Design Document

Omar & John

Needs Assessment

Client/Customer Definition (10 pts)

The customer base whose problem the product is designed to solve is centered around higher-end hospitals that have large ICU units that support hundreds of patients a week. The focus will be initially on health care institutions located in Ontario with the release of the product but will be aimed to be expanded nationwide as a common hospital utilization. The product will hopefully be a transformative device that leverages the potential of technological advancements in the health industry to improve the health care service by hospitals in Ontario.

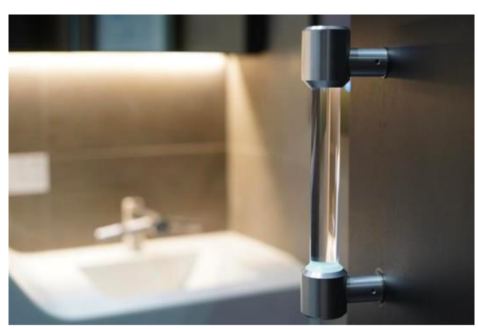
Challenges

The solution being an automatic UV-C light disinfectant device, meant to be secured right above a horizontal door handle, was intended to address the challenges of a constantly unsanitary and pathogen-filled environment [1]. Door handles and doorknobs are some of the most heavily touched surfaces in a hospital, capable of transmitting numerous diseases, germs, and bacteria with even the smallest interaction [2]. Nearly 100 000 deaths occur annually in the US because of healthcare-related infections [3]. Additionally, health care establishments are very fast paced, consequently resulting in low occurrences of surface area sanitizations. These challenges provide patients with lower confidence in the environment in which they are receiving treatment, and the capabilities of the staff treating them.

Competitive Landscape (5 pts)

One existing system is an automatic door handle sanitation system from Western Carolina University [4]. The device features a reservoir filled with disinfectant connected to a tube that pours the disinfecting liquid on the door handle after it is used. Some shortcomings of this solution include the uneven distribution of the disinfectant leading to ineffective disinfection, the large disruptive size, and the mechanism of sanitization which may leave residue or cause a slipping hazard.

Another existing system is one that comes from the Chinese University of Hong Kong [5]. This solution features a door made with a clear handle covered in a special film that can disinfect its surface once exposed to UV lights which are built into the door handle. Some shortcomings of this solution include the high costs, and installation difficulties as the system is integrated into the door and the door handle which makes it impossible to add to an existing door.



Another existing solution is one that comes from Tweaq.co, which uses a ring that travels across the door handle when activated using steam to disinfect the door handle [6]. Some shortcomings of this solution are possible issues with failure due to the complexity of the design, and possible difficulty with repairs.

Requirement Specification (5 pts)

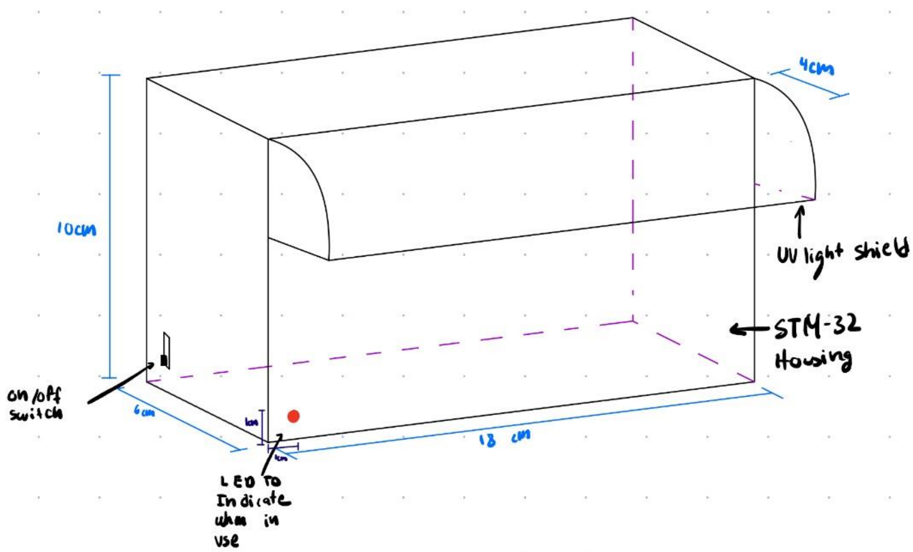
The requirements of the device are highlighted in this paragraph. The mechanism can transmit a sizable amount of 280nm of UV-C rays, although this capability passing the requirement tests is not easily testable, as diffraction slit tools to measure wavelength are not accessible by first-years in Computer Engineering at the University of Waterloo. The rays must target their wavelengths towards the top, front, and back surface of a door handle, having a total area of effect on all three areas. Each sanitization process will be active for 30 seconds in automatic mode. The device then will enter sleep mode, where the device sleeps for a time interval of an hour. The device will trigger another smaller LED light that flashes once every two seconds while the device is active to indicate the active status. As required as a safety precaution, it will not expend more than 30W of power during any of its phases once activated.

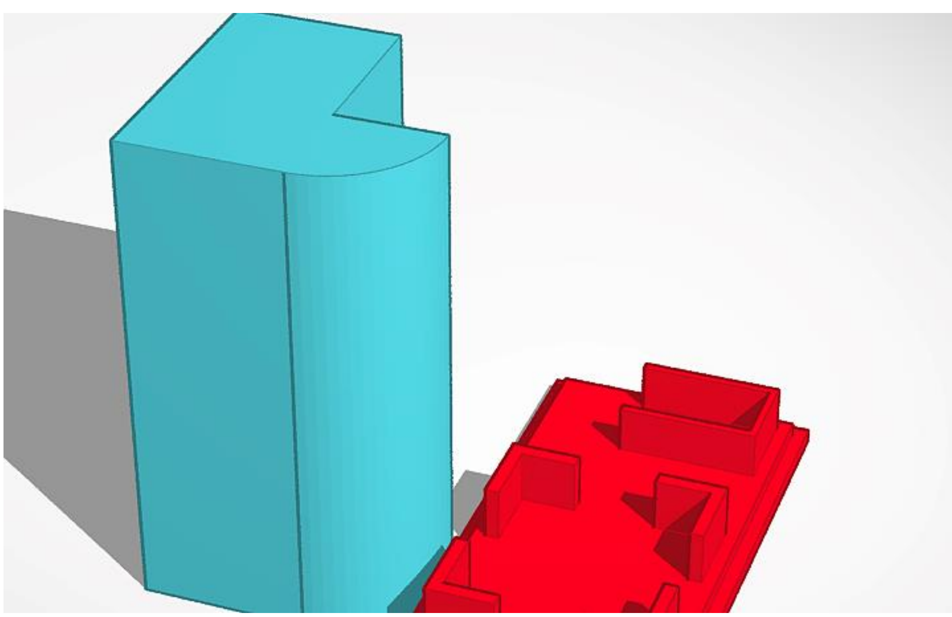
Analysis

Design (20 pts)

Automatic UV Door Handle Sanitizer

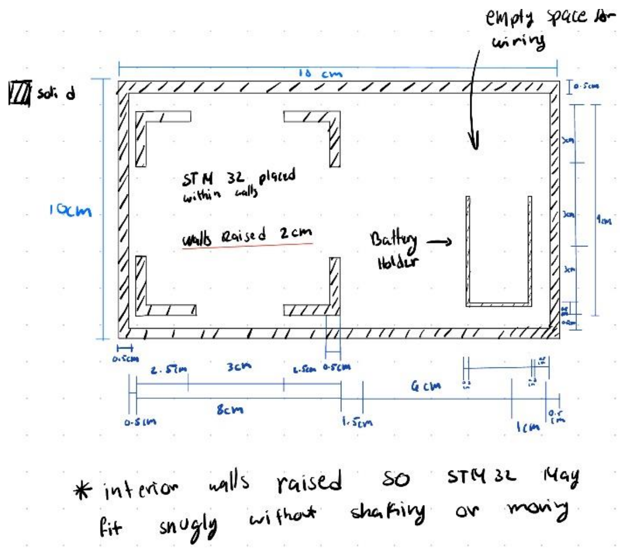
This device will sanitize a door handle using UV LED lights, it will operate automatically hourly for 30 seconds. A red LED is used to indicate when the device is running to avoid user exposure to UV light.



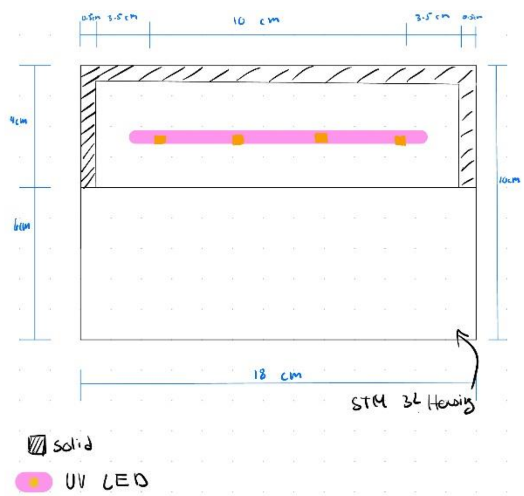


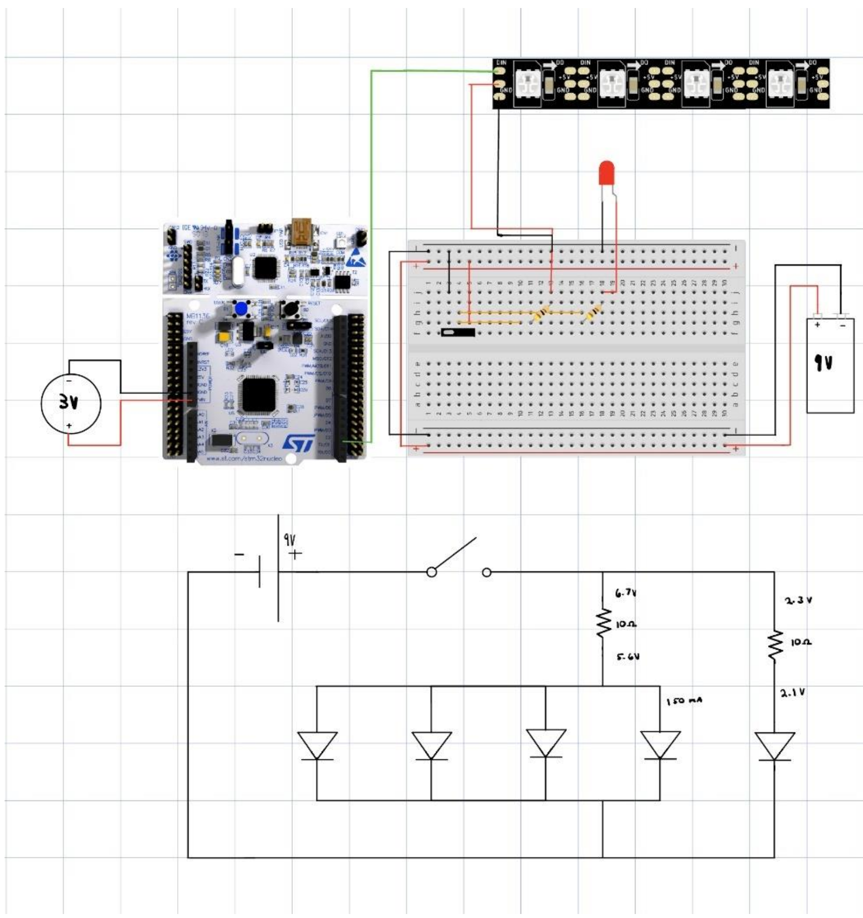
STM-32 Housing is to Be 3D-Printed.

Interior of STM32 Housing



Bottom View





Circuit Schematics for Automated Door Handle Sanitizer

<u>***In the implementation of the product the UV-C light will be replaced with a blue LED**</u>

Principles

1. Ohm's Law

   An electricity formula that shows the relationship between voltage, current, and resistance, defined as: V = IR. This formula is flexible in terms of rearranging variables, as the value of each is dependent on the others [7]. Two other forms of this formula can be written as $I = \frac{V}{R}$ or $R = \frac{V}{I}$, depending on what is already defined and what is the required value needed to be calculated. The voltage of the wires connecting the battery through to the breadboard and to the LEDs can be calculated using the current of the LED and the resistance of a 10 Ohm resistor. The power in watts is calculated from the product of voltage and current. This principle is required to calculate the voltage using the other two variables, and can be used for the power calculation, which is used in the next principle.

   DC forward current for UV-C LED: 120mA
   Resistance of Resistor: 10 Ω

   DC forward current for Indicator LED: 20mA
   Resistance of Resistor: 10 Ω

   Let V_{Cred} , V_{cuv} be the respective incoming voltage and V_{dred}, V_{dcuv} be the respective voltage drops.

$$V_{cred} = V_{dred} + I_{red}R_{red} = (2.1V) + (0.02A)(10\Omega) = 2.3V$$
$$V_{cuv} = V_{duv} + I_{uv}R_{uv} = (5.6V) + (0.12A)(20\Omega) = 6.7V$$

$$P = IV = (0.14)(6.7V) = 0.938W$$

2. Effective Irradiance

   Effective irradiance is the ratio of energy that is produced by the device to a specific area of space [8]. It can be calculated with the equation $E_{eff} = \frac{P}{A}$ where P is the power of the light measured in W, and A is the area of exposure of the light measured in cm^2. This determines what power the LED light should be set to stay within safety requirements of excess UV exposure and maximum power output of the device. This principle is a secondary step and is needed for the last and final step to determine the maximum amount of time a person can be safely exposed to the outlined size of UV radiation.

   $A = area\ of\ the\ LED\ light = length \cdot width = (0.4m)(1m) = 0.4m^2$

   $E_{eff} = \frac{P}{A} = \frac{0.938W}{0.4m^2} = 2.345\, {}^{W}\!/_{m^2} \cdot sr$

This number for effective irradiance is used in the next principle to calculate the amount of time someone can be exposed to the radiation rays without harm.

3. Permissible Exposure to UV Light

This principle is the main principle of which is required to calculate the maximum time interval humans can be exposed to this device without giving them long-term effects and consequently harming them. The permissible exposure to UV light can be expressed as an equation: $t = \frac{3mJ/cm^2}{E_{eff}}$ [9]. The top half of the equation $3mJ/cm^2$ is the acceptable limit for occupational exposure to UV radiation and dividing it by the effective irradiation from the previous principle gives the time humans can be exposed to UV light before becoming inflicted with skin damage. The time calculated can then be used to calibrate the time interval in the STM32 C++ program so that the exposure is within the permissible exposure.

$$t = \frac{3mJ/cm^2}{E_{eff}} = \frac{3mJ/cm^2}{2.345 {}^{W}/_{m^2 \cdot sr}} = 1.279s$$

This calculated time from the principle of permissible exposure shows that it becomes dangerous for people if they are exposed to the UV-C rays in this device for more than 1.279s.

Costs

Manufacturing Costs (5 pts)

STM32 Microcontroller – [10]

Manufacturer: STMicroelectronics (Agrate Brianza and Catania (Italy), Crolles, Rousset, and Tours (France), and in Singapore)

Vendor: Wstore (Ontario, Canada)

400 Tie Point Breadboard – [11]

Manufacturer: DFRobot (Shanghai, China)

Vendor: DigiKey (Minnesota, USA)

Indicator LED – [12]

Manufacturer: Bivar Inc. (California, China, Taiwan)

Vendor: DigiKey (Minnesota, USA)

Resistor – [13]

Manufacturer: Bourns Inc. (California, USA)

Vendor: DigiKey (Minnesota, USA)

UV-C LED – [14]

Manufacturer: Vishay Semiconductor Opto Division (China)

Vendor: DigiKey (Minnesota, USA)

Jumper Wires (M/F) – [15]

Manufacturer: SparkFun Electonics (Niwot, Colorado)

Vendor: DigiKey (Minnesota, USA)

Implementation Demo LED – [16]

Manufacturer: Luminus Devices Inc. (California, USA)

Vendor: DigiKey (Minnesota, USA)

9 V Battery Snap Connector – [17]

Manufacturer: Keystone Electronics Corp. (USA)

Vendor: DigiKey (Minnesota, USA)

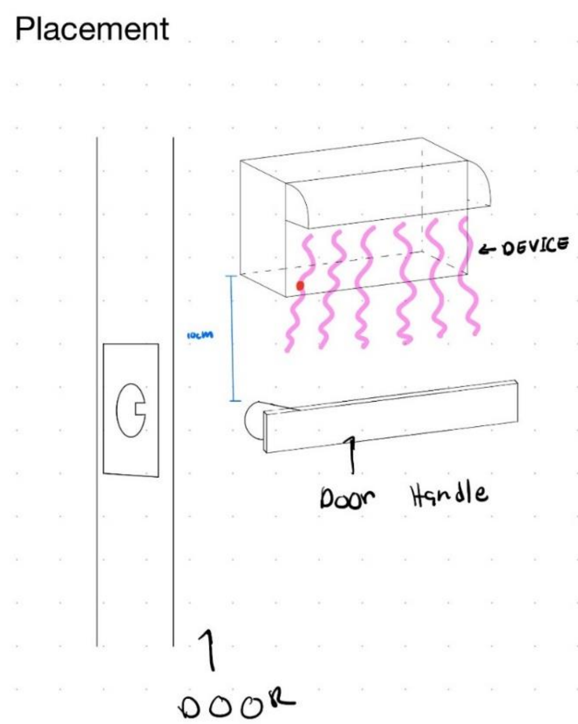
Sliding Switch – [18]

Manufacturer: C&K (Waltham, Massachusetts)

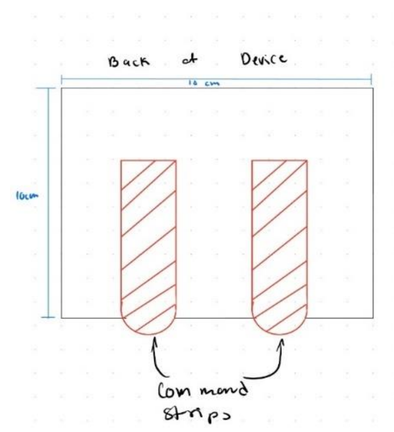
Vendor: Digikey (Minnesota, USA)

Implementation Costs (5 pts)

The device is placed on the door with the open part of the hood facing down and centered on the door handle. The device is placed with the bottom of the box no more than 10cm above the handle.



The device is attached to the door using two command strips placed on the back of the device. Evenly space out the command strips on the back of the device, peel off the protective plastic and place the device firmly on the door. Ensure to place the command strips so that the round edges hang off the device for easy removal.



Once the device is attached firmly to the wall, slide the switch found on the left-hand side of the device and it will automatically disinfect the door handle every hour.

Risks

Energy Analysis (5 pts)

$$P_{battery} = V_{battery}I_{battery} = (9V)(0.6A) = 5.6W$$

The baseline energy limit that will run through the LEDs is a power quantity of 5.6W from the power source and through the entire circuit.

PART	COLOR	RADIANT POWER (mW)			at I_F (mA)	WAVELENGTH (nm)			at I_F (mA)	FORWARD VOLTAGE (V)			at I_F (mA)	TECHNOLOGY
		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		MIN.	TYP.	MAX.		
VLMU35CB20-275-120	Ultraviolet	15	19	-	120	270	273	280	120	5.0	6.2	7.0	120	AlGaN

[14]

The current of 120mA was used to calculate the total power output of the device.

$$P_{UV} = VI = (6.7V)(0.12A) = 0.804W \text{ [19]}$$

700	RED	DIFFUSED	20	2.1	2.8	2	40	3RD-S

[12]

Baseline Power of System

$$P_R = VI = (2.3)(0.02A) = 0.046W \text{ [16]}$$

$$P_T = P_{UV} + P_R$$

There is no risk for significant energy storage, as our circuit does not have any capacitors or inductors and the only storage for electrical energy is present in the batteries used. Our design does not make use of any mechanical or chemical energy, so there is no risk for storage of these types of energy.

Energy of System

$$E_{electric} = P_T t = (0.85W)(30s) = 25.5\,J$$

The total electric energy of the system is 168J of electric energy.

$$I_{uv} = \frac{V_{uv} - V_{Duv}}{R_{uv}} = \frac{6.7v - 5.6v}{10\Omega} = .11A = 110mA$$

$$I_{RED} = \frac{V_{RED} - V_{DR}}{R_{RED}} = \frac{2.3\,v - 2.1v}{10\Omega} = 0.020A = 20mA$$

V_D indicates the voltage drop for each respective light, when calculating for the current the value falls well within the respective ranges of the LED according to their data sheets. The reference standard for the voltage of the UV-C LED is 6.v though the 5.6v is within the accepted range, and the current matches the

Risk Analysis (5 pts)

The door handle cannot be used while sanitized which may add congestion to hospital flow. The use of batteries across a hospital may have negative effects on the environment, as they need to be replaced and disposed of.

If users put their hands in the way of the LED, they may suffer skin damage due to the UV-C rays. If the user puts too much weight on the device, the device may be damaged or knocked off the wall. If placed too high, the UV rays will become less effective on the door handle below and disperse unequally to the environment around it, which is extremely dangerous, especially if that environment is a hospital with lots of people.

Using the device as a light source or using the device to disinfect objects by holding them. Under the light, both uses could result in exposure to UV rays which may cause harm to the user. Also putting anything reflective underneath the light may cause the light to reflect towards a person and will consequently result in severe burns to the skin and eye injuries such as photokeratitis.

One possible way the device could malfunction is the sanitization LED lights not turning off when the program terminates the current cycle, the warning LED light not turning on at the same time as the sanitization UV lights. Another possible malfunction is if the resistance is either too high or too low, due to a miscalculation, and resulting in the LEDs either exploding or emitting a very faint light.

If the device refuses to turn off, the hospital staff and patients will be unable to use the door handle safely due the UV light, causing a severe inconvenience, and ruining the hospital flow. If there is indeed a miscalculation in the resistance values and the required resistance, the LED could potentially explode, leading to harmful shards shot in multiple directions and harmful rays being dispersed into the environment around it.

Testing and Validation

Test #1: The sanitization LEDs will be active for 30 seconds during each cycle.

To set up this test, the STM32 is required to programmed and connected to power.

The room should be dim enough so that the LEDs are clearly visible, and the area of effect is visible and apparent.

The test input in this case will be the computer program that is coded into the STM32. When the program is executed, the UV-C LEDs is expected to turn on for certain time intervals.

The tester will use a stopwatch and measure the time in seconds accurate to two decimal places, this will be repeated for multiple cycles do ensure accuracy.

When the LED becomes active, a tester will start a stopwatch and time the activation process.

This test is passed if the timed activation is within $30s \pm 0.5s$.

Test #2: There will be an indicator LED during the sanitization process that activates, flashing once every two seconds for one second during the sanitation process.

To set up this, the indicator LED is required to be connected to the jumper wires of which are also connected to the breadboard. While pointing out the side of the 3D-printed mechanism container, the code for the indicator LED will also be programmed into the STM32 beforehand.

Unlike Test #1, the dimness of the environment matters less as the indicator LED is not programmed with the intention to have a specific area of effect, but rather to be clear enough to users that the activation of the UV-C sanitization process is currently ON.

The input for this test on the indicator LED is also the computer program in C++ that, when executed, causes the indicator LED to turn on for the time interval that the UV-C LEDs are activated.

The quantifiable measurement standard for this test is similar to Test #1; a tester is again using a stopwatch and measuring in seconds. The tester starts the stopwatch when the indicator LED is ON and stops it right as it stops.

The test is passed if the timer holds a time within the interval of $1s \pm 0.10s$, and the light is seen to have blinked 15 times during the sanitation process (30s/2s).

Test #3: The power of the entire system of circuits will not exceed more than 30W.

For this test, the system will be fully activated, with the back of the mechanism fully open to make space for a voltmeter and its wiring, both of which are also required.

Environmental parameters do not exactly apply to this test, if the test area is clean, safe, and includes an electrical output capable of emitting between 8-10 V, although this is the case for all testing environmental parameters.

The input of this test will be the electrons flowing into the circuit from the batteries, which is what is used to activate the device. This allows testers to use a voltmeter, attach its jumper wires to before the resistor and after the LEDs, reading the voltage drop of each resistor. This input can then be used to calculate the total power using the equation $P = VI$.

The measurement standard of the test input will be in Volts, and after calculations, the values needed to check whether the circuit stays within the safety wattage requirements will be stated in Watts.

The test is passed if the total power output of the circuit is below 30W.

Test #4: The system will cover and sanitize the total area of the top, back, and front of the door handle.

To set up this test, measurements need to be made on the door handle that is to be tested on by the mechanism. The door handle should be in the shape of a symmetrical rectangle for this test to be precise.

The environment should again be very dim, as the area covered by the effect of the LED is being tested to check if it covers the entire top, back, and front of the handle.

In this case, the test input will be the program that activates the device. There are other factors that cause the LED light rays to shine onto the correct amount of surface area, such as the shape of the light tunnel and the distance of the LEDs to the door handle, but the main input that activates the device is still the instructions written in C++.

The measurement standard for this test is done in cm^2, as the area of effect is calculated to verify this test. The total area needed to be covered by the LEDs is the sum of the area of the top, back, and front of the door handle, which should be measurable.

The test is passed if the area of the lit-up sections of the door handle is clearly seen through the dimness of the environment.

Test #5: The device will enter sleep mode after the sanitization process for a time interval of an hour. This process happens while the STM32 is still activated and will run through the sleep mode on extremely low energy output, as all the LEDs are turned off.

To set up this test, the first test of the sanitization LEDs is required to be completed, then setting up again a tester with a stopwatch to time the interval to which the device is in sleep. Though, for the parameters for this test, the sleep mode can be scaled down to one minute to ensure efficiency.

The test input for testing sleep mode is the program instructions that prompt the LEDs to turn off after 30 seconds of activation and 1 minute in sleep mode before looping the cycle once again, the time spent in sleep mode is being scaled down from an hour to a minute for ease of testing.

The environment is required to be mostly the same as the other tests: the room being dim enough to be able to detect when the LED turns off and turns back on.

The measurement standard is in seconds, accurate to two decimal places. It will be measured with a stopwatch.

The test is passed if, starting from when the sanitization LEDs turn off, they turn on once again after 60 seconds $\pm\ 0.5$ seconds.

Bibliography

[1] "Infectious Agents and Healthcare Workers," *CDC - Centers for Disease Control and Prevention*, 2019. https://www.cdc.gov/niosh/topics/healthcare/infectious.html (accessed Oct. 16, 2023).

[2] D. Reed and S. A. Kemmerly, "Infection control and prevention: a review of hospital-acquired infections and the economic implications," *The Ochsner journal*, vol. 9, no. 1, pp. 27–31, 2009, Accessed: Oct. 16, 2023. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3096239/

[3] H. Wojgani, C. Kehsa, E. Cloutman-Green, C. Gray, V. Gant, and N. Klein, "Hospital Door Handle Design and Their Contamination with Bacteria: A Real Life Observational Study. Are We Pulling against Closed Doors?," *PLoS ONE*, vol. 7, no. 10, p. e40171, Oct. 2012, doi: https://doi.org/10.1371/journal.pone.0040171.

[4] "Automatic Door Handle Sanitizer | ENGR199 Fall 2020 Project 3." https://yan.wcu.edu/engr199fa20p3/product/automatic-door-handle-sanitizer/ (accessed Oct. 16, 2023).

[5] "Self Sanitizing Door Handle," *James Dyson Award*. https://www.jamesdysonaward.org/en-US/2019/project/self-sanitizing-door-handle/ (accessed Oct. 20, 2023).

[6] "Watch: Self-sanitizing door handle designed for public spaces | Engineering360," *insights.globalspec.com*. https://insights.globalspec.com/article/16171/watch-self-sanitizing-door-handle-designed-for-public-spaces (accessed Oct. 20, 2023).

[7] Fluke, "What is Ohm's Law?," *www.fluke.com*. https://www.fluke.com/en-ca/learn/blog/electrical/what-is-ohms-law (accessed Oct. 14, 2023).

[8] A. Farooq, *ResearchGate*. https://www.researchgate.net/post/How-to-calculate-UV-Irradiance-W-m2-over-a-range-of-wavelengths-provided-power-in-watts-is-known (accessed Oct. 15, 2023).

[9] "Ultraviolet Radiation Safety Program," *Environmental Health & Safety*. https://ehs.utoronto.ca/our-services/radiation-safety/8904-2/#:~:text=Permissible%20exposure%20time%20(measured%20in (accessed Oct. 14, 2023).

[10] "STMicroelectronics," Oct. 2023. Available: https://www.st.com/content/ccc/fragment/corporate/company_information/company_description/group0/6b/3c/8b/65/8c/91/47/e7/Profile/files/profile.pdf/_jcr_content/translations/en.profile.pdf

[11] *DigiKey*. https://www.digikey.ca/en/products/detail/dfrobot/FIT0096/7597069 (accessed Oct. 30, 2023).

[12] *DigiKey*. https://www.digikey.ca/en/products/detail/bivar-inc/PM3RD/3488882 (accessed Oct. 30, 2023).

[13] *DigiKey*. https://www.digikey.ca/en/products/detail/bourns-inc/FW20A10R0JA/3777397 (accessed Oct. 30, 2023).

[14] *DigiKey*. https://www.digikey.ca/en/products/detail/vishay-semiconductor-opto-division/VLMU35CB21-275-120/16684687 (accessed Oct. 30, 2023).

[15] *DigiKey*. https://www.digikey.ca/en/products/detail/sparkfun-electronics/PRT-12794/5993859 (accessed Oct. 30, 2023).

[16] *DigiKey*. https://www.digikey.ca/en/products/detail/luminus-devices-inc/SST-10-SB-B130-M470/12170041 (accessed Oct. 30, 2023).

[17] *DigiKey*. https://www.digikey.ca/en/products/detail/keystone-electronics/233/68726 (accessed Oct. 30, 2023).

[18] *DigiKey*. https://www.digikey.ca/en/products/detail/c-k/JS102011SAQN/1640095 (accessed Oct. 30, 2023).

[19] "Milliamp-Hours Capacity ENERGIZER 522." Accessed: Oct. 30, 2023. [Online]. Available: https://data.energizer.com/pdfs/522.pdf