Design Document:

UV bacterial detection

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October 31 2023
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1. Client definition

Qvella™ is a clinical diagnostics biotech company specializing in clinical diagnosis. The company is dedicated to significantly reducing the time required to obtain microbiology lab results, with a specific focus on delivering faster lab results to clinicians; this is essential in reducing diagnosis wait times, a major challenge the company tackles [1]. As a private company with operations in Canada, the USA, and Belgium, Qvella™ particularly focuses on increasing morbidity and mortality rates for patients with Sepsis through the development of medicinal devices [2], [3]. The company's main challenge includes efficiently diagnosing Sepsis and decreasing the time it takes to obtain lab results.

The design targets the root of the problem; through detecting the potential existence of bacteria on mobile phone surfaces, our product increases awareness and promotes sanitization habits- a key aspect in preventing infections that might lead to Sepsis.

As one of the more deadly and expensive bacterial infections, hospitals in the US spend $62 billion dollars yearly on Sepsis [2]. Our product has the potential to reduce expenses for hospitals and research institutions by reducing the number of patient cases related to sepsis. Since bacterial infections such as Sepsis, are difficult to diagnose and treat; hence, maintaining cleanliness and hygiene among the public is of great importance.

2. The competitive landscape

2.1.0 Bacteria Culture Tests

A bacteria culture is a method to detect the presence of bacterial cells in a controlled laboratory medium [4]. This process is typically used for diagnostic purposes; a blood sample is incubated in order to detect bacteria, implying an acquired infection. However, bacteria culture tests can cause a delay in treatment, given the required amount of time needed for the bacteria to grow. While this procedure confirms an infection, our product detects bacteria for the prevention of an infection, which is much more effective at maintaining a healthy population.

2.2.0 Bacterial vaccination & healthcare

Vaccines decrease the probability of developing infections. By introducing antigens into the bloodstream, the body is able to create antibodies used as a defense against pathogens [5]. Vaccines do not provide 100% immunity. As more people get vaccinated, the less likely a population experiences a viral breakthrough [6]. This is known as "herd immunity." However, without implementing sanitary practices, the effectiveness of the vaccine will decrease. This design will encourage sanitary living conditions, ultimately decreasing the spread of bacterial infections.

2.3.0 UV flashlights

The UV flashlights available on the market are able to detect dog, cat, rodent, and bodily stains, and are usually used for deep cleaning [7]. However, the flashlight is unable to numerically analyze surfaces to detect bacteria; it is simply an LED light. The design will provide the user with a quantitative number (a percentage) of the contaminated surface. In doing so, people will be more informed about their surroundings. The product also has the potential to detect the types of bacteria on mobile phone surfaces by distinguishing the various colors detected on the UV-illuminated phone, which the UV flashlight is incapable of doing.

3. Requirements

3.1.0. UV-A light: fluorescence of bacteria

Ultraviolet LEDS illuminate bacterial colonies, making it possible for a camera to capture a photo for a computer program to analyze. Most pathogenic bacteria fluoresce under UV light. On the electromagnetic spectrum of light, UV light has a wavelength range of 100-400 *nm*. The range is further divided into three categories: UVA, UVB, and UVC, with UVA being the least harmful to human exposure with wavelengths from 315-400 *nm* [8]. In this project, the LED lights must be in the UVA range to be able to detect potential bacteria colonies and be suitable for safe exposure.

3.2.0. Camera sensitivity

A clear picture of the bacteria must be taken to be analyzed by the algorithm; this will ensure that the camera will identify an accurate percentage of bacteria within its frame. A low-light sensitivity camera connected to the microcontroller will be required to take an image of the illuminated bacteria. In this design, a Mega 3MP SPI camera module is used to take a picture of the pixel size 2048x1536. Typically low-light sensitivity cameras have a pixel size of 3 μm; the bigger the pixel size the better the performance of a camera[8].

In order to capture a clear and precise picture as an input into the algorithm, it is important the camera has low-light sensitivity, given the dark environment the camera will be placed in to take images. The camera must also have a high signal-to-noise ratio of at least 10dB to produce good-quality images [9].

3.3.0. Detection of color on the RGB scale

RGB hex color codes are used to accurately identify colors. The color code consists of three sections; each representing either red, green, or blue. Since these are primary colors, any color can be made by adjusting the values. For this project, an algorithm must be implemented to calculate the percentage of bacteria in a picture from the camera. The code will distinguish the black color pixels from the illuminated ones. Each pixel in a colored image can range from (0,255). The value of 0 represents back and 255 represents white. This allows for the identification by comparison of each colored pixel [10]. After identifying the pixel's colors a ratio will be used to find the percentage of the illuminated surface in the picture.

3.4.0. Display screen
The product must be able to output the percentage of bacteria to the user between (0-100)%. The Liquid Crystal Display screen will be connected to the STM32 nucleo-64 microcontroller to be able to control it using code [11]. A function will then be used to write data to the liquid crystal display from the algorithm. Using this function a text version of the percentage to the display to be seen by the user.

A 16x2 LCD screen is compatible with the STM32 nucleo-64 microcontroller. This size is ideal to output the title of “Bacteria” and the percentage. Some sequence of commands will be sent to the display to initialize the screen to output text.

3.5.0. Luminosity
For the Mega 3MP SPI camera module to accurately capture an image of the mobile surface, it is essential that the surface is illuminated to a certain degree. A measurement of 1 Lux is equal to the illumination of a $1m^2$ surface that is one meter away from a light source. According to a data table found on “Green Business Light UK,” for the mobile device to be relatively well-lit, a lux measurement of 200-300 Lux is required [12].

4. Design

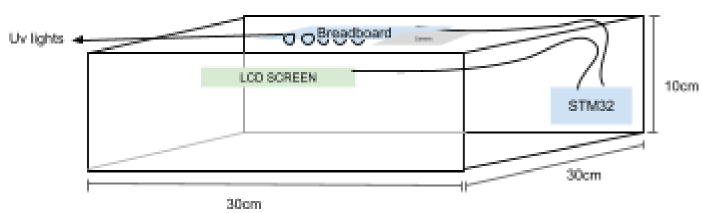


Figure 4.0. A skeleton design of the UV bacterial detector

4.1.0. Support Structure/ Environment
To be able to place a phone in an enclosed environment, a rectangular box of 20x20x10cm is required, considering an average phone can range from 14.7cm to 16.3 cm; the extra 4 cm are added to the design aiming to reduce congestion while placing the phone into the detector.

Due to resource and financial limitations, the design will be constructed out of cardboard with a thickness of 0.5cm. Black felt will be lined along the interior and exterior surfaces of the box to reduce the detection of visible light by the camera.

4.1.0. Pin configuration

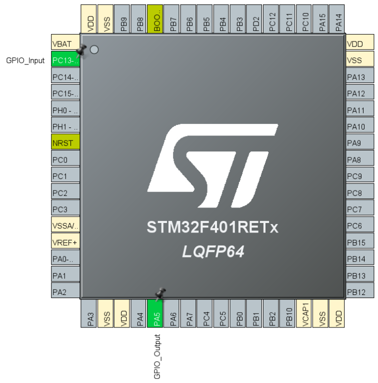


Figure 4.1 Pinout configuration schematic on CUBE-IDE. Source: CUBE-IDE environment

4.1.1. Camera connection

The camera used for this design is the “Mega 3MP SPI camera module” which is compatible with the STM32F401RE microcontroller (compatible with SPI interface). The camera is able to output pictures in RGB; the microcontroller will use these inputs to detect specific colors on the illuminated phone surface.

The camera has 6 pins, which need to be connected to the following pins on the microcontroller:

- VCC pin: CN6 pin 5 (this will provide the camera with its required 5V)

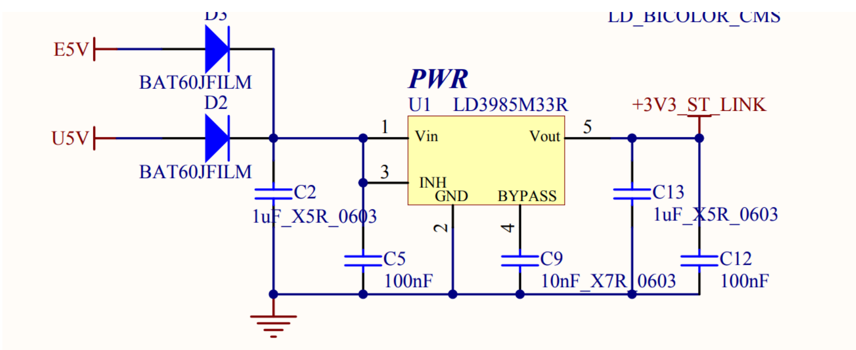


Figure 4.2 Power supply input pin for the camera on STM32 schematic [13]

- GND pin: CN6 pin 6(refer **Figure 4.2.0**)
- SCK pin: PA5 (synchronous data transfer between camera and microcontroller)
- MISO pin: PA6 (camera sends data to the microcontroller)
- MOSI pin: PA7 (used to send commands to the camera)
- CS pin: PA4 (used to indicate when the microcontroller wants to connect with the camera)

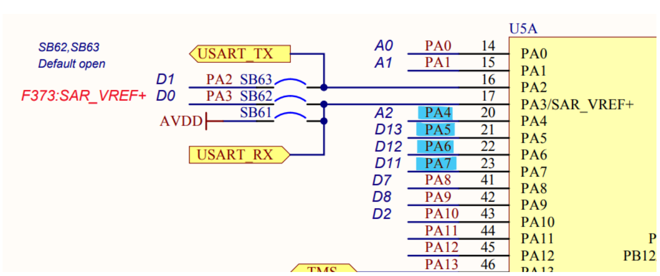


Figure 4.3 Pins on microcontroller used to communicate with camera highlighted in blue [13]

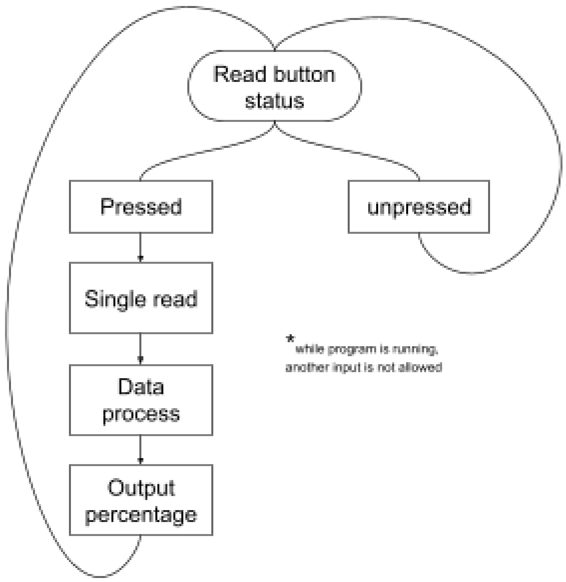


Figure 4.4. Skeleton flow code for the program
Using an input pin, the program code will determine the status of the button; if the button is pressed once, it will trigger a chain of functions to take a picture, process the image, and output the percentage of color.

4.1.2. LCD connection

A 16x2 I2C character LCD module will be used. The LCD requires 5V and simply has 4 pins that need to be connected to the STM32 microcontroller. This includes the following:

- VCC pin: CN7 pin 18 (provides 5V)
- GND pin: CN5 pin 7
- SDA pin (serial data): CN5 pin 9
- SCL (serial clock): CN5 pin 10

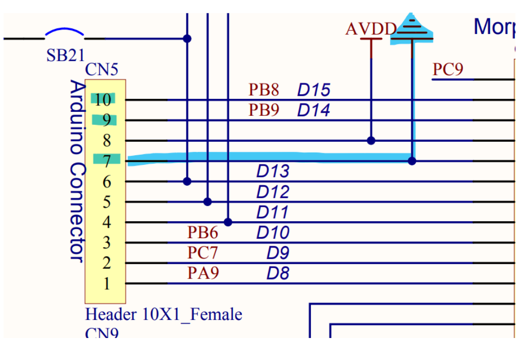


Figure 4.4. Schematics of the input pins the GND, SDA, and SCL pins of the LCD will be connected to [13]

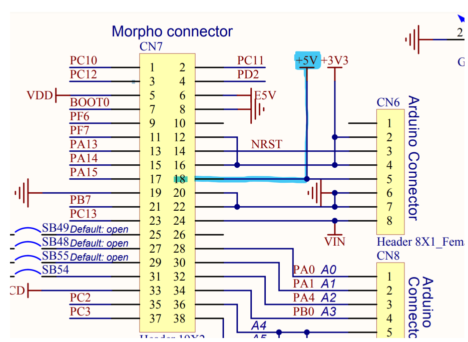


Figure 4.5. VCC pin connection to a 5V pin on the microcontroller [13]

4.1.3. Breadboard and UV lights

Construct a parallel circuit with UV LEDs using an 800-pin breadboard; the UV LEDs should have a voltage of around 3V. Connect the breadboard to the microcontroller via the 3V3 pin (CN6 pin 4). Considering the output pin will provide a voltage of 3.3V, and the LEDs have a voltage of around 3.0V, resistors of 15Ω will be used in this project. The circuit of LEDs will be grounded using the CN7 pin 8.

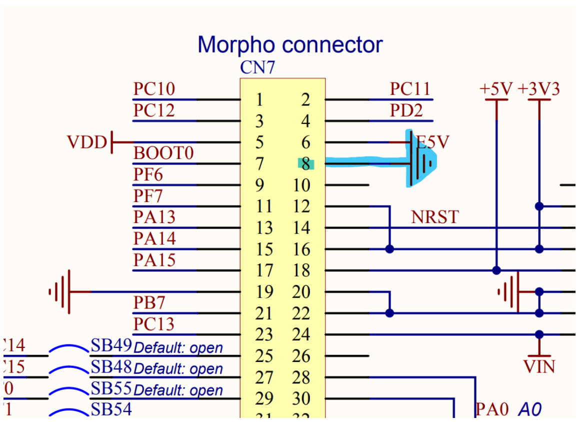


Figure 4.6. Pin for grounding the breadboard through The microcontroller [13]

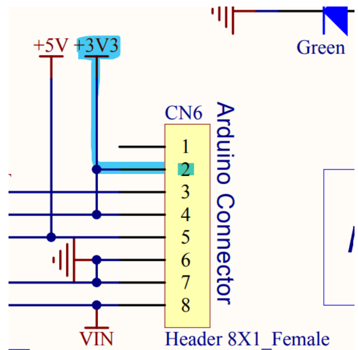
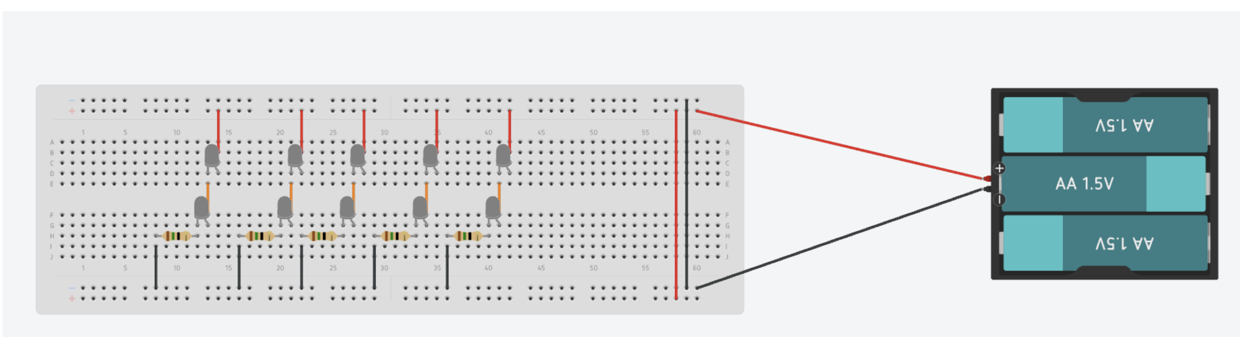


Figure 4.7. Power supply pin for the Breadboard [13]

Figure 4.8. A diagram of how the circuit will function; the STM32 pin 3v3 pin will be used instead of the batteries. Source: Tinkercad



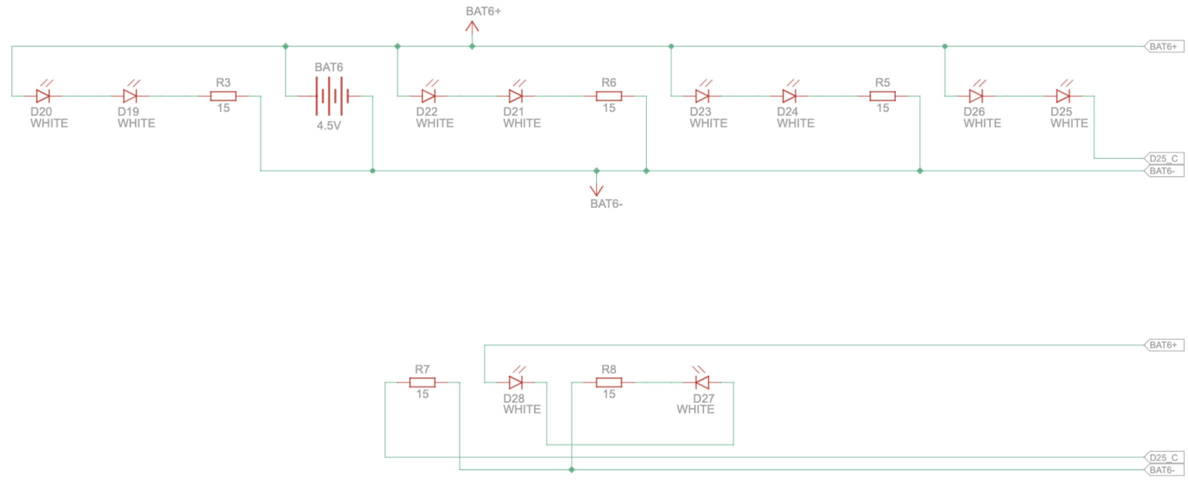


Figure 4.9. A schematic diagram of the LED circuit

4.1.4. External power supply

The microcontroller needs to provide a power supply to the camera, LCD, and UV lights. Hence, the VIN input power pin needs to be used (voltage range of 7-12V). To use the VIN pin as an external supply source, the following needs to be done:

- Connect the jumper between pin 2 and pin 3 of JPS
- Remove JP1 from 3
- Connect the positive wire (red) to the VIN pin
- Connect the negative wire (black) to GND pin (CN6 pin 7)
- Power on the external power supply (a switch is incorporated here to minimize the usage of power)
- Check that LD3 is turned on
- Connect the PC to USB connector pin (CN1)

4.1.5. Button

Using the blue button on the STM32 microcontroller, the entire circuit will be initiated. The LEDs will turn on, and the camera will take a picture for the algorithm to analyze. To do so, we will be using the PC13 input pin on the microcontroller.

5. Scientific and Mathematical Principles

5.1.0. Fluorescence

Fluorescence is a type of characteristic of atoms and molecules that absorb light at specific wavelengths, which then emits light of a longer wavelength for a specific period of time. When most bacteria are illuminated by UV light, their extracellular components emit green fluorescence. Porphyrin-producing bacteria emit red fluorescence, whereas *Pseudomonas aeruginosa* produces cyan fluorescence [14]. The color of luminesce entirely depends on the genome of the bacteria and the types of protein (in turn, chemicals) that are transcripted. Since red and cyan fluorescing bacteria are rare, in this project we will be outputting the detection of green fluorescence [14].

For this project, we will be utilizing bacteria's fluorescence property to detect its presence on mobile screens and calculate the percentage of coverage.

5.2.0. The EM spectrum

The electromagnetic spectrum is a range of EM radiation. Humans are only able to see visible light (300-780nm) [15], due to the limitations of our photoreceptors. Most bacteria are invisible to the human eye. However, with the fluorescence properties of bacteria, it is able to absorb energy (in quanta) in the form of UV light. The luminated bacteria then emits energy of a longer wavelength (since a certain amount of energy is lost). This wavelength the bacteria emits is in the range of the visible spectrum, hence, we are able to see possible bacterial colonies or pathogens.

Planck's formula for radiation energy:

$$E = \frac{hc}{\lambda}$$

Through understanding the EM spectrum, we are able to determine the appropriate instruments (the UV lights and the camera) to be able to capture an image clearly. In order to get a clear image, the object needs to be placed in an enclosed box. This box would need to be black in order to absorb the most visible light.

5.3.0. CSA C22.2 No. 250.13:22 (engineering standard)
National Standard of Canada
Light-emitting diode (LED) equipment for lighting applications

8.1.2

A current-carrying part shall be gold, silver, copper, copper alloy, plated iron or steel, stainless steel, or other corrosion-resistant alloys acceptable for the application. Trace conductors and wire bonds on a PCB may be of aluminum [16]. The current-carrying part of the jumper wires used in the circuit will be made of copper. This is because copper is the most efficient due to its superior low level of resistivity, making it a good conductor. The wiring must be corrosion-resistant alloys to ensure the longevity of the circuit. Corrosion can cause wiring of a circuit to be severed or create electrical connections in places where there should not be any.

6. Manufacturing Costs

6.1.0. UV lights

Amazon
XINCHENDIANZI
Zhenjiang Zhenjiang, China

6.2.0. 800-point breadboard
Rigidware- Eng Soc
Waterloo, Ontario

6.3.0. Jumper wires (M-M, M-F, F-F)
Amazon
Elegoo
Shenzhen, Guangdong

6.4.0. Jumper wires (for breadboard)
Amazon
Austor
Shenzhen, Guangdong

6.4.0. Liquid crystal display
Amazon
Sunfounder
Shenzhen, Guangdong

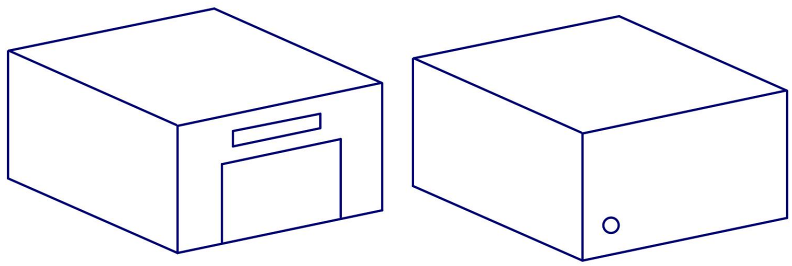
6.5.0. Battery
Amazon
Duracell
Bethel, CT

6.6.0. Black felt
Micheals
Creatology
America

6.7.0 Camera
Arducam (vendor & manufacturer)
China

6.8.0 STM32 Nucleo Board
UW store
STMicroelectronics
Europe and Asia

7. Implementation costs



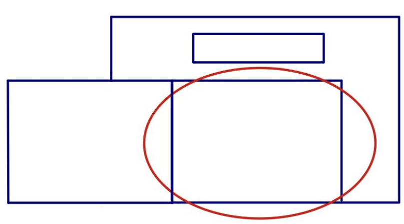
Front view Back View

Installation Guide:

Open a box containing a UV Bacterial Detection Box, and place it on a dry, flat surface. Connect the box to the power source using the USB connection. After connecting, use the button on the left side of the LCD to power on the Box. The power source will not come with the product, as a result, the user will have to purchase an appropriate power source. This item is best used in spaces with low room and sunlight.

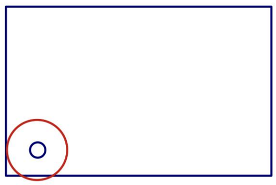
How the box works:

1. The opening at the center leads to the inside of the box where to place the device.

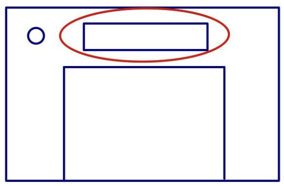


Opening

2. To power the product, press the button located on the left side of the back of the box. The liquid crystal display will have the output “Powered on” and then “Place device inside.”



Power on/off button

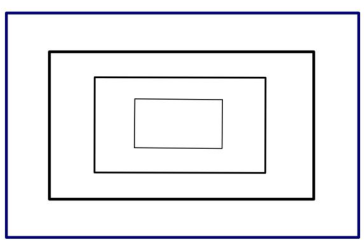


Liquid crystal display

Powered On

Place device inside

3. On the inside of the box will be 3 outlines of boxes with the different sizes of devices. Place your device within the associated outline, then close the opening of the box.



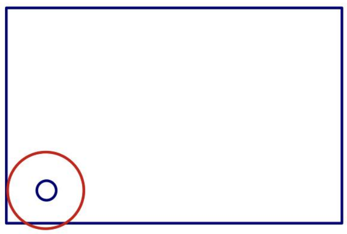
Lines for device placement

4. Once done, the percentage of bacteria will be written to the liquid crystal display.

46% Bacteria Detected

Liquid crystal display

5. Once the device is done being used, use the power on the button located on the left side of the back of the box to turn off the system.



Power on/off button

8. Risks

8.1.0.Energy analysis

Standard:

9.3. CSA C22.2 No. 338.19 (engineering standard)
National Standard of Canada
Type Class 2 power supplies (USB) and combination devices (receptacle/USB)

There are three types of standard USB configurations currently being used by the industry. The specified voltages and currents are

a) series A: 5 V, 3 A;
b) series B: 9 V, 3 A; and
c) type C: 5 V, 3 A or 9 V, 3 A or 15 V, 3 A or 20 V, 3 A, or 20 V, 5 A.

Table 8
USB ratings
(See Clause 9.3.)

USB type	Voltage, V	Current I, A	Max P, W	Power supply type
Standard	4.40 – 5.25	3	15	Series A
Standard	4.75 – 5.25	5	25	Series A
Non-standard	4.75 – 5.25	1.5 min to manufacturer's specified max	7.9	Series B
Powered	5, 12, 24	6	30, 72, 144	Series B
Managed power delivery	5, 9, 15, 20	3, 5	100	Type C

Figure 8.0. A figure table from the CSA standards [16]

The product uses standard USB Series A therefore the maximum values of Ohm's law:

Voltage: 4.75 - 5.25 V
Current: 5 A
Max P = 25 (according to the CSA standard)

By utilizing Ohm's it is acquired that the total energy used within the product's circuit is below 25W. This calculation was done using the total electrical energy in the product from the circuit.

Ohm's law:
P= IV; I = V/R

The voltage required by each component:
Camera: 5V
Liquid crystal display: 5V
Ultraviolet light-emitting diodes: 3V
Total resistance: 15 amps

V = (5+5+3) = 13
I = 13V / 15 amps

P = 13V(13V/15)
P = 11.26W

Therefore the total energy used by the circuit is below 25W. Since this design only contains electrical energy, we can conclude that the circuit does not go above power standards. In the design document, it is mentioned that the total energy is below 30W, which is fulfilled.

8.2.0. Negative consequences from intended use

- Heat associated with ultraviolet light-emitting diodes

Both infrared and ultraviolet light have high energy. The higher the energy per photon, the more energy it absorbs. The greater the amount of energy absorbed by the object, the more heat it produces [18]. The ultraviolet light produces more heat compared to other variations of light due to the high energy per photon, as a result, this could pose a safety risk for the user. The heat from the ultraviolet light-emitting diodes could cause the circuit to overheat resulting in smoke or fire from the box.

- Possibility to be exposed to skin/eyes, which may ultimately lead to cancer
- Immune system suppression
- Photosensitive reactions in certain individuals

8.3.0. Negative consequences from incorrect usage

- 3D Surfaces:

If an object is correctly placed inside the ultraviolet bacteria detection box, but the surface is 3D the box will not be able to detect the percentage of bacteria on it. This is because an item with a surface that is not completely flat will be turned into a flat surface by the picture taken from the camera. As a result, the crevices and edges of that 3D surface item will not be captured, and therefore not taken into account for bacteria detection. Without the entirety of the surface detected the bacteria percentage is false.

- An item that supersedes the max height of the device opening:

Incorrectly following the recommended dimensions will result in inaccurate detection of bacteria. If the object is placed too high it will become too close to the camera and as a result, the image taken will be a close-up of the item, and no longer the entire scope of the dimensions. This will result in bacteria detection of the item close up which will skew the percentage output to be much higher than reality. This is because the bacteria is calculated in comparison to the total surface area of the item.

- Using detection devices in wet areas:

The packaging clearly states that the ultraviolet bacteria detection box should be placed in a dry region. When placed in a wet region, this puts the circuit at risk of encountering water and results in a short circuit that trips the fuse. Their short-term effects are caused by water film formation. Long-term failures are from water-induced degradation [19]. If the moisture reaches the power source, it will react with the alkaline inside and cause irreversible damage. Corrosion can occur over a period of time, and using this product in wet regions will lead to corrosion over a period of time and eventual malfunction. If water gets under the liquid crystal display, and reaches the digitizer, that liquid crystal display will shut down.

8.4.0. Negative consequences from misuse

- Children misusing the device as a toy:

A child may see the purple light given off from the ultraviolet light-emitting diodes as a toy to play with. This is dangerous as the child may try to see inside and have their eyes exposed to the ultraviolet light. Although the product's ultraviolet light is within safe wavelength, continuous direct exposure of ultraviolet light to eyesight is unhealthy. Prolonged exposure to UV rays can lead to cataract formation and bad eyesight and modifies lens proteins. Cancers of the eyelid, including basal cell carcinoma and squamous cell carcinoma, are linked to UV exposure [20].

- Drying nail polish:

The product is built for electronic dimensions which is justified by the rectangular shape and 30x30cm build. The ultraviolet light lamps used to dry gel nail polish are created with the dimensions of a typical hand in mind. As a result, the nail polish is dried within a relatively short amount of time. The Ultraviolet Bacteria detection box covers a larger surface area of 900 cm, which exposes the user to more UV light over a prolonged period of time. The study shows long wavelengths of ultraviolet light (UVA) from UV nail dryers can damage DNA and cause mutations in human cells that increase the risk of skin cancer [21].

8.5.0. Malfunction

- Led panel and camera collapsing:

If not properly latched onto the inside of the box, the natural gravity acting on the camera and ultraviolet light-emitting diode panel will cause it to fall down.

- Ultraviolet light-emitting diode malfunction:

If one or more ultraviolet light-emitting diodes malfunction and no longer work, this will create a blind spot in the detection process. The accuracy of the section of the device under the unlit light-emitting diode will be different compared to the rest of the object giving skewed results.

- External box collapsing:

If the box is not placed together properly, the box itself could collapse.

8.6.0. Consequences of malfunction

- Led panel and camera collapsing:

This may result in damages to the device placed inside the box, or the removal of wiring needed to make the circuit run.

- Ultraviolet light-emitting diode malfunction:

The accuracy of the section of the device under the unlit light-emitting diode will be different compared to the rest of the object giving skewed results.

- External box collapsing:

This will result in potentially sharp broken parts from the ultraviolet light-emitting diodes, camera, and liquid crystal display. The negative effects on the environment are wasted material, and the new required disposal of ultraviolet light-emitting diodes, liquid crystal displays, and cameras.

9. Testing and validation

9.1.0. UV-A light

It must be ensured that the LEDs emit light in the UV spectrum to ensure the detection of bacteria. Normally, to do so, one would use a spectrometer to measure the wavelength of light.; in this test case, we will be using an app, called the “Dominant λ Light spectrometer,” available on the app store.

This test case will be conducted in a dark room. After connecting the UV light to a battery, the LED should be placed 7 cm away from the surface of a mobile surface. Using another mobile device, the light emitted from the LED will be used as a test input to be measured. If the wavelength detected falls within the UV-A range of 315-400 nm, the UV light is safe to use. The light emitted from the mobile phone can also be analyzed to set RGB color parameters.

9.2.0. Camera sensitivity

To test for the camera sensitivity, the camera will be placed in a dark environment (likely in a dark room); it will take a picture of a mobile phone(14.5 cm x 7.7 cm) held 7cm away, to mimic the conditions of the design. Using photo editing software, the pixel size of the entire image will be obtained. To calculate individual pixel size:

Individual pixel size = physical size of object/ number of pixels the object covers in the image

If the value of the individual pixel size is around 3 μm, the camera is suitable to take clear pictures in dark settings, signifying a pass in the test case.

9.3.0. RGB color detection

The camera and the computer algorithm must be able to detect color in terms of RGB hex codes of the illuminated mobile screen accurately. To test RGB color detection, we will place a sheet of paper into the environment of the box; 50% of the paper will be white, while the other 50% will be purple (#800080). If the algorithm and the camera are able to output a percentage of 50 when the required hex code of #800080 is encoded into the algorithm, the test case signifies a pass. This can be done using varying colors as well.

9.4.0. Display screen

The function of the LCD is to display the percentage of a required color. For this test, the ability of the LCD to display a 1-digit, 2-digit, and 3-digit percentage is displayed. Thus, this test case requires 3 different pieces of paper. The first paper will be 5% purple (#800080), the second will be 50% purple, and the third paper will be 100% purple. If the LCD is able to display all these values, the test case is successful and the LCD is able to perform its intended function.

9.5.0. Luminosity

It is necessary for the LEDs to sufficiently illuminate the mobile screen surface. The mobile screen will be placed inside the environment of the box. The UV LEDs will be placed 7 cm away from the mobile screen. For this test case, the “Google Science Journal" app will be used; this app is able to measure Lux. With the LED lights on, the measure of illuminance on the mobile phone will be detected by the app. If the measured intensity is between the range of 200-300 Lux, the test case is successful.

References

[1] *Linked Incorporation.* “Qvella corporation, ”https://www.linkedin.com/company/qvella-corporation/?originalSubdomain=ca (accessed Sept 14).

[2] *Qvella: Microbiology in Minutes.* “Sepsis,” https://www.qvella.com/canada/ (accessed Sept 14).

[3] *Qvella Corp/ CA.* “Bloomberg,” https://www.bloomberg.com/profile/company/1697338D:US (accessed Oct. 2).

[4] K. Stewart, “An introduction to culturing bacteria,” Technology Networks. https://www.technologynetworks.com/immunology/articles/an-introduction-to-culturing-bacteria-355566 (accessed Oct. 3, 2023).

[5] “How Vaccines Work: Immune Response and the Body’s Reaction,” Pfizer. https://www.pfizer.com/news/articles/how_vaccines_work_immune_response_and_the_body_s_reaction (accessed Oct.4, 2023).

[6] “Vaccine efficacy, effectiveness, and protection,” World Health Organization. https://www.who.int/news-room/feature-stories/detail/vaccine-efficacy-effectiveness-and-protection (accessed Oct. 4, 2023).

[7] A. Gragert, “Can you use a blacklight to search for bacteria in your home,” Hunker, https://www.hunker.com/12531834/how-to-use-a-blacklight-to-search-for-bacteria-in-your-home (accessed Oct. 5, 2023).

[8] Maruthaiyan, Bremi, “4 Major factors that determine the low light performance of a camera,” e-con Systems, https://www.e-consystems.com/blog/camera/technology/4-major-factors-that-determine-the-low-light-performance-of-a-camera/ (accessed Sept. 19, 2023).

[9] “SNR (signal to noise ratio),” Research Gate. https://www.researchgate.net/figure/SNRsignal-to-noise-ratio-tested-results-of-the-images-a-the-relationship-between-SNR_fig2_331169362 (accessed Sept. 19, 2023).

[10] H. Dhussa “OpenCV - Counting the number of black and white pixels in the image,” Geeksforgeeks. https://www.geeksforgeeks.org/opencv-counting-the-number-of-black-and-white-pixels-in-the-image/ (accessed Sept. 18, 2023).

[11] “Brief of Arducam Mega SDK,” Arducam. https://www.arducam.com/docs/arducam-mega/arducam-mega-getting-started/ (accessed Sept. 17, 2023).

[12] “Introduction to our Lux, Lumens & Watts Guide,” Green Business Light UK. https://greenbusinesslight.com/resources/lighting-lux-lumens-watts/ (accessed Oct. 31, 2023).

[13] *Dallas makerspace – a community workshop*. Available at: https://dallasmakerspace.org/w/images/d/dc/NUCLEO-F401RE_Schematic.pdf (accessed: 15 October 2023).

[14] Rennie, Monique Y. Dunham, Danielle. Lindvere - Teene, Liis. Raizman, Rose. Hill, Rosemary. Linden, Ron. “Understanding Real-Time Fluorescence Signals from Bacteria and Wound Tissues Observed with the MolecuLight i: XTM,” Diagnostics, vol. 9, no.1, pp.22. March. 2019. Accessed: Sept. 22, 2023. doi: 10.3390/diagnostics9010022. [online] Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6468690/

[15] “The spectrum of visible light, the wavelength of the light,” Lena lighting.https://lenalighting.com/company/knowledge-base/1795-the-spectrum-of-visible-light-the-wavelength-of-the-light (accessed Sept. 30, 2023)

[16] *Light emitting diode (LED) equipment for lighting applications.* CSA C22.2 No. 250.13:22. 2022. Available: https://www.csagroup.org/store/product/2703316/

[17] Type class 2 power supplies (USB) and combination devices (receptacle/USB). CSA C22.2 No. 338.19. 2019. Available: https://view.csagroup.org/wnMxwm.

[18] “18 Facts Why Does UV Light Get Hot,” Infrared for Health. https://infraredforhealth.com/18-facts-why-does-uv-light-get-hot/ (accessed Oct. 15, 2023).

[19] “The detrimental effects of water on electronic devices” Science Direct https://www.sciencedirect.com/science/article/pii/S2772671121000152 (accessed Oct. 15, 2023).

[20] “Protecting your eyes from the sun’s UV light” National Eye Institute https://www.nei.nih.gov/about/news-and-events/news/protecting-your-eyes-suns-uv-light (accessed Oct.31, 2023).

[21] “Ask The Expert: Are the UV Lamps in the Dryers at the Nail Salon Safe to Use” Skin Cancer Foundation https://www.skincancer.org/blog/ask-the-expert-are-the-uv-lamps-in-the-dryers-at-the-nail-salon-safe-to-use/ (accessed Oct. 15, 2023).