UNIVERSITY OF JOHANNESBURG

Pulse Oximeter Design Report

Made by

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Submitted on the

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University of Johannesburg

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1 Background information on oximeter

A typical pulse oximeter showing SpO_2 and heart rate in bpm. The pulse oximeter has a display as the human-machine interface. The pulse oximeter is portable [3].

Oximetry is a scientific method used to surveil oxygen saturation in people's blood. A basic explanation of this method is calculating the oxygen level in a blood stream by measuring the amount of light a patient's fingertip can absorb. The measurements can also be performed using the user's earlobe, forehead, and other parts of the body. These continuous measurements can be used to mathematically generate a waveform signal that represents the heartrate or pulse of the user or patient.

The first pulse oximeter was implemented in the year 1972 by Bioengineers from Japan namely Takuo Aoyagi and Michio Kishi by making use of red to infrared light absorption ratio of pulsating components at the medical electronic manufacturer (Nihon Kohden) who manufactured it. Nihon, Sisumu Nakajima (a surgeon) then tested it in 1975. By 1987, the US standard care for the administration of a general anesthetic introduced the pulse oximeter and from there it spread out and continued developing into the modern advanced models of oximeters as stated by William W. Hay [1].

Some of the aims of a pulse oximeter are as follows according to [2]:

1. To monitor oxygen saturation in a blood stream when surgery which requires sedation is performed and after it has been performed.

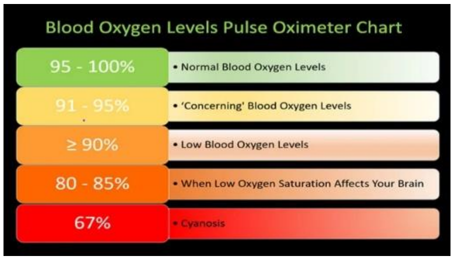
2. To assess a patient or user's ability to tolerate increased physical activity.

3. To evaluate whether the user's respiratory system at some point while sleeping stops.

To evaluate whether the user's respiratory system at some point while sleeping stops.

There are two types of oximeter probes of which are namely transmissive and reflective probes:

1.1 Transmissive oximetry working principle



Picture showing the blood oxygen levels/oximeter chart. Normal, concerning, low blood oxygen and cyanosis levels are shown [5].

This device continuously emits two wavelengths (wavelength range which is between 660nm and 940 nm) through a human body part to a photodetector which then detects absorbance changes for each wavelength. This enables it to pick up the absorbances by arterial blood only.

1.2 Reflective oximetry working principle

This type of a device does not need a human body part to be placed within of which makes it easier to use (as one can even place it one their forehead, chest and other body parts) compared to the transmissive pulse oximeter. In this device the LEDs are place on the same surface but still performs the same operation the transmissive oximetry performs according to [4].

1.3 High Level Capability Architecture

The figure below is a high-level representation of capability requirements expected for the pulse oximeter device to be designed.

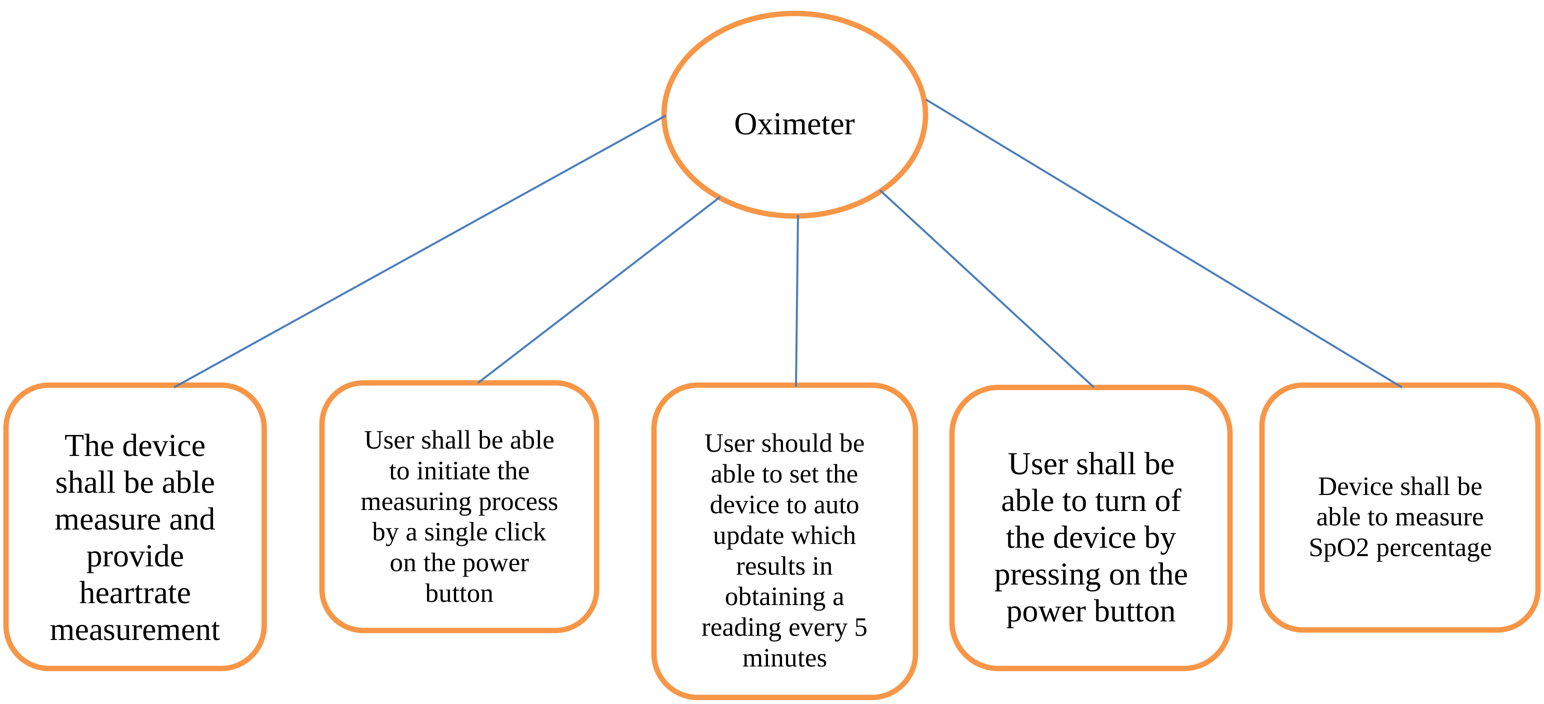


Figure 1: 1.3 High Level Capability Architecture.

2 Technical design

2.1 Technical components

Components	Rating
Photodiodes	700nm-1100nm
Infrared red leds	700 nm-1mm
Capacitors	Farads
Resistors	Ohms
Arduino	Arduino UNO
LCD	16X4 display
Buzzer	-
LM741	
Proximity sensor	-

2.2 Explanation on choice of components within application

One must note that the design being implemented is of a transmissive type of oximeter. The choice of each component was made accordingly.

2.2.1 Proximity Sensor

- IR-LED

The LED will be used as an Infrared Emitter, it will emit an infrared light that will then be reflected. The reflected light will be received by a photodiode.

- Photodiode

The Photodiode will be used as a receiver, it will receive the reflected light from an object (Finger) within the line of detection. The intensity of the reflected light will then determine the output voltage from the photodiode. If the output voltage has reached a required value, the LED connected to the output of the LM741 (comparator) will switch ON(High) to indicate that the object is within range [6].

- Potentiometer

The Potentiometer will be used to adjust the reference voltage, the voltage will then be compared to the voltage output from the Photodiode.

- LM741 (Comparator)

The comparator will be used to compare the reference voltage and the Photodiode voltage. If the voltage from the Photodiode is higher than the reference voltage the LED will switch on to indicate that the object is within range [7].

2.2.2 Oxygen saturation and Heart rate sensor

- IR-LED

The LED will be used as an Infrared Emitter, it will emit an infrared light that will then be reflected. The reflected light will be received by a phototransistor.

- Phototransistor

The Phototransistor will be used as a receiver, it will receive the reflected light from the blood (in the finger). The intensity of the reflected light will then determine the output voltage of the phototransistor [7].

2.2.3 Central Processing Unit

- Arduino

The Arduino will be used to process the Output voltage/current from the Photodiode, the Arduino will then determine the percentage levels of the Oxygen using an algorithm.

2.2.4 Display

- LCD

The LCD display will be used to display the Oxygen Level percentages, Pulse rate and error messages.

2.2.5 Signal Processing Unit (Resistor, Capacitor and Op-AMP(LM741))

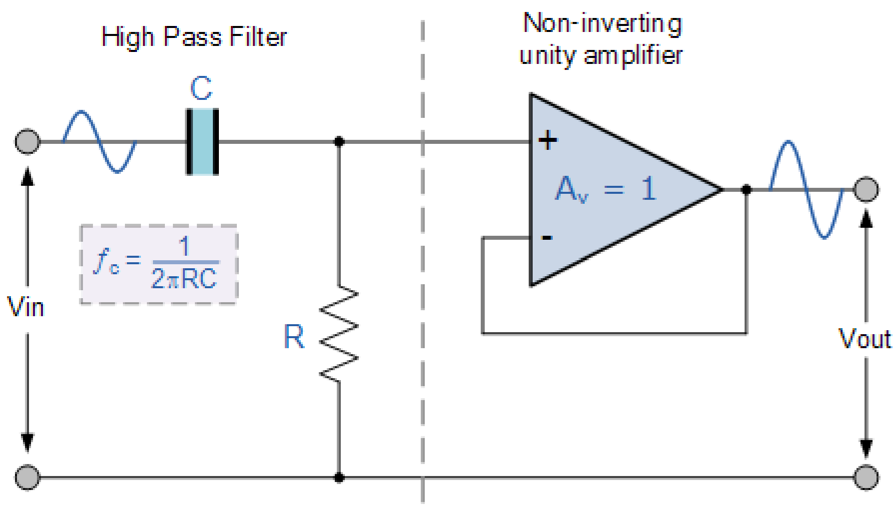


Figure 2: Active High Pass filter [8].

The filter will be used to filter out any interference from the other light sources, the result will be fed to the Arduino for processing. It will be designed such that the sensor only focusses on the required light.

2.2.6 Switch

- PUSH BUTTON

The button will be used to switch ON and OFF the Pulse oximeter when needed to be used. The button will be connected between the sensor and the Arduino.

2.3 Methodology to be used to verify effectiveness of pulse oximeter

A picture containing an electrical and electronic student soldering on a PCB at FEBE (University of Johannesburg).

The Before we go through the verification methods that will be used, we shall first explain few concepts and then off of those will be based our verification and validation methods.

As previously stated, an oximeter is a device that is designed to measure the blood oxygen level (SpO2%) without making use of any invasive means [9]. One needs to be aware that blood carries oxygen that is then fed to different part of the body to sustain their healthy functioning [9]. This means that if we restrain blood to prevent it from going through a certain part of the body, we shall also expect it to be reflected in the results of the measurements from the pulse oximeter.

Neutral's pulse oximeters are known for having an accuracy of 0.2% [10], This implies that if we decide to use them as a reference device, and aim for that same level of accuracy, then we shall expect our device to display close to the same level of accuracy.

There are various methods that can be used to verify the effectiveness of the pulse oximeter but Based on the findings and our chosen testing approach, we shall focus on the following listed below:

- Testing of measurement sensitivity of input to the signal processing unit.
- Testing of measurement sensitivity of output to the signal processing unit.
- Testing of electrical input to the CPU subsystem.
- Testing of the device accuracy by comparison to the reference device.
- Testing of the measurement of the device in comparison with a more accurate pulse oximeter.
- Comparing measurement from different parts of the body.
- Repeating measurement on the same part of the body.
- Perform tests on healthy female/male adult and compare with measurement from healthy female/male child (10- to 14-year-old).
- Testing for accuracy in case the user has polished nails.

Table 1: Summary of verification method,

Nature of verification method	Verification method	Description	Validation method
Design functional requirement	Testing of measurement sensitivity of input to the signal processing unit	This method consists in measuring the electrical current/voltage that results from the direct output from the photodiode.	Demonstration and analysis
	Testing of measurement sensitivity of output to the signal processing unit	This method consists in measuring the electrical current/voltage that results from the direct output from the signal processing unit.	Demonstration and analysis
	Testing of electrical input to the CPU subsystem	This method consists in measuring the electrical current/voltage that results from the direct input value to the CPU as received from the signal processing unit	Test and demonstration
	Testing of the device accuracy by comparison to the reference calibration	This method consists in observing the output value from the CPU on the LCD screen interface with the output observed from Figure 3: Pulse Oximeter calibration curve [9].	Inspection
Design operational requirement	Testing of the measurement of the device in comparison with a more accurate pulse oximeter	This method consists in using another oximeter with better calibration to check for accuracy of the readings	Inspection
	Comparing measurement from different parts of the body	This method consists in measuring the SpO2 level on different fingers of the same person with little time frame of interval between each measurement.	Inspection and analysis
	Repeating measurement on the same part of the body	This method consists in measuring the SpO2 level on the same finger of the same person with little time frame of interval between each measurement.	Inspection and analysis
	Perform tests on healthy female/male adult and compare with measurement from healthy female/male child (10- to 14-year-old)	This method consists in measuring the SpO2 level on the same finger of the same amount of female and male person with little time frame of interval between each measurement.	Inspection and analysis
	Testing for accuracy in case the user has polished nails	This method consists in measuring the SpO2 level on the same finger of the same person with different colors of nail polishing with little time frame of interval between each measurement.	Inspection and analysis

2.3.1 Calculation of SpO_2(%)

Our approach for calculation of SpO_2 level includes the pulse oximeter calibration curve as shown below.

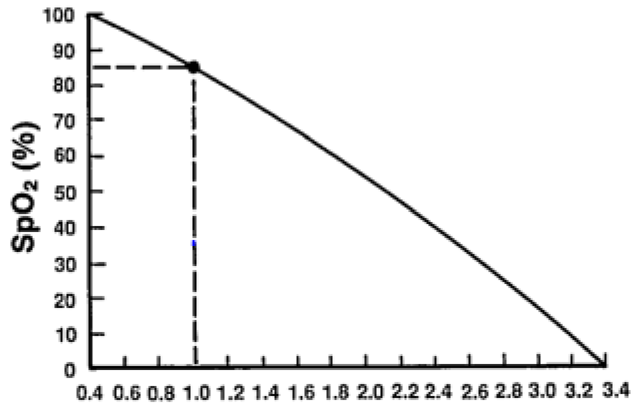


Figure 3: Pulse Oximeter calibration curve [9].

- The plot shown in the figure above assists with pulse oximeter calibration.
- Shown In the y-axis is the SpO2 level in percent and the R values are on the x-axis.
- The value of R needs to be calculated from the obtained data before using the calibration equations below.

Formulae: $$\boldsymbol{R = \frac{\frac{AC}{DC}}{\frac{AC}{DC}} = \frac{Red\ Led}{IR\ Emitter}}$$

Equation: SpO_2 =110-25R

- For example, if R was found to be 1.0: SpO_2=110-25*1=85.

Table 2: Table: showing R values ad their corresponding SpO2 levels.

R	SpO_2(%)
0,4	100
0,6	94
0,8	90
1	85
1,2	80
1,4	72
1,6	69
1,8	65
2	60
2,2	57
2,4	42
2,6	35
2,8	22
3	15
3,2	9
3,4	0

3 PCB design

The first step of the PCB design was to come up with an high level architectural diagram.

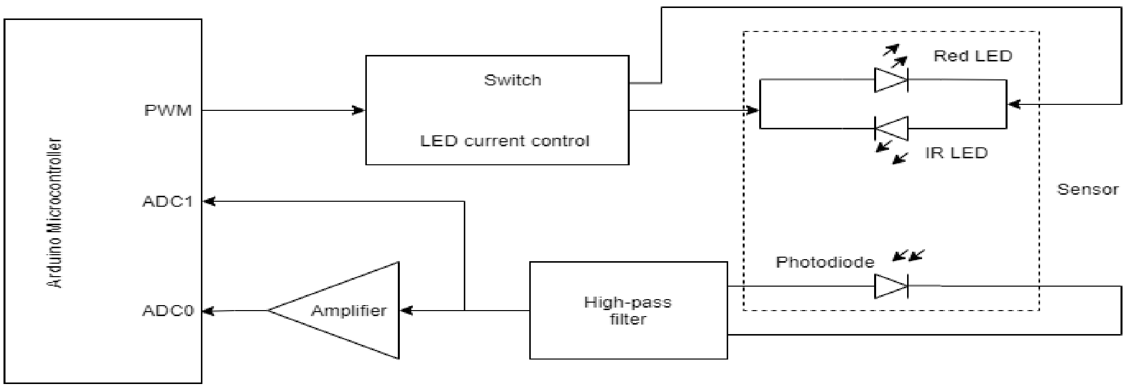


Figure 4: Architectural Diagram.

The second step of our design included detailing all the components that made up each subsystem.

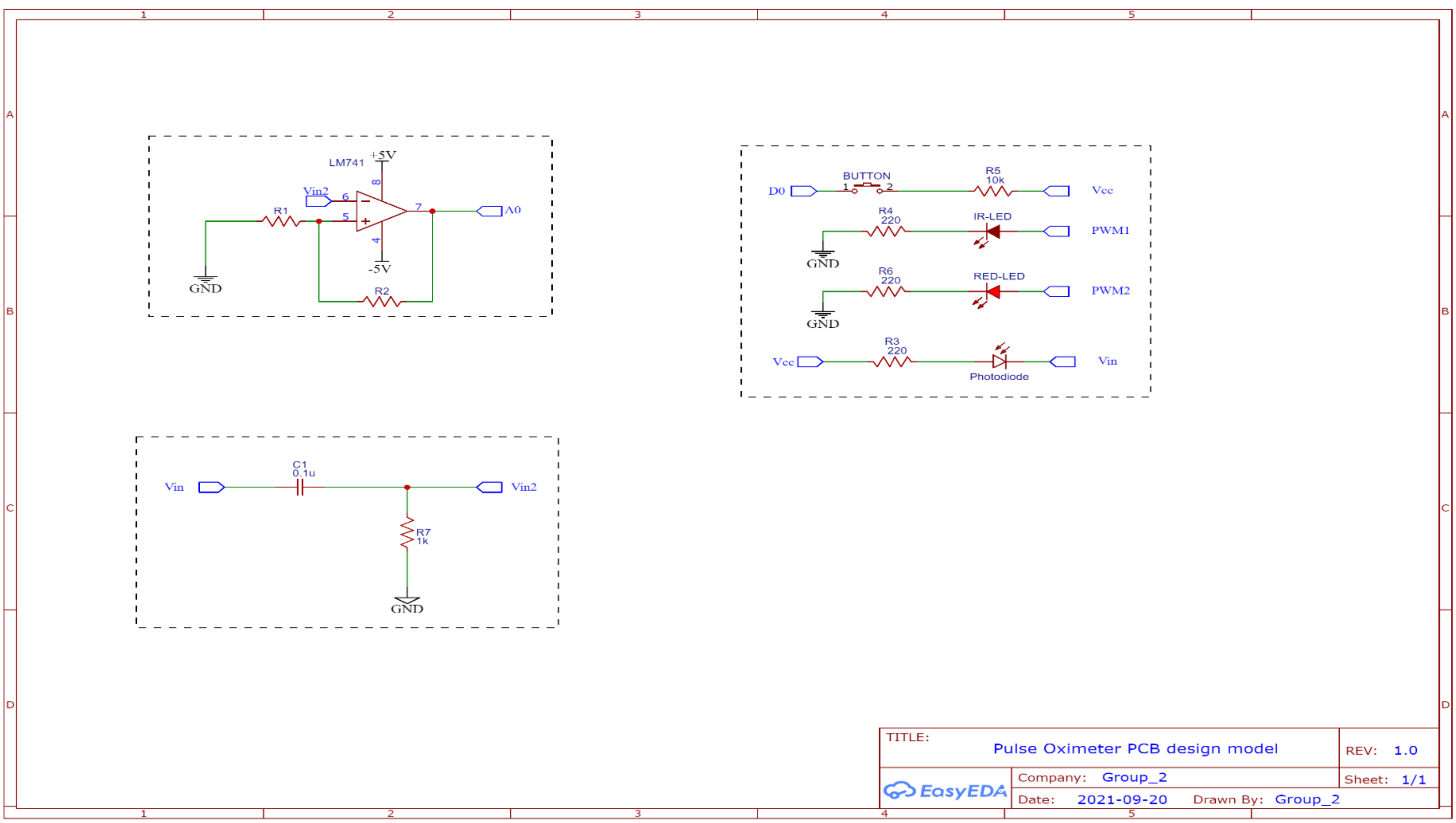


Figure 5: Subsystem architectural/circuit diagram.

The next step was to convert the Subsystem circuit into a PCB 2D design which could then be converted into a PCB 3D design using the easyEDA software.

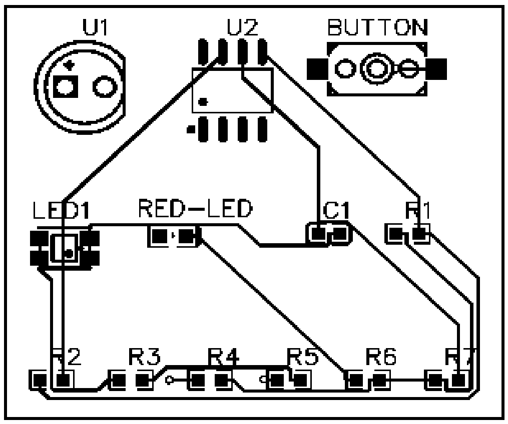


Figure 7: 2D PCB design.

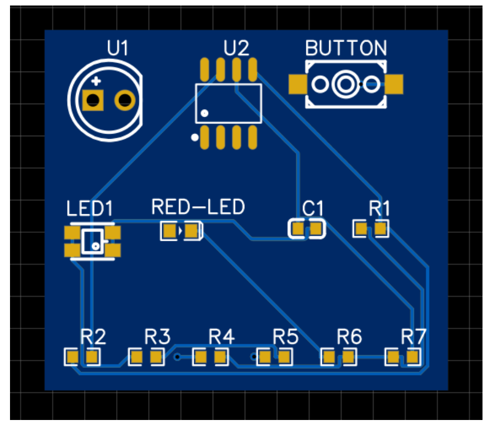


Figure 6: 2D PCB design.

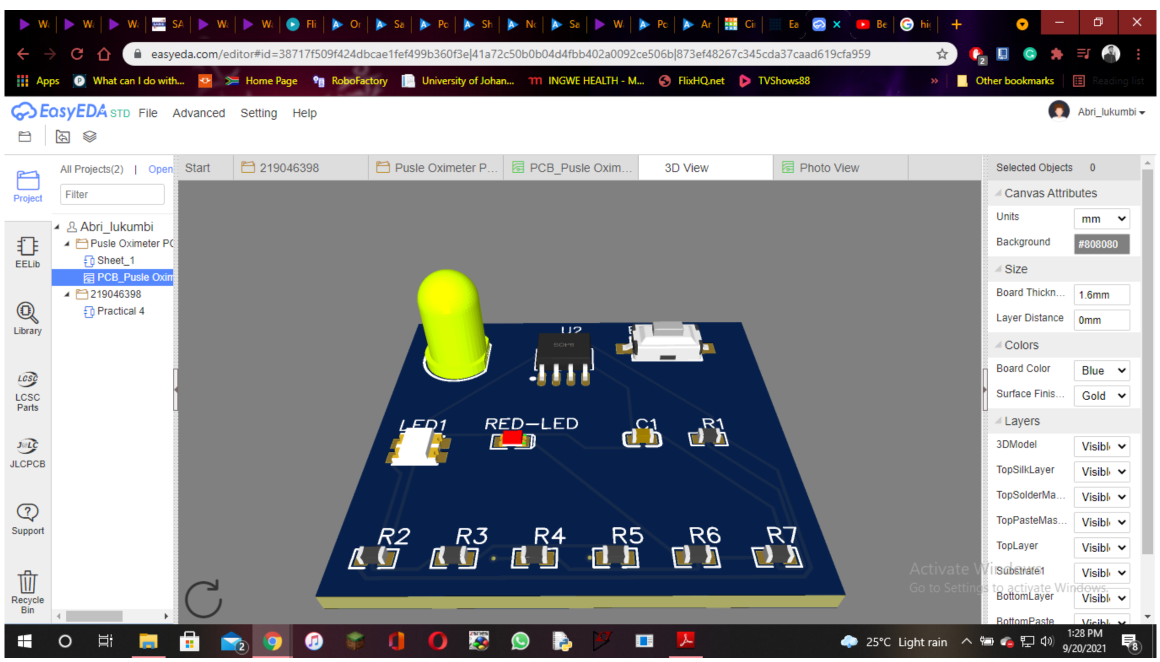


Figure 8: 3D PCB design view.

4 3-D casing design

Below are shown the 3D casing design of our oximeter device. The design was made using the TinkerCad software.

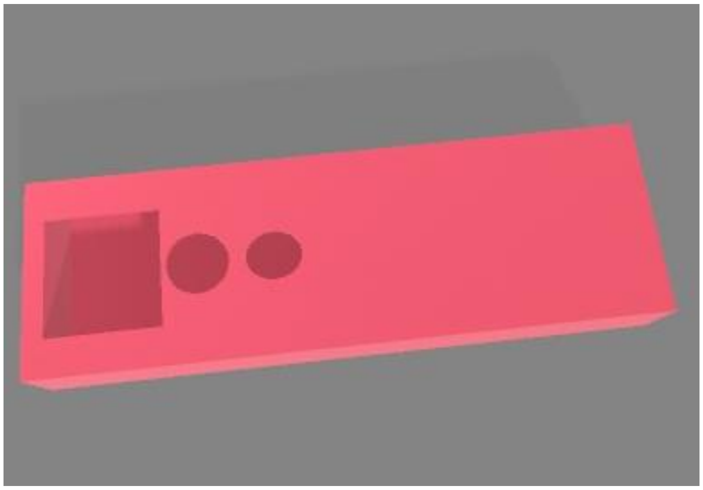


Figure 10: 3D casing design (view 1).

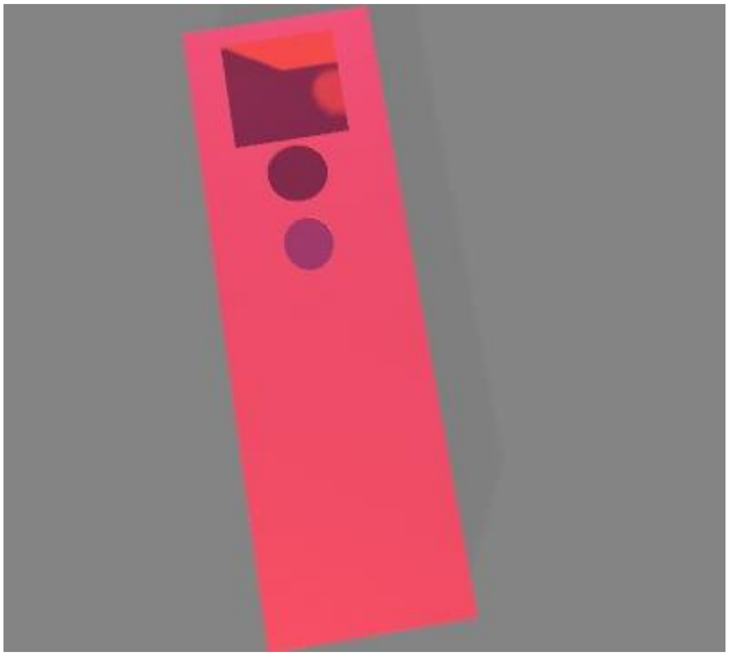


Figure 9: 3D casing design (view 2).

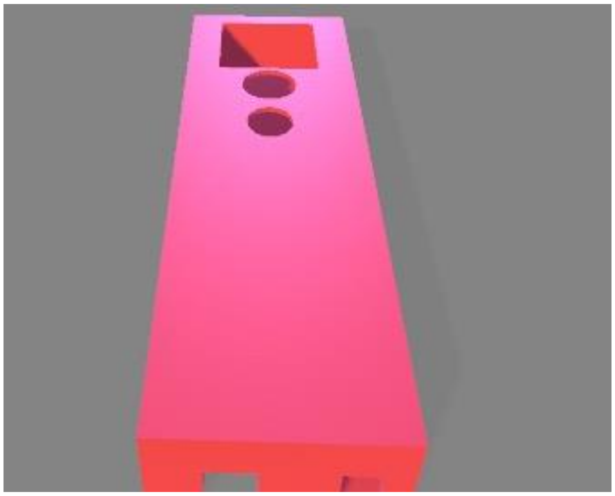


Figure 12: 3D casing design (view 3).

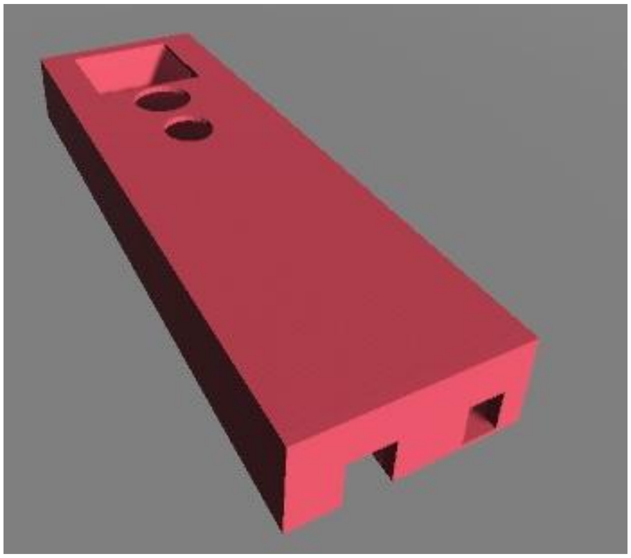


Figure 11: 3D casing design (view 4).

The rectangular hole at the top is designed to accommodate an LCD display. The circular hole just below the LCD display hole is designed to allow a finger for SpO2 and heart rate measurements. The two side by side rectangular holes on the side are designed to accommodate the two Arduino power/USB ports.

5 References

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