Biophotonics for All: Light transport through tissue

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ABSTRACT

Biophotonics is becoming increasingly prominent in value and visibility. What was predominantly an advanced field of research is now being included increasingly in undergraduate and postgraduate programmes. To increase biophotonics-related STEM awareness, we developed a simple demonstration kit using LEDs and a camera that allows visualising of the blood vessels beneath the skin (specifically the blood vessels in the fingers). The kit uses inexpensive blue, green, red and near-infrared LEDs to show the absorption of shorter wavelengths and transmission of longer wavelengths in the skin. As an outreach and educational tool, this demonstration kit will illustrate the potential of using light for diagnostics.

Keywords: LEDs, photonics, cameras, STEM, outreach, educational

1. INTRODUCTION

Biophotonics and biomedical optics is one of the fastest-emerging STEM research domains today. The field(s) combine concepts of physics, biology and engineering to realise novel approaches to medical diagnostics. Early optical research gave rise to today's mainstream devices, some examples include pulse oximeters and microscopes for the fields of medical and life sciences. With this rise in interest and significance, there is a need to better understand the optics involved, the technologies included and the fundamental interaction of light and tissue. To illustrate this, we have designed a simple kit using LEDs and a camera to show the differential interaction of light with skin tissue. The kit is aimed at a grassroots level, made easy to use and build, and focuses on inspiring more ideas and individuals towards biomedical optics and biophotonics research and innovation. To build this kit, one will need Zenodo repository[1] (which includes the attached Video 1), this paper and our ModLight illumination sources paper.[2] To better understand the field of biomedical optics, we draw your attention to two excellent resources, Jacques (2013)[3] and Prof Boudoux's textbook, Fundamentals of Biomedical Optics.[4]

Fundamentally, the range of frequencies of electromagnetic radiation can be broadly illustrated through the electromagnetic spectrum. This representation, as seen in Figure 1, shows the relationships between the ability of the radiation to penetrate the Earth's atmosphere, scale and object temperature. At shorter wavelengths (from left to right), the energy associated with the photon is high. Therefore, radio waves are safer for human beings than X-rays and gamma rays. These higher frequencies have found substantial medical applications for diagnostics and therapeutics. However, they are also associated with radiation-related side effects and therefore not suitable for multiple and/or continuous monitoring. Here is where using visible and near-infrared light is much safer. Narrowing down our spectrum to between 400 nm and 1000 nm, this region is commonly referred to as the visible and near-infrared wavelengths of light. This region is bounded by harmful ultraviolet radiation that can alter skin complexion at one end, to near-infrared wavelengths that water absorbs in the skin.[3] This 'diagnostic window'[5] is primarily where most illumination and detection strategies of optical systems reside. The advantage of using these wavelengths are:

1. From blue to near-infrared (NIR) wavelengths, the degree of penetration into the skin increases with increasing wavelength.
2. The range is (largely) eye- and skin-safe for human beings, unless high-powered lasers or LEDs are used.

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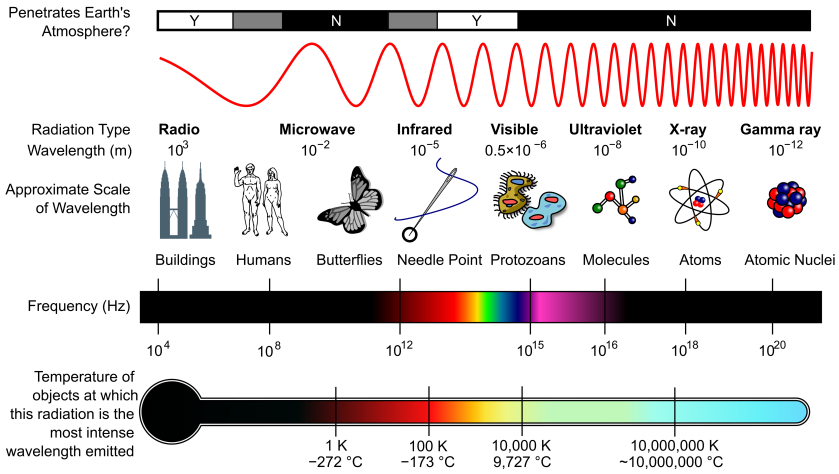

Figure 1. The range of frequencies (or wavelengths) of electromagnetic radiation is depicted through the electromagnetic spectrum. Image made available through the Creative Commons Attribution-Share Alike 3.0 Unported license.

3. The imaging systems in this range use silicon-based detectors which are widely available and relatively inexpensive.
4. In this operating range, imaging can be performed multiple times as the visible light range is safe.

We set out to build a demonstration kit that focuses on the visible and NIR regions of the spectrum, drawing on our research[6] and sharing the concept of light transport through tissue. The simple kit is designed and built as a tool that can add value and be a part of any optical laboratory in the world intending to contribute to outreach and engagement events. At the outset, it is essential to note that this article differs from a typical research paper. Here, it is our intention to provide the necessary information required to build and use the "Biophotonics for All" kit in teaching, training and/or outreach contexts. Some of the fundamentals mentioned may be widely known or considered fundamental to a few.

2. BUILDING THE KIT

The kit is primarily composed of four parts.

- Four, individual LED modules, covering blue, green, red and NIR wavelengths
- A mount that orients the four LED modules, overlapping the output light on a common target area.
- The electronic control circuit board
- A low-cost, off-the-shelf CMOS camera.

Table 1 identifies the parts needed for building this kit. These, along with the Bill of Materials, photographs and a demonstration video, are shared through the open-access repository (https://zenodo.org/record/7869026).[1]

2.1 LED Assembly, and PCB and Electronics

The LED assembly, adopted directly from ModLight sources,[2] is modular and can practically be built with any LED at any available wavelength, just as long as the LED fits within the module. Detailed build instructions are available in the ModLight publication. The same is the case for the PCB and electronics.

The LED modules are assembled using a combination of **S-M2.5-6**, **S-M2.5-12** screws, a PMMA lens, LED, 3D printed components and a heatsink. The process can be visualised from the illustration, Figure 3. LEDs can often be obtained ready-mounted on small round, metal-backed, PCBs, which help transfer heat from the LED to the heatsink. In cases where these are unavailable, separate PCBs can be fabricated using the

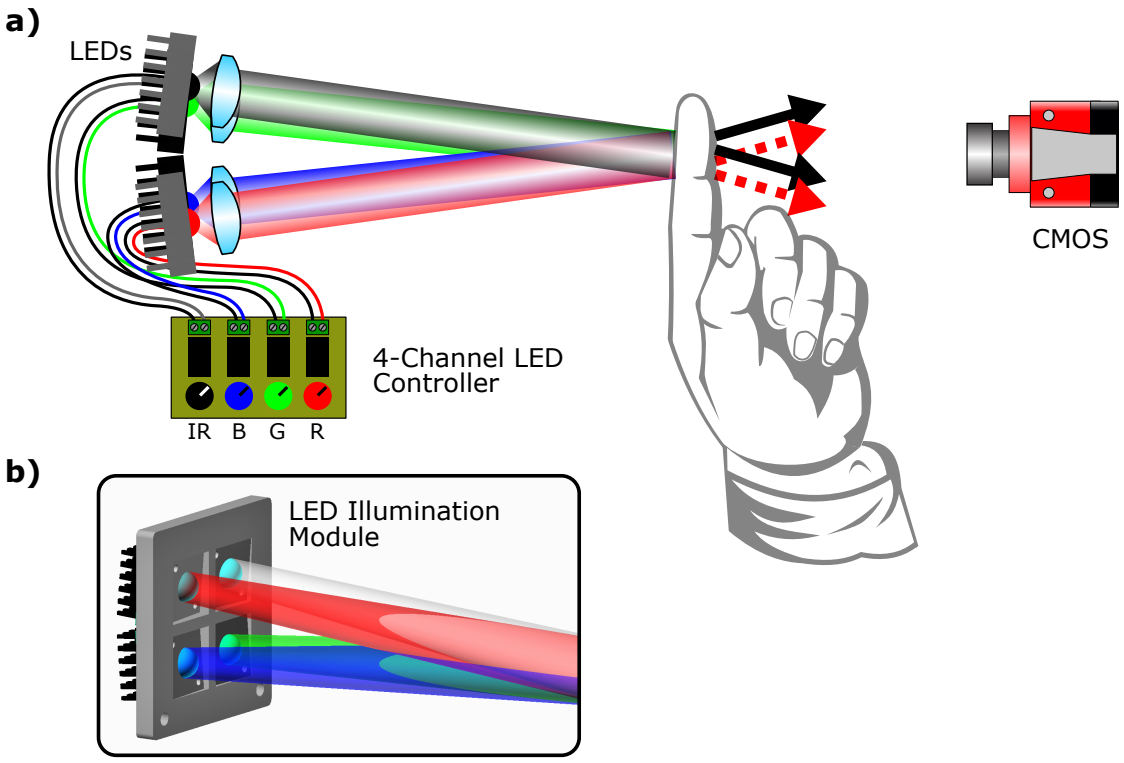

Figure 2. The 'Biophotonics for All' kit (a) is developed as a portable system of 4 LEDs and a camera to illustrate the differential interaction of light with tissue at different wavelengths. Each LED can be independently turned on and off, and its intensity controlled using the electronic control board. The camera on the other side of the finger/hand will capture an image of light interacting with the object. The LEDs are mounted at a specific angle (b) to ensure, within the system's overall design, to have an overlapping incidence on the finger/hand, placed approximately 150 mm from the light sources.

artwork file **MCPCBLuxeonCREE.pdf** and a suitable aluminium PCB prototyping board. In either case, it is recommended to use a small amount of thermal transfer paste between the PCB and heatsink. Similarly, a PCB board design is shared for the LED control electronics in the PDF file **LED Driver (PCB)**. This design offers control beyond simply turning the LEDs on and off, with the ability to control the intensity of the LEDs. Again, alternative fabrication processes are possible using veroboard or solderless breadboards.

2.2 Kit Assembly

To assemble the kit, gather the LED modules and the parts from the folder "Housing and Mounts."

1. Use the **Breadboard.svg** file to laser-cut a 6mm thick black acrylic sheet to act as the base. The mounting holes on the base can be threaded (M6 and M4) using appropriate "tap" cutters.
2. Using a Thorlabs optomechanics mount (e.g. slotted mounting base BA1/M) and a short piece of 1 inch diameter post or spacer, fix the camera such that the height of the camera lens aligns with the aperture of the end plate. A suitable camera mounting adapter can be fabricated from a short piece of 1.25 inch diameter aluminium rod, using **Camera_Mount_Drill_Guide.stl** to aid drilling the mounting holes. Alternatively, adapters can often be obtained from the camera manufacturers.
3. Proceed to use the components **Bracket.stl** and **End_Plate.stl** to mount the camera and end plate on the right-hand side of the acrylic base.

Table 1. This table lists the 3D-printed parts and formats, as made available in the open-access repository. Broadly, the kit consists of LED modules that are 3D printed and an electronics control circuit board that requires fabrication. If any assistance/clarifications are needed, please get in touch.

Design filename	File Type	Open Source License
LED Assembly		
Heatsink Drill Guide	STL, STEP	CC BY-SA 4.0
Heatsink Mount	STL, STEP	CC BY-SA 4.0
PMMA Mount	STL, STEP	CC BY-SA 4.0
PCB and LED Control (Electronics)		
LED Driver (PCB)	PDF, Gerber	CC BY-SA 4.0
LED Driver (Schematic)	PDF	CC BY-SA 4.0
LED Controller Box	OpenSCAD, STL, STEP	CC BY-SA 4.0
Dial	STL	CC BY-SA 4.0
Scale Plate	STL	CC BY-SA 4.0

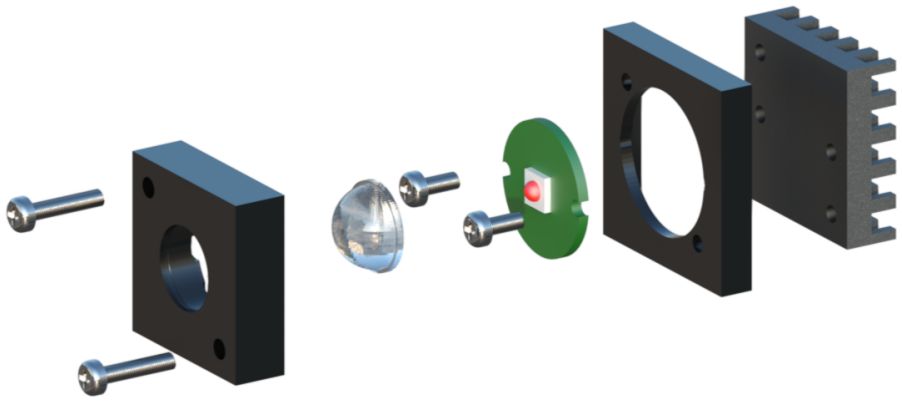

Figure 3. The LED modules in this kit are adopted from the ModLight light sources. The assembly includes a heatsink, LED, a PMMA lens and two 3D-printed parts (ref. to Bill of Materials). Author figure adopted from Gibson *et al* 2023.[2]

4. Using **LEDBase.stl**, mount the four LED modules into the recesses as shown in the photographs and figure 4. The LED modules may "push-fit" into the recesses but may require a small drop of adhesive depending on the 3D printing tolerances.
5. Once completed, the system will have the LED modules on the left, connected to the electronic control board (Figure 5), and the camera on the right.
6. Finally, take a second sheet of 3mm thick black acrylic and laser-cut using **Cover.svg**. Follow the measurements shown in **CoverLayout.pdf** and bend the sheet, softening the acrylic along the fold lines using a heated wire, to make a perfect fitting cover for the demonstrator. If the necessary tools are unavailable, the given measurements can be used to make a cover in any material and/or in individual sheets cut to size.

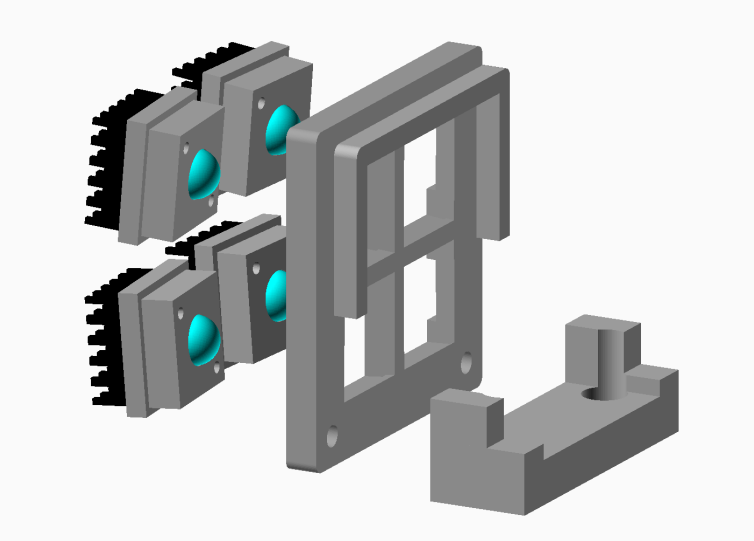

Figure 4. The LED illumination mount is specifically designed to house the LED modules in an orientation that results in the overlap of the light on the target. This means that each LED illuminates the same target area, or part of the hand. Also shown is the mounting bracket and cover stop, which can be glued to the illumination mount to help hold the cover in position.

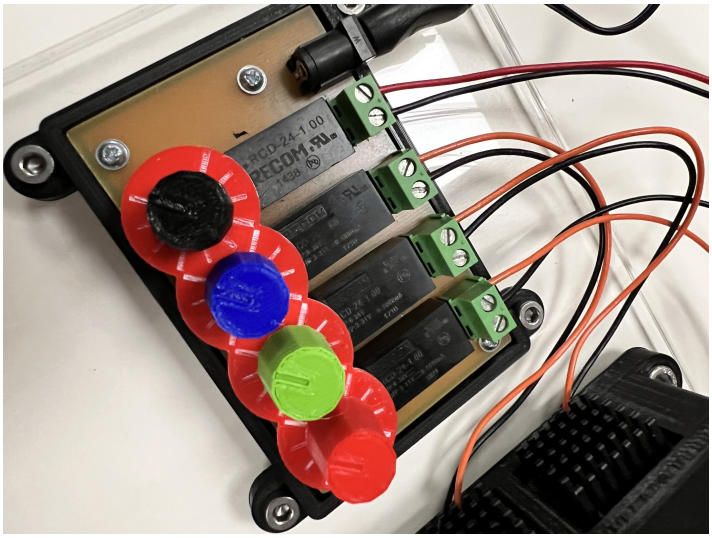

Figure 5. The PCB controller is used to independently turn each LED on and off and control their intensity. The latter is important as, fundamentally, light transport in tissue varies as a function of skin type and melanin distribution. The dials (left to right) control the NIR, blue, green and red LEDs respectively. Author figure adopted from Gibson *et al* 2023.[2]

3. DEMONSTRATION

Once assembled, the kit includes a 4-LED illumination module, electronic control circuit and camera, all mounted on an acrylic base plate. The LEDs are connected to the electronic control circuit board, from which the operation and intensity of each can be controlled. A close-fitting cover over the main section of the apparatus helps to prevent unwanted room light from reaching the camera. To demonstrate this kit, a short explanation is needed, as given in the introduction of the paper. Once introduced, use the kit as suggested below. These instructions are in no way restrictive as we encourage you to make the demonstration as vibrant, engaging and personalised as possible. Note that, fundamentally, light tissue interaction is affected by skin colour (due to the distribution of

melanin) and the brightness of each LED can be adjusted as needed to ensure the kit is suitable to all audiences.

- Give the audience an explanation of how shorter wavelengths of light (blue and green) get absorbed in the top layers of the skin due to the presence of melanin in the epidermal layers.
- Highlight the potential of longer wavelengths and their ability to penetrate deeper into, and through the human finger.
- Invite a volunteer to place their left hand (palm of the hand towards the camera) into the access slot in the acrylic cover, positioning the hand in between the illumination source and the camera.
- While reiterating the absorption of shorter wavelengths, turn on the blue LED (first), then the green LED (second), one at a time. In the live camera feed, you will notice only an outline of the finger/hand. This shows that the light has not passed through the finger/hand.
- Next, turn on the red LED. For the first time, some of the light will pass through, showing 'bright' fingers and some blood vessels. This is indicative of light passing through the finger.
- Finally, turn all the visible LEDs off and turn the NIR LED on. This wavelength is invisible to the human eye and therefore, there will be no light visible in the box. However, since the camera can capture NIR light, you will see a bright image with detailed blood vessel networks clearly seen as 'shadow' images. This is because the NIR light can travel through the finger but is absorbed by the blood in the blood vessels.

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