# BIOMENG 241: Instrumentation and Design

Assignment Tracking Sheet

## Student Information

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|---|---|---|---|
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| Family Name: | Crabtree | Given Names: | Ursula |

## Assignment Information

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|---|---|---|---|
| Assignment Name: | Final report | Due: | 11:59 a.m. - 31 Oct, 2020 (NZ Time) |
| Department: | Bio-Engineering | | |
| Lab / Tutorial Day: | Thursday | Time: | 12:00 |
| Lab / Tutorial Group: | Purple | Tutor: | Samuel Rosset |
| Notes: | | | |

## Declaration: (please read and sign)

By submitting this assignment, I confirm that I am aware of The University expectation that all students complete coursework with integrity and honesty as stated in the **Guidelines: Conduct of Coursework** available at:
http://www.auckland.ac.nz/uoa/home/about/teaching-learning/honesty/tl-uni-regs-statutes-guidelines

I confirm that this work represents my individual/ our team's effort and does not contain plagiarised material.
I have checked the above details and verify them to be correct for the assignment I am submitting.
I am aware of the course outline regarding the format, structure and submission of this assignment(see note 2 below)
I understand that the University of Auckland takes no responsibility for lost assignments and that I agree to provide a duplicate copy if requested
I understand that uncollected assignments will be retained in secure storage until two weeks after the start of the following semester and thereafter destroyed
I agree that I will provide or submit an electronic version of my work for computerised review if requested(see Note 3 below)

Signed: Ursula Crabtree Date: 30/10/2020

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# The ColourSEN-241

By Jordyn Chan, Ursula Crabtree, Britney Kerr, Nayuta Nishiyama and Qianru (Mona) Yin.

## Summary

The ColourSEN-241 is a colour meter designed and manufactured by Team Purple. It is intended to be an affordable device usable by individuals of all ages. As a result of extensive research it was decided that the key specifications are that the device must be moderately priced, reasonably accurate, safe and easy to use. Due to limited resources and time, the prototype is connected via some wires to a DAQ which is connected to a computer via USB. The output RGB values of the device are then displayed by a program called LabVIEW. Throughout this report Team Purple explores the process we undertook in designing and developing the colour sensor. We discuss the obstacles we faced, how we overcame them and to conclude the report we compare our finalised prototype against other products on the market and our initial specifications to establish whether our prototype was a success.

## Introduction

**General Problem:** According to Wang et al. (2016), human skin colour is vital for the cosmetic and medical industries where precision is required for diagnosis and consistent manufacturing. In the digital era, it is common to order online and partake in meetings such as telemedicine consultations from the comfort of our home. The selection of cosmetics and the diagnosis of skin conditions are heavily dependent on colour. Therefore, an objective colour standard is becoming a necessity and a household device which supplements such readings is in demand.

**Problem Statement:** Individuals of all ages (5+ years) need a cheap, ergonomic device for common households which measures and quantifies the colour of a surface, such as skin, to an objective standard (RGB scale of 255).

## Background Research - Two existing products from the market were researched and were evaluated on their advantages and shortcomings.

**Nix Pro Product Line - Specs[1]:** Weight: 17 - 43 grams, Dimensions: 3.81 x 2.54 cm - 5.84 x 4.06 cm.

Nix Pro is a product line of stylised, handheld, battery-powered colour meters for interior designers. It measures colour by shining a white light on a surface and displaying the reflected intensities as RGB values. Advantages are that it is ergonomic, lightweight and portable, with simple ease of use. It has a cross-server database that is updated via wireless Bluetooth data transfer to a corresponding smart device application. This, paired with a simple user interface, allows for a wider target market. The variety of sizes allows consumers to choose the most suitable size for their needs. Additionally, it has a high resolution of 16 megapixels and is industry accurate (±1%)[2].

A disadvantage is that the devices are expensive at 150 NZD - 540 NZD. Furthermore, the user must have a smart device with the system requirements to use the application. Therefore, usage may be somewhat limited for individuals who do not have or cannot use a smart device.

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[1] The Nix Pro 2 Color Sensor Is The Tape Measure For Color. (2020). Retrieved August 26, 2020

[2] Handheld Color Sensors. (2018, May 11). Retrieved August 21, 2020

Points of interest are that it can operate at a range of distances (mostly between 1.2cm - 6.0cm). This takes into consideration how lighting may change the perception of colour by the human eye. This is useful for the intended market of interior designers, however, this feature will not be included in our product. We will have the device lay flush against the measured surface to exclude external lighting.

**Color Meter PCE-XXM-20 - Specs[3]:** Weight: 120 grams, Dimensions: 5.5 x 3.2 x 15.3cm, Reading time: 1.5 s, Battery powered: 9V. On-screen display available. Accuracy: (±3%)

The Color Meter PCE-XXM-20 is a single-piece handheld device intended for many different professional uses, notably in the medical and pharmaceutical industry. The machine works by shining a white light and measuring the intensity of the light reflected from the object.

Advantages are that it is lightweight, a single piece and relatively small, making it portable. Additionally, results can be displayed on an in-built screen or be sent via a wireless or wired connection to an application installed on a phone or a computer. Another advantage is that it has a small aperture (6mm) which allows the user to measure smaller or less uniform surfaces which allows precise readings without increasing its complexity.

A setback is the cost as the device is a professional-use product on the market for 600NZD. It also has a complex user interface - not a dual button interface. It has limited operating conditions compared to its competitors as it is highly specialised, and is not suitable for common usage by general consumers.

Interesting points are how the measurements are obtained using the Tristimulus Principle; a system for visually matching a colour under standard conditions against red, green and blue. Information about common troubleshooting issues and safety notes for device upkeep is also given.

## Design + Case Design Justification:

From these current devices we deduced the following specifications:

- ★ Dimensions < 150 cm^3, Weight < 500 grams so the device can be handheld easily
- ★ Dual-button interface, for general consumer ease of use.
- ★ Neutral Laterality
- ★ Response Time: ≤ 0.1 seconds, as the competitors' response times are within 0.1 s.
- ★ Repeatability: Needs to be able to quantify 10 measurement in under 1.1s
- ★ Accuracy : Up to +/- 10% value, sufficient to be usable.
- ★ Resolution: > 1 part in 100
- ★ No sharp right angle edges for ergonomic design and safety.
- ★ Insulating Case < 0.05% chance of inducing pain by electric shock of more than 3/10 on the Mankoski Scale (Annoying enough to be distracted).
- ★ Controlled by 5V or less.
- ★ Red, Green and Blue components must have a resolution/precision of < 1%.
- ★ A 20mm diameter circular window and direct skin contact to reduce ambient light.
- ★ Signal from ambient light < 1% of the measurement signal. A flush circular window is used.
- ★ Production Cost < 30 NZD.
- ★ Target Market: Common household usage. Retail Price < 100 NZD. (Affordability)

**Design Process**

**Initial:** Britney's (see Appendix Figure 4), Nayuta's (Figure 6) and Jordyn's (Figure 5) designs have a two button interface, responsible for turning the product on/off and measuring. We considered this

[3] PCE Instruments. (2020). *Material Tester PCE-XXM 20 Manual.* Retrieved August 17, 2020

to be the simplest method. Nayuta and Jordyn's designs have no sharp edges, which is safer and more ergonomic. All the designs apart from Nayuta's, have a 20 mm circular window with direct skin contact.

Comparing how well each design meets the requirements with a decision matrix (see Appendix Figure 8), Jordyn's design was most suitable. Her design fulfilled many of the specifications, such as having round features and a simple interface, thus no significant changes were made. However, a recessed circular hole of a depth of 5 mm was added to house a window. The dimensions of Jordyn's Design are approximately 100cm$^3$ according to the CAD software we used to create the initial design. This meets our specification that they must be less than 150 cm$^3$.

**Explanation of Features**

Our case design (see Appendix Figure 11 and 12) is approximately 85.69cm$^3$ which meets our dimension requirements. Being hollow and composed of PLA, the constructed device should weigh less than 500g, allowing it to be handheld and portable. Additionally, its symmetry allows for neutral laterality. We decided a dual push button[4] interface, one for turning the device on and off and one for performing the scan was simpler than a single button interface performing both of these functions. The curvature of the device also allows use to be more ergonomic, safe and comfortable. To provide a suitable environment for scanning, a black colour was chosen for the casing to absorb ambient or stray light. Additionally, a 20 mm diameter circular window housing the LED and photodiode was added. This is meant to be lightly pressed onto the skin, allowing even pressure distribution and even surface contact. This will provide sufficient isolation from ambient light to allow the skin-to-window contact to reduce the variability of the RGB values. The rectangular hole at the end of the casing allows for the wires from the DAQ to be inserted into the device which would be connected to the laptop which holds the control program. This is only for our prototype. This will not be included in the final marketable product. The material being made up of Prusament PLA which is an insulator provides the product to be safe to the IEC60601 standards[5]. The device has basic insulation on the case as a precaution for if it fails.

**Final:** While we were prototyping, we decided that a singular button interface was more appropriate as the device could be turned on and run in one press. As a result, we added a 13mm diameter hole with a button shelf. Additionally, it was decided that a flush window would be more suitable than a recessed window, as it would allow more direct skin-to-window / surface-to-window contact. This would give us more accurate readings. After the circuit and the casing were printed, there was a misfitting issue between the transistors and button shelf on the circuit board and the case. The case was reconstructed to bear a flat surface (See Appendix FIgure 17) where the circuit board can rest in order for the LED and photodiode are able to reach the front of the case and emit light effectively. It was also noted that when the circuit board was wired up, the case struggled to contain it comfortably. Some wires seemed squished affecting the quality, safety and sustainability of the product. To account for these issues, we extended the height of the walls of the case to provide breathing room between the components of the circuit board and the top of the case. The combination of the insulating material of the case (Prusament PLA) and the breathing space given between the case and the wires gives it supplementary insulation. This meets the safety standards of Class 1 medical devices via IEC60601.

[4] ShenZhen2u Ltd (2014). Retrieved on 28 August 2020
[5] IS(2015). Retrieved on 27 Retrieved on October 2020

Another issue was that a button shelf needed to be inserted to house the singular button interface for easier use (See Appendix Figure 16). The user would hold the button down for the duration the individual would like to measure. The longer it would be held down the more readings it would take, allowing the user to see when the measurements stabilize. It was implemented as part of the case due to its sturdiness for repetitive use but also to account for reasonable excessive force. It also accounts for easier manufacturing if it were to be mass produced.

Inserts for screws were added for easier repair if issues were to occur along with a divider which would provide the photodiode with some protection from the direct LED light to ensure it is solely measuring for the reflected light. It is not directly in contact with the circular window because if it was, it would significantly reduce the amount of reflected light to the photodiode.

To accommodate for these changes, it was decided that the dimensions would be increased to 11.3 x 4 x 3.1 cm, to give a size of 140.12 $cm^3$ . This was deemed acceptable as the overall size of the device was still pocket-sized, thus it remained within the parameters of a compact, lightweight device.

The prototype is a three part device consisting of a computer containing the LabVIEW programme, a DAQ and the device itself. The wires from the DAQ are connected to the end of the device which then the USB cable would also connect to a laptop so it would power our ColourSEN-241. Once connected, a programming interface called LabVIEW must be opened and executed. The user may calibrate the device by first shining light on what is perceived to be as the colour black. From there, they would place or lightly press the device onto the surface desired to be measured. To measure the surface, the button must be pressed down and be held down for at least 0.1 seconds. This accounts for the period of each coloured light being emitted (30 milliseconds). After 0.1 seconds the RGB values are displayed in real time. This allows for it to measure surfaces that change colour throughout time and space. This could include skin colour changing as a result of a change in blood pressure, or sliding over surfaces that possess a range of colours. This allows the user to see a change in the values measured by our colour meter at different points along the surface.

**Circuit Design**

Our LED is powered by a 5V source. Each red, green and blue branch of the LED respectively contains its own NPN transistor circuit that acts as a switch (See Appendix Figure 18). This was done so we can control when each type of light is emitted. The NPN transistors were also required to amplify the current going through the LEDs.

When the light from the LED is shone onto a surface the reflected light is received by the photodiode sensor. The current generated by the photodiode depends on the intensity of the reflected light measured. It then flows through an inverting op-amp, which acts as a current to voltage converter (Figure 18). It is then followed by two cascaded non-inverting low pass filters. These each consist of a non-inverting op-amp and an RC filter (Figure 18). This enabled us to optimally attenuate the gain at high frequencies and provide us with suitable output voltages to avoid aliasing.

The ideal output range of values were from 0 to 4.5 volts which were to be received from the circuit. Originally, the gain from the two op amps in series were 20.8 which gave a range of values 0 - 1.5 Volts. As it did not suffice the output range of the desired values by 3 volts, we had to increase the range by 3 which is a gain of 62.4 via the calculations. 20.38 x (4.5 / 1.5) = 62.4 In order to achieve this gain, the resistor values had to be modified. The values were determined by as follows:

As we know if we have two op amps in series the total gain is the multiple of each gain. Therefore, we implemented 2 op amps which ideally would be similar if not the same as each other. Therefore $\sqrt{62.4} = 7.9$ meaning a gain if 7.9 was required for each op amp. To calculate the resistor values: $1 + R2/R1 = 7.9$ and because we set the R1 to be fixed to 1000 ohms or (1k ohms) for easy calculations the formula could be rearranged to $7.9\,R1 - 1 = R2,\ R2 = 7.9 * 1 - 1 = 6.9$ Thus, a value of 6.9k ohms for R2 was deemed to be suitable for this circuit.

As a result, the desired resistor values were determined to be 6.8k ohms for R6 and R7 and 1000 ohms for R2.1 and R2.2 (Figure 19).

The circuit was drawn up on the programme Altium Designer, where the PCB was created. Our circuit board was constructed without crossing over any wires and the components were placed in such a manner where wires were connected as short as possible to minimise noise from inductive coupling.

Modifications along the way were made in response to problems that arose and teacher feedback. Firstly, our cascading filters in the photodiode portion of the circuit were modified to non-inverting active low pass filters as when they were inverting, instead of the gain attenuating at high frequencies it was remaining at 1 (See Appendix FIgure 19). Secondly, the PCB layout was rearranged to connect up tracks without crossing wires over inorder to minimise noise from common mode signals (See Appendix Figure 20).

**Software Design**

We first built the function that set up the LED and then built the function that set up the photodiode. These both sit outside of the while loop(Figure 27). Within the while loop(Figure 28), we created a function to turn on the 3 R, G and B values of the LED one at a time, by setting them to high emitting 5, 1 and 3 volts respectively. From there inside this loop (i.e. so this is individually happening to each run through for R, G and B) 900 values were measured by the photodiode for each reflected colour across the sampling time. The first 450 values are deducted as they include those from when the LED was first turned on and the colour had not been reflected yet. The rest of these values are then averaged, and the minimum value (which is the calibrated value when the sensor is pointed at either pure white or black) is taken off this mean and divided by the overall range to get the ratio. We then multiplied through by the specific R, G, and B colour values from a range of 0 to 255. 0, 0, 0 is the value of black and 255, 255, 255 is the value of white, as black absorbs all light and white reflects all light. Finally, we added a section that takes the combination of the three R, G and B colour values and displays the output as a colour on the screen. We chose to do this as it makes testing efficient and the product more user friendly.

We first built the function that set up the LED and then built the function that set up the photodiode. These both sit outside of the main loop. Within the big main loop the function to turn on the 3 R, G and B values of the LED one at a time was formulated. From there inside this loop (i.e. this is individually happening to each run through for R, G and B) we averaged the values across the sampling time, then took the minimum value off this mean and divided by the overall range to get the ratio. This was then multiplied by 255 to get the specific colour value for that leg of the LED. Finally, a section that takes the combination of the three R, G and B colour values and displays the output as a colour on the screen allowing testing to be more efficient and user friendly.

## Experimental Verification and Discussion comparing our current prototype device to the market and our design Specification.

**Testing for Precision**

Firstly we tested the variability of the device by measuring the same surface in four different environments and then calculated the mean and standard deviation across the results for each value.

| | Dark Room | LED light | Sunlight | Yellow Light | Mean Value | STD |
|---|---|---|---|---|---|---|
| Red Value (avg) | 124.43 | 123.9 | 127.98 | 126.66 | 125.74 | 1.65 |
| Green Value (avg) | 78.20 | 77.57 | 79.82 | 78.88 | 78.62 | 0.84 |
| Blue Value (avg) | 122.32 | 124.08 | 127.36 | 124.23 | 124.5 | 1.82 |

A purple coloured cover of a book was tested for this sample and all the values seem to prove our device is able to quantify the colour reasonably consistently. There was a maximum of 0.72% (2dp) variability, which is reasonably low. Note that there was a calibration test, where the device takes into account what is perceived 'white' in that circumstance. The STD column communicates the resolution of our device. Only the resolution for Green met our resolution specification however the resolutions for Red and Blue were relatively close.

**Accuracy Testing - (**Please note that when accuracy is mentioned as a percentage it is the 'error compared to the given value,' in percentage.**)**

To test for the accuracy of the device we compared the RGB values of a palette which had RGB values of different shades of colour; the given standard for this course. The palette was measured via our device, by lining up the shaded region with our flush window of the colour meter and holding it down for at least 1 second. Measurements were taken for 5 shades of colour which were a range of dark to light values to ensure quality testing. The values were; red, green, blue, yellow and magenta (See Appendix Figure 20 - 25). The average variability for each R, G and B values were taken and converted into a percentage to compare the accuracy. This was done by taking discrepancies of each value compared to the standard value and calculating the average discrepancy for the specific R, G or B value for that colour (Figure 20 - 25). The averages were then divided by 255 to find the percent accuracy also stated as the accuracy. In the graph below the averages of all the R, G and B values for each colour were calculated. The average of each colours' average accuracy for R, G and B values were calculated to achieve the Average Accuracy Error. There was also a visual representation on LabView of what the device perceived the surface colour to be. So, if there was too much variability in the visual results to be valid it was noted down.

| | Red Colour | Green Colour | Blue Colour | Yellow Colour | Magenta Colour | Average Accuracy Error |
|---|---|---|---|---|---|---|
| Average Accuracy for R value (%) | 6 | 16.05 | 8.3 | 2.83 | 10.29 | 8.69 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Average Accuracy for G value (%) | 3.5 | 10.09 | 9.71 | 11.22 | 8.95 | 8.69 |
| Average Accuracy for B value (%) | 2.97 | 2.82 | 9.43 | 21.09 | 15.57 | 10.38 |

Accuracy of R value

It seemed that our circuit was reasonably accurate at perceiving the R values for the colours red, blue and yellow. However, it was considerably less accurate at quantifying the R values for green. Nevertheless, these values still fell within the expected range with an accuracy of 8.69%. During the measurements of red and magenta it is to be noted that as the shade got darker the accuracy of its R value decreased. This was especially apparent for the colour which had an R value of 177, a G value of 191 and a B value of 63. There was a discrepancy of 58.4 between this and the measured R value. For the green shade, it was consistently not accurate presenting a high variability of 16.05%. Despite being somewhat inaccurate with these other shades, while reading the yellow shade the results were reasonably precise and this is demonstrated in the low percentage of 2.83%.

Accuracy of G value

With regards to the accuracy in the perception of the G values, our device is competent in perceiving red and it was valid at perceiving other colours presenting an accuracy similar to R. It perceived most colours with reasonable accuracy except shades of blue which plummeted the accuracy of the G to 8.69%. During the measurements of the red colour, the discrepancy increased as the shade got lighter which is the opposite of when measuring the shades of yellow, the discrepancy decreased as the shade got lighter. Overall, G has consistently similar accuracy except measuring red where it was highly accurate (3.5%).

Accuracy of B value

Our B values for the three primary colours, red, green and blue were extremely accurate. However, the accuracy was very poor when measuring shades like Magenta and Yellow which are quite different shades compared to the other primary colours. This disparity decreased its accuracy to 10.38%, making it the least accurate of the 3 values. The accuracy of the B values was high when measuring shades of red and it was fairly similar to G, with the highest discrepancy being only 15.3 units. Our device had the greatest level of difficulty quantifying the green value for yellow as it correctly demonstrated only a 21.09% accuracy rate. The B values were of leading accuracy when measuring shades of green with the highest discrepancy being only 12.17 units. It is also to be mentioned that it also had difficulties perceiving values whilst measuring shades of yellow. Although in the standard it seemed to have 0 B value, the B values measured by the device were as high as 80.92 units. But reflecting on the visual representation produced by the program it did not differ much to what the shade looked like in reality. This was the other way around for when it was measuring magenta, there was high discrepancy amongst the darker shades; RGB values of 80,75,131 and 75,63,91 where it was measured as 55.04, 63.54, 92.24 and 117.35, 91.89, 136.43 and visually it was respectively seen as dark navy blue and dark grey. This may be due to that on average there were high accuracy errors in this certain colour.

Overall, one of the three R,G,B accuracy errors surpassed our range of expectancy (0 - 10%), thus it is not accurate enough to fulfil the specifications. However, our worst accuracy (10.38%), is fairly close to our limit (0.38% away), meaning this issue could be resolved with minor changes and is therefore somewhat valid. In conclusion, the experimental verification of the colour meter has determined that it is fairly consistent - having only a maximum variability of 0.72% - and has sufficient accuracy of 9.25% (average). This can be deemed somewhat sufficient as it is within our range of the specification. In comparison to the design specifications (See Appendix Figure 26), it has fulfilled all but one specification. This specification was having an accuracy of +/- 10%. In terms of accuracy it was somewhat fulfilled as mentioned above, hence, it would be an issue if it was to be put out on the market as there are still active issues. In future, we could compare more measured values to the standard to reduce random error. We could also add another RC filter or increase the quality of the components we use. However, as this would increase the manufacturing price, more precise calculations could alternatively be used. For example, instead of square rooting the total gain of 62.4 to have two identical op-amps with a gain of 7.9 each, more precise gains such as 5.2 and 12 may be preferred. This is because 7.9 x 7.9 = 62.41, whereas 5.2 x 12 = 62.4 which is more precise. It is also to note that the device is somewhat nonportable as it must be connected to a laptop via a DAQ which connects to the device. This could be improved had we been supplied a smaller DAQ, which would be contained in the case. This would increase its portability and overall convenience. However, this has more to do with the supplies given and available time. Finally, we would seek to improve our resolution specifically for the Red and Blue values.

Our prototype has smaller dimensions than the researched devices on the market, and it’s compact nature is an advantage. However, the biggest disadvantage is that it must be plugged into a laptop via a USB cable which is less convenient and portable than the others. Note that the final product would not have this issue; instead, all components would be contained within the device. Its accuracy (9.25% average) is significantly worse than the others (1% and 3%) which is another big disadvantage. However, it is much more user-friendly and cheaper which is the main purpose of our device. Therefore, while our device has its advantages, to compete in the market it must not surpass a 5% accuracy error as its accuracy would not be sufficient for its purpose as a colour meter.

## Conclusion

The purpose of the product was that it could be purchased by common households so that individuals of all ages (5+ years) could measure and quantify the colours of surfaces to an objective standard to help them in their daily activities. Fulfilling most of the specifications, we believe that the prototype was a success. Although the accuracy could be improved, it is acceptable. The singular button interface and simplicity of holding the button down to measure the colour of the surface allows for easy use. The round, ergonomic shape of the device and supplementary insulation makes it reasonably safe. The cheap manufacturing of the components makes for an affordable final product. The combination of these economic, ergonomic and safety factors and acceptable accuracy of the colour meter suffices the problem statement.

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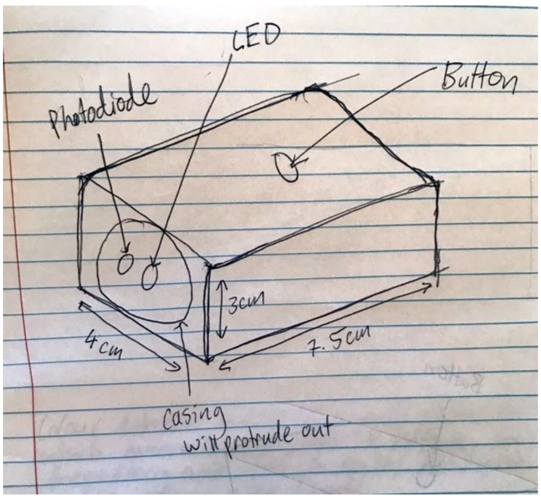
## Appendix:

Figure 1[6]: Nix Pro Product


Figure 2[7]: Color Meter PCE-XXM-20

Figure 3: Ursula's Case Design




[6] Nix Colour Sensor. (2020, August 25)
[7] PCE Instruments. (2020)

Figure 4: Britney's Case Design

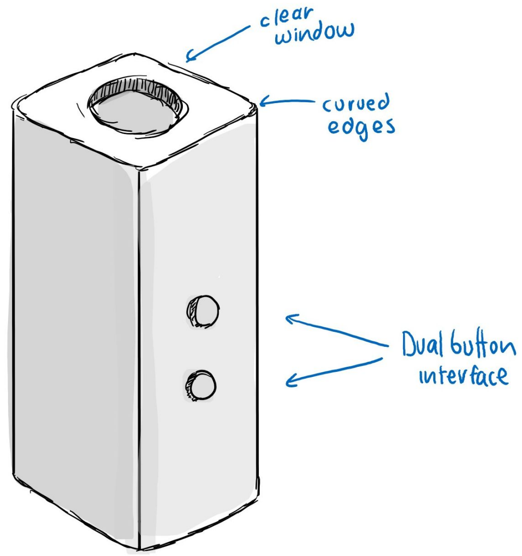



Figure 5: Jordyn's Case Design

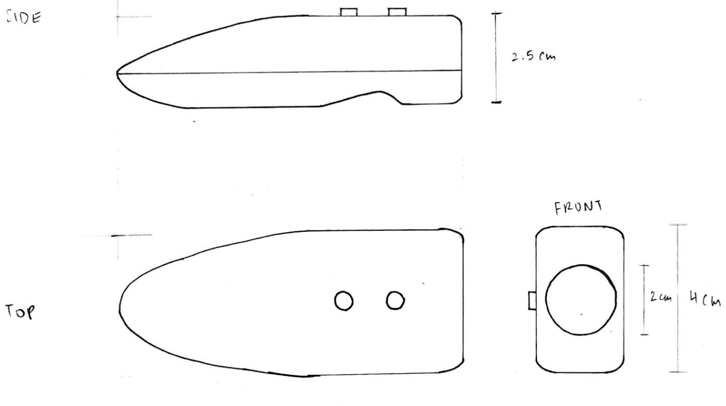



Figure 6: Nayuta's Case Design

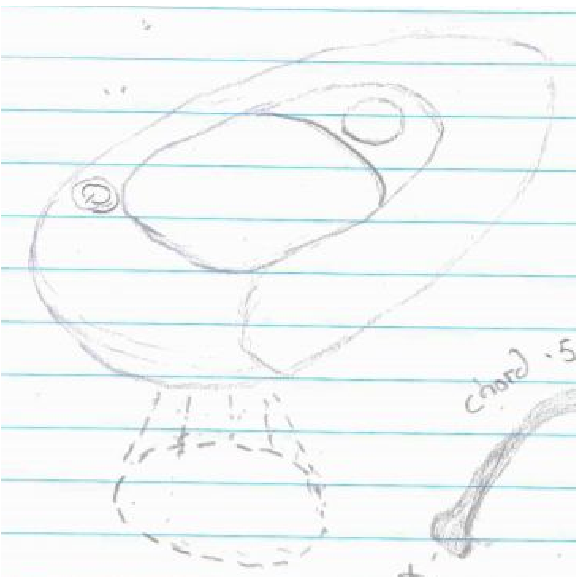



Figure 7: Mona's Case Design

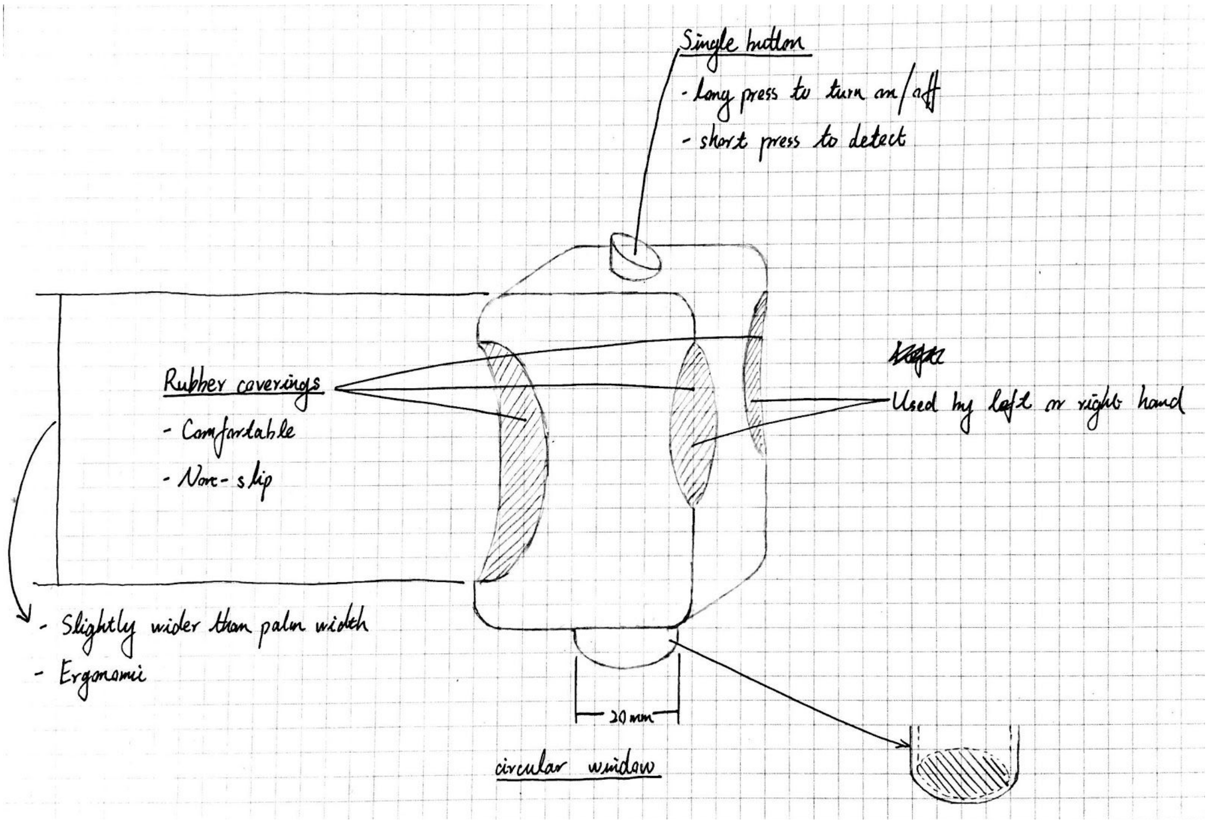


Figure 8: Decision Matrix

| | Ursula | Britney | Jordyn | Nayuta | Mona |
|---|---|---|---|---|---|
| Ambidextrous | S | S | S | S | S |
| Skin to Window Contact | S | S | S | - | S |
| Simplicity for User | - | S | S | - | - |
| Ease of Printing | - | S | - | - | - |
| Ergonomic | - | S | + | + | + |
| Portable | S | S | S | S | S |
| Safety | - | S | + | + | + |

Figure 9: Conceptual Sketch

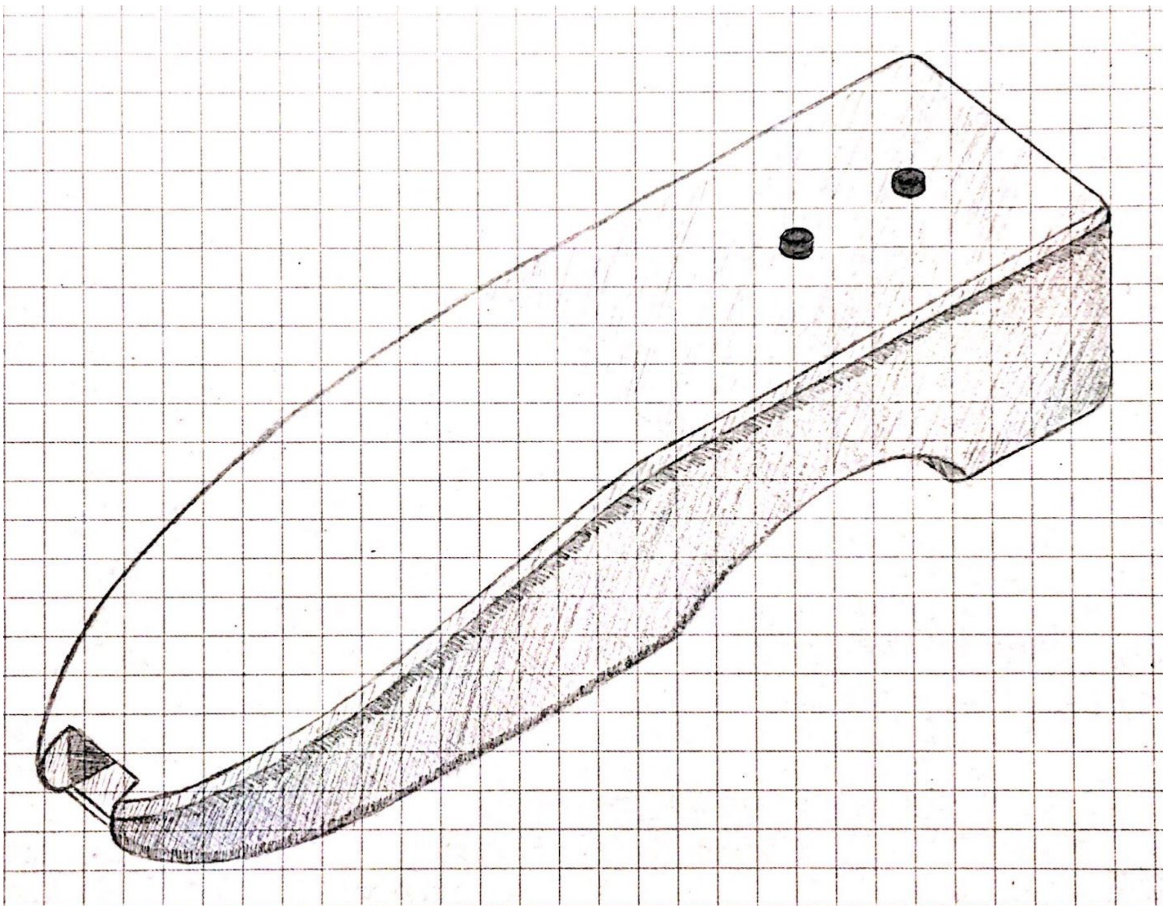


Figure 10: Orthographic Views of Conceptual Sketch

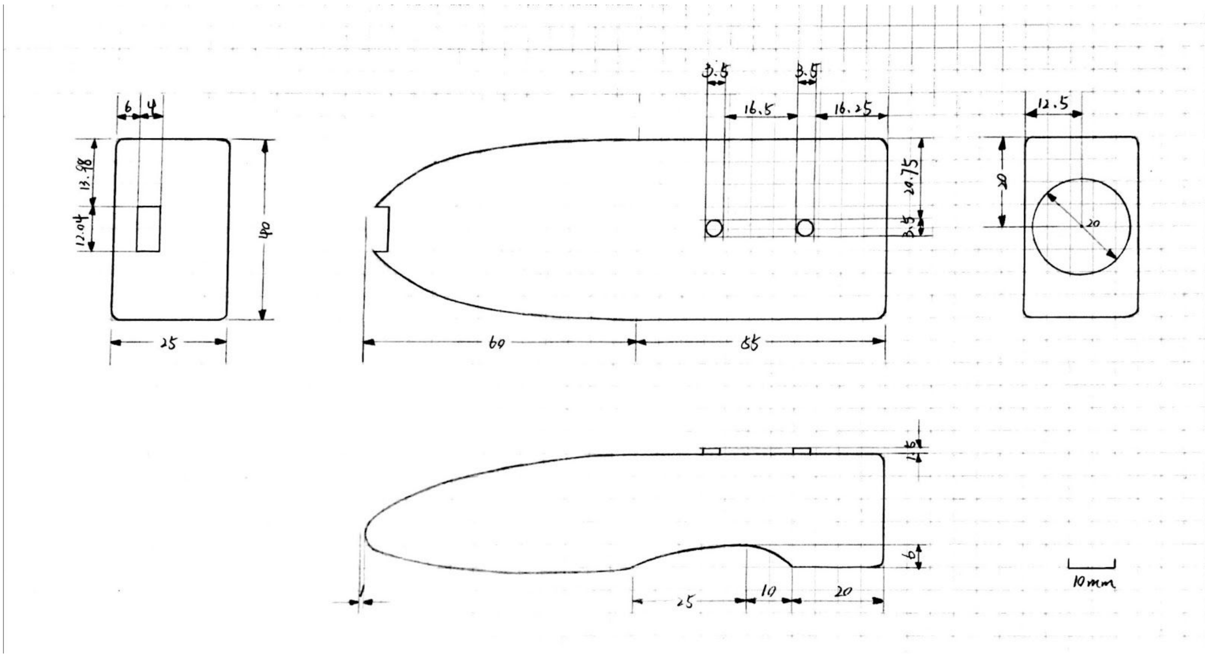



Figure 11: CAD Rendered Case Design

Figure 12: Top View of CAD Rendered Case Design

Figure 13: Casing CAD Drawing

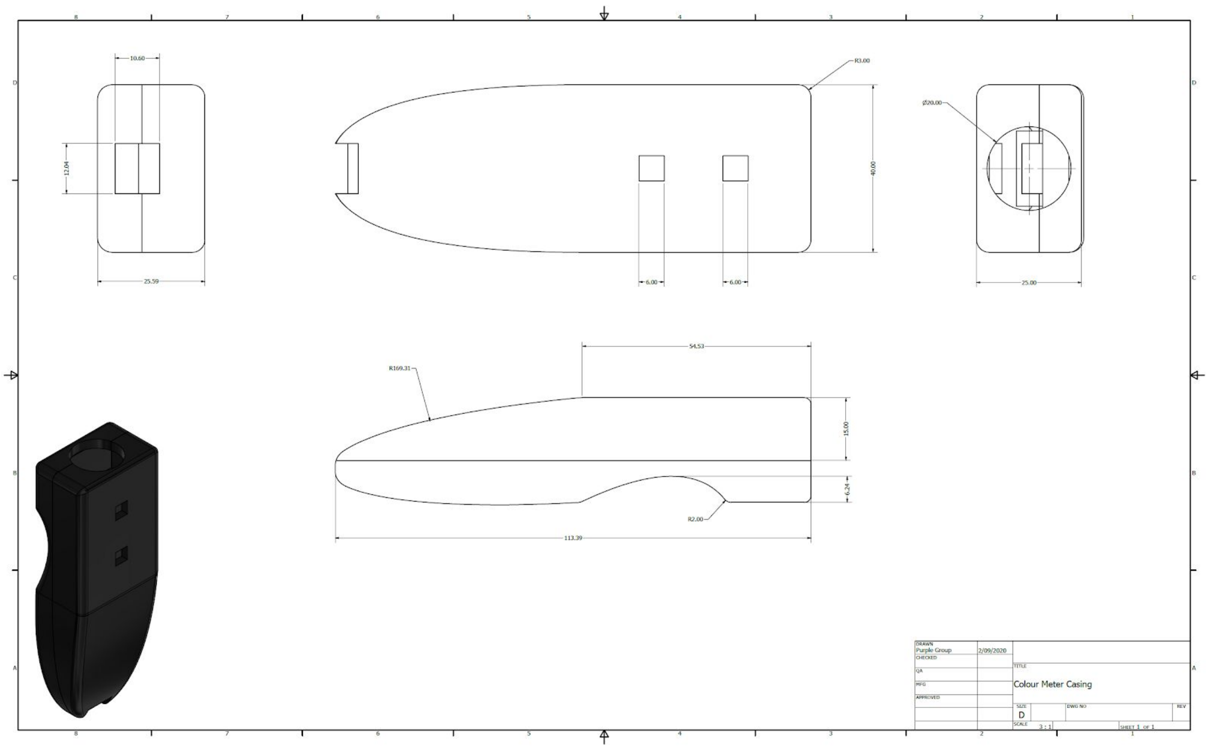



Figure 14: Assembled Casing CAD Drawing

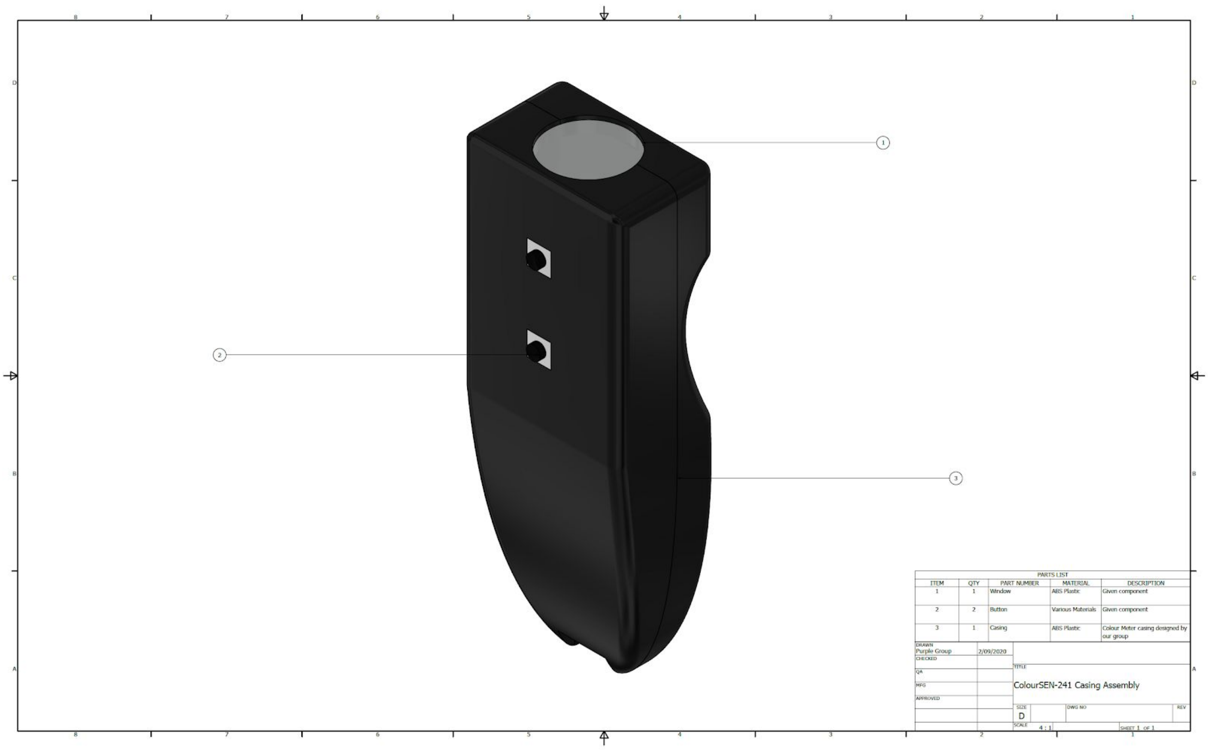


Figure 15: Circuit Diagram Schematic

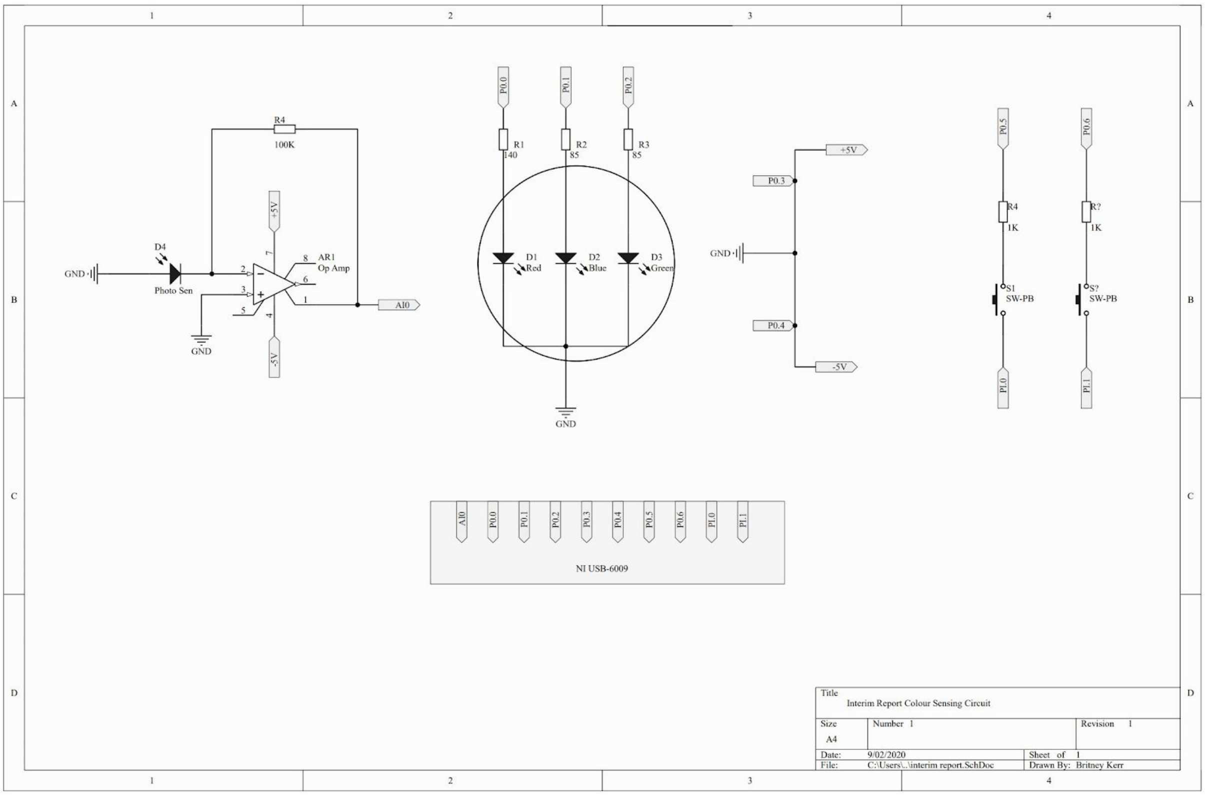



Figure 16: CAD Case Top part of the final prototype

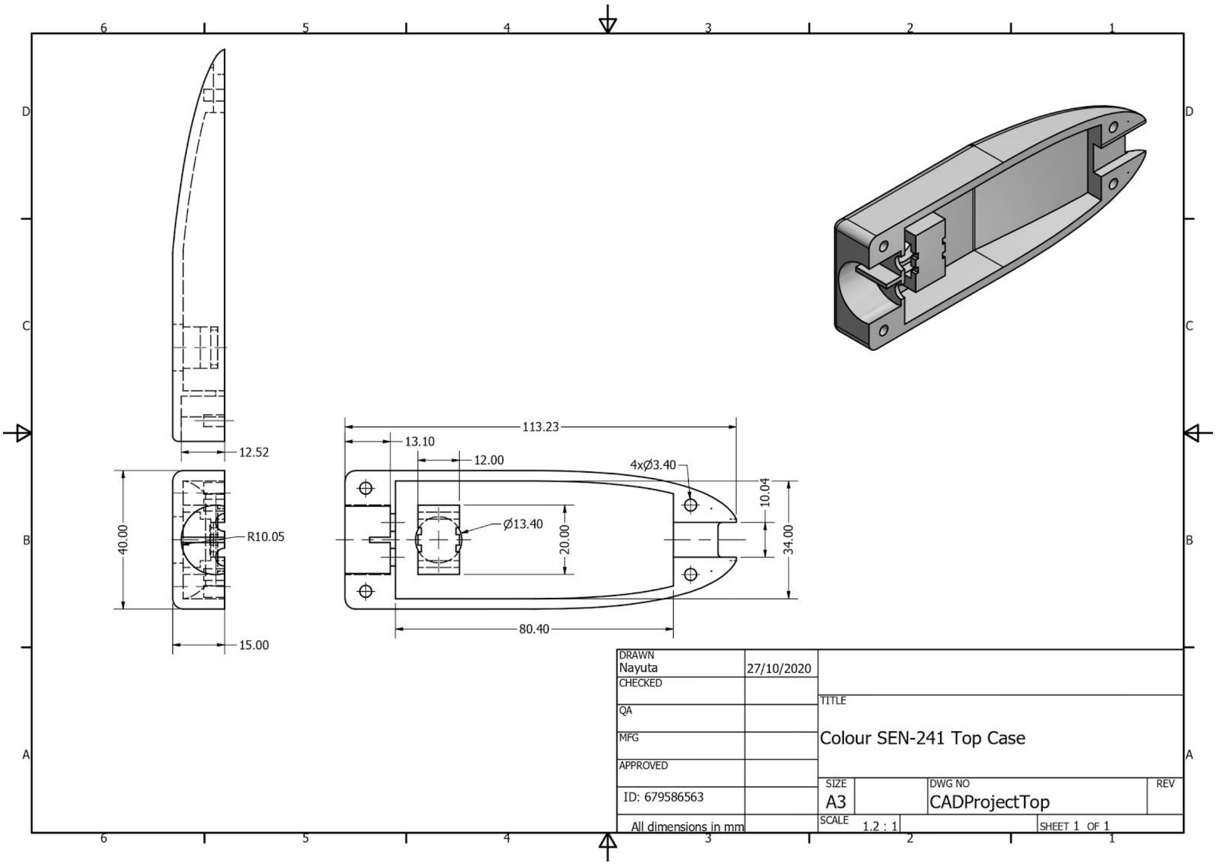


Figure 17: CAD Case Bottom part of the final prototype

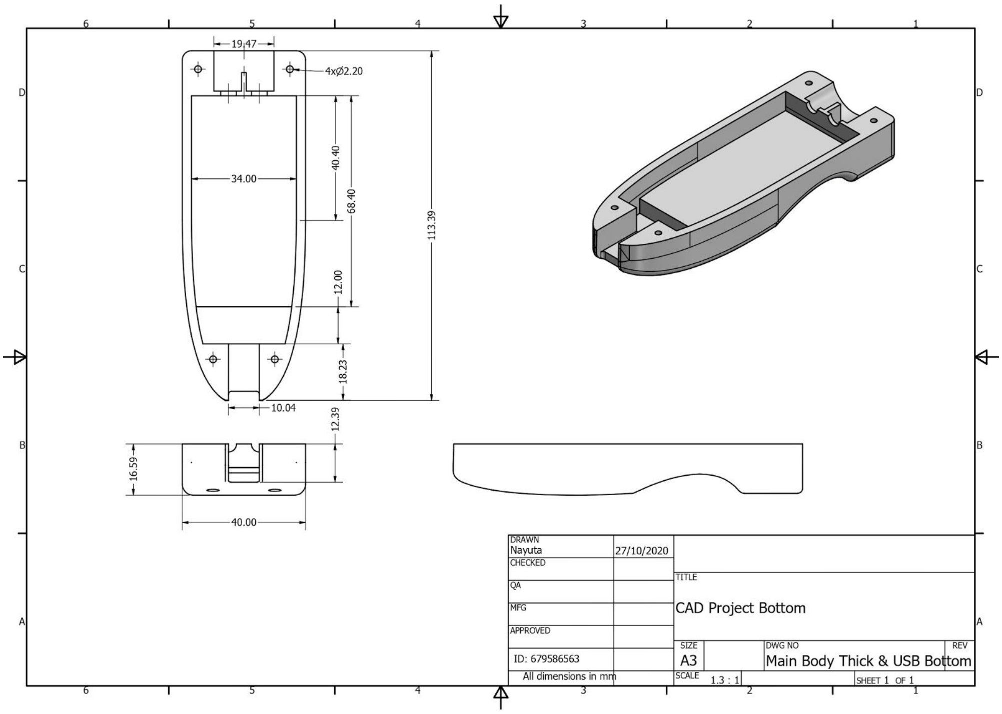



Figure 18: Schematic Diagram of the Initial Circuit

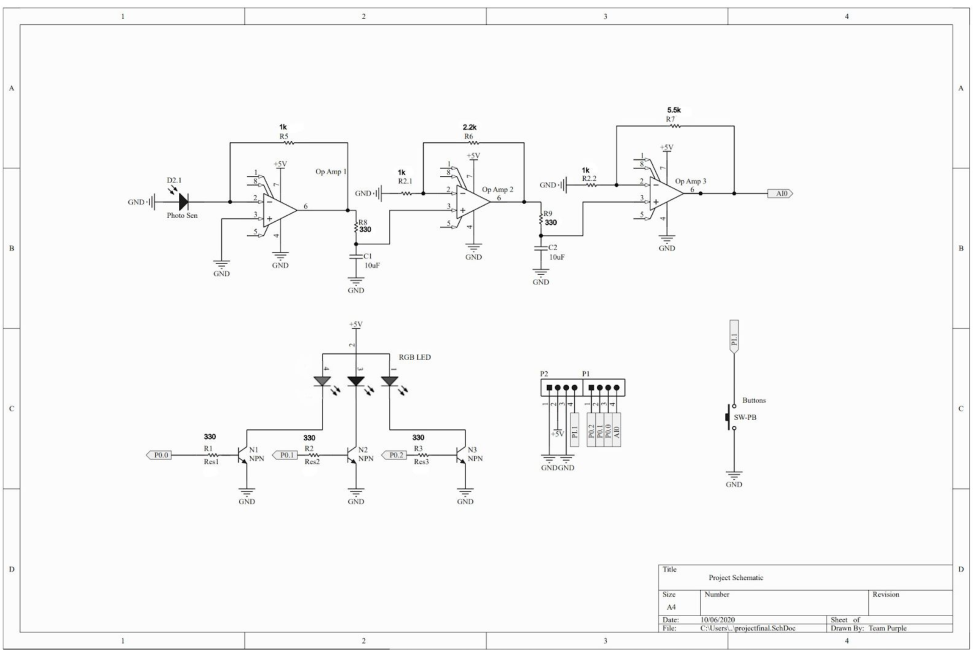


Figure 19: Schematic Diagram of the Final Circuit

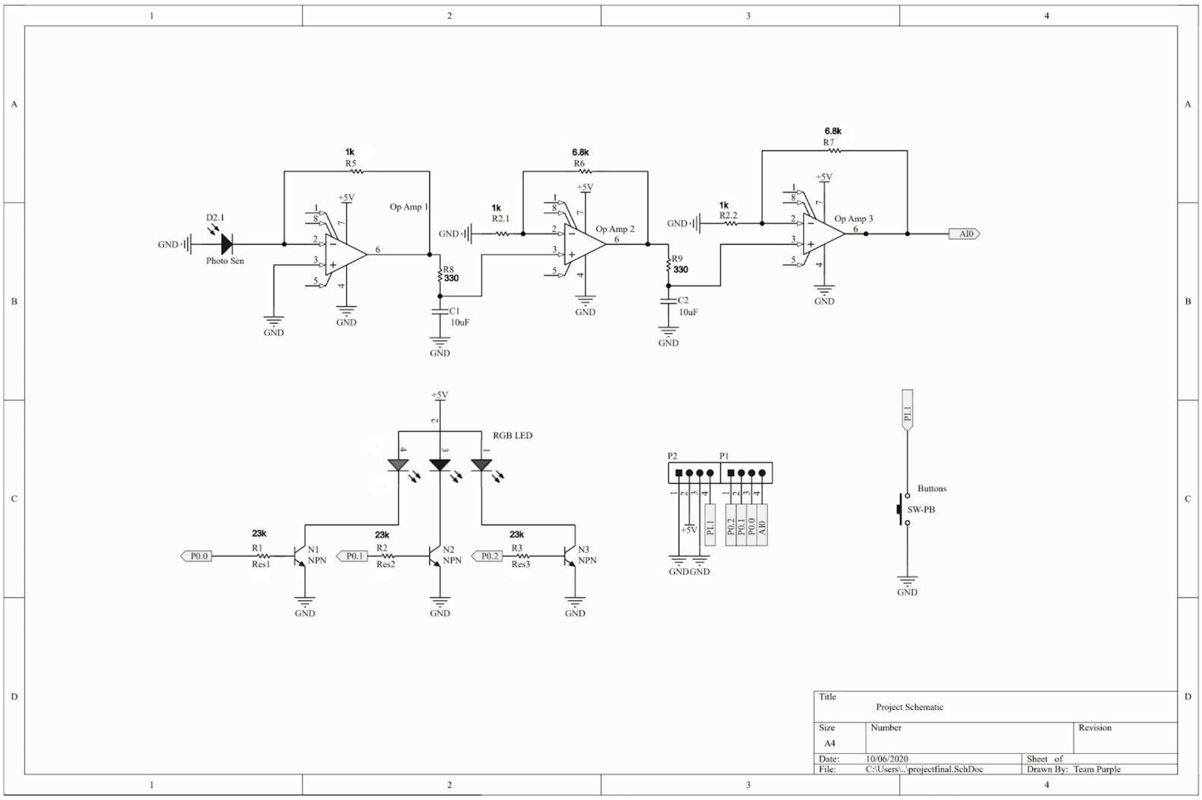



Figure 20: Printed Circuit Board (PCB) Layout

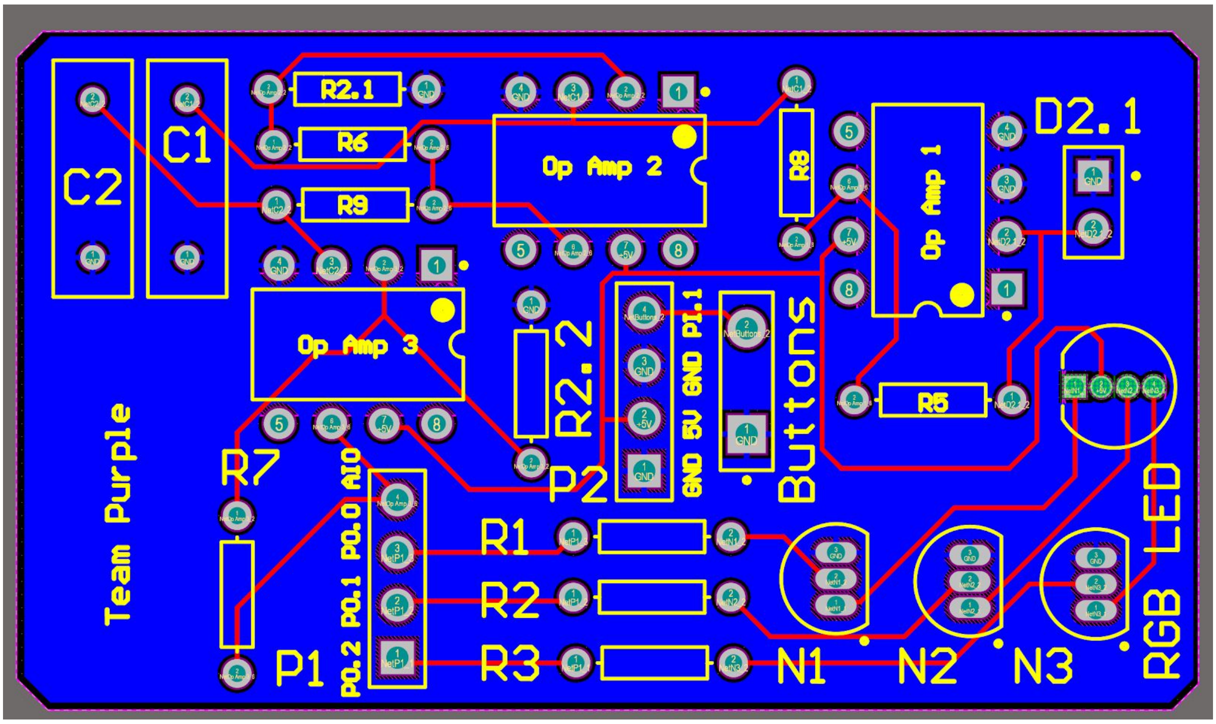


Figure 21: Results of experimentally measured values v standard values for the red palette

| Red Colour | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Average Variability (unit + %) |
|---|---|---|---|---|---|---|---|
| R Value | 164 | 173 | 208 | 235 | 201 | 208 | |
| G Value | 55 | 64 | 83 | 106 | 65 | 68 | |
| B value | 56 | 54 | 88 | 102 | 58 | 53 | |
| Experimental (R value) | 148.73 | 145.83 | 196.92 | 255 | 211.69 | 217.73 | 15.66<br>6% |
| Experimental (G value) | 53.65 | 54.1 | 61.55 | 105.04 | 56.56 | 56.81 | 8.82<br>3.5% |
| Experimental (B value) | 68.48 | 52.61 | 62.7 | 103.41 | 53.64 | 53.54 | 7.58<br>2.97% |

Figure 22: Results of experimentally measured values v standard values for the green palette

| Green Colour | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Variability (unit + %) |
|---|---|---|---|---|---|---|---|
| R Value | 97 | 177 | 190 | 128 | 184 | 224 | |
| G Value | 150 | 191 | 203 | 158 | 209 | 236 | |
| B value | 69 | 63 | 107 | 67 | 106 | 181 | |
| Experimental (R value) | 57.43 | 118.6 | 158.96 | 73 | 133.84 | 212.62 | 40.93<br>16.05% |
| Experimental (G value) | 111.25 | 159.03 | 184.39 | 116.27 | 195.99 | 246.25 | 25.74<br>10.09% |
| Experimental (B value) | 68.48 | 75.17 | 99 | 68.41 | 94.7 | 171.23 | 7.2<br>2.82% |

Figure 23: Results of experimentally measured values v standard values for the blue palette

| Blue Colour | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Variability (unit + %) |
|---|---|---|---|---|---|---|---|
| R Value | 26 | 129 | 216 | 31 | 90 | 162 | |
| G Value | 114 | 190 | 233 | 46 | 133 | 179 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| B value | 180 | 231 | 242 | 127 | 172 | 196 | |
| Experimental (R value) | 47.83 | 105.86 | 227.46 | 42.19 | 65.81 | 126.88 | 21.16 8.3% |
| Experimental (G value) | 82.88 | 168.44 | 250.62 | 60.27 | 100.02 | 147.9 | 24.75 9.71% |
| Experimental (B value) | 143.41 | 242.04 | 255 | 90.65 | 140.65 | 177.29 | 24.51 9.43% |

Figure 24: Results of experimentally measured values v standard values for the yellow palette

| Yellow Colour | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Variability (unit + %) |
|---|---|---|---|---|---|---|---|
| R Value | 250 | 255 | 237 | 248 | 249 | 244 | |
| G Value | 204 | 215 | 206 | 191 | 225 | 238 | |
| B value | 35 | 0 | 0 | 0 | 118 | 193 | |
| Experimental (R value) | 255 | 248.07 | 244.3 | 255 | 255 | 255 | 7.205 2.83% |
| Experimental (G value) | 172.65 | 178.71 | 196.18 | 166.28 | 217.56 | 253.98 | 28.6 11.22% |
| Experimental (B value) | 71.48 | 79.6 | 80.92 | 77.99 | 140.33 | 218.46 | 53.78 21.09% |

Figure 25: Results of experimentally measured values v standard values for the Magenta palette

| Magenta Colour | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Colour Standard | Variability (unit + %) |
|---|---|---|---|---|---|---|---|
| R Value | 80 | 132 | 229 | 75 | 148 | 195 | |
| G Value | 75 | 117 | 223 | 63 | 120 | 188 | |
| B value | 131 | 183 | 240 | 91 | 75 | 198 | |
| Experimental (R value) | 55.04 | 94.67 | 255 | 49.63 | 117.35 | 181.82 | 26.25 10.29% |
| Experimental (G value) | 63.54 | 88.37 | 226.69 | 57.44 | 91.89 | 164.96 | 22.82 8.95% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Experimental (B value) | 92.24 Looked like navy | 145.93 | 255 | 66.57 | 136.43 Looked like grey | 136.43 | 39.71 15.57% |

Figure 26: Comparison of Specification v Prototype

| Specification | Prototype | Fulfill or Not |
|---|---|---|
| Dimensions < 150 cm^3, Weight < 500 grams | Dimensions: 140.12 cm^3 Weight: 200 grams. | Fulfilled |
| Dual Button Interface | Single Button Interface | Fulfilled |
| Response time : ≤ 0.1 seconds | 0.1 second | Fulfilled |
| Neutral Laterality | Neutral Laterality | Fulfilled |
| Repeatability: Needs to be able to quantify 10 measurement in under 1.1s | Repeatability: Able to quantify 10 measurement in under 1.1s | Fulfilled |
| Accuracy Error: ≤ 10% | Accuracy Error: 8.69, 8.69, 10.38% | Somewhat Fulfilled |
| Ergonomic Design | No Sharp Edges | Fulfilled |
| Insulating Case | Supplement Insulation (No Shock) | Fulfilled |
| Controlled by 5Volts or less | Controlled by 5Volts | Fulfilled |
| Resolution/Precision < 1% | 0.72% | Fulfilled |
| 20mm diameter circular window and direct skin contact | Present | Fulfilled |
| Production Cost: < 30NZD | Production Cost: <25NZD | Fulfilled |
| Retail Price < 100 NZD | Retail Price: 70 NZD | Fulfilled |
| Red Resolution = 0.01<br><br>Green Resolution = 0.01<br><br>Blue Resolution = 0.01 | Red = 5/2^14 = .000305<br><br>Green = 1 /2^14 = .00018<br><br>Blue = 3 /2^14 = .000061 | |

Figure 27:

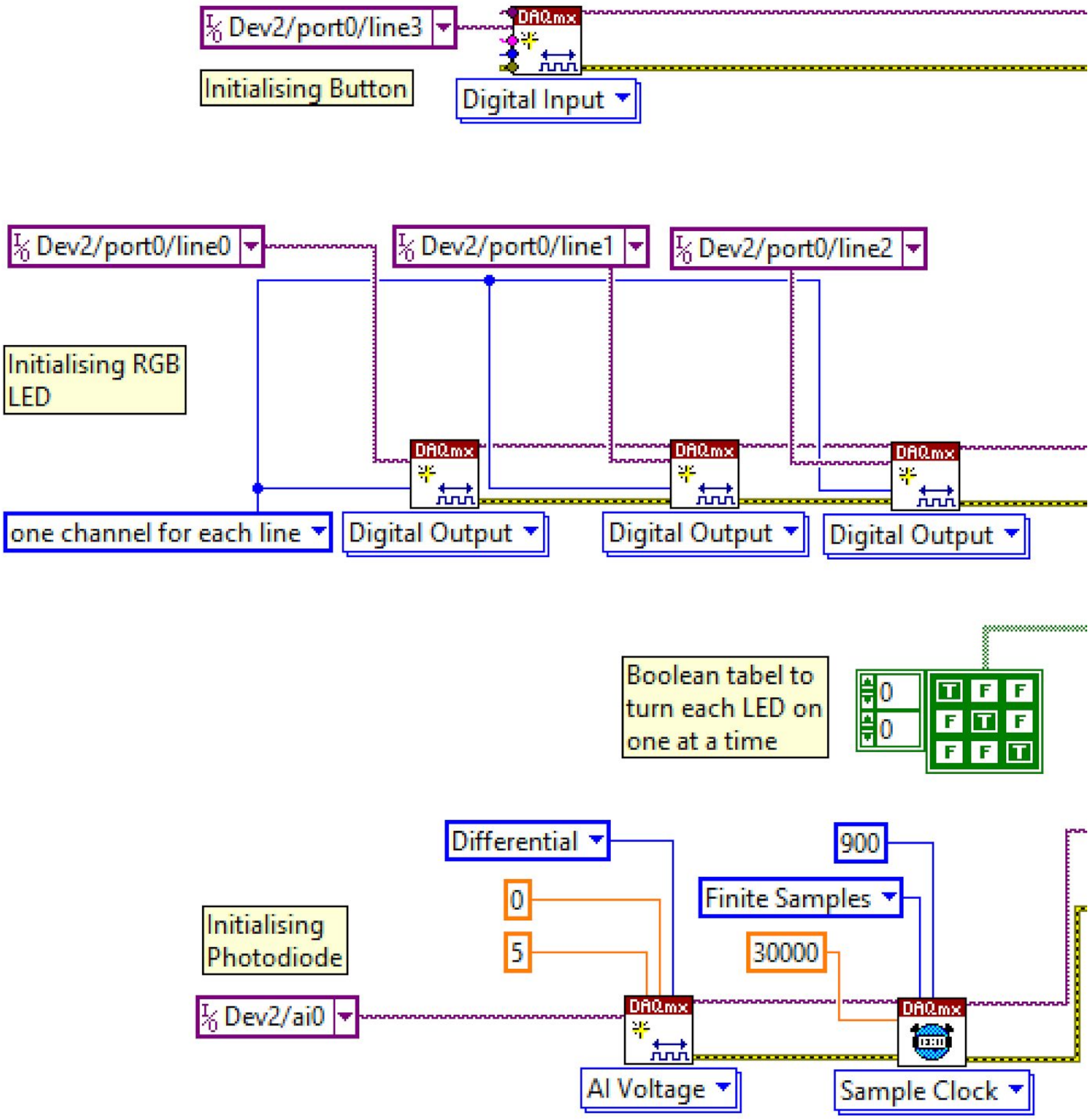
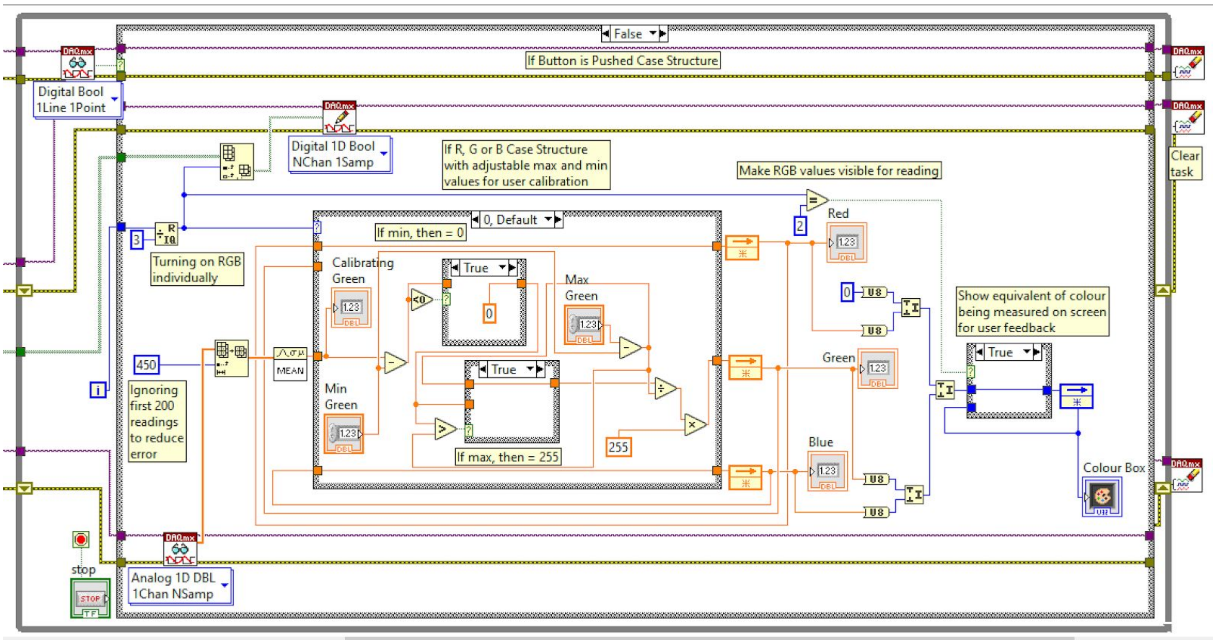



Figure 28:



False
If Button is Pushed Case Structure
Digital Bool
1Line 1Point
Digital 1D Bool
NChan 1Samp
If R, G or B Case Structure
with adjustable max and min
values for user calibration
Make RGB values visible for reading
Clear
task
Turning on RGB
individually
0, Default
If min, then = 0
Calibrating
Green
True
Max
Green
Red
Green
Blue
Show equivalent of colour
being measured on screen
for user feedback
450
Ignoring
first 200
readings
to reduce
error
MEAN
Min
Green
If max, then = 255
255
Colour Box
stop
Analog 1D DBL
1Chan NSamp