Georgian Technical University

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Designing Mobile Transilluminator Vein Finder

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We, undersigned, confirm that we familiarized ourselves with the thesis by Tohid Talebifar on “ Designing Mobile Transilluminator Vein Finder” and recommend it for reviewing by the dissertation council of the Faculty of Informatics and Control Systems of Georgian Technical University as a doctorate thesis.

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Abstract

Around more than 80% of all patients who are going to clinics in the world have IVs in the arm to receive medications. Sometime this procedure can be difficult for paramedics for some cases like infants and old people, obese people, dark skinned people and etc. one-third of hemophiliac's patients in clinics have this type of difficulties.

Because intravenous (IVs) is a common routine, sometime we forget about dangerous and risky issues about it for patients of even for staffs in clinic and medical centers.

Vein finder devices can reduce these risky issues and also decrease the number of time that we try to find the veins. It is non-invasive way just using long wavelength light to see the superficial veins. Biophotonics Visible Vein Finders use visible light yellow -red light to detect the veins (Superficial Veins). This type of device has a two advantages first its cheap compare to Infrared one second it is easy to use and manufacture. In this paper we try to represent our design and model of this type of device. We test two types of light; Red one and yellow one. Also we try to understand source of noises that we have in this methods of finding vein. We prepare and represent a guideline for designing this type of device for doctors, nurses, paramedics or any person who wants to find veins in a cheapest and fastest way. The result of our paper can be used in less developed country or regions that they have lack of resource in healthcare part. We use 3-D pen in making prototype for our device also it is possible to use 3-D printers to make prototype of this device. Advantage of using 3-D pen is that this method is cheaper and easy to use it without needing computer, but skills is matter in this method. For the guideline that we represent in the last part can be used by anyone who wants to design his own biophotonics vein finder. This paper also providing fundamentals of vein finder devices design for future work and for making advance devices with competitive price for any clinics that need healthcare equipment with cheaper price. Also at the end of this thesis we propose a new method for detecting vein based on phototransistor technology.

რეზიუმე

მთელ მსოფლიოში საავადმყოფოებში შესულ პაციენტთა დაახლოებით 80%-ს ექნებათ პერიფერიული შიდა არხი, რომელიც მოთავსებული იქნება წინამხარში ან ხელში სითხეების, მედიკამენტების და სისხლის პროდუქტების შესაყვანად. ზოგჯერ ეს პროცედურა შესაძლოა რთული აღმოჩნდეს ექთნებისთვის ან სხვა პერსონალისთვის, ახალშობილების ან ხანდაზმული ადამიანების, ასევე, ჭარბწონიანი პირების, ფერადკანიანი ადამიანების, ინტრავენური ნარკოტიკების მომხმარებელი პირების, ჰიპოტენზიური მოვლენების მქონე პირების, მრავლობითი დაზიანებების მქონე პირების შემთხვევაში. ასეთ სიტუაციებში შესაძლოა საჭირო გახდეს რამოდენიმე უშედეგო მცდელობა, რაც პაციენტში სტრესს გამოიწვევს. ჰემოფილიის მკურნალობის ცენტრების პაციენტების მესამედზე მეტს აღენიშნება გართულებული ინტრავენური პროცედურა.

რადგან PIVC (Peripheral intravenous catheters) წარმოადგენს ჩვეულ პროცედურას, ადვილად შეიძლება დავივიწყოთ როგორც პაციენტების, ისე სამედიცინო პერსონალის უსაფრთხოების რისკფაქტორებისა და გართულებების შესახებ. პერიფერიული კათეტერების არასათანადოდ მოთავსებით პაციენტებში გამოწვეული ტრავმების გამო ექთნების მიმართ სამართლებრივი საჩივრების რაოდენობა იზრდება, ამასთან, სტატისტიკური მონაცემების საფუძველზე, საკომპენსაციოდ გადახდილი თანხა საშუალოდ აღემატება 100 000 აშშ დოლარს. სარწმუნოდ არის დოკუმენტირებული მონაცემები სისხლძარღვებში მოკლე პერიფერიული კათეტერების მოთავსების შერმთხვევების ზრდის შესახებ. ვენის საძიებელი მოწყობილობები მნიშვნელოვნად ამცირებს ვენის საძიებლად საჭირო დროს. ისინი თავიდან აცილებენ ნემსების, შპრიცების, PICC-ის და სხვა მასალების ხარჯს. ეს მოწყობილობები არაინვაზიურია, რადგან ისინი იყენებენ სინათლის წყაროს კანქვეშა ქსოვილებში ვენების დასანახად. ხილვადი ვენების ბიოფოტონური მაძიებელი იყენებს ხილვად ყვითელ-წითელ სინათლეს ვენების (ზედაპირული ვენების) დასაფიქსირებლად.

მოწყობილობის ამ სახეს ორი უპირატესობა გააჩნია. პირველ რიგში ის იაფია ინფრაწითელ ანალოგთან შედარებით, ამასთან, მარტივია გამოსაყენებლად და საწარმოებლად. ამ ნაშრომში ჩვენ ვცდილობთ წარმოვადგინოთ ამ ტიპის ხელსაწყოს ჩვენეული დიზაინი და მოდელი. ჩვენ ვტესტავთ ორი ტიპის სინათლეს, წითელსა და ყვითელს. ჩვენ ასევე ვცდილობთ გავარკვიოთ ხმაურის წყარო,

რომელიც გვხვდება ვენის საძიებელი ამ მეთოდების შემთხვევაში. ჩვენ ვამზადებთ და წარმოვადგენთ გაიდლაინს ექიმებისთვის, ექთნებისთვის, პარამედიკებისთვის ან ნებისმიერი პირისთვის, ვისაც აქვს ამ მანიპულაციის ჩატარების აუცილებლობა. ჩვენს მიერ შესრულებული სამუშაოს შედეგები შეიძლება გამოყენებულ იქნას ქვეყნებსა და რეგიონებში, სადაც რესურსების ნაკლებობაა ჯანდაცვის სფეროში. ჩვენ ვიყენებთ 3-D კალამს ჩვენი ხელსაწყოს პროტოტიპის შესაქმნელად, ასევე შესაძლებელია გამოვიყენოთ 3-D პრინტერები ამ ხელსაწყოს საწარმოებლად. 3-D კალმის გამოყენების უპირატესობას წარმოადგენს ის, რომ ეს მეთოდი იაფი და მარტივია გამოყენებაში. კომპიუტერის გამოყენება არ არის საჭირო, მაგრამ უნარებს მნიშვნელობა აქვს ამ მეთოდის გამოყენებისას. ინსტრუქცია, რომელსაც ჩვენ ბოლოში წარმოვადგენთ შეუძლია ნებისმიერმა გამოიყენოს, რომელსაც სურს შექმნას ვენის ბიოფოტონური მაძიებელი. ამ ნაშრომში ასევე წარმოდგენილია საძიებო მოწყობილობის საფუძვლები მომავალი სამუშაოსთვის და თანამედროვე მოწყობილობებისთვის, რომელიც საშუალებას იძლევა დამზადდეს მოწყობილობა ადგილობრივად ან ნებისმიერ სხვა ქვეყანაში, რომელიც საჭიროებს სამედიცინო მოწყობილობების დამიშავებას კონკურენტუნარიან ფასებში. ასევე ამ დისერტაციის დასასრულს ჩვენ ვთავაზობთ ახალ მეთოდს ვენების გამოვლენის მიზნით, ვენის მაძიებლის შექმნაზე, რომელიც დაფუძნებულია ფოტოტრანზისტორების გამოყენებაზე.

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List of Abbreviations

BVF	Biophotonics Vein Finder
FoV	Field of View
Hb	Hemoglobin
HCD	Human-centered design
NIR	Near Infrared
PIVC	Peripheral intravenous catheters
IV	Intravenous

Acknowledgement

"The important thing in Science is not so much to obtain new facts
as to discover new ways of thinking about them"
William Lawrence Bragg

First and foremost, I would like to thank my family for their love toward me and their supports.

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Introduction

Relevance of Theme. Many patients all over the world who are going to clinics have IVs in the arm to receive medications. Sometimes for paramedics there are some difficulties to find veins. Vein finders are devices that we use in order to helps medical staff to reduce risky issues and also decrease the number of time that we try to find the veins. Many devices developed there are 2 main technology in Biophotonics devices first using visible light second NIR light. Each devices have advantages and disadvantages. Near-infrared light devices might be efficacious in selected subpopulations, but the available evidence does not support an overall benefit in the pediatric population. Transilluminators modestly improve pediatric PIVC. On the other hand visualization in NIR devices is main issues. Some devices use monitor or display to show us vein map some of them project the map of vein on hands. These processes increase the price and complexity of device. Last studies shows that we could not find out overall benefit of using near-infrared light devices for pediatric peripheral intravenous cannulation. But, this device might be useful for the patients in a difficult condition of successful cannulation. The current dissertation therefore conducts further research in a developing on IR Phototransistor sensor to detecting veins we also compare our devices with Transilluminator device. Our goal is to develop a device that helps medical staffs during IV procedure to find veins with minimal design and economic price for competitive market.

The scientific novelty of a problem. There are different methods to find veins we chose biophotonics approach. In this method we use visible lights and also IR radiation to find veins. We developed 2 type of devices. First one uses Visible Red/Yellow light source (Red/Yellow LEDs) to locate veins, second one uses IR light (IR LED) to locate veins on hand. Our goal in this thesis is to design devices that have simple or minimal design in order to decrease the price of this type of devices in the market. For Visible light source device we used "Modular design" approach. Modular design is a design approach that creates things out of independent parts with standard interfaces. This allows designs to be customized, upgraded, repaired and for parts to be reused. A well know example of module design are LEGO plastic construction toys. For IR one we use phototransistor as a sensor and detectors to find veins. By using phototransistors we measure intensity of reflected IR light from Dermis of skin. We know that IR lights (~940 nm) can penetrate into the skin more than 5 mm, and we know that Hb_s can absorb more IR lights compare to surrounding tissues. So we measure voltage drop through the indicators LED when the IR source and IR detector (IR phototransistor) get align with vein stream, voltage across the indicator LED drop it significantly so we can realize that we are on the vein. The interesting thing is that based on size of vein the intensity of indicators LEDs changes differently so with this method that is kina spectrophotometric approach we can even measure the size of vein. Note that the device that we developed in this project is analog by using microcontroller and display such as LCDs we can even visualize veins. The important thing about IR Phototransistors is that they give us better output signal compare to photodiode and they are just sensitive to IR radiation.

Statement of a problem. Many devices developed during last years, some of them works based on Visible transilluminator light some of them IR light. The main issue here is that device must have two important features in order to have impact on IVs procedures;

First, it must detect vein for us to decrease the number of time that we try.

Second, it must be easy to have a quick access to device at the moment in IVs part. IVs procedures are common things in most clinics especially in emergency section. Se device must be portable and easy to use.

Visible transilluminator device have better performance due to portability and ease of use. For IR radiation the main issues is about visualization some devices have display monitor or can connected to computer to show. This may have increase the complexity and affect the second issue that we mentioned above about ease of use and quick access to device. New IR device use image projection on hand, so they can construct vein map on hand based on IR spectroscopy then project this picture on hand again, the picture must be math with the location of vein on hand. This method is better than using monitor display but this method increase the complexity of device due to need to have high precision of projection and this has a big impact on price of device. Also maintenance and sterilizing of device is another issue. In this study we try to focusing on two main issues; ease of use and portability of device. Because for IR devices, due to invisibility of IR radiation for our naked eyes, the complexity of device for visualization is the main issue we try to make a device with minimal design in order to reach our goal which means portability and ease of use.

Methodology of Research. Device must have to main features; first it can detect veins, second must be portable or has minimal design. For First feature we use scientific method. We used IR phototransistor as a detector and IR LED (~ 940 nm) as light source. The IR Phototransistor that we used, has effective performance on 5 volts (DC), we have also use Red LED as indicators connected in series with IR Phototransistors, we measure voltage drop between Red LED leads, This voltage drop leads us to indicate location of vein on hand by plotting this voltage drop versus vertical axis on vein stream we can achieve a voltage deflection on vein position. This voltage deflection can be used as a signal to create visualization for vein location. For second feature we used Design methodology. we used Minimal and simplicity design theory in our structural model to strip down our design to fundamental elements as possible as we can, to reduce material and manufacturing cost of our device which means; Strip down our design to fundamental elements and Simple functionality and user interaction.

Practical Value. The results of this research can help product designer in medical parts to design Vein detection device with competitive price. Also it help us to have a comparison between different devices based on different technologies that they used. It may also help further researcher on this field to reconsider IR Phototransistor sensor as a possible candidate for detecting veins.

Chapter 1. Literature Review

1.1 Introduction to Biophotonics

Biophotonics or biomedical optics has become an indispensable tool for basic life sciences research and for biomedical diagnosis, therapy, monitoring, imaging, and surgery. [16] It is a multidisciplinary field that deals with all aspects of the interactions between light and biological material. [1] From a global viewpoint, biophotonics refers to the detection, reflection, emission, modification, absorption, creation, and manipulation of photons as they interact with biological cells, organisms, molecules, tissues, and substances. [1]

The technologies supporting biophotonics include optical fibers, optical sources and photodetectors, test and measurement instrumentation, nanotechnology, microscopy, spectroscopy, and miniaturization methodologies. Therefore, biophotonics combines a wide variety of optical methods to investigate the structural, functional, mechanical, biological, and chemical properties of biological material and systems. In addition, biophotonics methodologies are being used extensively to investigate and monitor the health and wellbeing of humans. The wavelengths used for biophotonics typically range from 190 nm in the ultraviolet to 10.6 μm in the infrared region, with numerous applications being in the visible 400–700 nm spectrum. Thus a broad range of diverse tools and techniques are employed in biophotonics. [1]

1.2 Basics of Cell Biology

The cell is the basic functional structural unit of all creatures that we know until today. The cell is the smallest unit of life. They are building blocks of life. The study of Cells is called Cell biology. Cells are made of cytoplasm, which contains many biomolecules such as proteins and nucleic acids. Most plant and animal cells are visible only by using microscope they have a range size between 1 to 100 micrometers. Organisms can be classified as or protozoa. Most protozoan organisms they are classified as microorganisms.

Our body is made up of 2 trillion cells. The largest cells of the human body are about the size of a hair's hair, but most cells are even much smaller than these, and may be as much as one-tenth the diameter of a human hair. Bacteria are the simplest type of cells today. Bacteria are a single living cell. Escherichia coli (or E. coli) is a typical bacterium as much as one-hundredth of a human cell (perhaps one micron in length and one-micron in width) and is not visible without a microscope. When your body becomes infected, bacteria float around large cells in the body, such as rowing boats next to a large ship. The e coli bacterium has a capsule-like shape. The outer part of the cell is the cell membrane that is orange in the image below. The e coli cell has two protective membranes. Inside the membrane, there is a cytoplasm made up of millions of enzymes, sugar, ATP, and other waterborne molecules. The DNA is in the center of the cell resembling a crushed ball. The DNA inside the bacterium has no protection, and it floats inside the cytoplasm and almost in the center of the cell. There are long strings outside the cell called the flagella that move the cell. Not all bacteria, of course, have flagella. In the cells of the human body, only the sperm cells have flagella.

The cells of the human body are much more complex than bacteria and have a nuclear membrane to protect DNA. Human cells also have extra membranes, structures such as mitochondria and the Golgi apparatus, and other advanced features. Of course, the basic processes of bacteria and cells of the human body are the same.

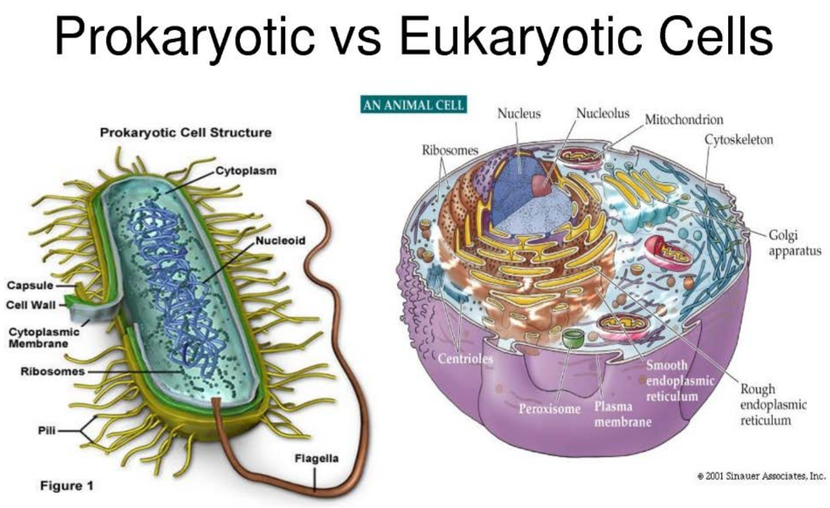


Figure 1. Prokaryotic vs Eukaryotic Cells.

Cells are divided into two groups according to the nucleus wall. Cells that do not have a nucleus wall are called prokaryotes and are called cells with a fusiform nucleus called eukaryotes.

In eukaryotic cells, there are different organelles that each perform a part of their cellular function and function. Some organelles have distinct structures and have membranes. They have important organelles such as the nucleus and mitochondria. Accordingly, the organelles are categorized into four categories: Here is common types of cells in animal organisms:

Membrane-free organelles: Organelles such as the ribosome are not enclosed in any membrane and are present in the prokaryotic and eukaryotic cells.

Single-membrane organelles: Some membrane-bound organelles are confined to a single-layer membrane. These organelles are found in plant and animal eukaryotic cells, including the Vacuole, the Golgi apparatus, the Endoplasmic reticulum, and the Lysosome.

Organoids with Dual Layer Membranes: Organoids such as Nucleus, Mitochondria and Chloroplast have double layers and are present only in eukaryotic cells.

Here is a brief introduction to the some organelles of eukaryotic cells:

Cytoplasm: Cytoplasm is a fluid and jelly material that surrounds the intracellular space around the nucleus. This part of the cell in some books is not considered to be a cellular organ. But it is a very important substance in the cell that actually forms the "protoplasm" or living cell of the cell, with other organelles floating in it. Many important cellular processes, such as protein production and cellular respiration, occur within the cytoplasm. These organelles play a role in the movements inside and around the cell.

Cytoskeleton: A network of tall fibers that make up the overall structure and configuration of the cell. The cytoskeleton has many functions. These functions include determining the shape of the cell, participating in cell division, and allowing the cell to move. It can also control the movement of other organs.

Endoplasmic reticulum: This network helps to process molecules that are produced in the cell. The endoplasmic reticulum is effective in transporting intracellular molecules into and out of the cell. The net is made up of a set of interconnected bags called the Cisternae. The endoplasmic reticulum, like other cellular organelles, is enclosed in the membrane and is divided into two very different parts in terms of structure, including the soft and coarse endoplasmic reticulum.

Soft endoplasmic reticulum: As its name implies, this part of the endoplasmic reticulum is known as the "Smooth Endoplasmic reticulum" because it has no ribosomes on its surface. This part of the network is involved in the synthesis of lipids and carbohydrates involved in the production of plasma membranes. The soft endoplasmic reticulum has many functions, including vesicle displacement, production of liver enzymes, contractions in muscle cells, and production of hormones in brain cells.

Rough Endoplasmic reticulum: Unlike the soft endoplasmic reticulum, the "Rough Endoplasmic reticulum" has ribosomes on its surface. For this reason, it plays an important role in the production of proteins. The coarse grid helps produce antibodies and insulin and transfer proteins to the soft endoplasmic reticulum.

Nucleus: The nucleus acting like brain for cells, and most cellular activity is regulated by this part. The organelle, which has a bilayer membrane, is made of materials such as "Chromatin", "Nucleoplasm" and "Nucleolus". There are pores on the membrane of the nucleus that are used to transport materials. The nucleus is the place of storage of genetic information and important cellular proteins. In eukaryotic cells, the nucleus is encapsulated in the membrane and controls the activity of various cellular organs using genetic information and protein production and cell division message delivery. In prokaryotic cells, the nucleus lacks the membrane and the genetic information of the cell is stored in an environment called the nucleoid. Nuclei in the cell nucleus also play an important role in the production of ribosomes.

Ribosomes: Ribosomes are one of the smallest cellular organisms in which there are specific RNAs and proteins. These organelles are made up of two small and large parts that bind together during protein production. In cells, the ribosome has the direct function of producing protein using RNA and "amino acid molecules". This process involves decoding RNA codes and selecting the appropriate amino acid for protein production.

Mitochondria: Mitochondria are one of the largest cellular organelles. Mitochondria have DNA compared to other organelles and are therefore a semi-automatic organelle. In addition, the mitochondria have a bilayer membrane with a folded inner membrane. The mitochondrial inner membrane folds are called "cristae". The mitochondrial inner membrane space contains a substance called the mitochondrial matrix. Mitochondria are the center of cell energy production and play an important role in the respiratory process, where ATP is produced. Because of the amount of genetic material it can encode some of the proteins it needs. There are always some ribosomes in the mitochondrial interior to produce the proteins needed for mitochondria.

1.3 Components of optical systems

All optical systems are consist of basic building blocks. These basic blocks are: [3]

1. Light source
2. Medium or components that manipulate the light
2. Medium where light propagates into it
4. A detector

For example, in our eyes fist light manipulate by our lens for focusing then propagate through our eyes onto retina (detectors). Retina cells convert light to electrical signal and send it to brain for processing.

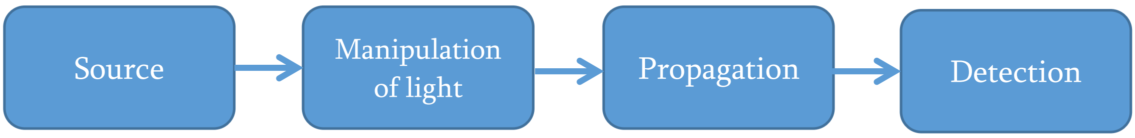


Figure 2. Components of optical system

1.3.1 Light Sources

We have two type of light source natural and artificial. Here we introduce some of the most comment arterial light sources; [3]

1- Incandescent or halogen light
2- Light emitting diodes

3- Laser diodes

4- Gas lasers

What is LASER?

The nature of lasers and ordinary light are the same, and both are electromagnetic waves (including energy packets called photons). There are three main differences between lasers and ordinary light:

1- Normal light from a lamp contains all colors (all visible frequencies), so-called white light. But laser light has less frequency bandwidth and can ideally produce "monochromatic" light. For example, a laser can produce a beam of different colors, often green and red or even colorless at infrared and ultraviolet frequencies.

2- The light emitted by a lamp is scattered in all directions; even with the use of lenses or reflectors in the lamps, the light is convex and eventually diverges. The light from a laser, however, is a narrow beam that goes much longer than normal light due to very low divergence. This concept is known as longitudinal "coherence".

3- A lamp produces beams in different phases. In fact, the phases of each beam, or more precisely each beam of radiation, are different at each time and there is no particular order in them. This is if the rays from a laser are all in phase and at one time all reach their maximum and amplitude. This is known as temporal coherence. The laser beam can be likened to the regular parade of army soldiers who all walk in the same row and in the same motion. While the light from a light bulb is like that of a train passenger, they all rush to the exit doors in an irregular fashion.

To get a better understanding of how a laser works and how it works, you need to be familiar with the subject of atomic radiation. In short, an electron in the energy circuits around the nucleus moves to higher levels by absorbing energy. This electron is not stable at high levels and tends to go into a steady state. As a result, the excess energy radiates itself into the photon, moving itself to lower levels. The frequency or wavelength of the irradiated photon depends on the energy difference of two levels. Now suppose that a large number of these high-energy unstable electrons all (at our control) go to a lower energy level and radiate; by amplifying this radiation in the cavity environment, high-energy Laser light is produced and driven by lenses.

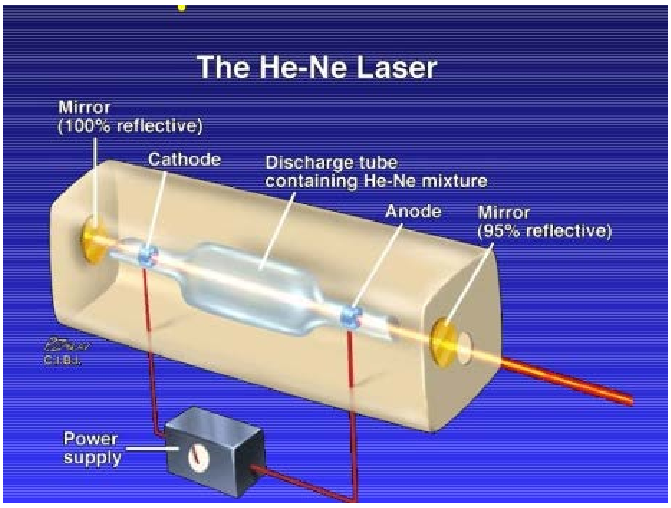


Figure 3. He-Ne laser structure

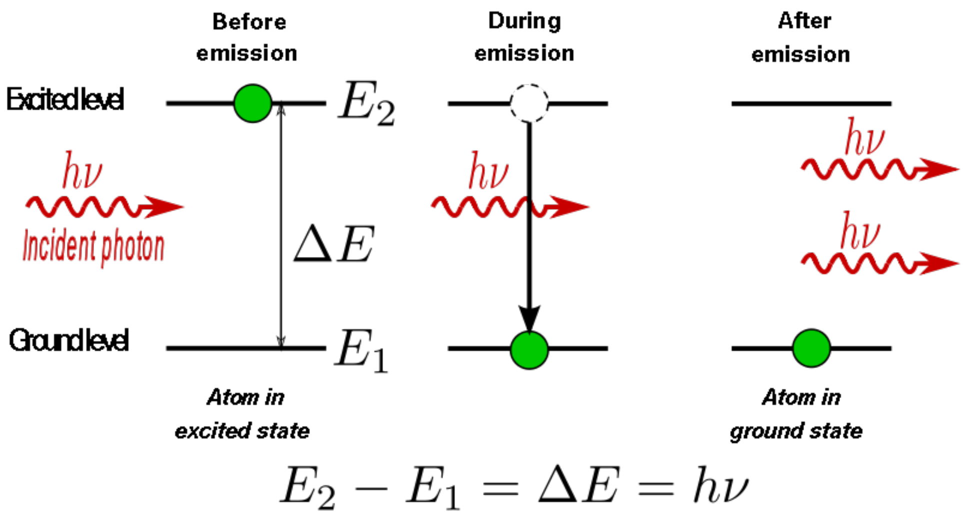


Figure 4. Stimulated emission

LED (Light Emitting Diode)

LEDs or luminous diodes are electronic components that have a huge impact on hardware today. Used in television screens, monitors, automobiles, hardware components, etc. Light-Emitting Diode (LED), also known as the translation of some leaflets, books, and treatises on luminous diodes, light emitting diodes, and light-emitting diodes, is an electronic piece of the diode family.

Monochromatic LEDs, like the other diodes, have two anode and a candle base. Dual (or more) LEDs have a common base (usually a cathode, known as a "cathode-joint"), and each base has another base (usually anode). LEDs use the phenomenon of electroluminescence to produce light.

The light spectrum of LED lamps includes all visible and UV and infrared spectra and is extremely narrow. The color of LEDs depends on the constituent crystal. The amount and color of LEDs depends largely on their current, which is why it is common to use a current source to power them. Illuminated diodes have many advantages over traditional light sources, such as lower power consumption, longer life, more robustness, smaller size, and faster turning on and off.

1.3.2 Light detection

Light detection is one of the most important part of any optical systems. They convert light to electrical signals that can be used by our devices for processing. One of the natural famous light detection is retina cells in our eyes that they can convert visible light to electrical signal for processing in our brain. We use light detectors in our systems to detect light and intensity of light into electrical signal sometime we also use amplifiers. [3]

Photon detectors

Photon detectors as their name tell us they are directly respond to incident photons. The incident photon that absorb by detector can change the electronic characteristic of the detector [9].

Photo detectors
- 1-Photodiodes
- 2- Phototransistors
- 3- Photomultipliers

Photoconductivity or optical transducer components are basically PN transducer sensors or detectors that are composed of N-type PN bonds and are sensitive to light. These components can detect visible and infrared light levels. Optical transducers are specifically designed to detect light, and these types of photoelectric light sensors include photodiodes and phototransistors.

Photodiode: The structure of a photodiode light sensor is similar to that of a normal PN bond diode, with the photodiode coating transparent or having a transparent lens to focus the light on the PN bond and increase its sensitivity. This graft responds better to visible light, especially longer wavelengths such as infrared, than visible light. [3]

The photodiode current is directly proportional to the light intensity emitted by the PN bond. One of the main advantages of photodiodes used as light sensors is their rapid response to changes in light levels. But one of the disadvantages of this type of optical component is its relatively low current.

Phototransistors: An optical replacement for an optical diode is an optical transistor or phototransistor, which consists essentially of a photodiode capable of amplification. When exposed to light, the phototransistor sensor has a reverse bias collector-base PN link.

Phototransistors work similar to photodiodes, except that they have a current gain and are more sensitive to photodiodes, with their current being 5 to 5 times larger than standard photodiodes. Any ordinary transistor can be easily converted into a phototransistor light sensor by connecting a photodiode between the collector and the base.

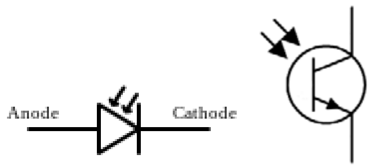


Figure 5. Electronic symbol for a phototransistor (right) and photodiode (left)

Photomultiplier: Photomultiplier or optical multipliers are the most sensitive type of visible, ultraviolet, and near-infrared radiation detectors. In normal photoelectric mode, we get one electron per photon, but here we have about 10 to 7 electrons each so the current and output signal is amplified and sensitivity is very high. These detectors are composed of a number of panels called dynodes, which are responsible for amplifying current and are located between the cathode and the anode. Each time the impact of electrons on these plates will increase the number of electrons.

The combination of many features has made photo multipliers maintain their essential position in various sciences;

1- Attributes

2- High efficiency

3- Very low noise

4- High frequency response or equivalent

5- Super fast response

6- Great variety

7- Applications

8- Nuclear and particle physics

9- Astronomy

10- Medical diagnoses including blood tests, medical imaging etc.

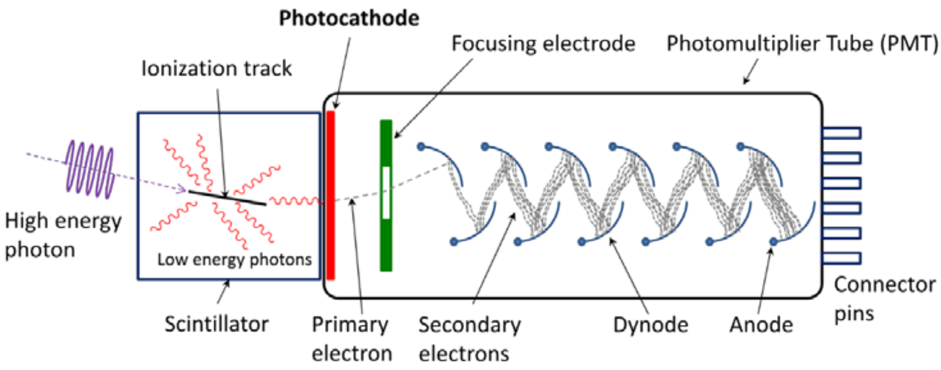


Figure 6. Schematic of a photomultiplier tube coupled to a scintillator.

This arrangement is for detection of gamma rays.

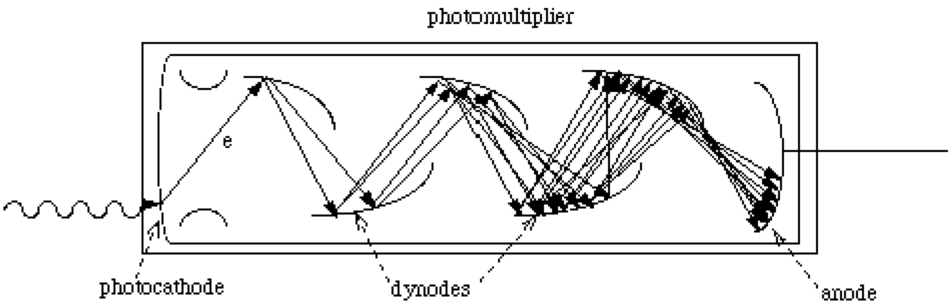


Figure 7. Photomultiplier

Noise in Photodiode

We can calculate the total noise current by given equation: [3]

$$i_n = \sqrt{i_j^2 + i_D^2 + i_L^2}$$

The first term is Johnson noise we can calculate it by given equation: [3]

$$i_j = \sqrt{(4.k.T.f)/Rsh}$$

k ; Boltzmann's constant,
T; absolute temperature of the detector element
f; noise bandwidth,
R_{Sh} ; shunt resistance. [3]
The second term in Equation can be calculated by: [3]

$$i_D = \sqrt{2.q.Id.f}$$

q ;electron charge

Id; dark current.

for third term we can use this equation: [3]

$$i_L = \sqrt{4.q.Il.f}$$

1.4 Interaction of Light with Matter

Interaction of light with matter

1- Reflection

2- Refraction

3- Diffraction

4- Interference

5- Absorption

1.4.1 Reflection

The return of light from the surface of objects is called the reflection of light. It reflects whenever a beam is illuminated along polished surfaces such as water surfaces or on mercury-lined glass like mirrors. In this case, the beam of light that is exposed to the surface of the object is called the beam of radiation, and the reflected beam from the surface is called the reflection beam, and the point where the light shines is called the beam. [3] [33]

$$A_r = A_i$$

(A_i; incident angle, A_r; reflection angle.)

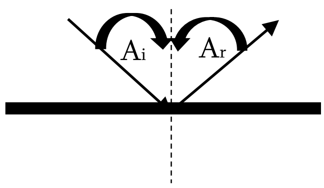


Figure 8. Reflection from mirror

1.4.2 Refraction

Deflection of light when it enters from one transparent environment to another transparent environment is called the refraction of light. Here we can see Snell's law that represent relationship between incidence angle and refraction angles: [3]

$$N_1 \mathrm{Sin}\ (a_1) = N_2 \mathrm{Sin}\ (a_2)$$

(N1 and N2 refer to the refractive index in medium 1 and 2, also a1 and a2 are the angle of incidence and refraction in medium 1 and 2, respectively)

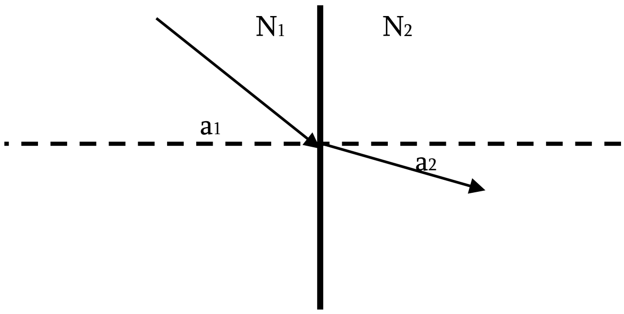


Figure 9. Refraction

1.4.3 Diffraction

So far, we are familiar with the two properties of reflection and wave failure, and we have examined the behavior of reflection in barriers and passing from environment to environment. But what if the alternating wave passes through the gap? As you can see in figure 10. , the wave bends after the slit, i.e. flat waves, after passing through the slot, are almost circular in shape. This is called wave diffraction. [3]

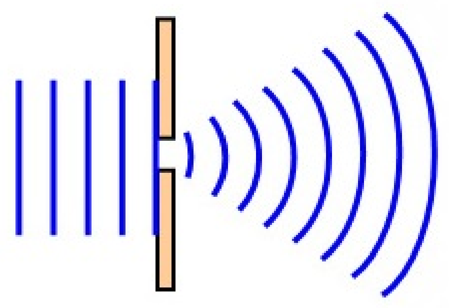


Figure 10. Diffraction of light

1.4.4 Interference

When two or more waves collide, there is a disturbance in their initial position in the environment. The sum of two or more waves in the same initial space of the rippled waves is called the interference of the waves. [3]

The result is the interference of the waves. The interference of the waves creates a wave combination that causes the destructive or destructive interference of the initial waves and can be quite different at any time and place.

The waves we see in reality are not simply definitions of simple waves or waves on the water! Simple waves are produced by simple harmonic oscillations and are sinusoidal shaped. But the more complex waves have different shapes and are strange. Most simple waves that come together have quite complex waves, but fortunately the law of waves is very simple and the amplitudes of waves are easily aggregated.

To analyze the interference of two or more waves, we use the principle of superposition. For mechanical waves, the principle of superposition states that if two or more traveling waves combine at the same point, the resulting position of the mass element of the medium, at that point, is the algebraic sum of the position due to the individual waves. The superposition principle can be understood by considering the linear wave equation. In Mathematics of a Wave, we defined a linear wave as a wave whose mathematical representation obeys the linear wave equation. For a transverse wave on a string with an elastic restoring force, the linear wave equation is: [32]

$$\frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y(x,t)}{\partial t^2}.$$

1.4.5. Absorption

We know that light travel like packages of energy that we call it photon. When light goes through a medium some of the light or photons can be absorbed by this medium and reduce intensity of light also during this absorption process photons can give their energy to the medium, we can feel it as a heat. We can calculate intensity reduction of light by following formula;

$$I = I_o e^{-al}$$

(l is the distance light traveled in the absorbing medium with absorption coefficient of a)

Light transmission (T) through absorbing medium;

$$T = I/I_o$$

1.5 Hemoglobin and Infra-Red radiation Interaction

Hemoglobin (Hb) absorbs light. The amount of light absorbed is proportional to the concentration of Hb in the blood vessel. We understand this phenomena we have law in physics called “Beer’s Law”. Beer’s Law: Amount of light absorbed is proportional to the concentration of the light absorbing substance. [15] [33] [35]

$$A = \varepsilon l c$$

Where

e = molar absorptivity,

l = path length (the distance the light travels through the material),

c = molar concentration of a specific component,

Hb absorbs more red light HbO2. [15] As we know Veins are blood vessels that carry blood toward the heart. Most veins carry Hb blood from the tissues back to the heart; exceptions are the pulmonary and umbilical veins, both of which carry oxygenated blood to the heart. In contrast to veins, arteries carry blood away from the heart. [16] [35]

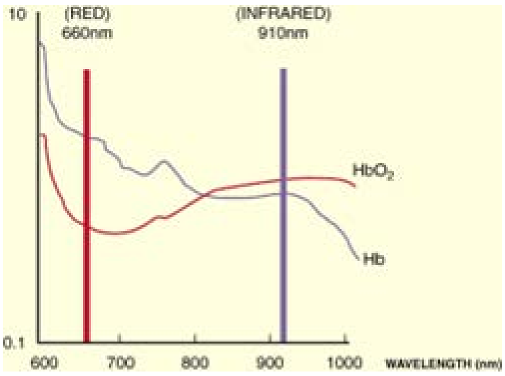


Figure 11. Absorption spectra of oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (Hb) for red and infrared wavelengths.

So Hb in the blood absorbs red light; so when we use the device above the skin, veins appear in contrast to surrounding tissue. [35]

Chapter 2. Methods of Vein finding in PIVC

2.1. Modern methods for Vein detection

Around more than 80% of all patients who are going to clinics in the world have IVs in the arm to receive medications. Sometime this procedure can be difficult for paramedics for some cases like infants and old people, obese people, dark skinned people and etc. one-third of hemophiliac's patients in clinics have this type of difficulties.

Because IVs is a common routine, sometime we forget about dangerous and risky issues about it for patients of even for staffs in clinic and medical centers. Vein finder devices can reduce these risky issues and also decrease the number of time that we try to find the veins. It is non-invasive way just using long wavelength light to see the superficial veins.

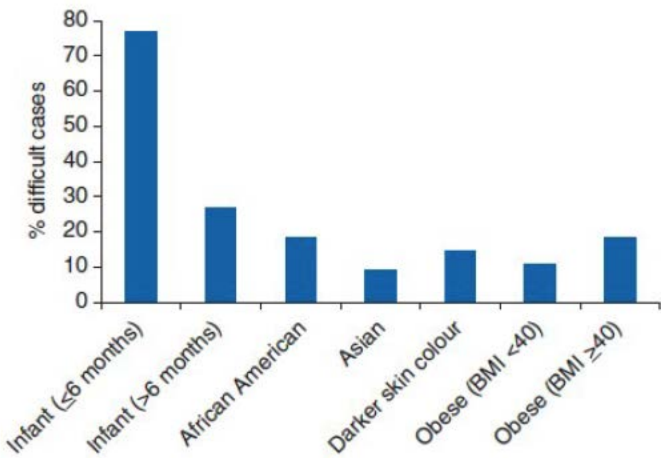


Figure 12. Percentages of difficult cases in IVs.

We have 2 main types of Vein Finder;

1. Passive Vein Finder: They are filtering light like a sunglasses. No electrical or energy source part they have.

2. Active Vein Finder: They all need energy source to operate. This type of vein finder also can divided into two subcategories;

2.1. Visible light transilluminator

2.2. Near infrared (NIR) spectroscopy

There are another different types of Vein Finder such as Ultrasound (US) devices, Pressure sensor or Multispectral camera.

Near infrared (NIR) spectroscopy

In this method we use near infrared light (700-900 nm) they can penetrate deeper than visible lights. In this type of device we can see veins on monitor or in some models they can project pictures on our arms.

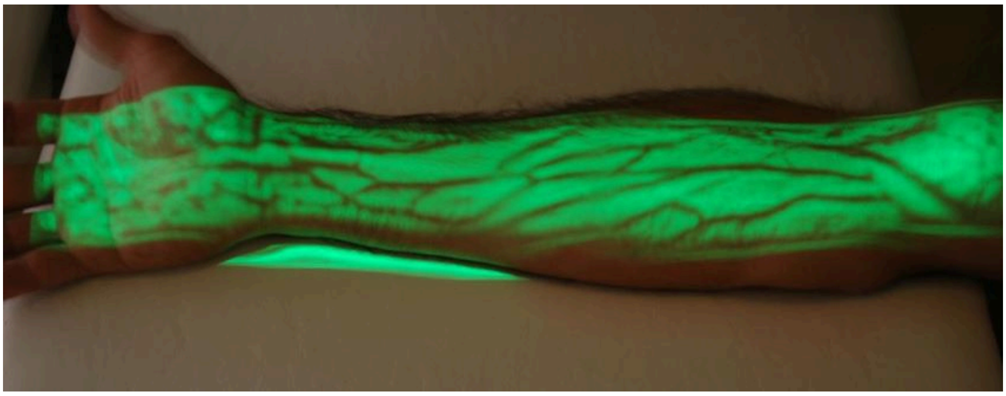


Figure 13. Vein Viewer is a medical system designed by Memphis-based Company Christie Medical Holdings that uses near-infrared light to create a high-definition image of a patient's vein, which is then projected in real-time onto their skin to help clinicians insert.

Principle of Near-Infrared Imaging in Vein Illuminator. The unique characteristic of NIR radiation is it can penetrate into biological tissue up to a depth of about 3 mm, in which the veins are located. Arteries are more deeply seated than veins and NIR cannot penetrate further beyond 3 mm. Moreover, in contrast with arterial blood which is mostly occupied by oxygenated hemoglobin (HbO2), the reduced, or deoxygenated, hemoglobin (Hb) in the venous blood absorbs more of the radiation in this spectrum than the surrounding tissue. This concept is illustrated in Fig. 14, which describes the absorption spectra of Hb and HbO2 and water, main component of the neighbor tissues such as fat, and muscle. According to the figure, only Hb and HbO2 are the primary absorbers of NIR light (600–1300 nm). In this region, venous blood still maintains a higher absorption capability when the absorption coefficients of both oxygenated and deoxygenated blood dramatically fall with the wavelength beyond 600 nm. Also, there exists a peak at approximately 760 nm for HbO2, and the absorption difference between both kinds of hemoglobin is most prominent within the 700– 900 nm range. Therefore, it is significant that the wavelength of the NIR light source is chosen to be between 700 and 900 nm or around 760 nm, ideally. [36]

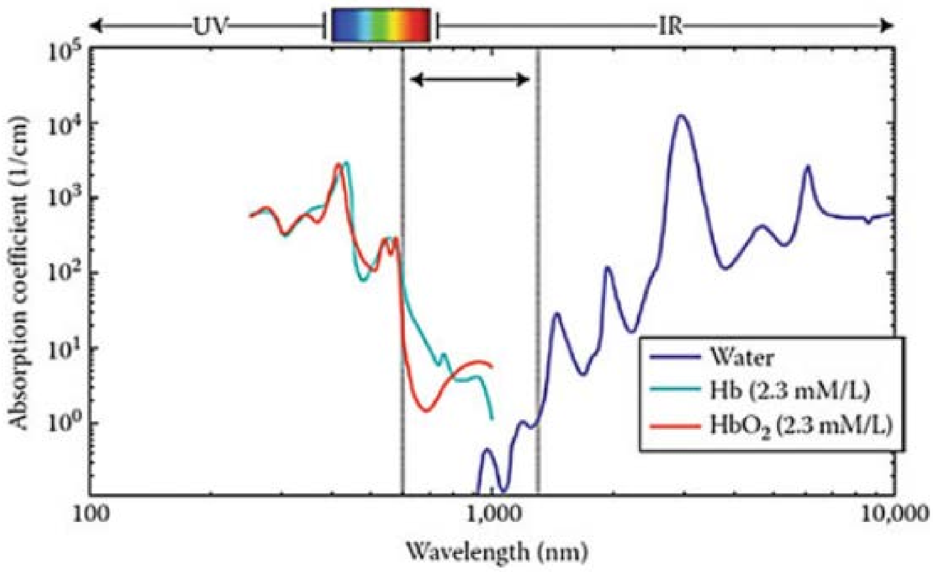


Figure 14. The absorption spectra of water, Hb, and HbO2

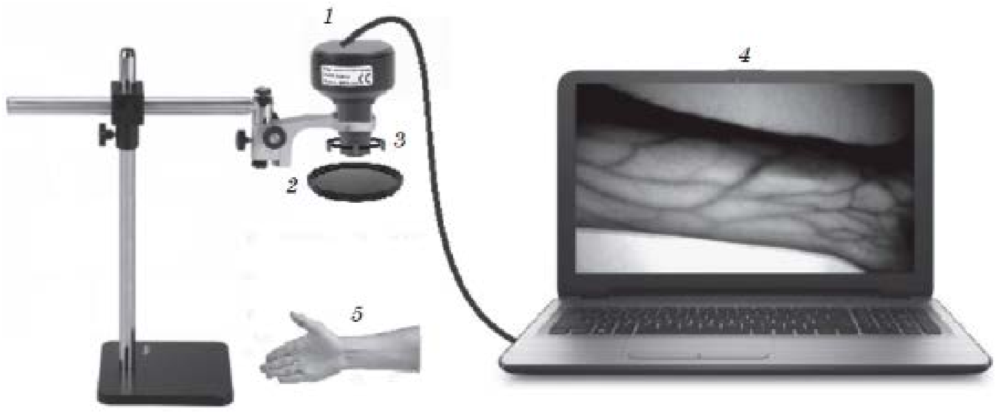


Figure 15. The layout of the collection of data on the venous pattern of the study area: 1 - digital camera DCM 510; 2 - infrared cut-off filter; 3 - ring with IR LEDs (4 pcs.); 4 - computer; 5 - study area.

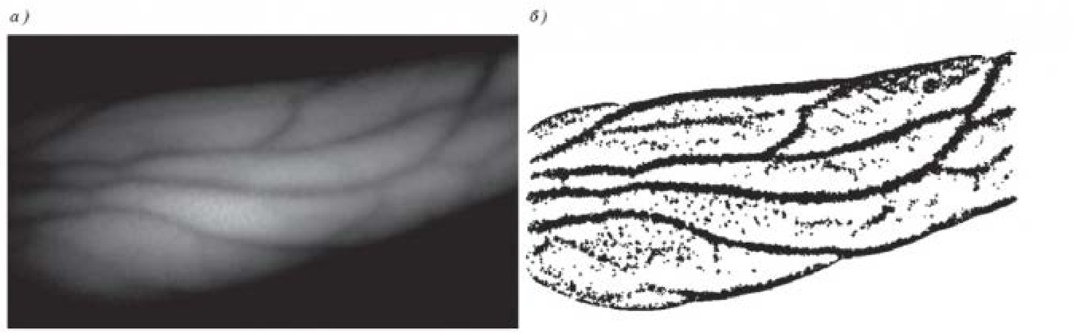


Figure 16. Implementation of the algorithm for preliminary processing of the venous bed: a - image of the venous bed received from the camera; b - pretreatment of the venous bed.

The processed image of the patient's superficial vein pattern can be projected back onto the skin surface in real time (Figure 17.), providing the user with a near real time, enhanced video of the vascular system. A 97% increase in the detection of possible intravenous catheterization sites in difficult cases has been reported with NIR technology [17]. The mean number of visible sites that were found across all age groups without any vision assistance increased with the infrared vein finding (VF) device (Figure 18.) [17]. A vision system providing multispectral images in the NIR and visible spectrum, associated with 3-dimensional information of the arm topography, yield reliable results for automatic vein detection.

Figure 17. View seen through the Veinsite™ near infrared imaging device.

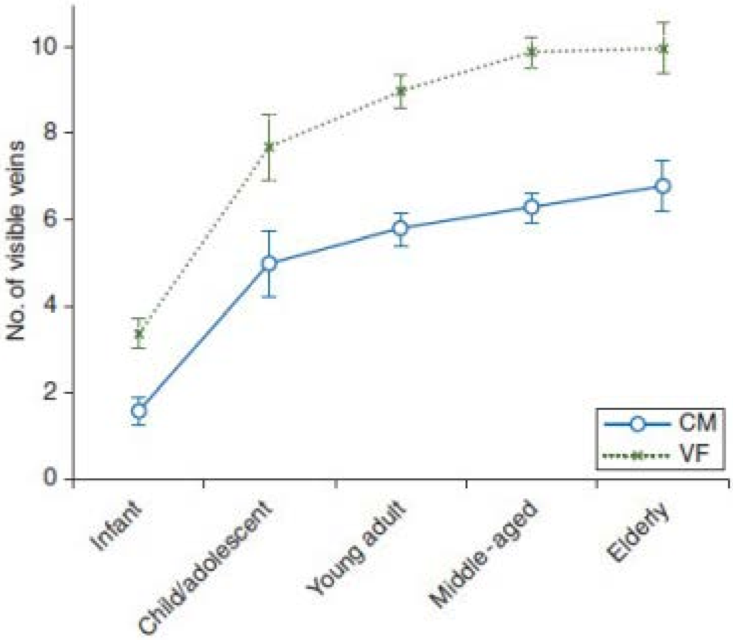


Figure 18. A comparison of infrared vein finding (VF) and conventional method (CM) visible sites [mean (SE)] across age groups.

Pressure sensor:

The Vein Entry Indicator Device (VEID™, Vascular Technologies Ltd.) designed to assist PIVC consists of a plastic box weighing 8.5 g containing a pressure sensor, a signal indicator and a processing unit. The pressure sensor, which has operating pressures of 5-100 cm H 2 O, detects pressure changes when the vein is entered, emitting a beep within 0.1 sec to alert the operator to stop advancing in order not to puncture the back wall of the vein. The VEID alerts the operator when there is doubt about the location of the needle tip. This small device, approved by the FDA, attaches to any female Luer Lock IV catheter. VEID increased the success rate in children from 70% to 90% and in adults with difficult veins from 26% to 90% [17]. The method does not improve vein visibility, but insertion is faster and more accurate.

Multispectral camera:

Multispectral imaging involves collecting data from two or more ranges of frequencies along the spectrum. Eyes-on™ glasses use multispectral light-based technology for imaging most peripheral veins [17]. A built-in computer integrates the images generated using four different wavelengths, including the near infrared part of the spectrum. While the computer projects a 3D view of the vasculature onto the clear lenses of the glasses, wearers can still look past the transparent vein map before their eyes to see what is going on in the room. The glasses include 3D imaging, wireless connections, digital storage and interfaces with hospital electronic medical records systems for seamless documentation. An accessory to the device uses US to reveal veins located farther beneath the skin surface. The same technology with an exceptionally strong lens system and convenient adaptations to field conditions is used in the military. Critical patient information is obtainable with eye movement downward [17].

Robotics systems:

Efforts have been made recently to develop robotic systems for PIVC and drawing blood but none have reached the market. The system, as described in one such study [17], operates as follows: The patient slides his or her arm into an inflatable cuff, which acts as a tourniquet. An infrared light illuminates the inner elbow for a camera that searches for a suitable vein using software that compares the camera's view with a model of the veins of the arm. Once sufficient blood flow in the chosen vein is confirmed by US wave, the robotic arm aligns itself with the chosen vein and inserts the needle. Another innovative system, in development phase, SAGIV™, is a semi-automatic guided intravenous device (Figure 19). Using infrared technology and an online LCD monitor, the SAGIV enables operators to identify appropriate veins for cannulation, and on demand automatically inserts the needle and cannula. Using an electrical feedback, the device precisely penetrates the vein and ensures appropriate catheter positioning. Once the catheter is in place, the SAGIV removes the needle to an easily discarded sealed housing [17].

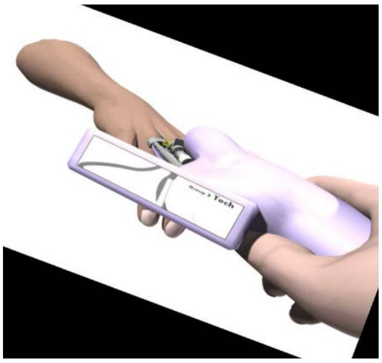


Figure 19. SAGIV™ automated IV

Visible light transilluminator:

In this type of device we use visible lights we know that Red lights can absorb by Hb .Most veins carry Hb blood from the tissues back to the heart; exceptions are the pulmonary and umbilical veins, both of which carry oxygenated blood to the heart. In contrast to veins, arteries carry blood away from the heart. So Hb in the blood absorbs red light; so when we use the device above the skin, veins appear in contrast to surrounding tissue. A clinical study with one such a device, the Veinlite™ vein finder, showed us that accuracy of device is 85% compared to 74% with the standard method. This device is effective in children and they can use in emergency of hospitals. [17] [35]

Figure 20. Veinlite LEDX

Table 1. Advantages, disadvantages and costs for each technology.

Method	Color Vision[a]	Pressure Sensor	LED	Infrared	Ultrasound[b]	Multi-spectral[c]
Pros	Simple No battery No electricity Suitable for outdoor light Portable Wearable	Simple Fast detection For use in every environment	Simple Portable Various wavelengths Veins depth and diameter can be evaluated Keep the vein from rolling	Various wavelengths Vein map shows on the skin Up to 15 mm depth No patient contact Works in light or dark	Large screen Can see the needle inside the body Needle guide device Vein depth and diameter can be estimated Very deep peneterating	Multispectral camera Ultrasound Real-time sharing Portabale No patient contact Wearable
Cons	Will not work in the dark Not for the colorblind	No image No visability improvment	Need a dark environment Many kinds of products Requires patient contact	Vein depth and diameter can be estimated Requires practical training	Not portable Expensive Complicated Requires practical training	Heavy (300 gr without battery) Requires practical training
Price [USD]	~ 300 (for glasses or bulb)	120	200-630	~ 27,000 not portable/4,500 portable	~ 27,600	~ 10,000
% of Improved PDVA		~ 91%	80%	93%	93%	

[a] The success rates for the color vision glasses are not presented because the glasses were originally made for the colorblind
[b] The price is for a specific designated ultrasound machine. The price of an ordinary ultrasound machine starts from 20,000 USD
[c] The success rates for the multispectral glasses are not presented because they only recently came on the market

Figure 21.Advantages, disadvantages and costs for different technologies that we use in vein finding. [17]

2.2 Similar Devices

2.2.1 Visible light transilluminator devices:

Veinlite's Vein Finder

The device is infused with infrared waves to display all available superficial veins, allowing the nurse to select the most appropriate vein for injection. It can only be used by turning on the device and shining it on the surface of the body. It should be noted that it is free of any side effects and reduces stress during injection and because of its ease of use and portability. Suitable for use in all medical centers. You can view the veins from the V-shaped area of the head by tapping the skin on the desired location and then turning on the device. This device is free from any side effects so it will not cause any concern for the patient.

Portable Tracer is suitable for all ages of infants, children, adolescents, youth and adults. This appliance is used in all centers including medical, medical, clinics, laboratories, offices and any centers related to injections and vessels. Lack of light and light in places and places where dark conditions and scarcity of light may be required for the desired treatment. Other items include:

Difficulty finding a vein due to narrowing of the vein, vein muscle contraction, and poor blood supply, as well as difficulty in injecting and injecting, sampling, bleeding and bleeding.

This device greatly reduces patient stress during injections or bleeding and also reduces the error of the expert by clearly seeing the vein.

For infants due to injection sensitivity, blood sampling, blood sampling and vein complexity People with varicose veins.

Figure 22. Veinlite device model; LEDX Adult Transilluminator Vein Finder

Figure 23. Veinlite device model; EMS Adult Baby Transilluminator Vein Finder

Figure 24. Veinlite device model; EMS Adult Baby Transilluminator Vein Finder.

2.2.2 Near infrared (NIR) spectroscopy:

Accuvein AV300: Seeing veins with Accuvein display technology can help specialists find the right vein for injection. Simply place the vessel on top of the skin, the vessels appear on the surface of the skin. Because of their ease of use, these veil detectors can save valuable time for patients and nurses.

- Hint & Click: Easily place the vein finder on a piece of skin and press the button to make the veins appear below the surface of the skin. The device does not require calibration and adjustment and can be used quickly.
- Small size: This machine weighs only 275 grams and you can easily hold it. Even when not in use, it is small enough to fit in your uniform pocket.
- Usability without engaging hands: You can place the device on a stand or attach it to a bed with a clamp if you need to get your hands involved.

- No need to touch the patient's body: Since this device is designed to not be touched by the patient's body, there is no need to sterilize the device after each use.
- Operate in dark or luminous environments: The device shows veins well in dark or luminous environments.
- Rechargeable Battery: This device does not require electricity.
- Motion tolerance: Since the device displays veins momentarily, it can match the patient's motion. This is a critical feature for accessing the veins of children or restless patients.

Limitation of Accuvein: In obese patients, the existence of substantial deposits of subcutaneous fat makes it difficult to locate veins either by touch or vision. Also, the adipose tissue often tends to take the appearance of a vein leading to unsuccessful draws in the area. These misplaced sticks can be avoided if the nurse or phlebotomist is trained to be able to differentiate between adipose tissue and veins. Geriatric patients have veins which can collapse easily due to loss of their elasticity while pediatric patients possess veins that are taut but fragile and very small in size. [19]

2.3 Conclusion; APPLICATIONS OF VEIN VIEWER

Here are some applications of Vein viewers: [19]

• Suited to providing a map of the superficial veins to aid vein graft harvest.

• Used for plastic surgery procedure.

• Used in microsurgical anastomoses to bridge vascular defects and to form vein conduits for nerve regeneration.

• Useful in dark skinned, obese and elderly patients in whom it is often difficult to identify a suitable vein.

• Provides a detailed map of the superficial veins following tourniquet application.

• Essential for venipuncture as a stethoscope is for examining the heart and lungs.

• It can be used to find valves and bifurcations.

Figure 25. AccuVein AV400 Vein Finder

Chapter 3. Methodology – The Design Process

3.1 The Design Process

The Design Process is a way that Designers, engineers even scientist use it to design artifact, they break down process of design into systematic steps [20]

The design process have 6 steps: [20]

1. Define the Problem

When you understand the problem that you want to solve, you are on half of your way.

2. Collect Information

You need to collect all data, sketches, photos and anything that can help you and inspire you.

3. Brainstorm and Analyze Ideas

In this stage we start to create ideas by sketching, make a conceptual design analyzing these ideas and so on.

4. Develop Solutions

In this steps after analyzing ideas we choose specific solution for our problem and developed it also make a prototype and testing it.

5. Gather Feedback

After making prototype we need to gathering feedback from users and professionals and analyzing this feedback

6. Improve

Design in not and open loop process it close loop so base on your feedback you can improve your design and maybe find new problem that you need to solve it and back to the first step.

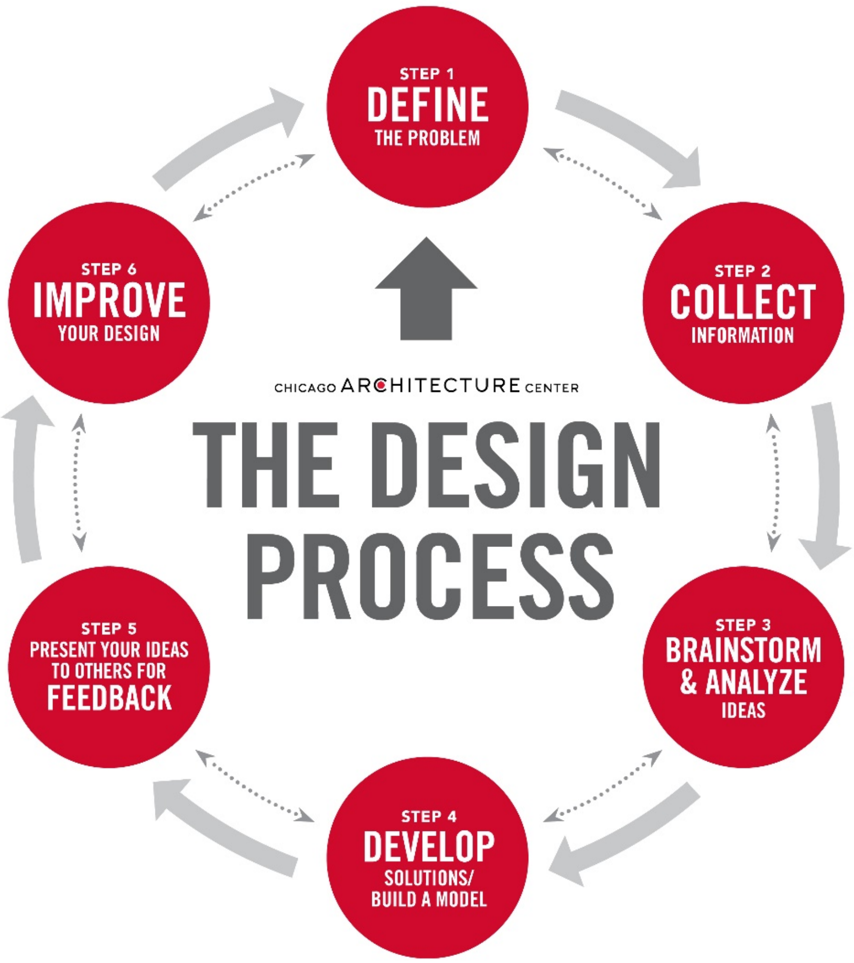


Figure 26. The Design process info-graph.

Also we can have another view to process of designing new product as industrial designer we can divided design process into 3 main stages;

Planning

Development

Production

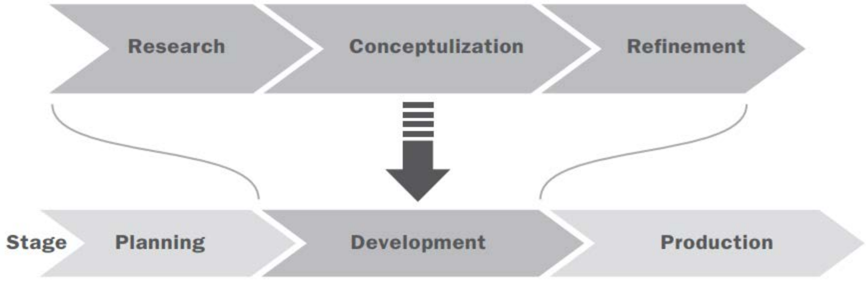


Figure 27. Stages in industrial design of any products. [21]

Product	Customer Stakeholder	User	Other Stakeholder
Barcode Scanner	• purchasing agent • IT services • store manager	• checkout clerk • inventory specialist • registry customer	• service and repair • tech support • sales force
Mobile Phone	• average consumer • service provider • retail outlet	• average consumer	• service and repair • tech support • sales force
Baby Rattle	• gift giver • parent • retail outlet	• baby • parent • siblings	• sales force

Figure 28. Examples of Identifying customers and users in planning stage. [21]

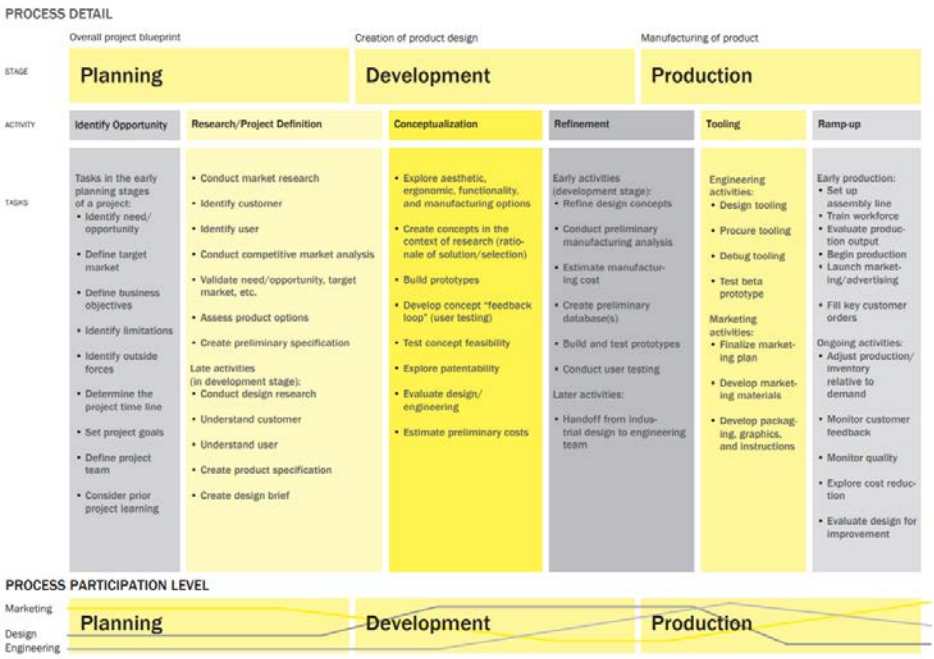


Figure 29. Process detail of design. [21]

Now we discuss more about how we can design a product and which factor can affect it.

The process of developing a new product to deliver to customers is called product design. Of course, this is a far-fetched definition. Product design is a broad concept that leads to the creation of new products through the production of ideas and the development of ideas. Design experts work on concepts and ideas, eventually turning them into tangible inventions and products.

The product design expert for the creation of these products deals with art, science and technology. Nowadays, with the help of digital tools and sophisticated techniques, the need to form large teams has been reduced and the ability to simulate the product before it has been made possible.

Product Design Process:

Each design team takes a different approach to product design and development. The process founded by Koberg and Bagnell shows how to turn ideas into physical products. This process starts with understanding the concept and, as we go through the process of conceptualizing and building prototypes, ultimately leads to product creation. This rule follows the same conventional method of production as well as critical evaluation to identify the corrections needed.

This method has three steps; the second and third steps may need to be repeated several times during the process.

1. Analyze

At the beginning of the process, extensive research is needed on the facts and figures. Then through this data we have to find the best way to solve the problem. In other words, here are two steps ahead:

Problem Acceptance: Designers are responsible for the project and finding solutions to existing problems. Achieving this goal can best be guaranteed by using the resources available.

Analysis: At this point, the design team begins researching and collecting relevant data to find a solution.

2. The general idea

Once the problem and the appropriate solutions have been identified, the final solution must be selected and defined in detail. Also, the different aspects of the solution should be implemented in a way that meets the needs of the customer. One of the first steps in this step is to define:

Definition: In this step, the design team identifies the main problem (s) and provides the information needed to define the problem and objectives. This is done through activities such as removing sub-factors and finding the factors that require change.

3- Combination

At this point, solutions are transformed into ideas, and the best of them is the markup. These ideas form the prototypes on which real products will be built. This step is divided into four steps:

Ideation: At this point, different ideas and solutions pop up. You can come up with the best set of ideas when you do not stand against different ideas and judge without prejudice.

Choosing: From the ideas presented, the one that has the best results must be selected. In this step we can design the production program.

Implementation: In this step a prototype is generated and the program is executed experimentally.

Evaluation: Finally, the prototype should be tested and the necessary corrections made. If the prototype performance process was based on predictions, additional ideas could be implemented.

Product Design Steps

1. Design Summary (design statement)

The summary of the Design guides us by outlining the main purpose and identifying the problems. So the design team can see it as a starting point. In any case, the design summary alone does not provide useful information on how to begin the design process.

2. Product Design Description (PDS)

The description of the product plan is a very important and often overlooked step that is often overlooked and misunderstood. Before working on devising a solution, we must have a deep understanding of the problem identified. The information in this section should be collected after talking to the customer, market analyst and taking into account existing competitors. In the next steps, the design team should refer to this information for efficient guidance.

3. Outline ideas

Now the design team is starting the solution with the help of the information from the previous step. At this point, the design is more conceptual; we welcome the next step with details of the main components. The details at this stage depend on the type of product being designed, so understanding the product-related aspects is important. These aspects may include activities such as production, sales and production costs. This initial understanding of the value of the rework chain and reduces or eliminates overwork.

At this point it is necessary to know the general idea and evaluate it. Among the many ideas, identify each product that meets the needs outlined in the previous steps, and then evaluate them to find the best option.

4. Choose from outline ideas

At this point, the design team may need to consult with more people to review details of ideas gained from previous steps. In this regard, the best group that can benefit from their feedback includes experts from various disciplines who will be very effective in providing creative ideas and solutions. We should encourage everyone to come up with ideas and thus increase the likelihood of innovation.

5. Evaluating the overall idea

Among these potential ideas, the design should be selected to meet the product characteristics obtained in the previous steps. This is a prelude to future decisions on the final plan. Here again, a team of experts from different backgrounds must gather to evaluate all aspects of the project. Now the idea that is closest to solving the identified problem and responding to the most needs of the plan is being expanded in detail.

6. Detailed Design

At this point the final idea is chosen. The complexities are simplified and the idea is designed with the necessary details, dimensions and features. At this stage, production of one of the prototypes will probably be necessary to test the original product. At this point, it is important for the design team to work closely with other units such as production and computing to ensure the correct implementation of the production and supply aspects.

7. End the repetition of product design steps

The above steps are usually repeated several times. But by asking these questions you can reduce the frequency of repeating the steps above:

Production: Can we make the product with the available features?

Sales: Can we produce what the customer wants?

Shopping: Are the components required or do we have to order them?

Cost: How much does it cost us to build this project?

Transportation: Are different dimensions of the product suitable for existing modes of transport? Do you need a particular way of transportation?

Breakdown: How will the product break down at the end of its life?

Factors affecting product design

1. Cost

One of the biggest factors affecting product design is the cost of production, which includes the cost of raw materials and manpower. These costs affect pricing policies that must be consistent with the value of the product to the customer.

2. Adaptation to human needs and characteristics

The product should be user-friendly and comfortable with its performance. According to human standards, small and large changes in product design may have to be made to meet basic needs.

3. Materials and raw materials

Making the materials needed to be easily accessible is critical to product design. In addition, you should not overlook new developments in technology.

4. Customer needs

An important and defining factor in designing a product is its customer and needs. Capturing the customer during the theoretical and planning stages is as important as motivating them against any prototype. Even if the need to use advanced technology and add exciting functionality to the product reduces interest and also creates negative emotions in the audience, it should be avoided.

5. Factory (Brand) reputation

The factory's reputation is a source of pride, though, so it may be necessary to design a particular product or color combination and its capabilities to suit that reputation. The company logo may need to be affixed to the product for specific purposes in a subtle or subtle way. It may be necessary to incorporate the capabilities that the plant's reputation depends on in design.

6. Aesthetics

Depending on the situation, the product may need to be fashionable or in a certain shape to reflect the technology of the product. It may also affect the anticipated production process.

7. Fashion

Trends and fashion trends also influence the design of some products. Product design should take into account that customers want the most up-to-date products.

8. Culture

If the product is designed for a market with a particular culture, you have to keep this in mind during the product design process. A product that is acceptable in one culture may be considered offensive in another and may not be attractive to a different culture.

9. Performance

What problems is the product going to solve? The performance and usage of the product affect its design.

10. Environment

Another consideration when designing a product is its impact on the environment. Most consumers today are more aware of and care about environmental issues than ever before. The recyclability of the materials used, the way the product decomposes after its expiry date, and the way it is decomposed into packaging are some of the things to consider.

Essential considerations in product design

Product design is a complex process. Because each investor has a different expectation of the product. Examples of complex expectations that need to be considered in product design are:

1. Economics

The purpose of the manufacturing sector is to produce the product at the lowest possible cost to maximize its profit and ensure product sales. A product that will inevitably be produced at a high cost will have a higher price and make customers flee. This dilemma often results in redesigning the product and reducing its quality.

2. Price, appearance and fame

The customer is always looking for a famous, functional, yet attractive product. It also wants the price of the product to be reasonable. Appearance may not be as important as performance, but if there are several other similar products on the market, the appearance of the product will be a factor.

3. Performance

The efficiency and productivity of the product must also be given due consideration. Certainly the product should have a return on the value stated above. The audience may buy the product because of its side features or appealing appearance, but the satisfaction and survival of the sale will only occur when the product has the highest return.

4. Repair and maintenance

Product designers, manufacturers, and maintenance workers like products made from smaller parts. The simpler the independent parts of the product, the more flexible the product will be, so the original parts can be changed if needed to redesign the entire design; the manufacturer can easily remove the problematic factors without altering the entire production process. Maintenance is slow and there will be no need for maintenance workers to separate all parts and save time on repair.

3.2 Sustainable Design

During the last 200 years, humans have created new tools and inventions that have arguably improved the quality of human life, decreased infant mortality rates, and increased standards of living. This in turn has caused a dramatic increase in the global population, resulting in the destruction of habitats, pollution of the environment, and the extinction of many species of plants and animals. By the late twentieth century, some designers saw that the current path of humanity was unsustainable and began to focus on devising strategies for creating a more sustainable approach to product development. The concept of sustainable design is still in a formative stage but is a growing concern among design professionals. A lynchpin of sustainable design is the concept that the needs of business (profits), the needs of people, and the needs of the planet are not mutually exclusive. [21]

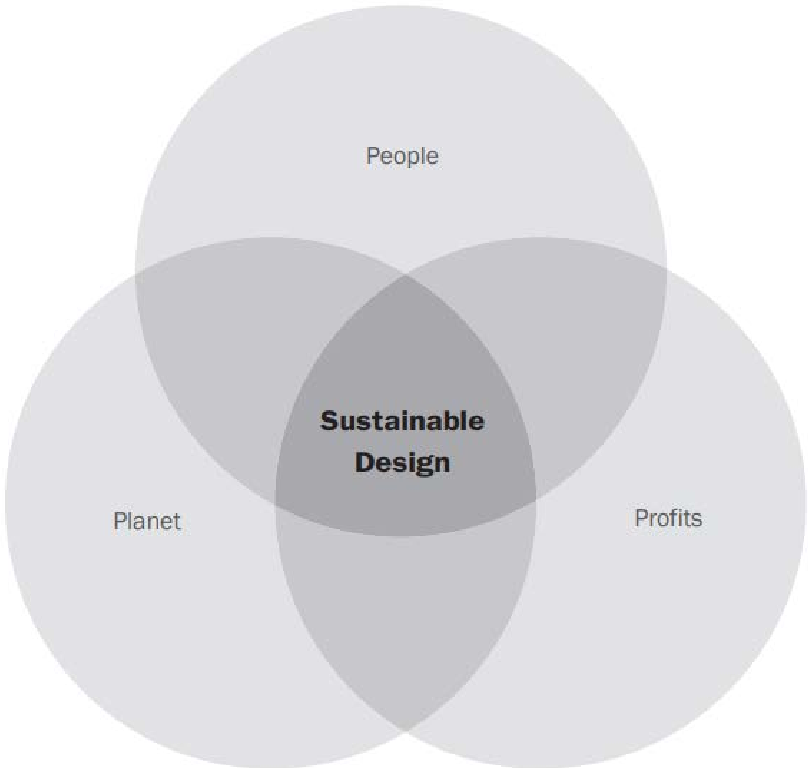


Figure 30. Sustainable design takes into account the health of the planet, people, and company profits.

The Product Life Cycle represents every stage in the creation and use of a product. Understanding the overall cycle dramatically increases the opportunities to address sustainable issues. [21]

1. **Material Selection**: What are material options? How has the material been extracted or processed? Is it biodegradable, recyclable, recycled, durable, non-toxic, lightweight, and renewable?

2. **Component Manufacturing:** Are environmentally sound practices employed? Are materials and resources used effectively and efficiently? Is production waste minimized or eliminated? Are fair labor practices observed?

3. **Packaging:** Is packaging effective and efficient? Are materials reusable or recyclable? Does the packaging inform the user and is it easy to interface with?

4. **Distribution:** Have weight and bulk been minimized? Can production happen locally? Is the most effective transportation system being used?

5. **Installation and Use**: Is it intuitive and useful? Is it safe? Have the ergonomics been improved? Is it modular or multifunctional? Is it upgradeable and customizable? Are consumables minimized? Does it efficiently use energy resources? Is emission-free or low emission? Is it durable and repairable?

6. **Disposal:** Has it been designed for disassembly? Can it be taken back to the manufacturing source (for recycling, reuse, or remanufacturing)? Can the materials be selected for the design of a new product?

In each stage of the product life cycle, the opportunities to address sustainable issues are numerous, as are the advantages for business. For example, lightweight materials mean lower shipping costs, a healthy workforce is more productive, less packaging lowers costs, useful products build customer loyalty, and reuse of materials lowers raw material cost. Clearly, sustainable design is compatible with profitability. Taking responsibility and effectively planning is necessary for manufacturers, and designers have the ability and responsibility to assume the role of champion for sustainable issues. [21]

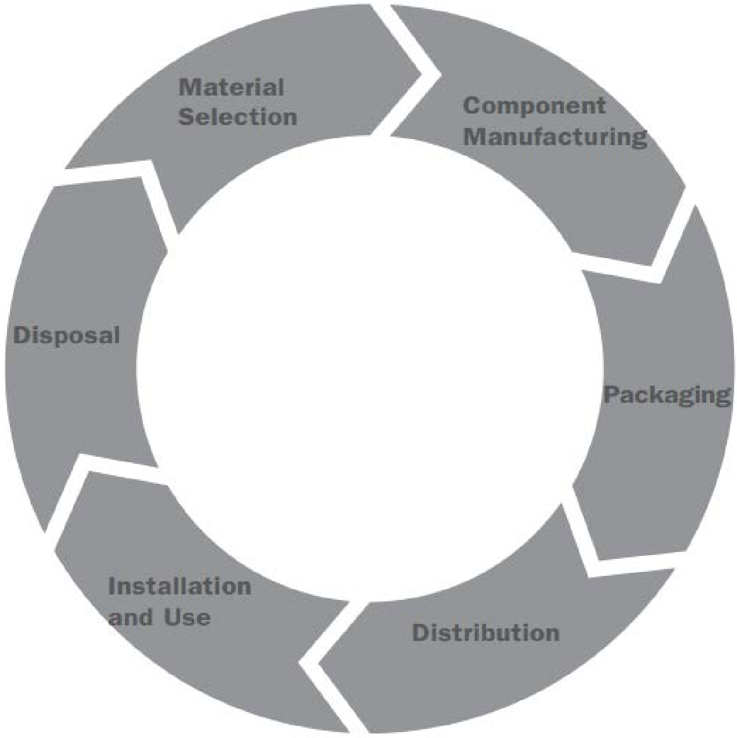


Figure 31. The Product Life Cycle info-graph.

3.2.2 Human-centered design (HCD)

Design is a complex process that is shaped by different patterns and many factors in mind. During the correct design process, one of the most important things to do. Based on this, there are generally three types of process patterns, including technology-based design, human-centered design, and environmentally sustainable design.

These three templates are used for product or service design. At different stages of human-centered design, human needs and constraints are prioritized over other types of design. In this model, designers must, besides analyzing and resolving the existing problem, also design and accept a product or service designed to achieve the goals set in the real world. This pattern will lead to a concept called empathy design.

Another definition for the human-centered design process is presented. Human-centered design is an approach that makes designing and deploying interactive systems more effective by applying human and ergonomic factors and the operation of science and technology.

The term human-centered design is user-centered design, derived from Donald Norman's research at the University of San Diego in California in the 1980s, and is described in a joint book entitled "User-Based Design: A New Perspective on Human-Computer Interaction." In a research article by Joseph Giacomic of Brunel University, six features of human-centered design are presented as follows:

- Adopt multidisciplinary experiences and perspectives
- Understand users, tasks and environments
- User-centered evaluation based design
- Attention to overall consumer experiences
- Involve the customer in the design process
- Perform alternate and sequential processes

In the wake of the human-centered design awareness, this model's impact and performance expanded across a wide range of design models such as interactive design, user experience, empathy design and usability.

Chapter 4. Designing Vein finder

4.1 Define the Problem

As we mentioned in chapter 3, the design process starts when we have a clear idea of what the problem is: [20] [22]

- What is the problem or need?
- Who has the problem or need?
- Why is it important to solve?

What is the need?	Assistant devices for helping us to find vein location on arm during in PIVC procedure. With low cost based on our market and also with better handling and Usability.
Who has need? (User)	Physicians, nurses and paramedics who perform this procedure and patients that this procedure has been performed on them. But users of this device are Physicians, nurses and paramedics
Why is it important?	Because IVs in hospitals are one of the high-risk procedures. It can makes many problems bacterial infection, nerve damage and etc.

Table 1. Problem statement table for assistant vein finder device. [22]

4.2 Collect Information

As we mentioned we need to Collect sketches, take photographs and gather data to start giving us inspiration: [20] [22]

- Users or customers → Research our target user or customer

- Existing solutions
  - Research the products that already exist
  - Research how our product will work and how to make it

4.2.1 Target Users

Who needs?	Physicians, nurses and paramedics
Who buys?	Medical Centers or Personal customers
What does my target user need or want in a Vein Detection device?	Locates Veins on arm clearly
How much would my target user be willing to pay for a Vein Detection?	It depends on market that we face.
What size should I make Vein Detection for my target user?	The size in mobile size which means handy size in general view

Table 2. Target user research table [22]

4.2.2 Similar Products

Here we introduce 3 popular Transilluminator Vein Finder (Portable) Devices: [23]

1. **Veinlite EMS Pro – for both Adults and Children**

The device is infused with infrared waves to display all available superficial veins, allowing the nurse to select the most appropriate vein for injection. It can only be used by turning on the device and shining it on the surface of the body. It should be noted that it is free of any side effects and reduces stress during injection and because of its ease of use and portability. Suitable for use in all medical centers. You can view the veins from the V-shaped area of the head by tapping the skin on the desired location and then turning on the device. This device is free from any side effects so it will not cause any concern for the patient.

Use the Veinlite for:

- Mapping superficial veins
- Varicose veins imaging
- Identifying spider veins

Weight: 13.4 ounces

LED Bulbs: 12 orange, 4 red (near-infrared wavelength), 8 white (flashlight mode)

Power: 150W

Batteries: two AA batteries (3.5 hours of continuous use) Inside Ring Diameter: 21mm

Dimensions: 15 x 55 x 21 mm

Added Accessories in the package:

- Light shield (eye protection for the caregiver)
- 50 disposable plastic covers (to prevent cross-contamination)
- Adapter
- Carrying case that attaches via a belt clip

Veinlite pros

- Lightweight, portable and ready to use – hand-held device and comes with a carrying case
- Very easy to use
- You don't need a tourniquet.
- 5-year warranty
- Relatively low price
- Works great in dim situations

Cons

- No need for battery charger. However, even if you use it several times a day, batteries will last for at least 2 months.
- May not work for dark skin with deep veins.

Figure 32. Veinlite LEDX

The powerful LEDx has thirty-two bright LEDs embedded around its large opening.

There are 24 orange lights and 8 red. This color combination is very effective for seeing deeper veins even if the skin is thick or dark-colored.

2. **Venoscope Transilluminator II**

Fit for: adults and children

The Venoscope II is a lightweight, portable high intensity LED vein light (near infrared), with a FDA 510k approval.

It works for both adults and children – without a pediatric adapter – and is effective for the obese and dark-skinned as well.

To use it, you prepare the patient (tourniquet etc.) and dim the light a bit to a point the vein light performs best.

Figure 33. Venoscope Transilluminator

- It works with 3 AA batteries (not included when you order).

Venoscope Pros:

- Lightweight – weighs less than 7 ounces
- It has a light indicator for a low battery so you know when to change them
- Doesn't heat too much even after 15 minutes of continuous use
- 1-year warranty
- Can be cleaned with alcohol or bleach (but do not submerge it)
- Relatively **affordable price**

Cons:

- No battery charger (but batteries will last a couple of months)

3. **Wee Sight (Best Pediatric Vein Finder)**

Figure 34. Wee Sight vein finder

A pediatric vein transilluminator is an amazing tool to decrease babies' and toddlers pain when drawing blood or starting IVs.

Works with 2 AA batteries.

Wee Sight Pros:

- LEDs work for years with no problem
- Small enough that can be used inside an incubator
- Lightweight; just 4 ounces
- Curved shape helps to stabilize the infant hand/foot
- can also be used for thin-skinned adults
- Works without a Tourniquet

Cons:

- Relatively pricey (for a small device) – but works as promised.

4.2.3 How Transilluminator Vein Finder Device work

In this type of device, we use visible lights we know that Red lights can absorb by Hb. Most veins carry Hb blood from the tissues back to the heart; exceptions are the pulmonary and umbilical veins, both of which carry oxygenated blood to the heart. In contrast to veins, arteries carry blood away from the heart. So Hb in the blood absorbs red light; so when we use the device above the skin, veins appear in contrast to surrounding tissue. A clinical study with one such a device, the Veinlite™ vein finder, showed us that accuracy of device is 85% compared to 74% with the standard method. This device is effective in children and they can use in emergency of hospitals. [17].

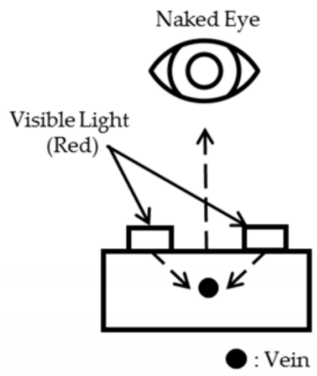


Figure 35. Penetration method using Red light to locate vein

4.2.4 Specify Requirements

Design requirements state the important characteristics that your design must meet in order to be successful. [22]

One of the best ways to identify the design requirements for your solution is to use the concrete example of a similar, existing product, noting each of its key features. [22]

Now we analyze Venoscope Transilluminator Device as sample model for our design. First we start with "Needs" table.

Major Needs	**What is Essential to Meet the Need (Possible Design Requirements)**
Device must **locate veins** (superficial veins)	Short wavelength light (Red LED) can penetrate through skin and absorbed by deoxygenated hemoglobin in venous blood and show up as dark areas on the skin.
Device must have **good handling** that can use by one person during PIVC	Mobile design, ergonomically design, easy UI for users, using simplicity design concept as mentor for our design.

procedure and easy to use and maintenance	
Energy consumption	3 scenarios we have for this issue: First, using Urban Electricity network so we need adaptor and specific design for it. Second use disposal battery Third using battery charging system (Charging capability)
Price of device must be low (economic)	For this issue 2 important issues we need to consider; First; Design of device Second; production (such as materials, methods , …)

Table 3. "Needs" table for Vein detection

Now we want to analysis structure of Venoscope Transilluminator Device (Venoscope II | VT03). First we identify every individual piece of the product on the picture and then draw the “Product Analysis” table.

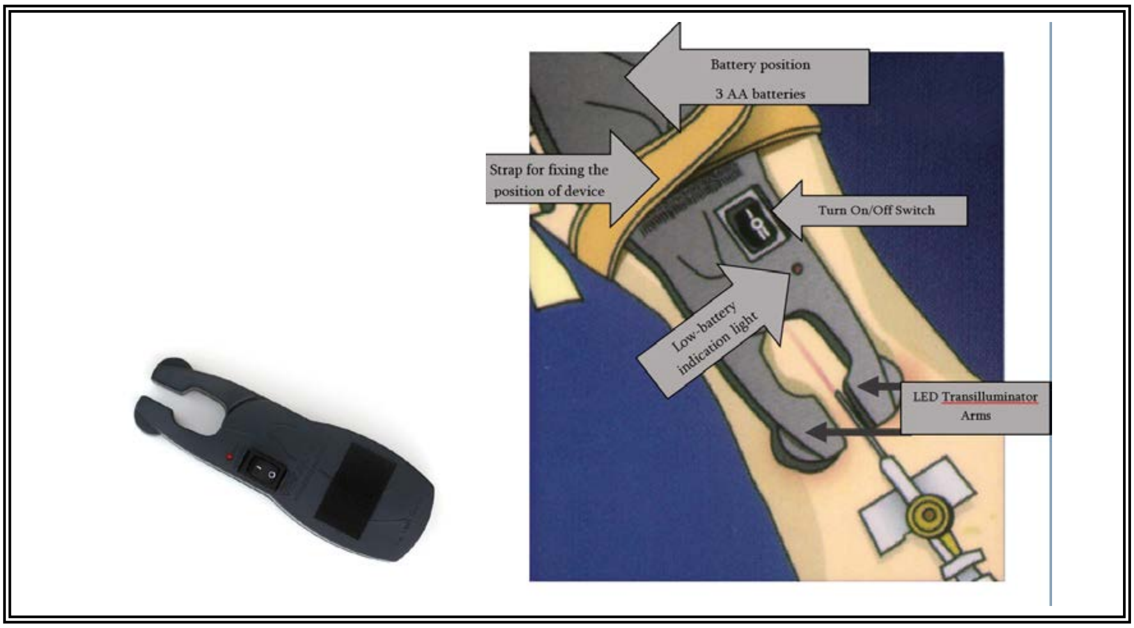


Figure 36. Identifying every individual piece of the product Venoscope II | VT03.

Feature	Function: Purpose of Feature
Main Body structure	Batteries place, surface for using Strap to fixing the device, place for other components (Switch, light, …)
Turn On/Off Switch	Turn On/Off device when we need it.
Low-battery indication light	To light up and alarm when the batteries are low to replace them with new ones.
LED Transilluminator arms	Illustrate Red LED light to locate Veins as a shadow line between two arms.

Table 4. "Product Analysis" 1.

An Essential Feature	LED Transilluminator arms (part)
A necessary Function	Illustrate Red LED light to locate Veins as a shadow line between two arms.
features that competes with other Products (competitive features)	Body structure design + Power supply = Economic design

Table 5. "Product Analysis" 2.

4.3 Brainstorm and Analyze Ideas

There are different structures for transilluminator vein finder, we categorize and name them into 3 categories;

1- U type: LED Transilluminator arms, Illustrate Red LED light to locate Veins as a shadow line between two arms, 1. Venoscope Transilluminator II

2- C type: LED Transilluminator in round shape, Illustrate Red LED light to locate Veins as a shadow line inside illuminated round surface among the LEDs.

3- I type: LED Transilluminator, Illustrate Red LED light to penetrate thin skin and locate Veins as a shadow line.

In figure 37. You can see sketching of preliminary ideas, after different consideration first we work on U type the main reason is because we can use only 2 LEDs for illumination and this design can give us to consume less energy and increase the durability of batteries. But the main problems of this type of device is that functionality of this device it is too hard to make difference between fake shadow and vein shadow. Here are some Challenging issues that we face during design process of device

1- Ergonomic Handling

2- Consume less energy

3- LEDs illumination (using less LEDs and more illumination)

4- Minimal and Sustainable Design

5- Economic price (cost effective)

6- Ease of use (Human-Centered Design) and maintenance.

Another problem about TI (Transilluminator) vein finder devices is that these devices work on dim light condition. The more we dimming the light, the better visibility of veins we will get. In dark room the quality of visibility of vein is maximum. But for nurses and paramedics that do the IVs it is not comfort and sometimes it is not possible to controlling the light of the room the practical work that they can do is to darken the room, but in dark room doing the IVs procedure is too difficult. So for this problem we think about 2 options;

1- Separate the procedure of finding the vein and doing the IV procedure: In this method first we dim the light or it is better to darken the room and find the vein then by using Medical Sterile Pen or Marker sign the location that we want to do IV then we can turn on the light and do the IV procedure.

2- The Second method is that using dark box to make regional darkness. You can see the conceptual idea about this. In this method we don’t need to dim the light of the room but disadvantage of this method is about Dark box part that can increase the elements of Vein finding operation and can make some cost for us.

We choose the combination method and strategy in our design, for this purpose we consider another design and structure for our device that we call it OC type of device. In this structure LEDs (in our work 4 red light LEDs) form in a complete circle and a little gap for injection access. So in this structure we can find vein inside the circle and then mark it with medical pen or doing injection procedure in real time.

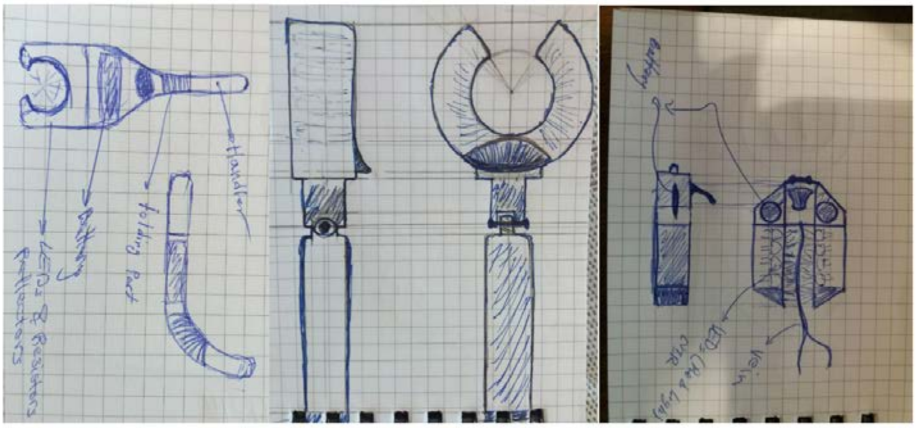


Figure 37. Sketching of preliminary ideas.

Figure 38. 3 types of Vein finder (from left to right); U type - Venoscope Transilluminator II, C type – Veinlite, I type - Wee Sight.

Chapter 5. Results

5.1. Overview of Optical Vein Detection System

5.1.1 Visible Light Transilluminator

In this type of device, we use visible lights we know that Red lights can absorb by Hb. Most veins carry Hb blood from the tissues back to the heart; exceptions are the pulmonary and umbilical veins, both of which carry oxygenated blood to the heart. In contrast to veins, arteries carry blood away from the heart. So Hb in the blood absorbs red light; so when we use the device above the skin, veins appear in contrast to surrounding tissue. A clinical study with one such a device, the Veinlite™ vein finder, showed us that accuracy of device is 85% compared to 74% with the standard method. This device is effective in children and they can use in emergency of hospitals. [17].

5.1.2 Near Infrared (NIR)

Spectroscopy

In this method we use near infrared light (700-900 nm) they can penetrate deeper than visible lights. In this type of device, we can see veins on monitor or in some models they can project pictures on our arms. [17]

5.1.3 Structure of Device

The device has 2 main parts;

1- Rounded Section: Rounded circle structure that Red LEDs for illumination locate on that part.

2- Battery Section: we will use 3 volts' coin cells batteries for powering device.

3- Illumination Adjustment part for changing the intensity of light. (This is optional)

5.1.4 3-D Model of device

Model 1: BVF-O

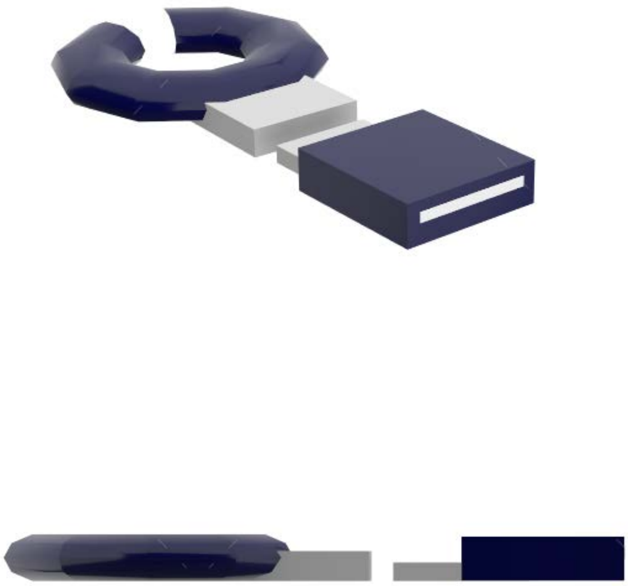
Here we represent our conceptual 3-D model for device. Device must have minimal structure small and portable. In Figure 39 we can see 3-D model of device from different perspectives.

- The size of device is something about 4 ^{cm} * 6^{cm}.
- The diameter of field of view (FOV) is about 1.5~1.6^{cm}.
- The best color for device is black because it has less reflection so it cannot be distracting our eyes.
- If we connected Led$_s$ in series structure, we can use max 4 led$_s$ with two coin batteries (each 3 volts).
- If we connected Led$_s$ in parallel structure, we can use (base on physical constraints of device) max 12 Led$_s$.

Figure 39. Conceptual 3-D model of device (Model BVF-O). (Design by https://www.vectary.com)

Model 2: BVF-OC

In this model we have one important advantage we separate power source from transillluminator part. In this case we can change the color of LEDs by choosing the corresponding transillluminator part. The size and specifications of this device are also similar to previous model, just we can separate power source from transiluminator part. Here we can see the conceptual design of BVF-OC model.



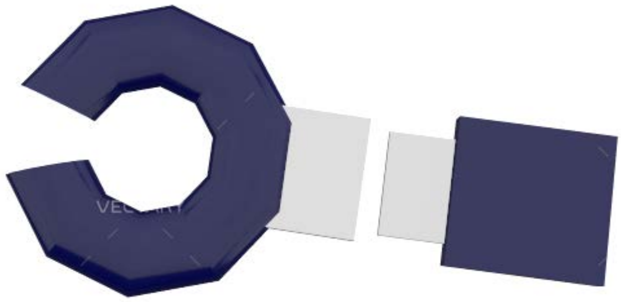


Figure 40. Conceptual 3-D model of device (model BVF-OC). (Design by https://www.vectary.com)

5.2. Experimental Part of Designing Device (Scientific Part)

5.2.1 Illumination Design in Transilluminator Vein Finder

As you can see in Figure 41. Larger spot size enables greater depth of penetration.

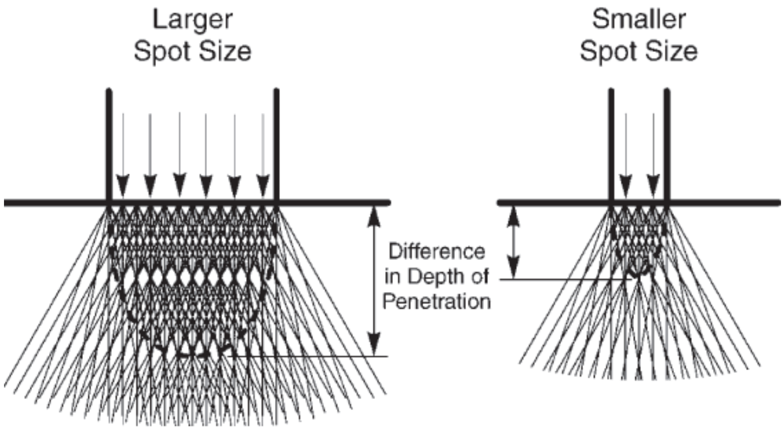


Figure 41. Depth of Penetration based on spot size.

So if we want to have deep and better illumination we can use larger spot size LEDs or use optimal and sufficient numbers of smaller size of LEDs in proper design. In our experiment we use two 10 mm LEDs (Figure 42.)

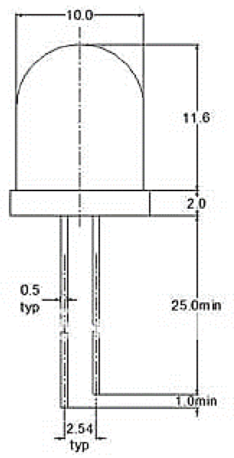


Figure 42. 10 mm LED dimension specifications.

Method of Experiment: in Figure 43. we can see the method and structure design of our experiment. We use penetration method Side-transillumination using Red LEDs, so the vein must be visualizing as a black shadow. [33]

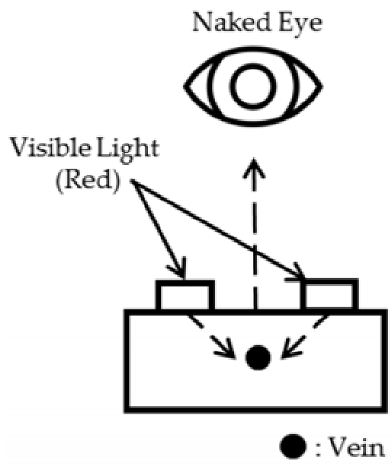


Figure 43. Method of experiment: penetration side-transillumination method using Red light.

Equipment of experiment:

- 10 mm red diffused LED
- Camelion Lithium 3v Battery, CR2032

Results and discussion:

1- Illuminating skin without using of led peripheral cover: in Figure 45 you can see the result.

Figure 44. Length between two black indicators is 1 cm.

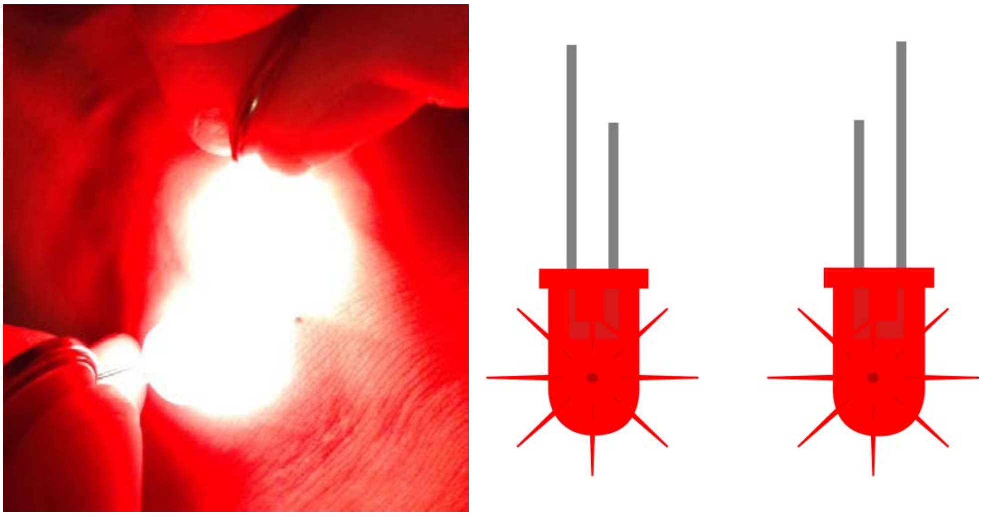


Figure 45. Illumination of skin with 10 mm diffused red LED without cover.

2- Illuminating skin with using of led peripheral cover: in Figure 46. You can see the result.

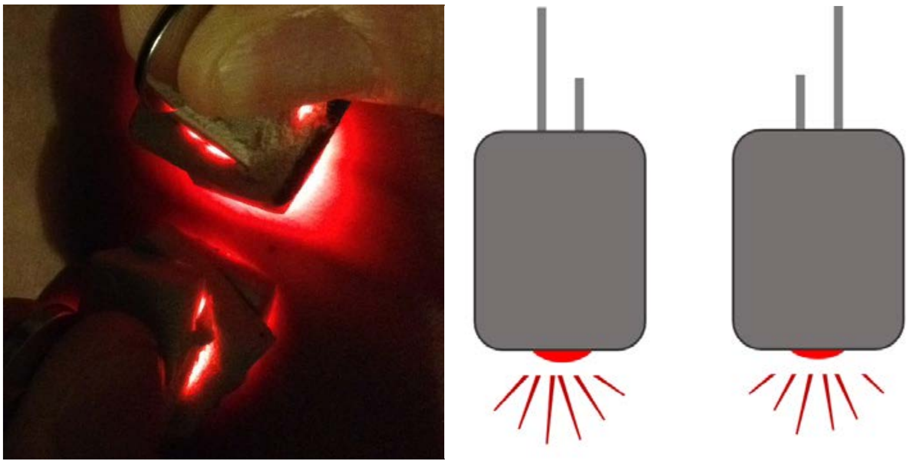


Figure 46. Illumination of skin with 10 mm diffused red LED with cover.

Result: we know base on theory deoxygenated hemoglobin (Hb) absorbs more light compare to oxygenated one (HbO2) in Red light region but first light must be reach to the Deoxyhemoglobin (Hb) in veins so the important thing is that fake illumination which means reflected light from upper part of skin can distract our vision and give us so shiny visualization that we cannot see the vein in the form of black shadows. So we need to see those reflection of light that can reach the vein and then reflected to our eyes so 3 types of lights can distract our eyes: [33]

1- Peripheral light in environment.
2- Upper skin reflected light (before reaching veins)
3- Directed light from LEDs to our eyes.

So the best situation is that we use this type of device in dim (dark) room and by using peripheral cover and proper design prevent types 2,3 (distraction) lights that we mentioned above. [33]

5.2.2 Wavelength of LEDs

We use two type of light that we can find in Georgian Market;

1- Yellow light (LD05-Y HU-FLAT 2500.MCD 30`); this type of Leds have 2500 MCD illumination and because of having flat structure it has good practical application in our work.

2- Red light (LD05-R HU-FLAT 2500.MCD 30`); same as a yellow one flat structure with 2500 MCD illumination.

Figure 47. Leds that we use (https://dac.ge/)

The differences between yellow and red light is that for seeing branches of veins or narrow vein we can use yellow light but for deeper veins we can use red lights. The quality of veins in yellow light is better than red one; we can see the border of veins with surrounding tissues better than red light also shallow veins or surface tiny veins we can see more clearly. But in practical application red light is more applicable than yellow but in some cases with tiny veins we can get better result with yellow one.

5.2.3 Prototyping

3-D Pen

What does 3Doodler do?

It is a three-dimensional painting tool. Imagine that a thermal glue gun uses plastic strands instead of glue. Whenever you press the button, the hot plastic is extruded from the tip of the pen. It allows you to paint in the open space and create 3D objects. It uses two type of material;

- Acrylonitrile butadiene styrene ("ABS"),
- Polylactic acid ("PLA"),
- “FLEXY”, thermal polyurethane (“TPU”)

We use 3-D pen for making our prototype. The advantages of this method is that it is faster than 3-D printer and we can have direct interaction between our conceptual design in our mind and what we make in reality.

Figure 48. 3-D pen

Making Bio-photonic Vein Finder

Here in figure 49. you can see our prototypes. For yellow Transilluminator we use 8 leds and for red one we use 7 leds. Also for yellow one we use magnifier for better visualization of tiny veins.

Figure 49. BVFs prototypes (from left to right); Power source, Red arm, Yellow arm.

Figure 50. Red arm attach to power source, reedy to use.

Figure 51. Red arm attach to power source, reedy to use.

Figure 52. Battery that we use; CR2032 Lithium Battery.

5.2.4 Testing the Device and analyzing the results

Contrast is the difference in luminance or color that makes an object (or its representation in an image or display) distinguishable. In visual perception of the real world, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view. The human visual system is more sensitive to contrast than absolute luminance; we can perceive the world similarly regardless of the huge changes in illumination over the day or from place to place. The maximum contrast of an image is the contrast ratio or dynamic range.

As you can see our goal in BVF devices is make distinguishable contrast between vein and sounding tissues so we can see vein as a dark shadow in FoV region. We test on more than 20 cases. For 15 case we took picture before using device and after using device. For Red light we can visualize deep vein (not more than 5 mm depth) as a Blur shadow. For yellow light we can see clear shadow with clear border but not so deep. We can say that for more wave length (λ) we have deeper penetration but lees quality of visualization or it's better to use image sharpness/blurriness factor. We can say that;

λ (wave length) α d (Penetration)* σ(Blurriness factor)

It seems that base on testing on different person both of lights can be use but in some cases with tiny veins yellow light work better than red one. We cannot find any specific pattern between BMI of person and color of light for finding veins. About skin color definitely in white color it is easier to find veins because of contrast of veins with surrounding tissue even without using device but the main factor is vein pattern of arm. In some cases, vein pattern is in deeper part of skin so we need to dim the light and try to find a deep blur shadow that has a signaling fluid behavior. How we can distinguish between fake shadow and true one is that true shadow has a behavior like fluid it is disappear and appear light fluid flow. Fake shadow appear and disappear instantly. We can say that true shadow is flowing and fake ones are moving instantly. The reason is that the true shadow is result of absorbing the light by Hobs and Hbs are flowing in veins. Here we can see some of the results when we use BVF device.

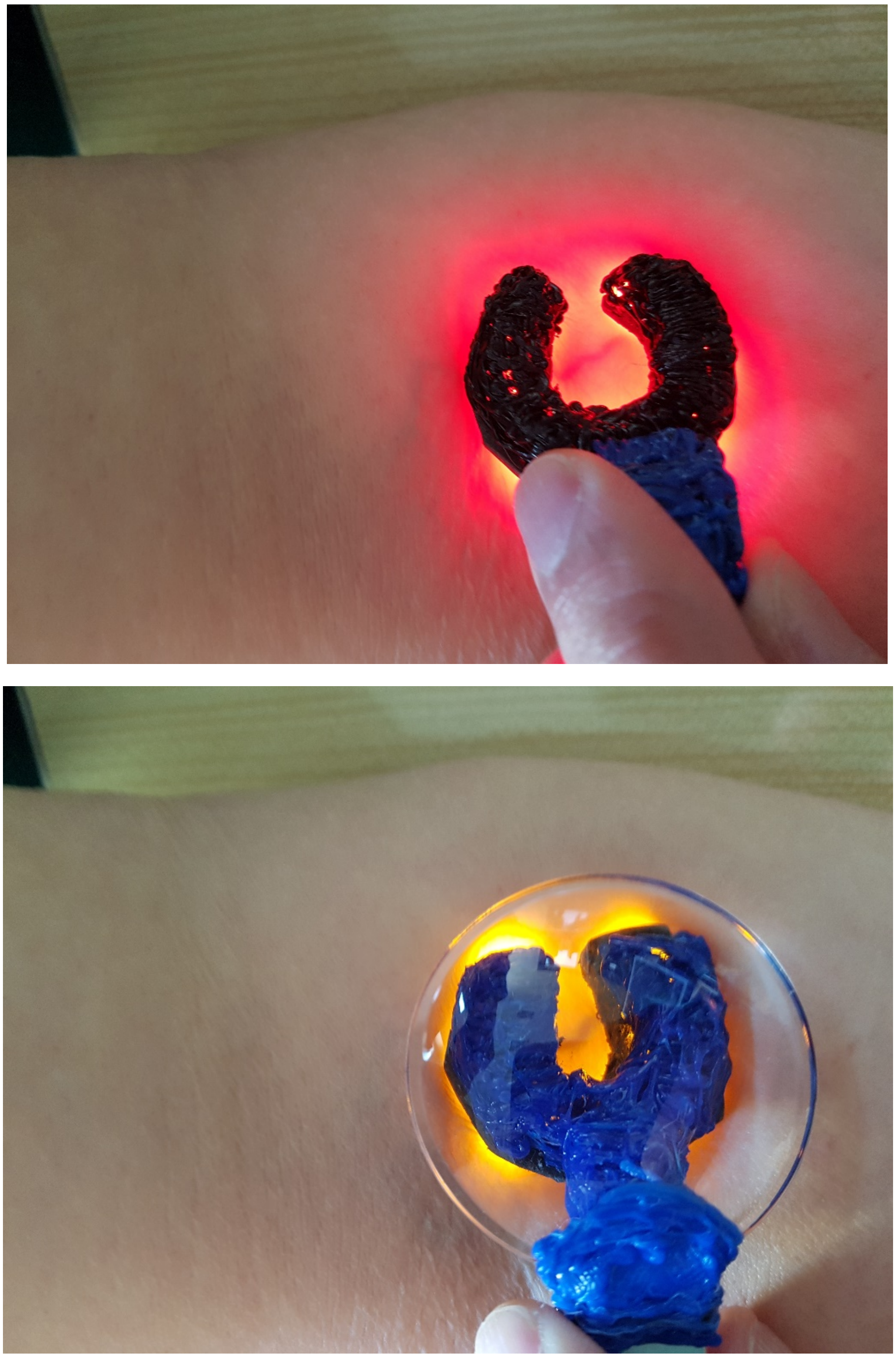


Figure 53. Using yellow lights (BVF_Y) (Top) And Red lights (BVF_R) (Down), Sf/W, A61, W100, and H157.

Figure 54. Using yellow lights (BVF_Y), Sf/W, A27, W55, and H167.

Figure 55. Using yellow lights (BVF_R), Sm/WB, A19, W130, and H182.

Figure 56. Using yellow lights (BVF_R), Sm/WB, A19, W130, and H182.

Figure 57. Using yellow lights (BVF_R), Sf/W, A55, W58, and H157.

No.	Skin color	Sex	Age	W (kg)	H (cm)	Result (O= done N= cannot find)
1	w	M	21	74	175	O
2	w-b	M	45	61	165	O
3	w	F	52	100	170	O
4	w-b	M	19	75	184	O
5	w-b	M	19	75	172	O
6	w	F	61	100	157	O
7	w	F	51	67	157	O
8	w	F	33	43	159	O

Table 6. Data of testing device on 8 cases as example

5.3. Other Devices

Now we want to compare the results of our Visible Light Transilluminator (VLT) device with NIR spectroscopic camera and then represent our new idea to make NIR vein sensor with minimal design and then compare results also respect to the NIR camera and VLT. Firs we look at the structure of our NIR camera and how we did experiment.

5.3.1 NIR Camera

At figure 58. You can see the schematic of experiment we use 4 NIR LED-5mm. (You can see technical data shit of this type of NIR LED on this site: https://dac.ge/pdfs/02614.pdf

Here at figure 59 you can see the results of using NIR spectroscopic camera method to obtain vein location on forearm.

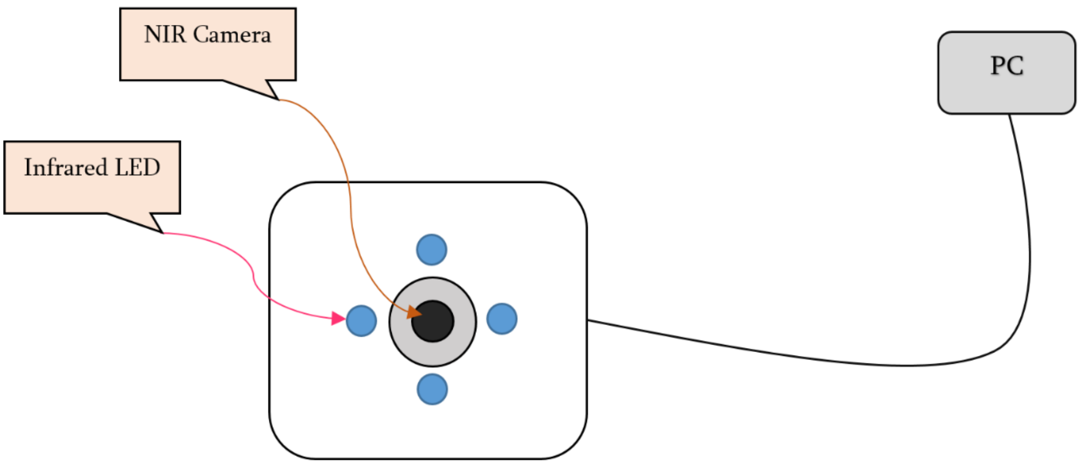


Figure 58. Structure of NIR camera system

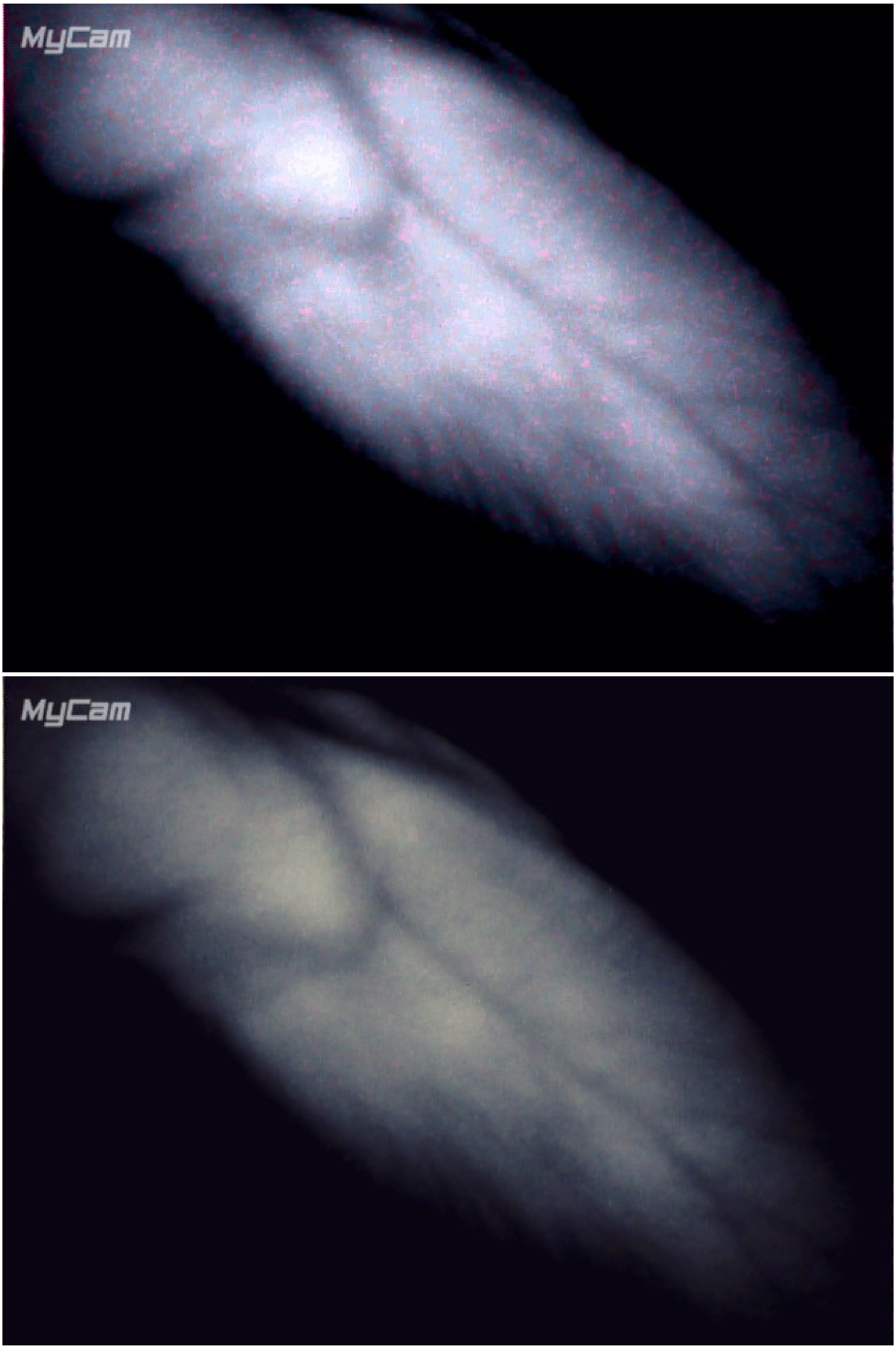


Figure 59. Results of using NIR spectroscopic camera method to obtain vein location on forearm, using different filters.

5.3.2 IR Phototransistor vein detection device

Here now we represent our method to detect vein through using IR Phototransistor and compare it with visible transilluminator device.

The main idea is that veins can absorb more infrared compare to its surrounding tissues.

A phototransistor is an electronic element that relies on light as the gate control mechanism and current regulator. Most phototransistors are made in the form of a bipolar transistor, meaning that the base-collector-emitter structure is used. The main difference is that the base semiconducting material is designed so that it is sensitive to a light source. As photons enter into the base structure, they are converted into a current flow that acts as the BJT base current that acts to enable the transistor.

The phototransistor is housed in a transparent casing to allow for easy light passage. Often, they have casings that help to enhance and focus light entry to the critical and sensitive components of the transistor. When the base current is formed from light entry, this allows a large amount of current to pass from the emitter to collector.

Since light acts as a switch in the case of a bipolar phototransistor, these devices are used in many electrical circuits that have important light sensitivities. This could include fire alarms and computer equipment like CD players or infrared devices.

In this method we use one IR Phototransistor that is sensitive to IRs and one IR Leds as a light source. In figure 60 & 61 you can see circuit diagram and structure of device respectively.

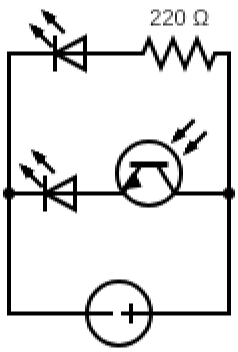


Figure 60. Circuit diagram of IR Phototransistor vein detection

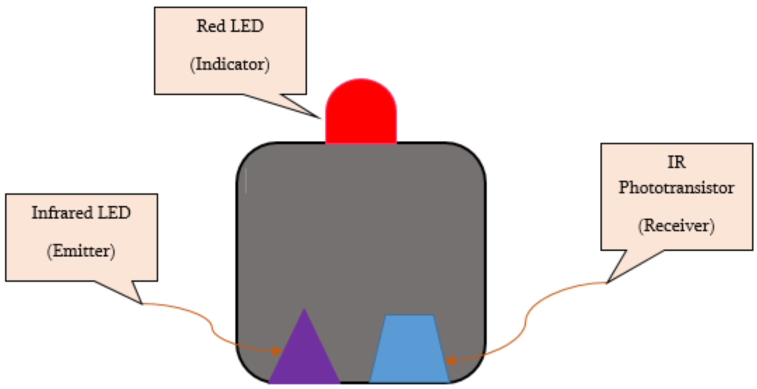


Figure 61. Structure of IR Phototransistor vein detection device

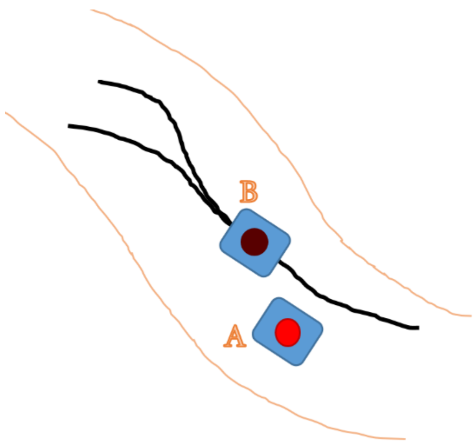


Figure 62. Procedure to find vein.

As you can see in figure 62. when we put device on the top of the vein position because most of IR radiation is absorbed by vein, so we have less current between collector and emitter of phototransistor and the intensity of indicator LED decreases. In figure 63. You can see the results of IR Phototransistor vein detection on forearm and leg.

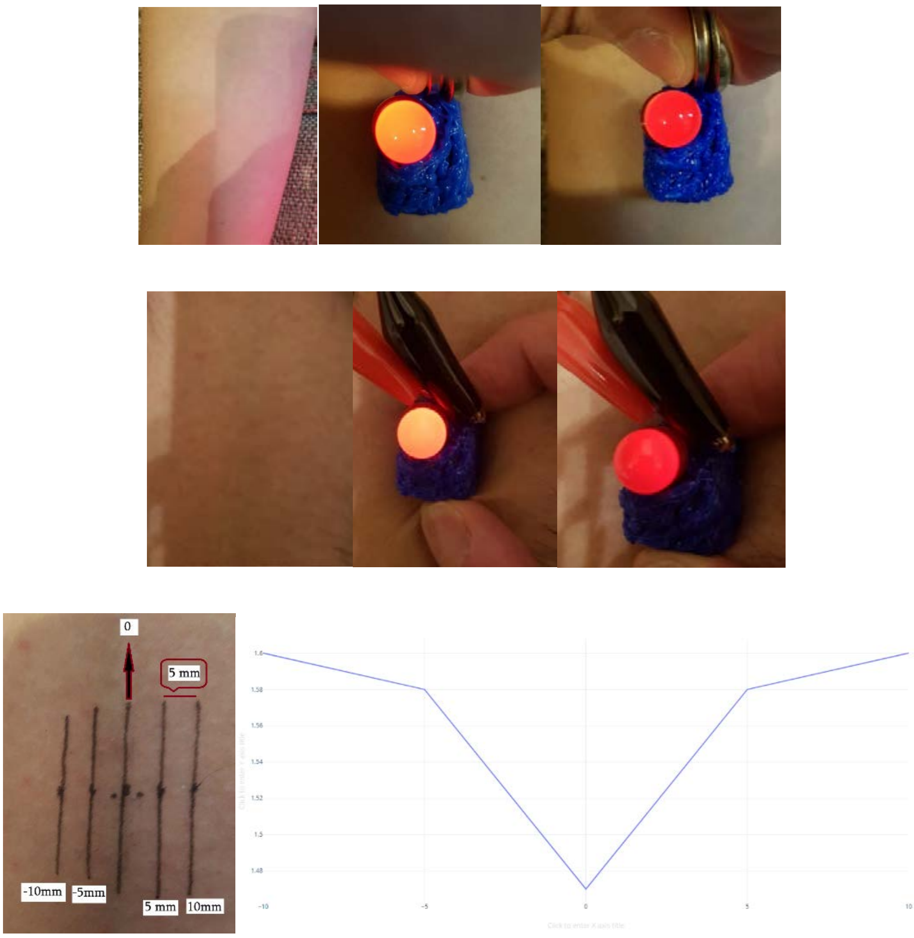


Figure 63. On the top is a forearm of a female and at the middle there is a leg of a male case. From left to right; Left: Without using device, mid: using device in a place that there is no vein (we use is as a reference indication), right: when us put device on the top of the vein (as you see the current and following that the intensity of indicator decreases. At the bottom Left: we set vein as a zero point (X=0) then each 5 mm away from vein in both side we check the device and measure voltage drop across the indicator LED. Right: Voltage drop across the indicator led vs. location of device from vein. As you can see at zero points the voltage drops from 1.60 v (reference point) to 1.47 v which means veins absorb more IR so less IR can reach to photo-sensor.

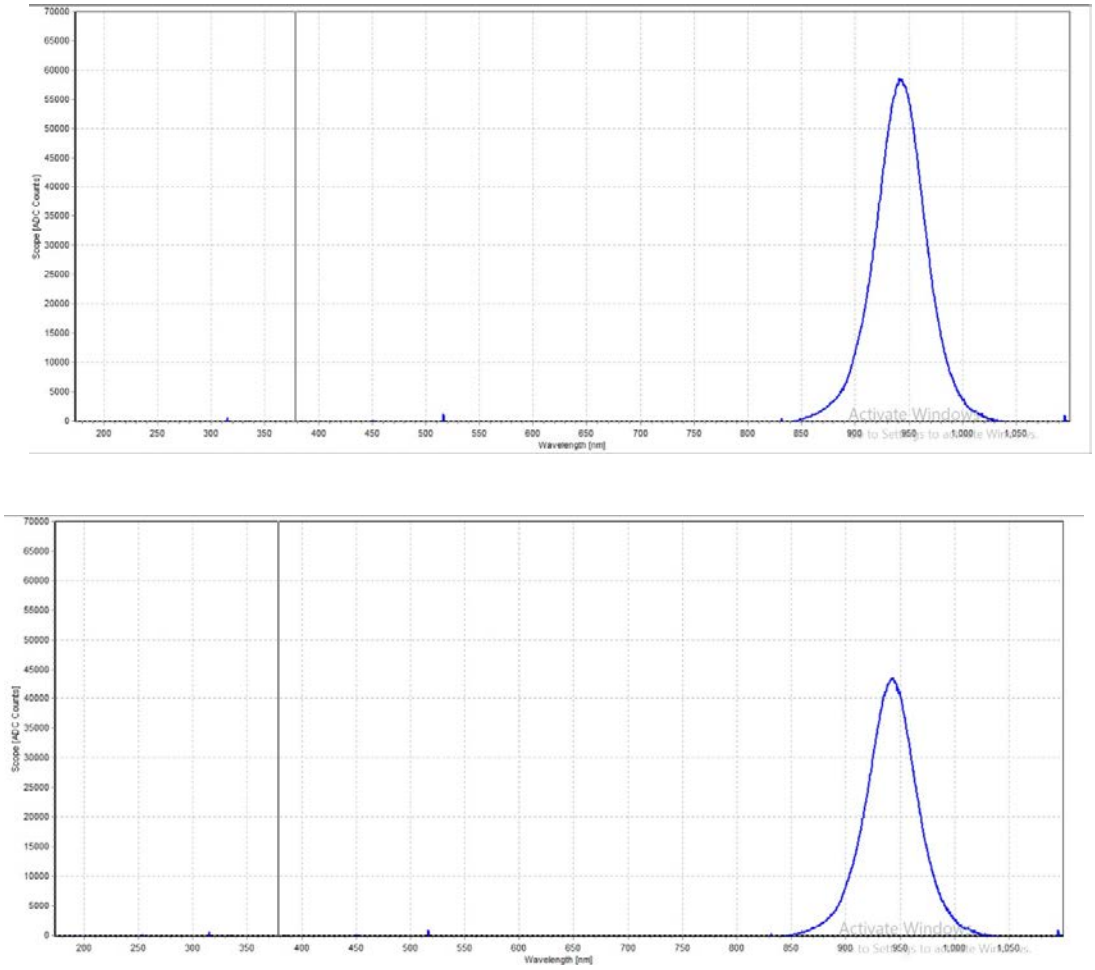
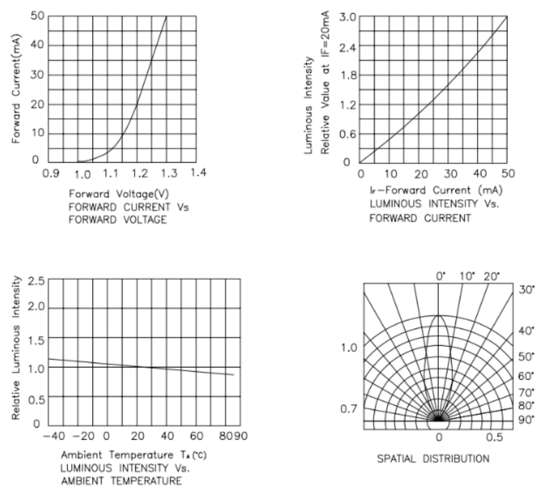


Figure 64. Spectrophotometry of IR LED that we use in our devices as a source when we applied 20 mA (up) and 15 mA on its leads. As you can see we use NIR around 940 nm as a source light. (Measured at Vladimir Chavchanidze Institute of Cybernetics of the Georgian Technical University).

L-53F3C, L-53F3BT



Item	Symbol	F3&SF4	SF6&SF7	Units
Power Dissipation	Pd	100	100	mW
Forward Current	I_F	50	50	mA
Peak Forward Current	I_P	1.2	1	A
Reverse Voltage	V_R	5	5	V
Operating Temperature	Topr	-40~ +85	-40~ +85	°C
Storage Temperature	Tstg	-40~ +85	-40~ +85	°C

Notes:
1. 1/10 Duty Cycle, 0.1ms Pulse Width.
2. 4mm below package base.

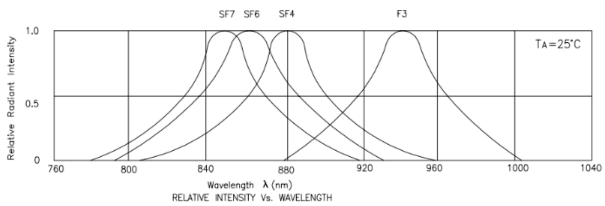


Figure 65. Data sheet of IR LEDs. LED that we used can radiate 940 nm NIR made with Gallium Arsenide (F3).

How to construct Visual image for IR Phototransistor vein detection?

For constructing a visualization for our device we can use 10 Segments bar graph arrays as you can see in Figure 66. Each LEDs segment is connected to IR phototransistor circuitry. When any IR phototransistors located above a vein the result is voltage drop across the corresponding leds indicator leads and we can see it as result of decreasing in intensity of LED light. Not that using 10 segment of bar array is an example of how we can visualize veins location in IR phototransistor in real practical work we can have our own indicators array based on modify scales for using on hand. (Like Figure 67.)

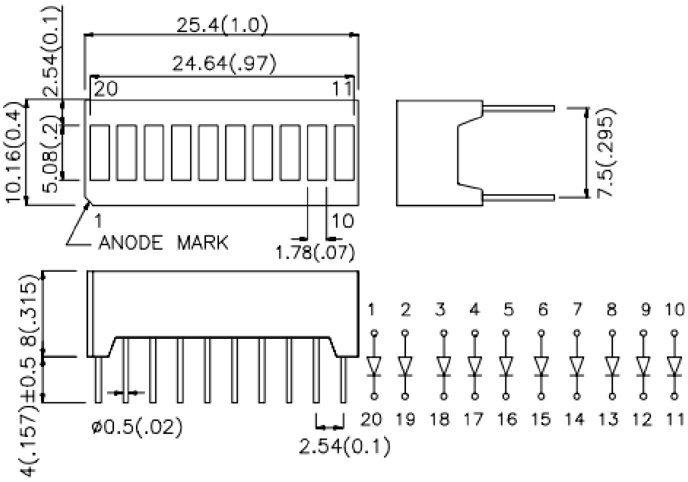


Figure 66. Package Dimensions & Internal Circuit Diagram of 10 segments bar graph arrays.

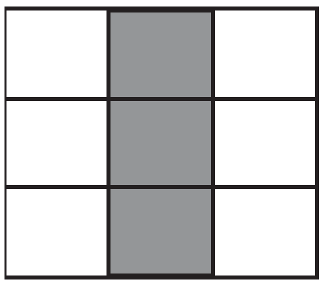


Figure 67. As you can see we can make our own segments array based on our need to use in vein detecting as you can see if all 3 middle segments located align on vein stream we can see vein stream as a shadow on segments arrays.

Conclusion

Here we listed main important results of our study:

1. For Transilluminator Device both red light and yellow light, can be used for finding veins. Based on different patterns of veins in different cases, one of them or both of them, can be used but for tiny veins yellow light has better results. With yellow light we can see branches of veins also, but in practical issue, sometime just finding the main branch is enough, for us to do injection. So based on situation we can use one of these lights.

2. In Transilluminator device for faster performance and reduce costs and materials we have separated power source of device means battery from transilluminator arm. So with one power source and two type of transilluminator arms we can replace trans-arms whenever we need it.

3. Biophotonic visible vein finder we can detect veins as a dark shadow in FoV. Categorize noises in our system 2 type of noise we have; one is Fake shadow and second is Shiny effect. For avoiding these two noises device must work in dim light. We can make separation from fake according the result of absorbing red light by Hb appear and disappear as a flowing darkness or signaling darknes, but fake shadow can appear and disappear instantly. We can distinguish Vein's shadow from fake's one by knowing this fact that fake shadow can apear and disapear instantly, but vein's shadow can move like fluids.

4. We used the "Modular design" approach. Device consists from independent parts with standard interfaces. This allows designs to be customized, upgraded, repaired and for parts to be reused.

5. Using IR phototransistors, as an option alongside other technologies, can help medical product designers to design competitive product to make portable device by reducing the size of device. Portability is main issue for vein detector devices due to IVs procedure condition.

6. For tiny vein it is too hard, to understand current attenuation we need, to work on sensitivity of device in IR phototransistor vein detection. Best option for tiny veins is, using visible yellow light transilluminator device. IR phototransistor device work based on Spectrophotometry principle, so results show us, that different veins based on size, can give us different signal, this can be used to measuring the size of vein.

Appendix

Biophotonic Vein Finder guideline

Why do our veins look blue when our blood is red?

In the past, noblemen were called blood-blue because of the well-being of their lives, the veins of their bodies could easily be found under clear skin, but the veins of deprived persons were not visible due to their darker skin and burnt sun. But why do all humans, including the noble and the deprived, have blue veins while the blood flowing through the veins is red, not blue.

All five liters of blood are pumped through the heart to all parts of the body. The blood that leaves the heart with high pressure is red because it has oxygen. Oxygen is consumed by organs such as the brain, muscles and skin.

In the tissues, the blood loses some of its oxygen and absorbs carbon dioxide. As the blood becomes depleted of oxygen, it slowly changes from light red to dark red, but at none of these stages does it become blue-like. The blue color of the veins is due to four factors.

The first reason is how light affects the skin at different wavelengths. The light absorbs the skin and reflects again. The researchers found that the veins near the surface of the skin reflect a very small component of red light and much of the blue light, which means that the blue is much more visible and visible.

The second factor is the amount of oxygen in the blood. As the oxygen level decreases, the color of blood changes from light red to dark red, though still red but slightly closer to the mysterious blue of the veins.

The third factor relates to the specificity of the veins themselves, especially how thick and deep they are below the surface of the skin. If the vein is slightly below the skin, it may look red, but most veins are more than half a millimeter deep. However, due to the laws of optical physics, the veins appear blue.

The fourth factor is the human brain. The brain implements many processes on messages coming from the retina. For example, is a pink body always pink? No. When it gets close to red, your brain changes its pink to a shade of blue. In the case of veins, the contrast with the skin gives the veins a blue color.

So the key point is that if we illuminated skin with just red light then the veins appear as a dark stream or shadow in FoV.

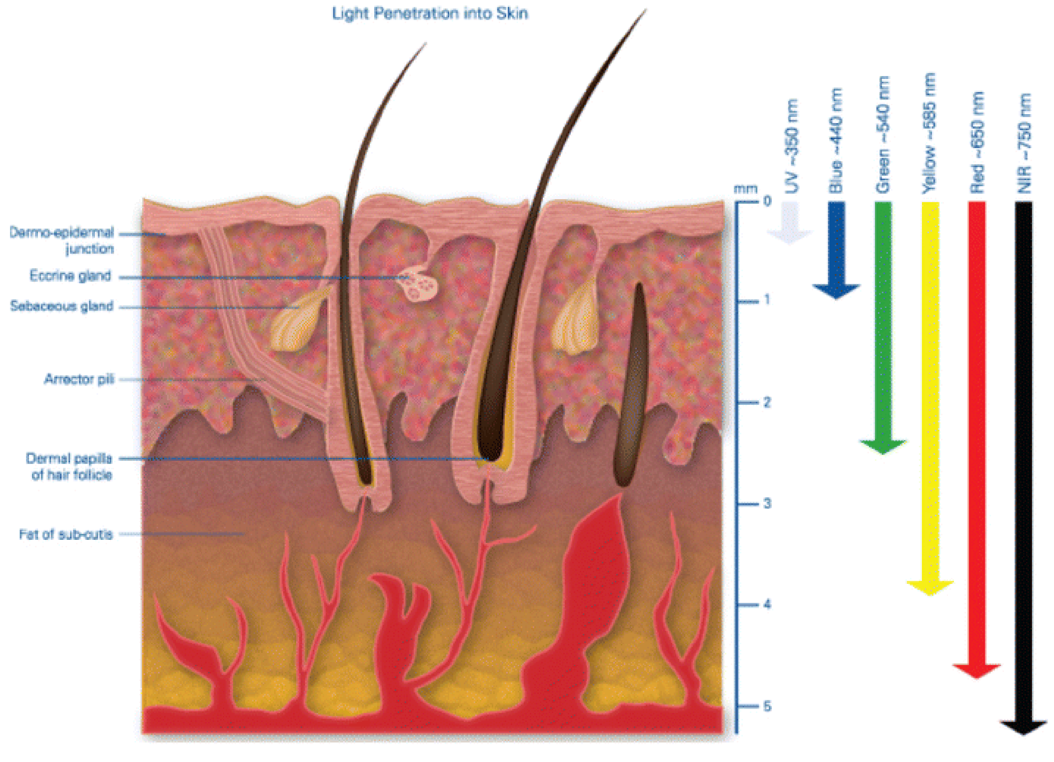


Figure 68. Different wavelengths have different penetrations.

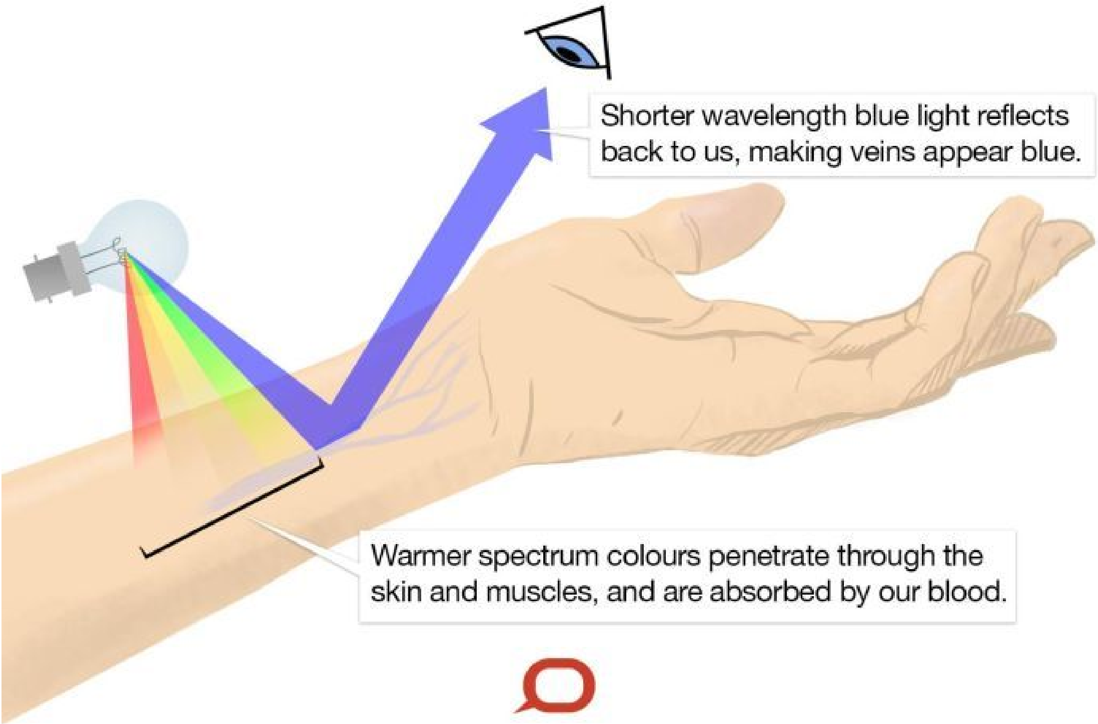


Figure 69. Blue color reflects back to our eyes causing that we see veins in blue color. [25]

Electronics of device

We use LEDs in parallel array so in this array voltage drop is just about 1.8~2 volts. So we can calculate by using ohms' law; V=IR (I; it's better to set 20mA). Here in fig.70 you can see table that we use an online calculator platform (https://www.amplifiedparts.com/tech-articles/led-parallel-series-calculator) to calculate for use technical value that we need for designing our electronic part of our device. We use one 3 volts' coin battery for our device. This calculator uses two equations that are important for designing electronics:

Ohm's Law=I×R and the Power Equation P=I×V

Results:

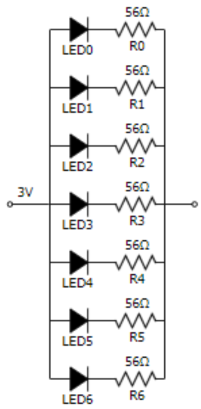
Number of LEDs	7
Supply voltage, V_s	3V
LED forward voltage, V_f	2V
LED forward current, I_f	20mA
Individual Diode Power Dissipation	40mW
Total Diode Power Dissipation	280mW
Recommended Resistor Wattage	1 Watt Resistors
Solution 1	 Current Draw: 140mA

Figure 70. Technical data for electronic part.

Physical Architecture of device

3D doodling (pen)

What does 3Doodler do?

It is a three-dimensional painting tool. Imagine that a thermal glue gun uses plastic strands instead of glue. Whenever you press the button, the hot plastic is extruded from the tip of the pen. It allows you to paint in the open space and create 3D objects. It uses two type of material;

- Acrylonitrile butadiene styrene ("ABS"),
- Polylactic acid ("PLA"),

- “FLEXY”, thermal polyurethane (“TPU”)

We use 3-D pen for making our prototype. The advantages of this method is that it is faster than 3-D printer and we can have direct interaction between our conceptual design in our mind and what we make in reality.

Figure 71. 2 types of model for making device.

Figure 72. Model B; 7 Leds in parallel array with one 3 volts’ battery.

Prototyping of Device

In this section we will talk about how to make a BVF device step by step;

Materials

- 3D doodler device

- 3D filament

- 3 volts' coin battery (CR2032)

- Battery holder for CR2032 coin battery

- Fixed switch

- Wires

- Soldering equipment

- 7LEDs (LD05-R HU-FLAT 2500.MCD 30`)

- Foam or sponge

- USB connectors (female and male)

- Resistor (you can calculate the value of resistor in this website; https://www.amplifiedparts.com/tech-articles/led-parallel-series-calculator)

In the following picture you can see the materials that we use for making our device. Picture are taken from www.dac.ge. Note that anyone can use different materials or process for making this type of device we just try to show our way.

Figure 73. USB connectors (male left side, female right side).

Figure 74. LD05-R HU-FLAT 2500.MCD 30.

Process

1- First mark on the foam or any base structure material 4 straight lines with 45-degree phase difference between them. The length of each line should be 2 cm.

2- Make some holes to put LEDs inside them. 7 holes for 7 leds.

3- Locate the LEDs inside the holes.

4- Now wiring all of the positive side of LEDs together.

5- Again wiring negative side of LEDs together.

6- Check the LEDs that they are working properly. If you connected (+) side to (+) side of battery and another side to (-) side of battery you can see that all of leds turn on. Here we have parallel structure of LEDs.

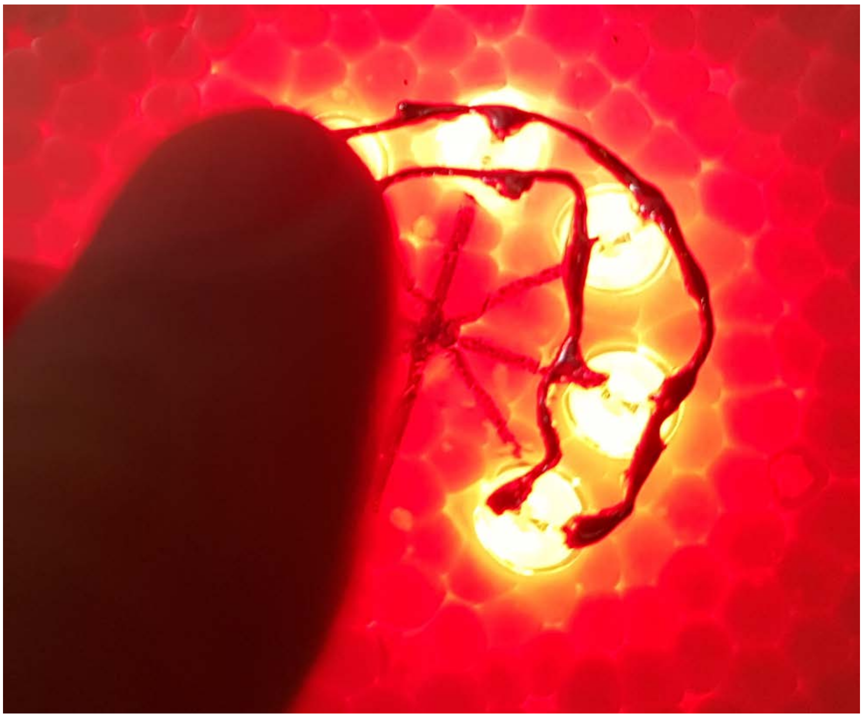


Figure 75. Check LEDs.

7- Connecting the positive ring to one of the outer leads of female USB. Outer leads of USB as you can see in figure are for transferring the electricity.

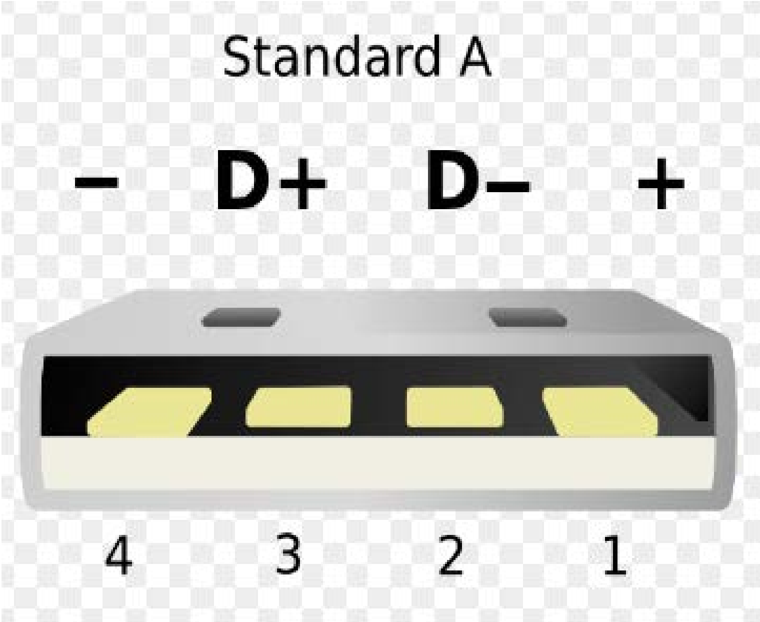


Figure 76. USB Pin out structure.

8- Connecting the negative ring to ground of female use.

9- Connecting the USB-male leads to positive the negative side of battery holder with a switch for on and offing the device.

10- Power on the 3D pen.

11- Make a 3-D structure for LEDs ring as following picture.

12. Use cutter and cutting the extra foams from device.

13. Cover up bottom of ring also with 3D pen.

14. Covering the UBS parts with 3D Pen and complete the device.

Figure 77. BVF device.

How to use the Device.

Here in the following picture we can see how to using device to find the veins also we put some pictures of the results of device.

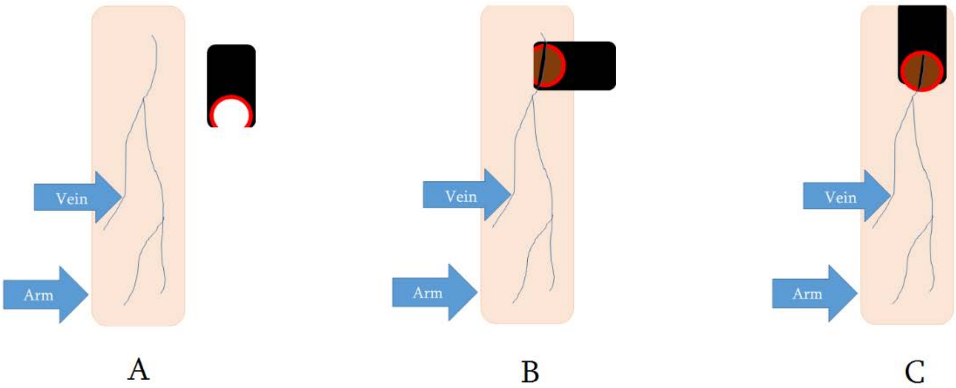


Figure 78. Procedure of finding vein

As you can see in figure 78. ;

A. First turn on device,

B. use devices perpendicular to the arm bone and go up and down to find shadows (veins), C. then when you find best vein for injection you need to turn the devices parallel to arm bone and do the injection.

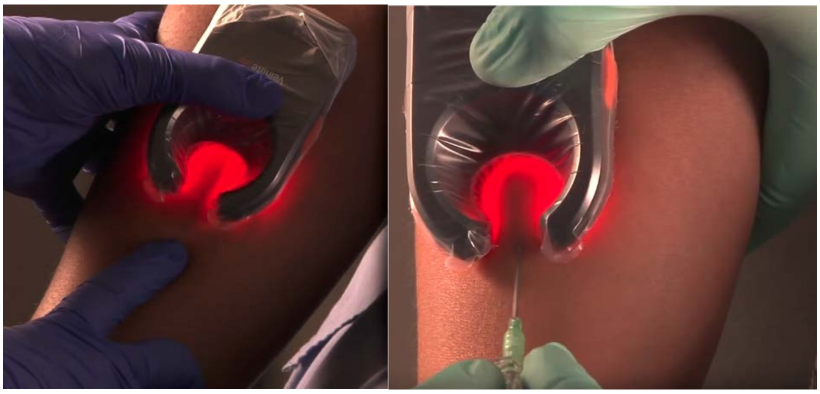


Figure 79. How we handling device when we want to do injection into the vein. (Veinlite®)

Figure 80. BVF device with two arms; yellow one right side and red one.

Figure 81. Testing device on female case with yellow light.

Figure 82. Testing device on female case with red light.

Figure 83. Testing device on leg of male case with red light.

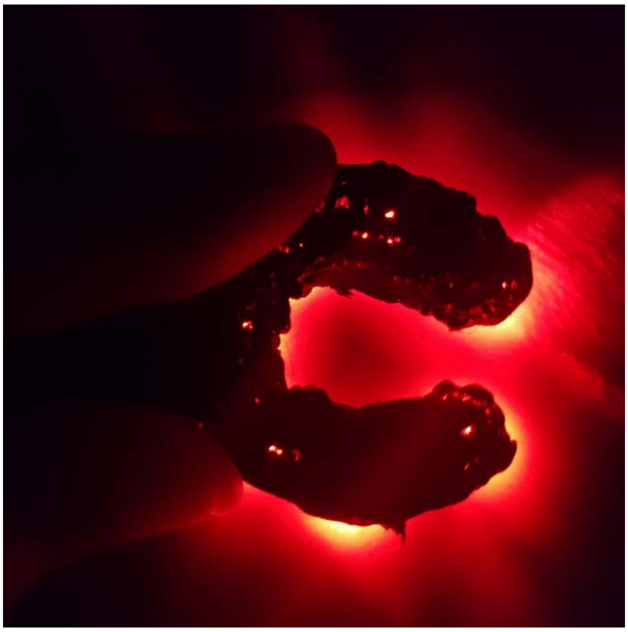


Figure 84. Testing device on foot of male case with red light.

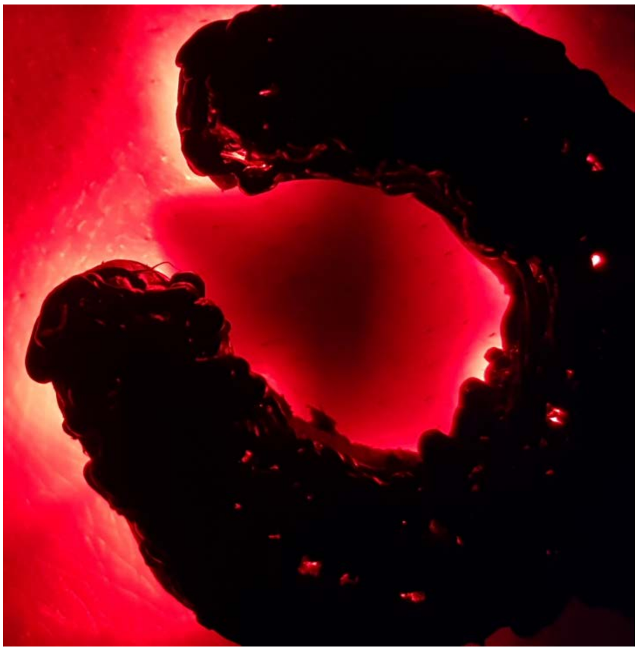


Figure 85. Testing device on wrist of male case with red light.

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