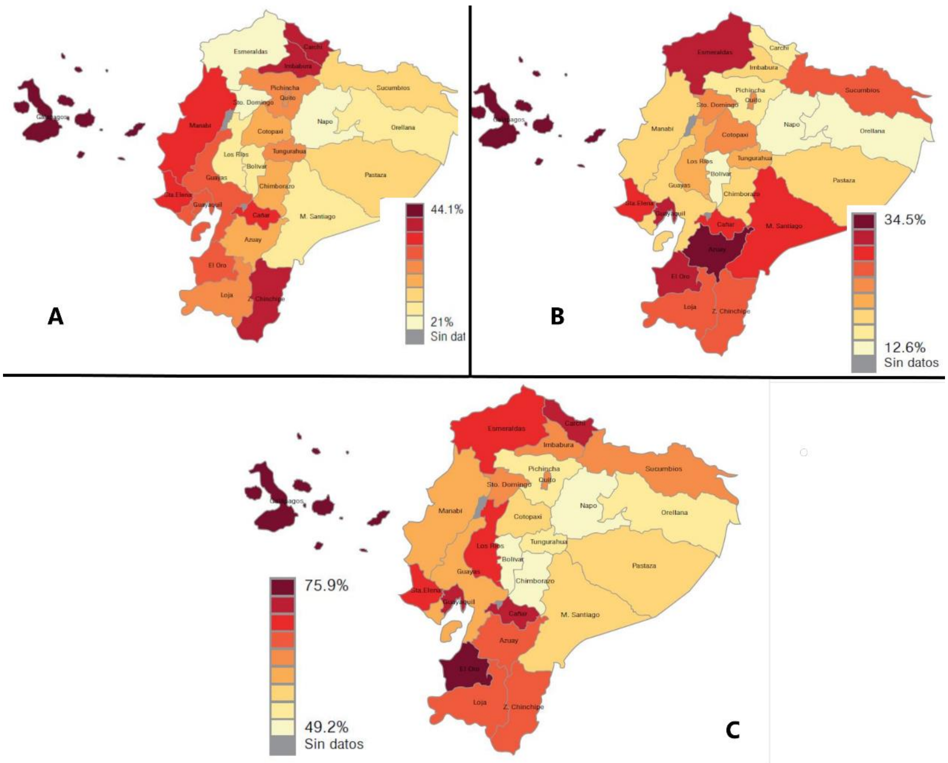


Figure 9. (A) Localization of the percentage of the population that shows obesity or overweight for children between 5 and 11 years old. (B) Localization of the percentage of the population that shows obesity or overweight for teenagers between 11 and 19 years old. (C) Localization of the percentage of the population that shows obesity or overweight for adults between 19 and 60 years old [18].

Obesity is one of the main reasons for people to have HTFV because fatter people tend to have their veins buried deeper and are thus harder to find. However, there are some other conditions that becomes any venipuncture procedure more difficult, but they are not as relevant as obesity or overweight. Since according to the statistics, the problems with obesity in Ecuador are serious for all the different age ranges.

A major part of obesity and overweight problems are presented in the Coast of Ecuador. For the different age ranges, all the percentage are over the 35% in Guayas, Manabí, and Esmeraldas.

The use of a vein localization device could ease the problems that arise when performing a venipuncture process in these places where the population already has a complication for the procedure. Furthermore, there is people with more than one complication, obesity combined with dehydration or even worse cases where the veins get hidden.

Similarly, people with small veins, patients who are dehydrated, older people and chemo patients (Fig. 10), tend to have HTFV due to the reduction of collagen, diameter, and elasticity of their veins [19].

Low levels of water in the body cause the veins not to appear clearly and it is a common problem for patients with fever which develop dehydration by liquid and electrolyte loss. Skin darkening and cracking makes venipuncture procedure more difficult [20].

Furthermore, there is people who gets nervous only by seeing the doctor, a condition that could complicate the procedure and make it longer and painful.

Figure 10. Chemotherapy patient hand [21].

Many vein locator devices with similar technologies are commercialized nowadays, but the problem is how costly they are and how difficult to get one of those at least in Ecuador. The working principle of the major part of the devices in the market is using the near infrared radiation;

however, not all of them have the same result or accuracy for locating the veins and some of them are not portable.

Figure 11. Veinlite device, transillumination technology [22].

In terms of the cost of the devices are extremely high (Table 1), the prices in some other more developed countries are excessive, and if the technology is commercialized in Ecuador the price will be impossible to afford. The different devices described in Table 1 are overpriced.

The cheapest one is about $629 but is not even close to the result that a given near infrared camera could achieve because it uses a trans-illumination technology (Fig. 11), which also uses infrared radiation but in a different and less efficient way compared to a modified visual camera.

Furthermore, a similar device to the one aimed to create in this project is around 5,000 US dollars, keep in mind that this is the price in U.S.A.

The production cost of the device on this project will be not higher than $300, it is not as accurate as some of the ones displayed in table 1, but it will give an idea of what it is possible to do with a vein viewer and opens a new road for future investigations in Ecuador.

Infrared cameras are becoming cheaper, taking a normal visual camera, and doing some modifications, the result will be a cheaply near infrared camera ready for any medical imaging application. The quality of the result will depend on the quality of the sensor that the camera has.

Neither the device, nor the sensor are fabricated in the local market, and they are not even commercialized. So, the device development will have three main stages:

- First, to find and choose the correct method for acquiring the image, and the corresponding modifications of it if needed.
- Second, the design of the software for processing the acquired images.
- Next, to create a friendly user interface for the manipulation of the resulting images with the veins pattern, the database and finally test the device in real situations.

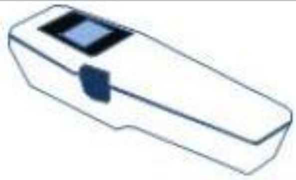
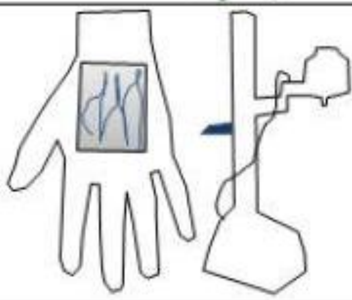
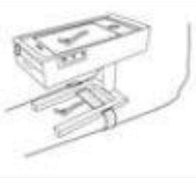
Vein Locator Systems	Company	Working Method	Price Indication (Approx.)	Schematic Presentation
AccuVein AV300 Vein Viewing System	AccuVein ®	Near infrared light is used to locate peripheral veins beneath the surface of the skin. [17]	US $2,000 [18]	
Vein locator BS2000+	Wuxi Belson Medical System Co.,LTD	Vein locator BS2000+ uses near infrared light and LED as light source. [19]	US $5,000 [20]	
Veinlite®	Warrior Edge, LLC	It works by illuminating the de-oxygenated blood in veins. [21]	$629 [22]	
Economical Dualhead Vein locator BM1000	Wuxi Belson Medical System Co.,LTD	It uses near infrared light source. [23]	$1,050 [24]	
VascuLuminator	DKMP bv	It works with the help of near infrared light source. [25]	US $10,000 [26]	
Luminetx VeinViewer	Luminetx	A near-infrared LED source differentiates red blood cells of subcutaneous veins from surrounding tissues and arteries. [27]	$25,000 [28]	
Veinsite hands-free system	VueTek Scientific	It uses near infrared light to image superficial veins to a depth of 7mm. [29]	$ 4,595 [30]	
Nottingham Trent University	N/A	It can use near infrared and/or infrared with mobile phone technology. [31]	Not in the market yet.	

Table 1. Current vein viewer devices sold in other countries with prices and brief description [23].

3. GENERAL AND SPECIFIC OBJECTIVES

General Objective

- To create a vein locator device with the best, affordable and accessible technology for Ecuador, applying all the acquired knowledge on electronics, programming, and biomedical devices to get a prototype of the machine capable of seeing veins in the hand dorsum.

Specific Objectives

- To analyze all the possible technologies that could be used and to choose the type of technology that will be used for the development of the device.
- To identify the necessary elements for the creation of the device and to make the necessary modifications to be able to acquire images.
- To design the infrared lighting system and the visible light filtering.
- To design and develop algorithms that allow the processing of images.
- To create a user interface to simplify the use of the system.
- To create a database for the organization of the different patients.

4. METHODOLOGY

The designed and implemented system in this thesis consists of a vein detection system and a digital image processing system housed in a computer (see Figure 12).

4.1 Design and Implementation of the Vein Detection System.

For the selection of the vein detection system, a detection design based on a camera illuminated with an infrared light source was decided. This decision was made considering the key factors mentioned in the introduction regarding the types of sensors on the market. First, it was decided to acquire a CMOS sensor inside the country, but it was not successful.

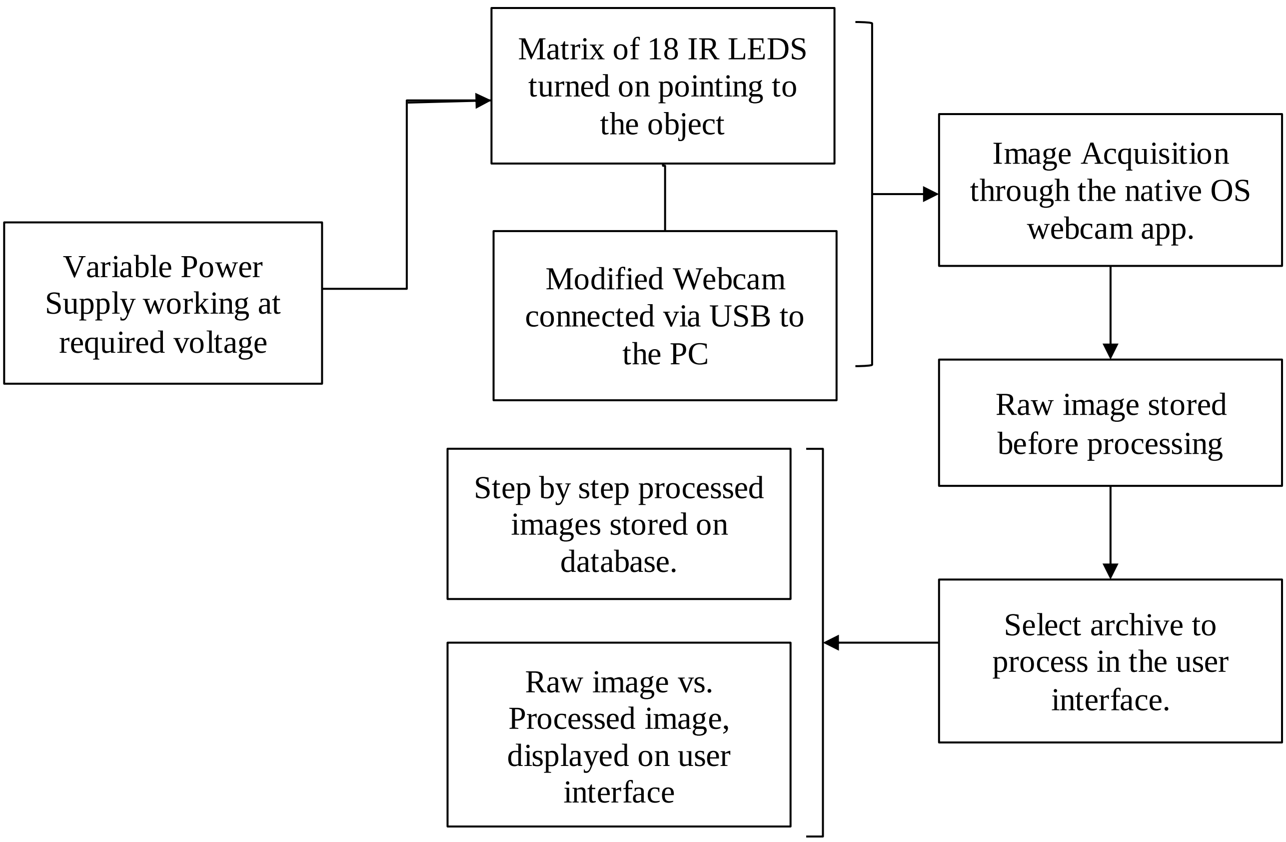


Figure 12. Schematic representation of complete system.

The methodology used in each stage of system development is presented below.

Thus, they proceeded to look for purchase alternatives outside the country and reached a company located in the United States, TELEDYNE E2V. This company specializes in the sale of

CMOS sensors and equipment. After locating the company, a sensor was chosen from its catalog (Fig. 13), this sensor was postulated as the best option for creating the final device.

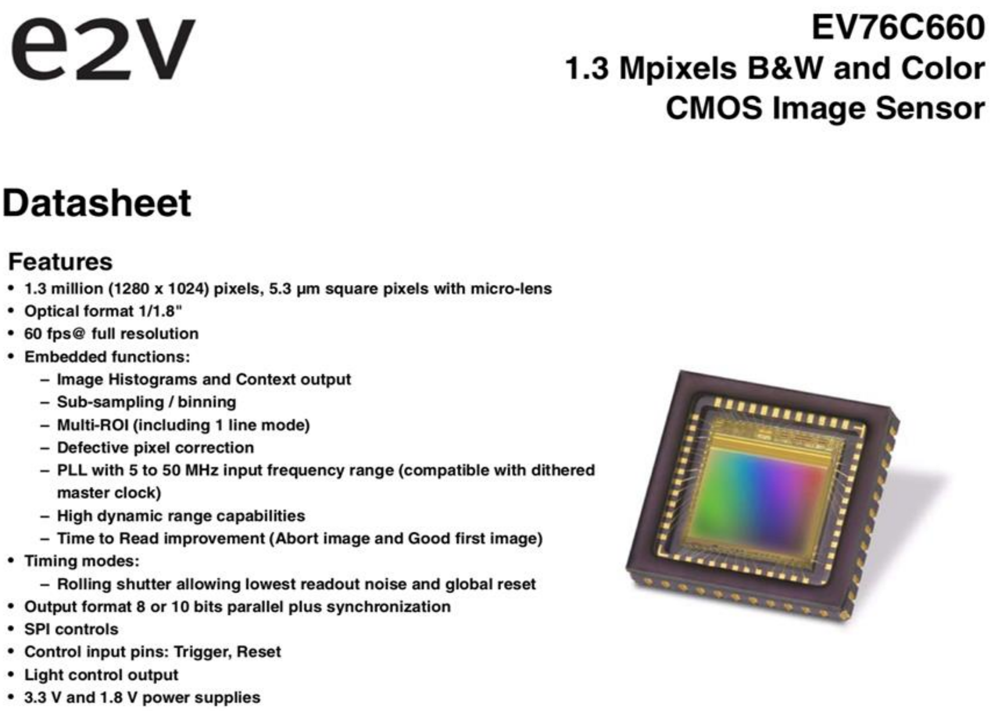


Figure 13. CMOS sensor [24].

However, at the time of contacting the company, the responses were not encouraging, this company is dedicated solely to the mass production of sensors, so they do not make sales to individuals, much less a minority.

Unfortunately, it was necessary to opt for another type of sensor, the CCD, which would not be able to match the results of a CMOS sensor but would be the best option considering the costs and the ease of acquiring it in Ecuador.

Furthermore, the numbers presented in figure 14, show that the most accurate technology is the near infrared radiation. When taking images from veins with visual, near infrared, and infrared cameras, the lowest average error goes for NIR. In this case, a 17,16% of error is presented when comparing the obtained images with an exact template of the vein pattern created by doctors. So, the decision to use a NIR camera was made [23].

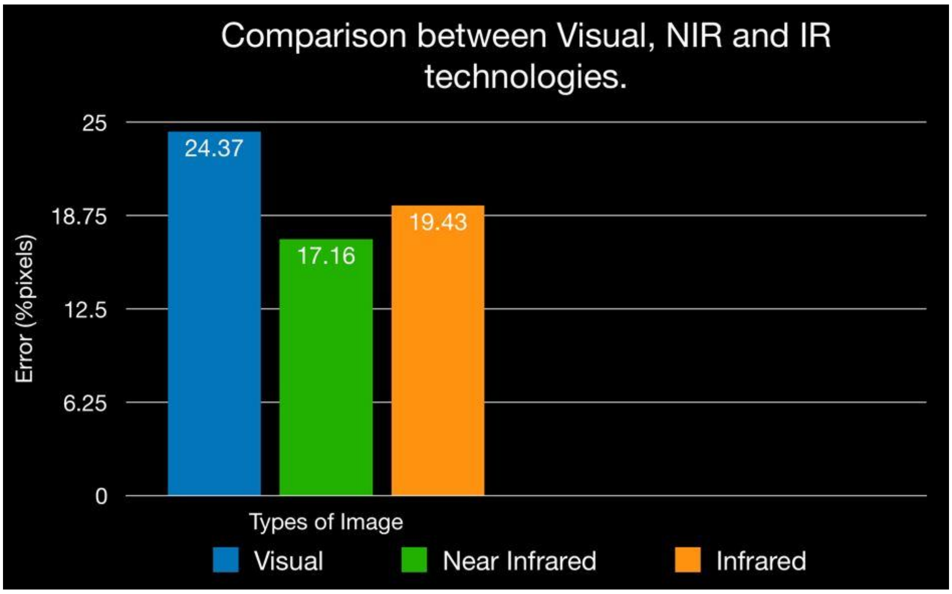


Figure 14. Average error (%) for three different technologies [23].

4.2 Camera

For the design of the vein detection system, it was decided to use a Genius brand Webcam model Facecam 1000x, which uses a CCD sensor. The choice of this camera was important for the development, as not all the cameras on the market can be modified in the necessary and useful way for this project. The mentioned modification involves that the filter of infrared light come separated from the CCD sensor. Since, if we use a camera with the filter integrated with the CCD sensor, it will suffer a damage and will be useless.

Generally, normal cameras have a filter that blocks infrared light placed in front of their CCD sensor. This filter has rainbow like color and needs to be apart from the sensor, and not to have a fixed focus. This filter was removed and replaced with a visible light filter (Fig. 13). Although this is not possible in all cameras, this replacement was made thanks to the configuration of the CCD sensor of the chosen webcam, in this way, it only captured infrared light, since visible light is now filtered and mostly blocked (Fig. 15).

Once the original filter is removed from the sensor, it needs a new filter to avoid the visible light to reach the CCD sensor. After looking for some professional options that were not possible to acquire in Ecuador. We decided to use a homemade filter to check if the camera was correctly modified and the sensor is working perfectly.

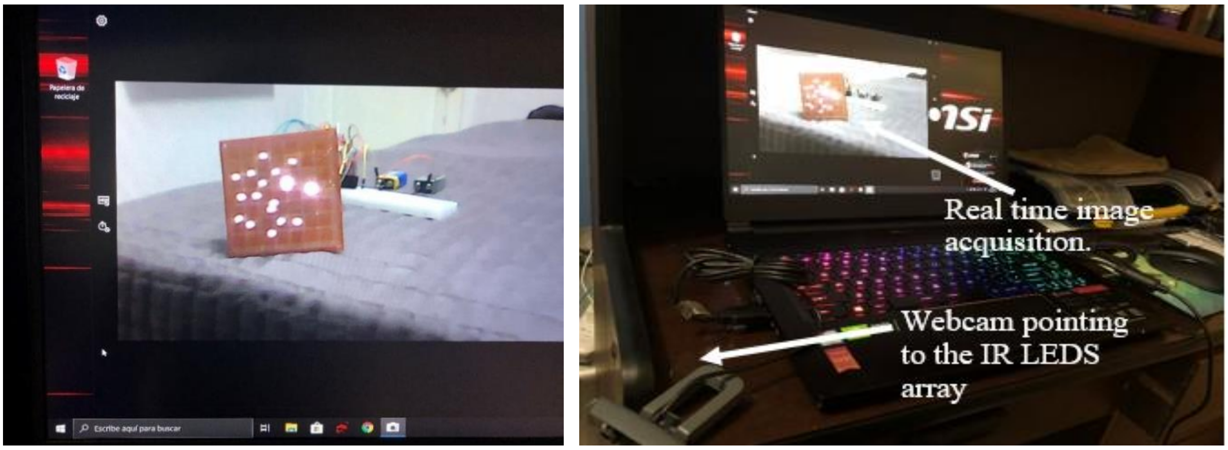


Figure 15. First image of the Webcam after removing the original infrared filter (left), looking at a matrix of IR LEDs lit (right).

The internal part of a floppy disk was used provisionally for the visible light filter (Fig. 16), placing this film in front of the camera's CCD sensor to obtain only infrared light. With this film, relatively good results were obtained, but the image was darkened. In some specific situations this filter did not work, when the ambient light was low, the acquired image was very dark. On the other hand, with high ambient light intensity, the filter was useless because all the visible light was reaching the CCD sensor and colors start to appear in the image.

Figure 16. Internal part of the floppy disk used as a visible light filter in the early phases of the project.

In a later stage and looking for an improvement, the floppy disk got replaced by a 25 mm diameter glass infrared filter at 850 nm used in professional digital cameras (Fig. 17). This was the best option for the project, but it is complicated to acquire one of this mostly because of the size. Since a 25mm filter is not common. This new filter only allows infrared rays above 850 nm to pass and without obscuring the image. The behavior in low light conditions and high light conditions is a lot better than the floppy disk, and it adds resistance to the device because it is made of polycarbonate.

Figure 17. 25mm Glass Filter at 850nm. Taken form: Amazon.com

4.3 IR Light Source

Once the new filter was added to the camera, the project was ready to continue, giving way to the lighting system with infrared LEDs whose wavelength was 940 nm. This is not a good option for getting the best result possible, but it works. Since LEDs with shorter wavelengths within the range corresponding to the near infrared NIR could not be found in the national market (see Fig. 18).

In the case of the infrared light source, 18 LEDs connected in series were used (Fig. 20), specially arranged to achieve uniform illumination of the object and to allow the CCD sensor to be placed together with the 850 nm filter in the middle of all LEDs (Fig. 21). Initially, the LEDs and the camera were implemented separately to verify that the camera and the LEDS were working correctly, as shown in Fig. 19.

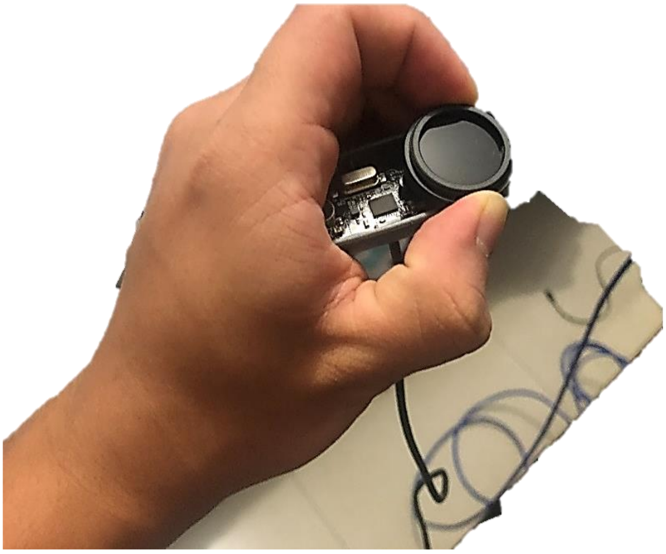


Figure 18. 25 mm Glass Filter at 850 nm placed in front of the CCD sensor.

Figure 19. Array of LEDs and Camera separated.

In the first testing phase, an experiment plate was used before proceeding to solder all the components on the final plate. After checking the electrical circuit of the LEDs, their connections were soldered to avoid the use of excess cables. Subsequently, a hole with the exact size of the CCD sensor was made in the middle of the LEDS array to position the already modified camera together with the filter in the center (Fig. 21).

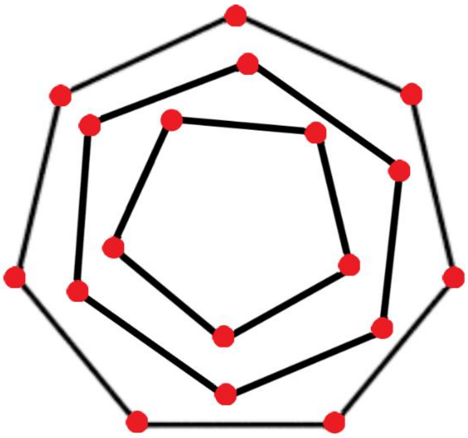


Figure 20. Organized LEDs' array.

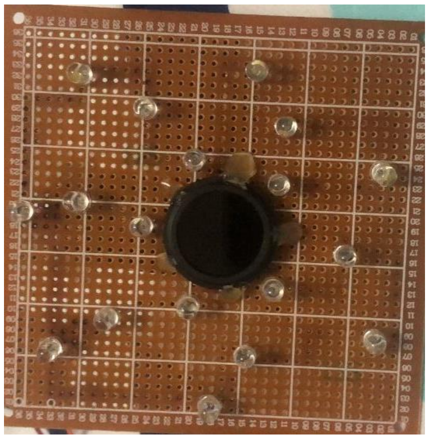


Figure 21. Perforated Bakelite.

4.4 Variable Power Supply

Up to this point, two 9-volt batteries connected in series were still used to obtain 18V as the power source for the LEDs (Fig. 22). During the test phase of the circuit, it was found that the electrical power provided by the batteries was not sufficient to be able to generate the correct light intensity. Since the LEDs were connected in series, it means that each of the LEDs was receiving only about one volt. Unfortunately, the correct working voltage for the LEDs used in this project was 1,5V to 2V, and using another extra battery was not an option.

Furthermore, the batteries did not allow the possibility of regulating the voltage instantaneously, if any circumstances required it. In this case, sacrificing the portability of the device by using a variable power supply was necessary to have the advantage of regulates the voltage for any specific situation. Situations where the light intensity needs to change to obtain the best result from the camera itself.

The adjustable voltage source was implemented to obtain different lighting intensities depending on the variation of the voltage provided by the power supply. In addition, the implementation of this power supply provides a manual regulation of image quality, based on the different situations that could arise due to ambient light.

A previously designed circuit was used for the adjustable voltage source [25], which was implemented in a printed plate, but it did not work. Therefore, it was provisionally implemented in an experimental plate with the same components and the same scheme (as shown in Fig. 23).

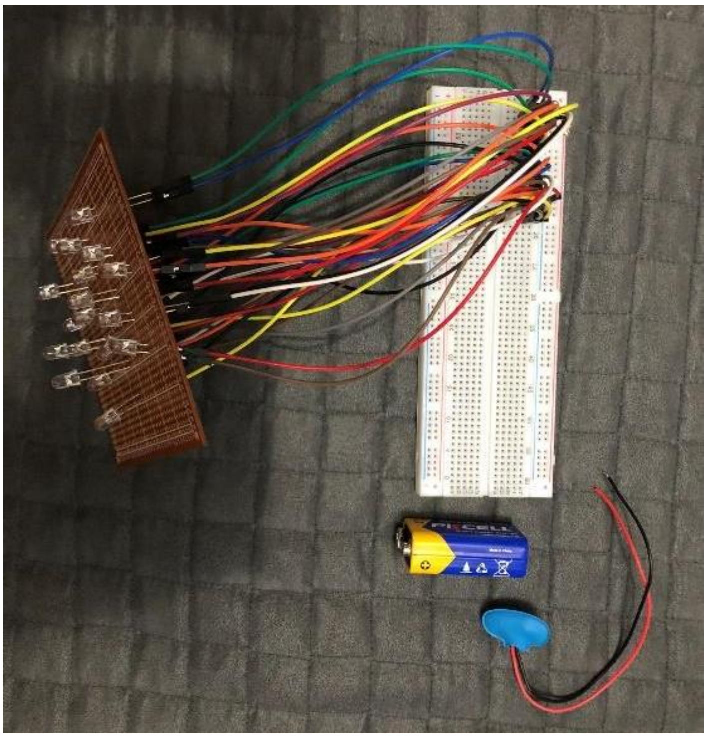


Figure 22. Array of LEDs provisionally connected to a 9V battery.

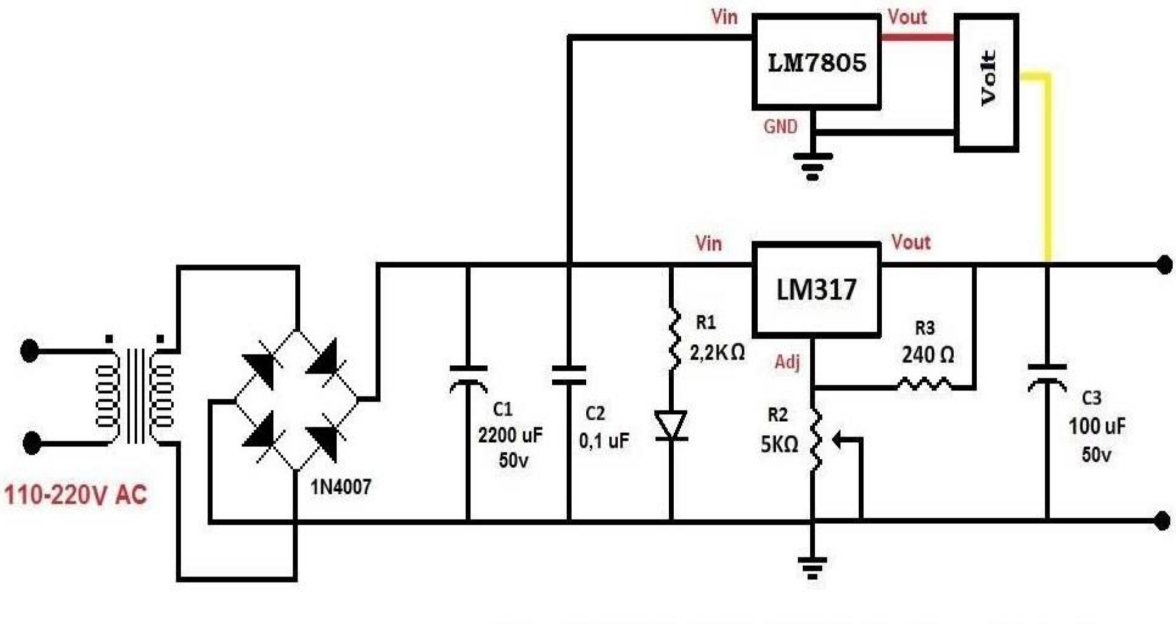


Figure 23. Circuit design for the Adjustable Voltage Source [26].

The implemented adjustable voltage source is based on the LM317 chip and allows us to obtain voltages in the range from 0.034V and 25.01V from an alternating current input of 110 or 220 V (Fig. 24 and Fig. 25). This variation in voltage is configured with a variable resistance of the circuit [27].

This gives the option of manipulating the voltage in real time, based on the ambient lighting, since in dark places less intensity of infrared light will be needed (lower voltage) otherwise the image will have too much saturation. Similarly, in case of being in a place with too much light in the environment, the output voltage must be increased so that the image is seen in the best possible way.

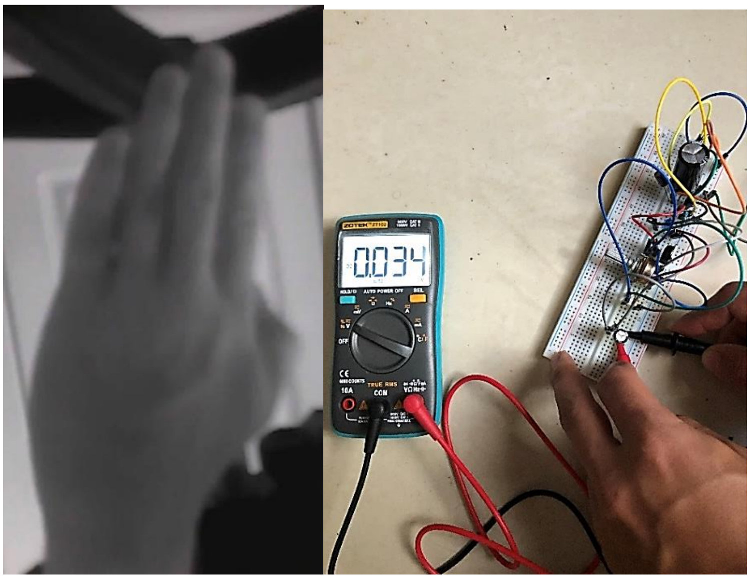


Figure 24. Capture of a raw image in a very bright environment with a voltage of 0.034V.

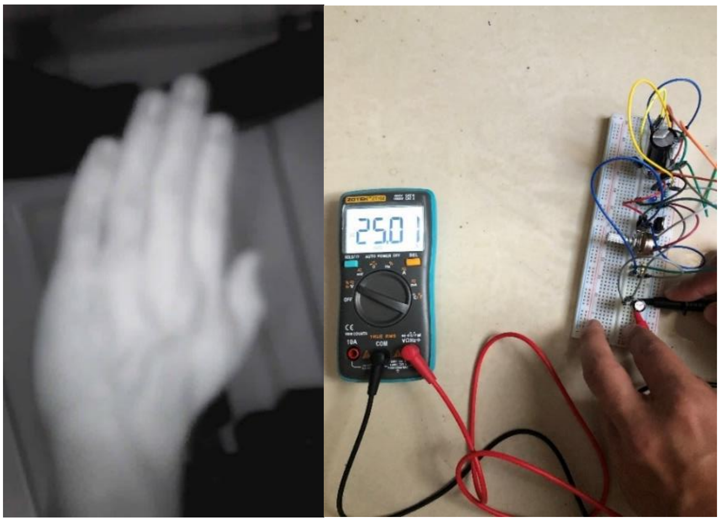


Figure 25. Capture of a raw image in a very bright environment with a voltage of 25.01V.

It is clear that the case previously presented, when there is a large incidence of ambient light, the best result is obtained by placing the intensity of the LEDs to the maximum allowed through the adjustable voltage source, that is, with 25V power for the 18 LEDs in series.

4.5 Design and implementation of the vein detection code.

The vein detection code is based on the digital processing of the image that was acquired with the hardware presented in the previous section. This complete algorithm is presented in figure 26 and consists of several stages to achieve a correct result.

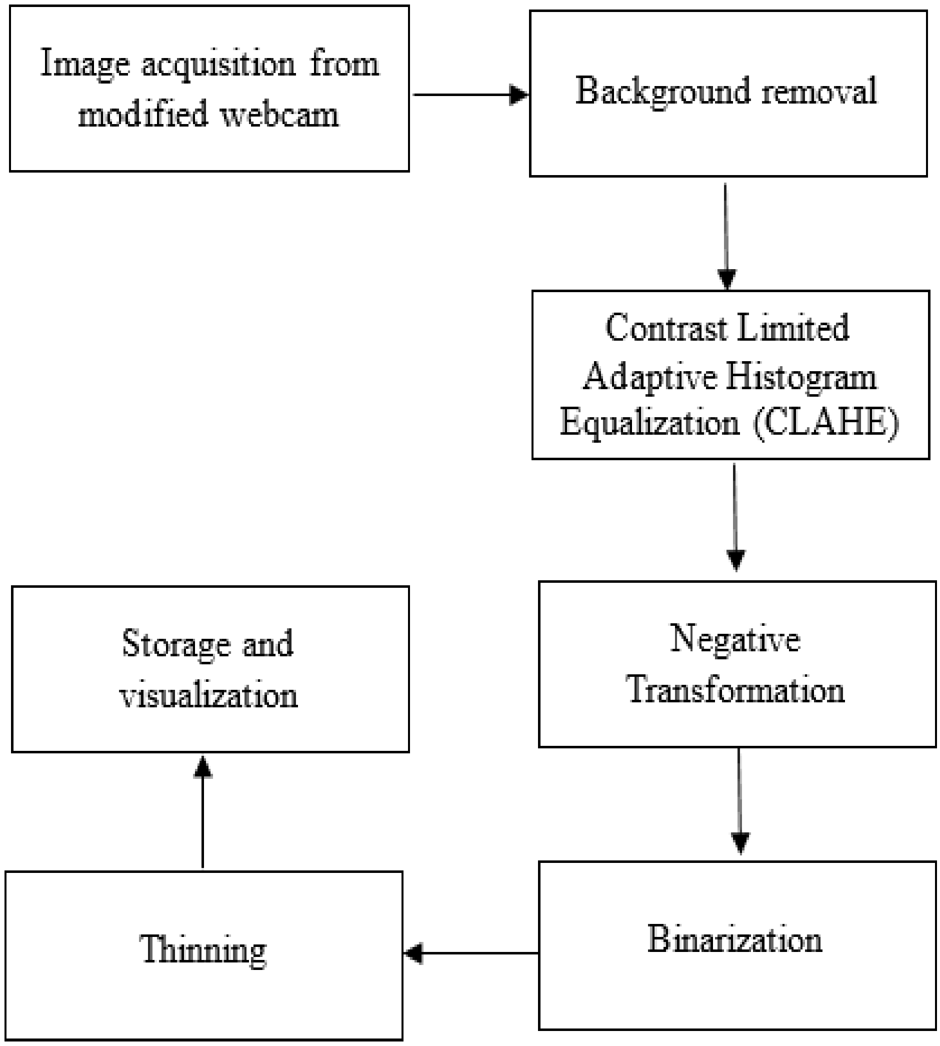


Figure 26. Flow diagram corresponding to image processing after acquisition through the webcam.

Next, each of the processes presented in Fig. 26 are explained in detail. For the acquisition of the image, the native Windows application for the Webcam was used, since to meet the objectives of this technological development it was not seen the need to think about creating a new application to capture the image.

In figure 27 there is displayed a part of the algorithms used for the image processing. The programming language used for this project is python.

The first step is the acquisition of the image with the implemented system (modified webcam).

The characteristics of the acquired image are image size = 1280 pixels by 720 pixels; image extension = ".jpg"; which means that you get a raw image in HD resolution at 720p with 96 pixels per inch.

```
File  Edit  View  Help     application.py - ...\Python38\s
application.py
import ...
def RemoveLbl(Img, ImgB, color):
    height, width, z = Img.shape
    for i in range(height):
        for j in range(width):
            if color == 0:
                if ImgB[i,j] == 0:
                    Img[i,j] = 0
            elif ImgB[i,j] == 255:
                Img[i,j] = 0
    return(Img)

#Remove Background
def remove_bg(img):
    grayscaled = cv2.cvtColor(img,cv2.COLOR_BGR2GRAY)
    ret,th = cv2.threshold(grayscaled, 80, 255, cv2.THRESH_BINARY)
    test = RemoveLbl(img, th, 0)
    cv2.imwrite('static/1_rmv_bg.jpg', test)


def clahe():
    img = cv2.imread('static/1_rmv_bg.jpg',0)
```

Figure 27. Part of the script containing the algorithms for image processing.

In the next stage, this acquired and stored image, the background is removed from the image (Fig. 28). For this, the OpenCV library and the function "cv2.threshold" of the binary type are applied [28].

The process carried out by this library consists of eliminating everything that is not desired to be processed from the image. This means, if the image of the hand is captured, and around it there are objects that could interrupt in the processing and affect the result, these will be eliminated before proceeding to the next stage of the process.

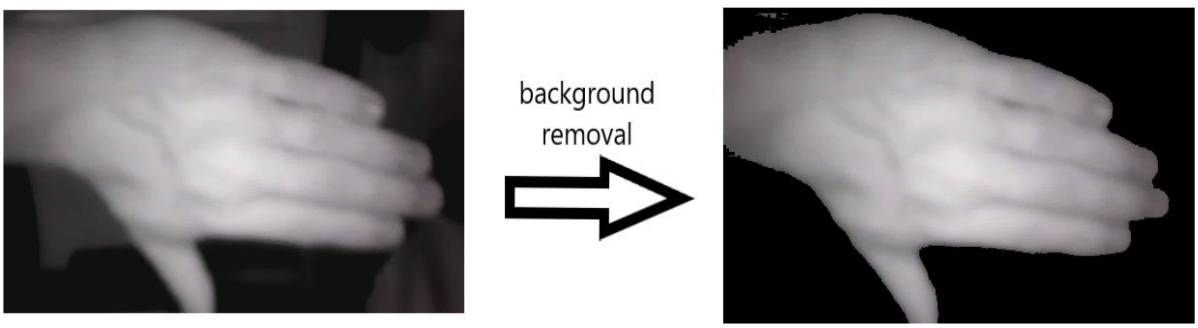


Figure 28. Elimination of background. Raw image (left). Resulting image (right).

The result of the previous stage produces an image of the same dimensions as the original. The second step is to apply the Contrast Limited Adaptive Histogram Equalization (CLAHE) process (see figure 29), which is a variant of Adaptive Histogram Equalization but limits the contrast to avoid noise amplification [29]. With this step it is possible to obtain an image in which it is easier to differentiate the surrounding tissue from the clearest veins present in the hand.

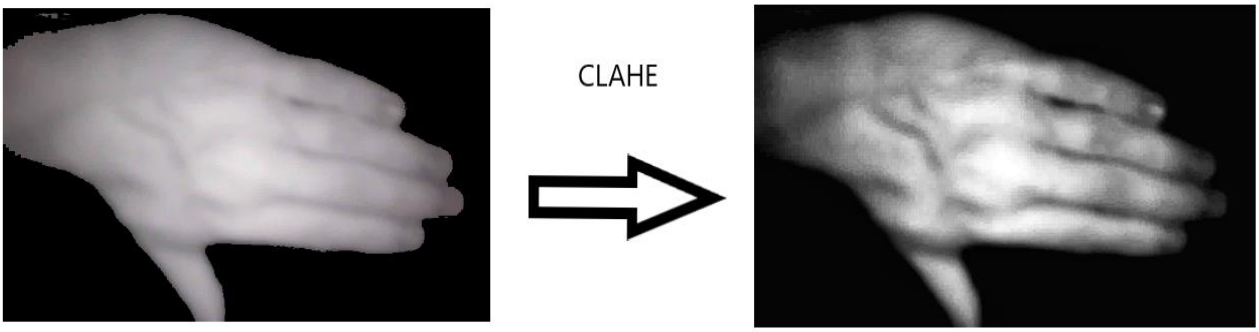


Figure 29. Contrast Limited Adaptive Histogram Equalization.

In order to obtain a binary image in which the veins are white and the rest of the tissue is black, before moving to binarization, a negative transformation of the image is performed (Fig. 30), causing the colors present in the image to be reversed.

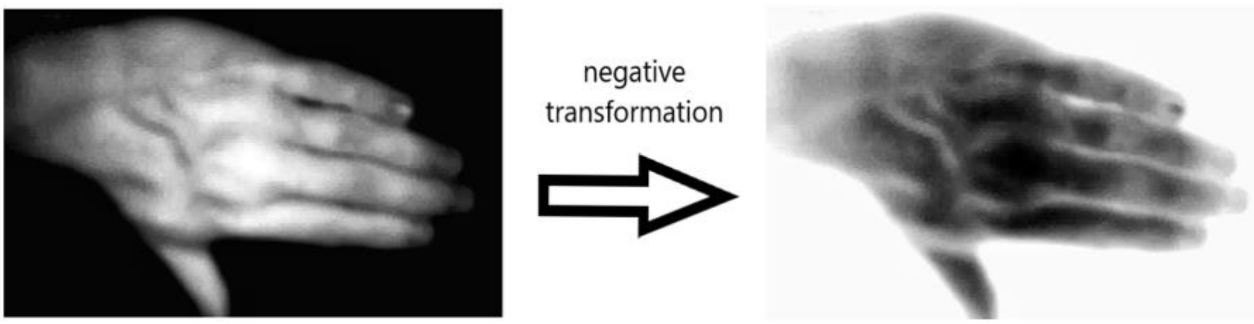


Figure 30. Negative transformation after CLAHE. Result (right).

The negative transformation is a key algorithm to obtain what is desired, because if this is not performed, the colors of the veins in the final image will be black. At the moment of projecting the image over the skin, there will be no illumination because the veins are black in the image. Using laser technology for the projection the black color will be not as visible or notable as if it is white.

Finally, two functions are executed: 1- the binarization function and 2- the erosion function. The binary function is a technique that consists of carrying out a scan in the matrix of the digital image, through loops or recursion, for the process to produce the reduction of the gray scale to only two values (Fig. 31). Black (= 0) and white (= 255), or what is the same, a binary system of absence and presence of color 0-1.1[30].

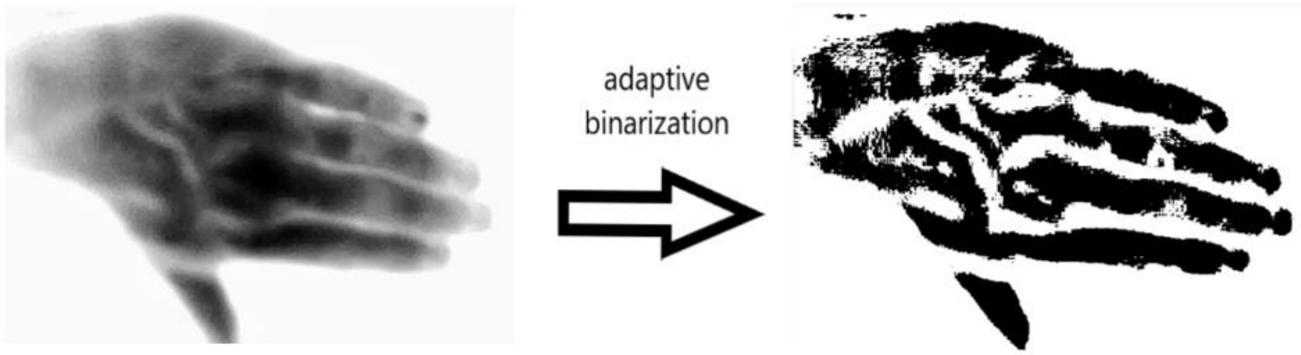


Figure 31. Adaptive binarization where white parts, represent the vein pattern.

The erosion function provides a more precise location of the veins by reducing the diameter of the white channels present in the hand to better relate to the veins in real time (see figure 32). To do this, a morphological operation is carried out that results in the thinning of the area that makes up the image [31].

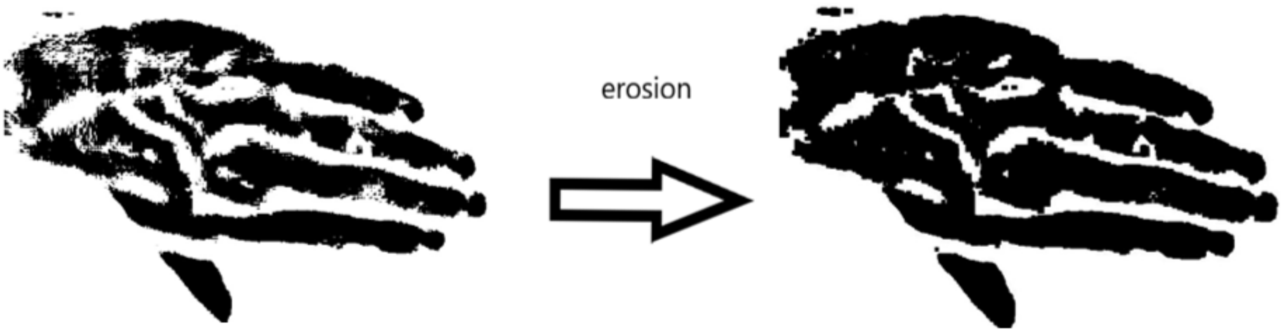


Figure 32. Erosion or thinning of vein pattern.

Several tests of the algorithm were carried out and after obtaining good results, a user interface was developed for the execution of said processing that is much simpler and more user-friendly when presenting the results.

For this, the FLASK framework along with Python was used. To start the interface, execute the commands presented in figure 33.

In this figure, the green rectangle indicates the URL in which the developed user interface will be displayed. This URL must be placed in the browser chosen by preference. The red rectangles are the code lines to start the user interface.

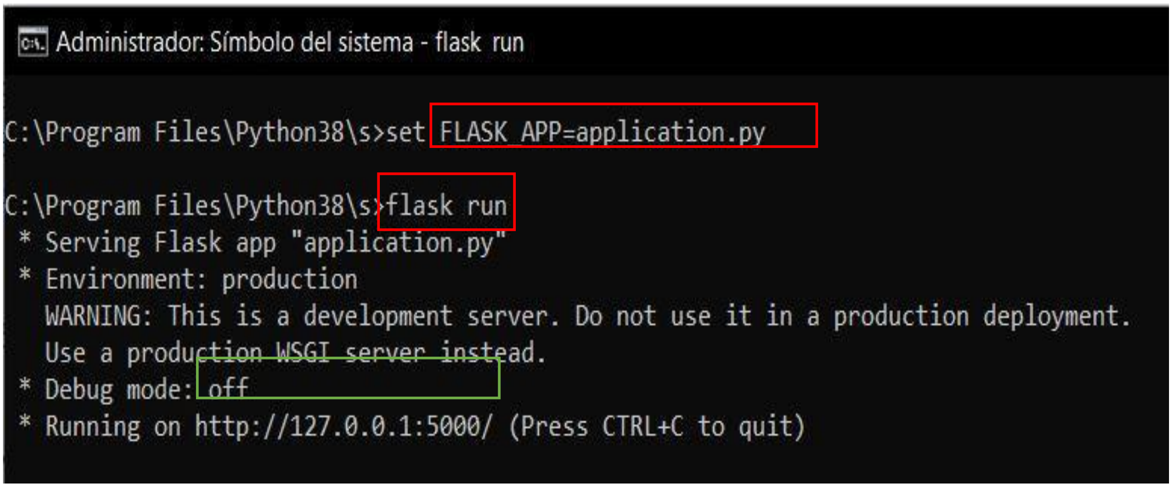


Figure 33. Lines of code used to execute the framework that contains the image processing codes.

After placing the URL that the command console displays in the browser, you will access the page found in figure 34. There you are requested to enter the address of the image you want to analyze. The image must have been previously acquired with the camera's native application and be stored in the folder that contains the application.

Figure 34. First dialog box presented after typing the URL found in the Windows command console.

Once the address in which the image is located has been written, the user must click on the "process" button, and then the algorithm fires the entire process detailed in figure 26. As a result, only the original image and the final image fully processed after all stages will appear.

Furthermore, to ensure that all the image processing has been correct, at the end of each stage of the process, a new image is generated. These images are stored in the native folder of the application in case you need analysis of the parameters and configure them in favor of a certain image to obtain better results.

5. RESULTS AND DISCUSSION

The implementation of the design as a combination of hardware and software, presented here, was promising. The most relevant result is the clear detection of the veins with the use of infrared technology together with different image processing systems.

In Figure 35 you can see the sequence of intermediate and final stages of the complete process:

- The raw image is in the figure 35a.
- In figure 35b you can see the result of removing the background, where any part of the image other than the hand was removed.
- After finishing the equalization process, the resulting image is the one shown in figure 35c. In this image you can see how noise amplification was avoided by changing the contrast.
- Before going to the binarization, the inverse transformation is executed (Fig. 35d).
- Now, in figure 35e you can see the result of the binarization, everything in the image is black or white, in this case, white is for veins.
- The result of erosion can be seen in figure 35f, making the veins look more accurate in terms of size compared to the real ones.

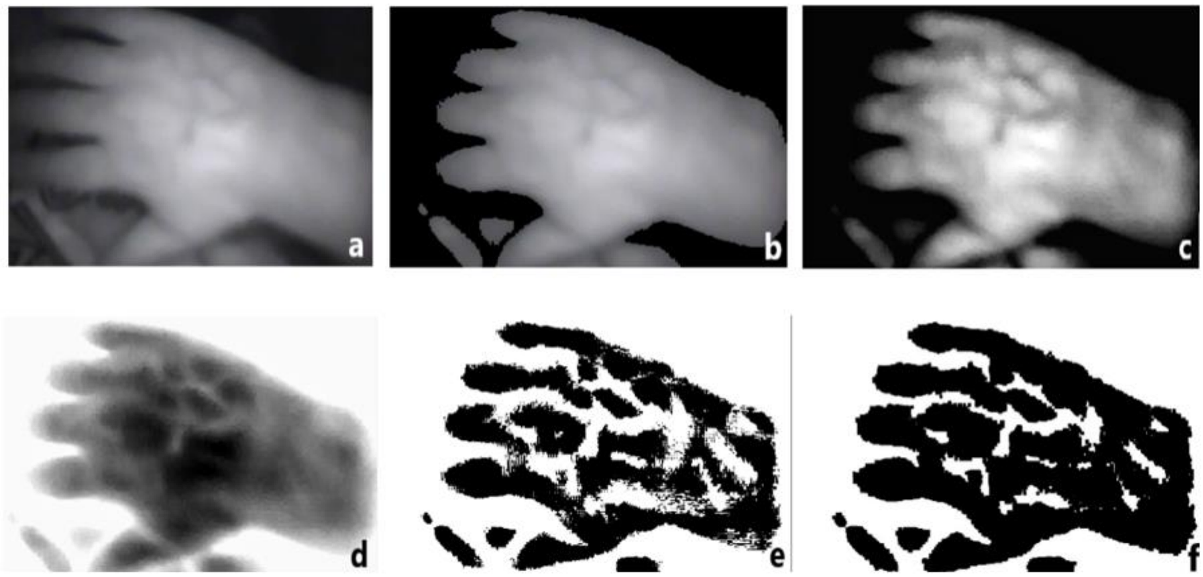


Figure 35. Different stages of image processing.

In figure 36 you can see the result after going through all the processing stages, starting from the raw image acquired by the camera to the execution of the last code. In the raw image (left), it is possible to see that the veins are already becoming noticeable thanks to the principle of absorption of infrared radiation by the deoxygenated hemoglobin.

On the other hand, the processed image shows the silhouette of the hand, where all that is black is the tissue that surrounds the veins, and the white channels correspond to the veins. Starting from the initial resolution of the image mentioned in the methodology section, a resizing of the image is also carried out during the process. Thus, the dimensions of the final image are 768 pixels by 432 pixels; image extension = ".jpg"; but keeping 96 pixels per inch so as not to lose quality in the image.

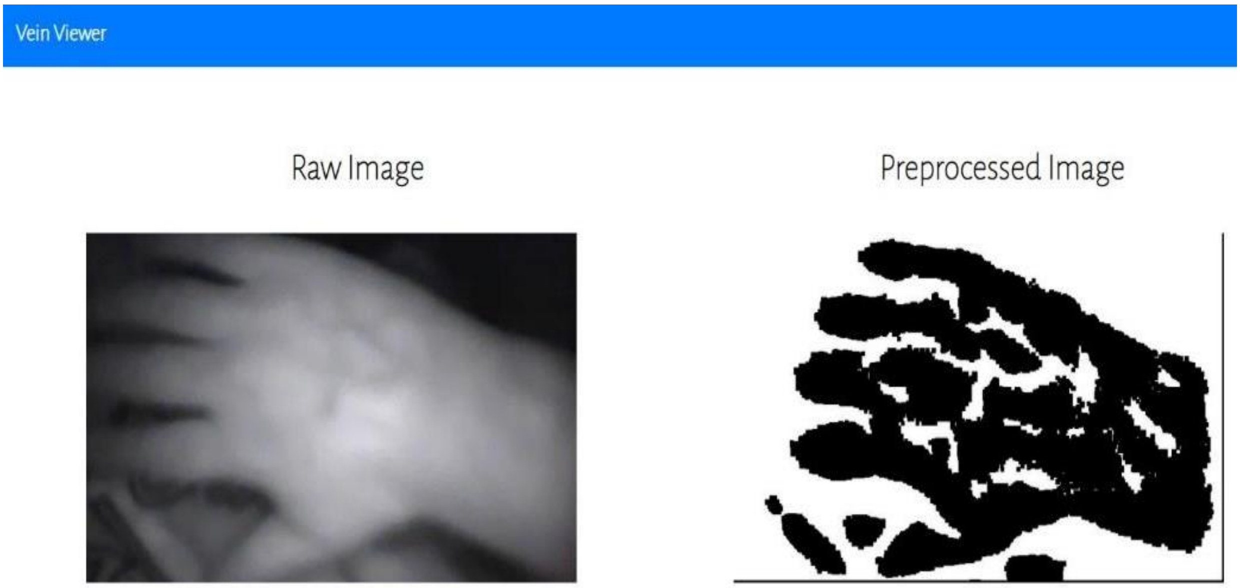


Figure 36. Result of the user interface.

Furthermore, during the execution of the program, each one of the different steps carried out by the application will be stored in a folder external to the application (Fig. 37). If you need to see each of these processes, you can do it, either to modify some parameter within the codes or understand everything that has been done to get from the starting point to the final image. To improve the results and give a better follow-up to everything that is done.

This becomes a database ready to retrieve any clinical history of any patient previously analyzed, allowing access to their information at any time if needed. The database developed in this project is not optimized but it works.

To generate data for a new patient, for now, it is necessary to change the name of the archives manually, and they need to be a different names for what it is declared in the algorithms each time they write a new image in the folder.

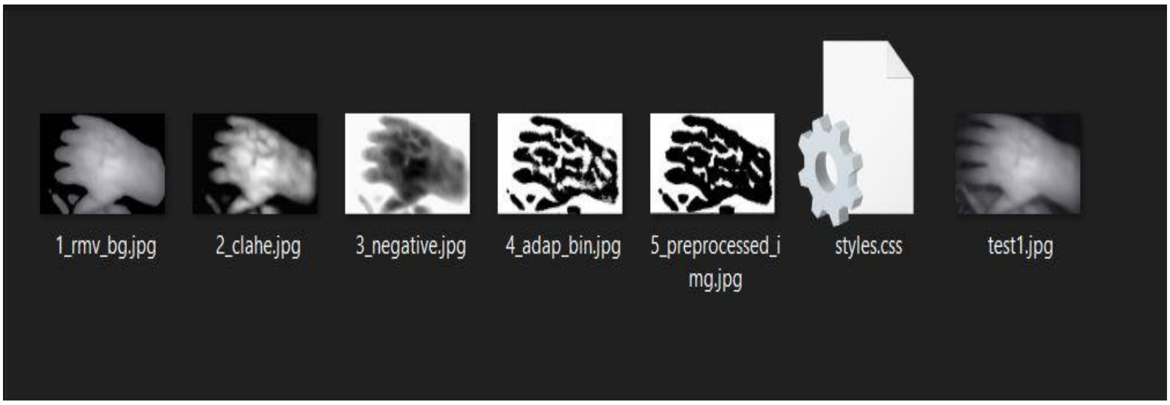


Figure 37. Step-by-step processing database.

The purpose of the device is to be used to visualize the vein pattern found on the back of the hand (Fig. 38a). However, keeping in mind that this is not the only place where venipuncture processes are commonly performed. Tests were performed trying to visualize the vein pattern in the forearm (Fig. 38b), where it can be verified that it is possible to locate the veins with the device.

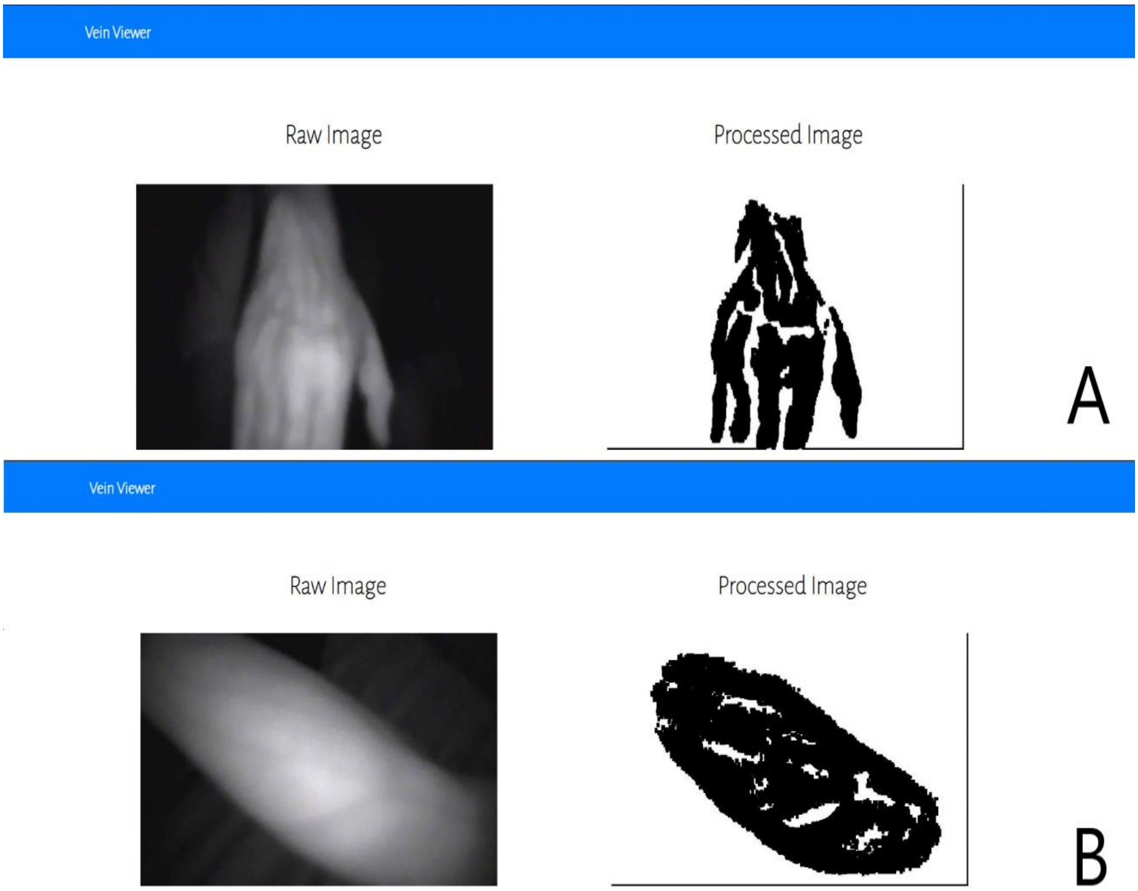


Figure 38. Different vein patterns obtained with the device.

Despite the good results in the forearm, when compared with what is obtained by analyzing the back of the hand, these are not as relevant as in the other case. This is probably because the veins on the back of the hand are closer to the surface and the wavelength used in the infrared LEDs does not penetrate the skin sufficiently to reach the veins in the forearm. However, the obtained result is better than not having a device for vein location. It could give a general idea of where the veins are located and increase the accuracy of the procedures.

6. CONCLUSIONS AND RECOMMENDATIONS

To put an end to this Thesis I will draw some conclusions that emerge from its approaches and developments. There are some limitations when trying to develop a new device in Ecuador.

One of the complications was the available technology in the country. At the beginning of the project I was decided to use a CMOS sensor after the corresponding research about it because of the advantages it presents over the CCD imagers. Unfortunately, it was not possible to get a good priced sensor here, and difficult to acquire only one unit from the big companies in other countries.

However, after being forced to use the CCD sensor, there was another important limitation for the project, the IR LEDs. The LEDs that are commercialized in Ecuador were not the best for the project.

The corresponding wavelength for the LEDs was not the correct one to obtain the best result possible. I used 940 nm infrared LEDs, which according to the carried out investigation, the penetration on human skin was short compared to any other wavelength between 700 nm and 850 nm.

Furthermore, once the webcam was selected, I noticed that the resolution of the camera was extremely poor and will affect the resulting image. When I realized the quality problem from the camera, it was difficult to acquire a different one due to the time, price, and availability in the market.

Despite of all the problems mentioned before, the result is promising for the low cost vein locator system. As we can see in the previous section, it is possible to identify the vein pattern in hand dorsum, as well as in the forearm but with some limitations.

Using this device will help the venipuncture procedures to be more comfortable for patients and more efficient for doctors. It will reduce the hurting attempts from doctors to identify where the vein is located, and the waste of materials used in venipuncture procedures after each one of the attempts.

The device is not only useful for avoiding pain, it is also a good option for helping the doctor localize the veins in those cases where it is not easy due to any singular condition from patients, such as; obesity, overweight, chemotherapy patients, dehydrated people, etc.

Considering the user interface and the database, both are key parts for the desired handling of the device. Creating a good easy user interface, increase the probability for any person apart from doctors to use a device like this. Since the venipuncture procedures are made in many other places where there are not specialist present.

On the other hand, the database is an advantage in any case, if somebody wants to see how the patient is evolving through time. It will be easy to look for the name of the patient and understand what is going on.

Furthermore, some recommendations for future projects like this will be helpful. Starting from the sensor, nowadays, it is still kind of difficult to get a better sensor for a good price to develop a prototype like the one created in this project. It doesn't mean that it is impossible, if there is any chance to get a CMOS sensor as the one I was trying to acquire at the beginning of the development, it will be a good step in the way to improve the resulting image.

If there is any complication getting a CMOS sensor, the other option is trying to get a better CCD sensor. As I mentioned before, the resolution of the camera I chose was not the best one and there were some other cameras with a better sensor. However, you must keep in mind that the camera needs to have an easy access to the IR filter because we need to remove it to place the new filter. Furthermore, CMOS sensor are noticeable smaller compared to CCD sensors.

When we talk about the size of the sensor, we are referring to the portability of the device. For this I recommend the use of a more efficient power supply. Rechargeable batteries capable of giving the correct voltage to the LED's will be the best option.

Getting IR LEDs in the correct range of wavelength for this medical application will be the best recommendation to have a considerable improving in the result. By using 700nm to 840nm IR LEDS, the penetration on the human skin will be larger and the absorption rates from the deoxidized hemoglobin also will be better. This is traduced in a clearer localization of the veins and getting the vein pattern of veins that could be a little deeper in the surrounding tissue.

Another recommendation talking about the LEDs is to connect them in parallel, so the power supply will need less intensity. Furthermore, it will be easy if instead of using normal LEDs, as the ones used in this project, to replace them with high intensity LEDs. This will allow to use less LEDs but having a similar or even better illumination on the object. This will be also helpful for reducing the size of the device and the weight. Unfortunately, high intensity LEDs are not easy to acquire in Ecuador, even worse in the near infrared range.

The resulting system on this project is not capable to project the vein pattern over the skin for exact location. For this, it is necessary to use any kind of projection technology capable of displaying the vein pattern ate the same time we are moving around the device trying to see the veins. Using a simple projector provisionally or introducing laser technology will accomplish the goal of the device.

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