# Development and implementation of a portable low-cost vein finder

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## Summary

*Nowadays, solutions oriented to non-invasive veins visualization by physicians are not numerous neither cheap. For that reason, the main purpose of this project is to design a portable and low-cost biophotonic device, which allows veins visualization and facilitates venepuncture and intravenous line procedures, reducing the method invasiveness. 3D printing process will be essential to replicate current available commercial solutions like Veinlite® reducing significantly the cost of the device making it more affordable.*

## 1. Motivation

According to some studies, almost eighty per cent of the hospitalized patients receive a peripheral intravenous (I.V) cannulation. [1] In fact, although it is considered as a routine procedure (also a procedure indispensable for human health), their related complications are often unknown and undervalued. A recent published study in the British Journal of Anaesthesia showed the ratio of difficult venepuncture cases in different populations group. The percentage of those difficult cases is shown in figure 1.

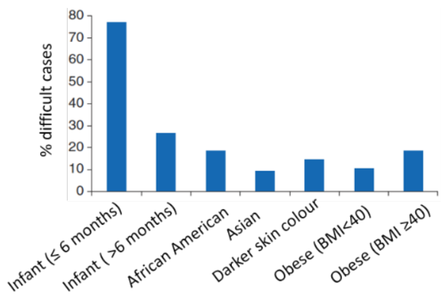


***Figure 1.*** *Percentage of cannulation difficult cases [2]*

Associated complications, derived from unsuccessful cannulation procedures include bacterial infection, extravasation, phlebitis, thrombosis, embolism and nerve damage. These ones, often have attached other complications such as economical indemnities.

The different populations groups that can take advantage of a vein visualization device include the following ones:

- Obese patients: The adipose tissue surrounding vessels often complicates cannulation procedures.
- Elderly people: The loss of muscle tone and the potential risk of damaging a vessel are some issues to deal with when cannulating elderly people.
- Patients with blood flow reduction (hypovolemia) in which vessels are not visible.
- Chronicle patients, patients with multiple prior hospitalizations, patients under a chemotherapy treatment, patients with oedema, drug abusers, undernourished patients, burned patients or those ones with vascular diseases can also take advantage of a vein seeker device.

Furthermore, there are some situations in which choosing the suitable vein is even more important that doing the cannulation or venepuncture process accurately: Avoiding sensitive places derived from venous fibrosis, local infections or inflammations, fistulae or vascular grafts are some examples of that situations.

For all of the previous reasons the use of a vein seeker can facilitate blood extraction and cannulation procedures.

## 2. Light-tissue interaction

The different technological approaches, later described, take advantage of mainly three optical phenomena: absorption, scattering and reflection.

- Absorption: process by which electromagnetic radiation is captured by matter producing an intensity attenuation. In the epidermis layer, lipids, melanin and hemoglobin are the main chromophores (absorbing molecules). Skin blood chromophores are confined on the vessels of the dermis and the main absorption peaks are located as it is shown figure 2:

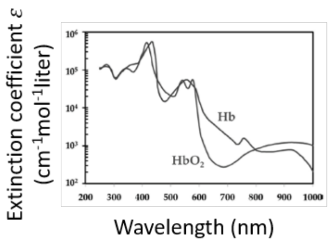


***Figure 2:*** *Hemoglobin absorption spectra [3]*

For oxyhemoglobin (an oxygen molecule is bounded to hemoglobin) the absorption peaks appear at 418, 542, 577 and 925 nm. For desoxyhemoglobin (there is not oxygen molecule) the peaks are located at 550, 758 and 910 nm.

- Scattering: process in which the light path is deviated from a straight trajectory, once it encounters objects with a refractive index distinct from its surroundings. Depending on the incident light energy balance, there can be different scattering process. Mie Regime (a kind of elastic scattering) will arise in this application due to the object size is comparable to the incident light wavelength.

- Reflection: process in which a light ray encounters a surface that split two different dielectric media and is not able to cross such interface. It is estimated that about the 4% - 7% of the light is reflected as a consequence of the difference of refractive index between air and skin. The remaining light will suffer absorption and scattering phenomena.

The great majority of biophotonic applications are between an optical window which goes from 600 nm to 1300 nm, called *therapeutic window for biophotonics.* Light is not strongly absorbed by tissues; therefore, the *light transport* is mainly dominated by scattering. The lower absorption in the optical window will allow us to develop the ***vein finder***, permitting us to deepen considerable under skin.

Parameters such as *effective attenuation coefficient, effective penetration depth and total extinction coefficient* in which the *absorption* and *scattering coefficients* are involved, will determine the success of the application.

Most of the tissues are considered as *turbid* tissues. This means basically two facts. The first one is that there exist interactions, which cannot be neglected, among light that have been scattered from one scatterer to the light from other scatterers existing in the media. The second fact is related to the heterogeneous structures with different optical properties that formed the tissues. Therefore, it is said that the light inside the tissue is *diffuse or cloudy*. Because of the difficulties of studying this kind of problems (light propagation along turbid media), some mathematical models are developed to study light propagation. The *radiative or radiation transport theory (RTT)* is useful to describe light propagation when multiple scattering phenomena are presented. The main purpose of RTT is to track the transport of light energy through a medium, incorporating elements of classical and quantum descriptions of light. RTT theory is based on tracking photon changes (energy flow) in an *infinitesimal volume* which will be called $dV$, within differential *solid angle* $d\Omega$ around $\hat{s}$ direction. Changes in energy flow can be caused by incoming, outgoing, absorbed and emitted photons. Figure 3 illustrates the energy flow.

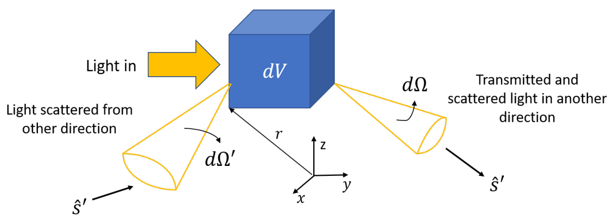


***Figure 3.*** *Light propagation schema in RTT theory.*

Finally, the response to light by an irradiated tissue depends on certain parameters such as: the wavelength of the incident light which will determine the penetration of light, the optical power emitted by the light source, the irradiation time, the pulse duration and the number of pulses, the light polarization state, and the light exposure rate are some of those parameters.

## 3. State of the art

Nowadays, there are different approaches by which a physician can see in a non-invasive way the patient's vessels. A summary of all of them is presented in figure 4.

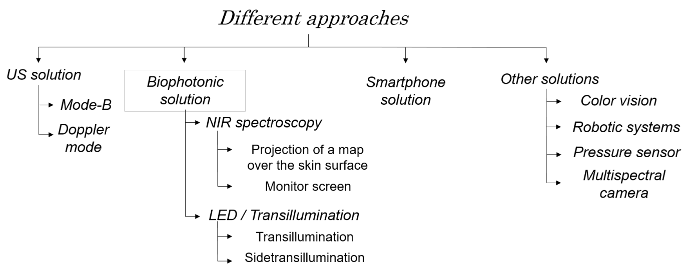


***Figure 4.*** *Different non-invasive vein visualization approaches*

Ultrasound (US) biomedical imaging systems have been used for assisting cannulation from a long time ago. The non-invasive, the real-time acquisition and the portable features have done from US one of the most common ways for I.V. procedure. Site-Rite Prevue® Ultrasound System developed by Bard Access Systems, is an example of US systems already used. For their part, inside biophotonic based solutions there are two possible options:

- Solutions that take advantage of *NIR spectroscopy principles*: These solutions, commonly project, in real time, over the skin surface a map of the blood vasculature employing a visible wavelength. The projections are achieved by previously radiating the skin surface with NIR light and quantifying the amount of light absorbed by the blood (haemoglobin) and reflected by surrounding tissues. The device will capture the information, process the data and finally project over the skin surface the veins distribution. AccuVein®, VeinViewer® and IV-eye®, are the most well-known devices which takes advantage of this principle.
- Solutions that take advantage of visible light together with skin optics properties, also known as *transillumination* solutions: They are based on the use of *LED technology.* Skin surface is irradiated with the appropriately visible wavelength/s allowing directly the vein visualization by differences in tissues properties. These differences are absorption and reflectance. Skin reflects short-wavelength (blue and green) whereas absorbs long-wavelength (orange and red), therefore, the emitting wavelength is consciously chosen to maximize the absorbance by the vein (which has deoxygenated hemoglobin) and the reflection by surrounding tissues. As it has been presented in section 2, there are many chromophores in the skin. The absorption differences between skin chromophores and blood chromophores will allow us to see the veins. Venoscope®, Veinlite®, Wee-Sight Transilluminator® and Illumivein® solutions follow this approach. An important consideration in this last approach is that the intensity of the light reflected is usually higher than the light transmitted to the vessels. Therefore, difficulties of superficial vein visualization arise, given that too powerful light and shadows pattern will emerge. To overcome this issue, *side-*

*transillumination method* can be used instead of transillumination. This method, uniformly illuminates a small region of the skin to reduce the shadows and allowing light penetration up to 6 mm in depth.

Smartphones have also been used in the vein visualization task by acquiring reflectance information thanks to a RGB conventional camera and using multispectral Wiener estimation [4].

Finally, other approaches not fully developed are been under research like robotic systems or pressure sensors to facilitate blood extraction.

### 3.1. Scientific evidence of the potential benefits of using a vein finder

There exist several studies which affirm that the use of a vein finder (independently of the technological approach employed) can help the physician in procedures like cannulation, blood extraction, and I.V. In fact, figure 5 proves a higher vein visualization rate when using a vein finder device.

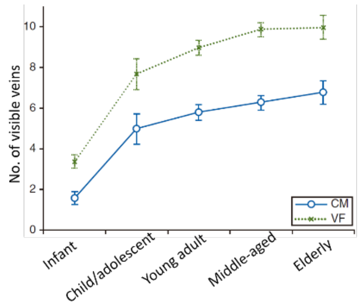


***Figure 5.*** *Number of visible veins when using the Conventional Method (CM) and a Vein Finder device (VF)*

For instance, in [5], researchers analyzed the reliability of transillumination devices (Veinlite®) in pediatric emergency department. The main conclusion of this study was that I.V. procedure accuracy was improved in the first attempt and within two attempts, therefore, VF method was declared better than CM. An interesting result extracted from [6], one of the first which reviewed the use of NIR spectroscopy solutions, suggested that not only veins could be highlighted with VeinViewer®, but also some of them invisible to the naked eye and too shallow for ultrasound detection could be visualized.

## 4. Design and methods

A vein finder device is designed following the biophotonic approach. LED technology in a side-transillumination solution will be used, imitating Veinlite® device which reported an accuracy of 85% compared to the 74% with the standard method. Some of the reasons for choosing this approach are: the light source (LED) is very cheap, the development is easier than other solutions (like NIR) and also it offers a clearly advantage when mobility and availability are the key points for physicians.

Different designs with different shapes, wavelengths, number of LEDs, distance between LEDs and size of LEDs were developed to assess which design was the more suitable one for vein visualization. Hereafter the final design development and implementation is explained.

### 4.1. Design of the case

3D printing technology was employed to develop the case of the vein finder. Solid Edge: Siemens PLM software *(ST9)* and 3D Builder were the chosen software to design the pieces. A screenshot of the design process and the final aspect can be seen in figure 6.

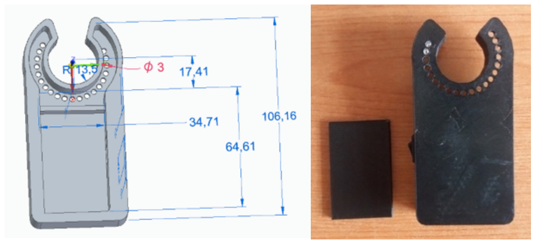


***Figure 6.*** *Final implementation design*

As it is shown in the previous figure, the vein finder follows a *c-shape*, has a battery hole which is connected to a rocker and an homogeneous LEDs distribution. 3D printing process was made thanks to Cura software in a period of time of five hours. The device was printed with a *Bq Witbox 2* printer with polylactic acid (PLA), a resolution of 150 microns per layer applying the fused deposited modelling technique (FDM). After printing the prototype, some manual corrections were made to facilitate the assembly process such as opening some LEDs holes. The final dimensions are: 106.16 x 51.94 x 22.0 mm. These measures were chosen thinking of optimizing as much as possible the available space.

### 4.2. Light source

LED technology is characterized for being cost-effective, simple, with low energy consumption, high lifetime, small size, reduced heat emission, and, also, almost every visible spectrum wavelengths are available. A particularity of the LEDs employed in the vein viewer device is that their luminous intensity is greater than normal LEDs, those LEDs are called Ultra / Super Bright LEDs (the ones used were between 6000-8000 mcd), see figure 7. For this project, twenty Super Bright LEDs (3 mm) with two different wavelengths range were used. The red ones (650-670 nm) which have a higher penetration power and the orange ones (600-610 nm) with a better contrast.

Studies related to the suitable luminous intensity (mcd), and the aperture angle were also carried out.

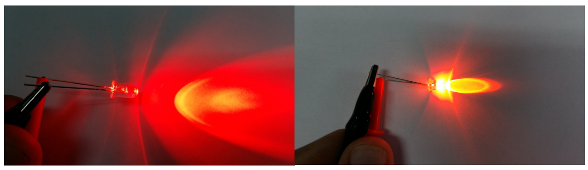

***Figure 7.*** *Super-bright red and orange LEDs*

### 4.3. Power supply

A 2.4 V and 2500mAh accumulator was bought as a source of energy. According to the datasheet, the recommended operating voltage value for each LED is 2.1 V. Therefore, the equivalent resistance to avoid LEDs failure was estimated as it is shown in figure 8.

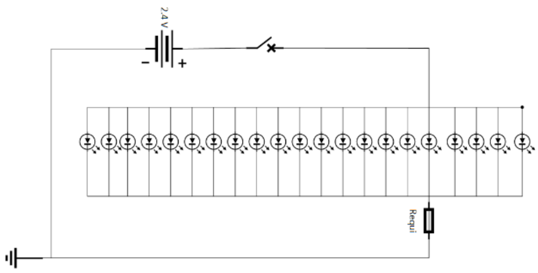

***Figure 8.*** *Super-bright red LEDs power supply*

Finally, we assessed that the electrical circuit fulfilled the *Maximum continuous discharge current* limitation.

### 4.4. Costs

Table 1 shows the total cost for the final implementation. These costs are very dependent on the 3D printing process; however, we have to consider that in an industrial environment, 3D printing might not be the employed technique. Instead, molds could be used, reducing even more the costs.

| **Total costs** | | | |
|---|---|---|---|
| **3D printing** | 13.35€ | **Rocker** | 0.96€ |
| **LEDs** | 4.47€ | **Battery** | 4.65€ |
| **Final material cost: 23.58€** | | | |

***Table 1.*** *Cost structure*

Other material costs like wires and resistances are negligible. On the other hand, an estimation of the average time to build a prototype was done. This time is two hours and a half. Furthermore, 3D printing time is about five hours. Both times should be taken into account to estimate a final cost for each prototype, which in all cases should be lower than 100€.

Costs for other transillumination commercial solutions like Veinlite® are between a range of 239$-629$.

## 5. Results

Experimental results were carried out under different populations groups and under variable light conditions. Also, the anatomical structures evaluated were forearms (in which blood extraction process is done), the back of the hand (cannulation process) and the calf muscle (well irrigated).

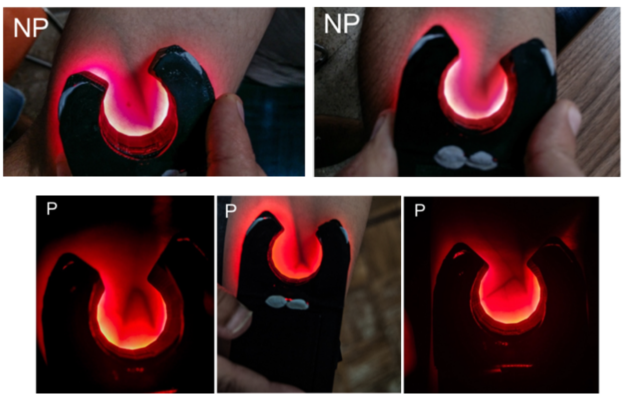



***Figure 9.*** *Finding veins with the developed design. From up to down. Forearm of an Aboriginal individual in light conditions. Forearm of a Mediterranean individual in half-light conditions. Calf muscle of a Mediterranean individual in darkness conditions*

As we can appreciate in all the pictures a vein enhancement is achieve, which can help and improve the physician success rate.

## 6. Conclusions

We have designed and developed successfully a low-cost vein finder [7]. The final implementation of the device has been possible only after an exhaustive analysis in which we studied different variables like the shape, the power supply and the light source distribution. Therefore, the non-invasive vein visualization is enhanced, in some situations with our vein finder. Furthermore, we have found that the veins visualization does not lean primarily on the skin colour but on the amount of surrounding 'fatty tissue'. Also, we concluded that red light is more useful to see deeper vessels whereas, with orange illumination the contrast seems to be better. On the other hand, in well-lit environments the finding task becomes more complicated. Other applications combined with image processing could be considered.

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