Deep-UV Cabinet-Enhancement of Bag Cabinets in MAPUA Laboratory with Gizduino

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***Abstract*—With the emergence of the novel coronavirus (Covid-19) pandemic, disinfecting or sterilizing of objects has become more essential in our daily lives as part of the new normal to avoid the spread of the virus and other microorganisms. The UVC is known for killing or disabling such microorganisms which is the main technology in the design of a disinfecting cabinet system of this study. Aside from known features of an available UVC cabinets, the proposed system utilizes UV sensor and reed switch in always determining the state of the cabinet. Three tests were conducted to determine and classify the functionality of each feature of the UVC cabinet which the results of the banana test show the optimal location, that is in the center, and time at 60 minutes to ensure complete disinfection of the object's surface. Overall, the prototype for the design of a UVC cabinet system can be considered for a practical use in the Mapua laboratories as it has been functional without any significant negative effect to five common objects of a Mapua students.**

***Keywords*—Covid-19, UVC, cabinet, Mapua, Laboratory, banana test.**

I. INTRODUCTION

Cleanliness is one of the major aspects that contribute to a better environment which in turn creates a healthy environment. A clean environment does not only measure the objects that are visible to our naked eye, but it can also include microorganisms and particles that are not visible to the naked eye. With the recent surge of the Coronavirus or Covid-19 Pandemic, it is evident that a clean environment against this virus and its variants is a must which can be provided through disinfection and sterilization. Through small particles, the virus can spread as it attaches to surfaces that had a contact from an infected person [1]. As communities become more resilient to these viruses, some schools now allow face-to-face classes. Mapua being one of the most prestigious and top schools, limited face-to-face classes has begun which includes laboratory classes for a more in-depth learning experience. Students travelling from various places may have been in contact with infected person which in turn they become carriers thus, it is important to disinfect their belongings. A cabinet disinfectant for Mapua laboratories would be one of the methods to achieve this together with ultraviolet radiation specifically deep-ultraviolet range or the UV-C which wavelengths ranges from 200 to 280nm [2].

The study will incorporate an electronics design aimed to develop a deep-UV cabinet-enhancement of bag cabinets in MAPUA laboratory with deep-UV illuminations to disinfect 5 (five) different objects, specifically: (1) school bag, (2) letter size documents, (3) gadgets, (4) pens, and (5) calculators. The following are the specific objectives: (1) To build and develop a cabinet that emits ultraviolet lights ranging from 200-280nm (UVC). (2) To characterize the optimal location in the cabinet for exposure from UV-C lamp. (3) To evaluate the disinfecting performance for the five different objects specified above.

The study will significantly benefit students, faculties, and the institution of Mapua University such that a cabinet disinfection will be available for students in laboratory classes. Furthermore, a UVC cabinet could also be incorporated to other facilities such as in healthcare sectors, bio-facilities, research facilities, and even in homes or apartments. Additionally, it could also contribute to further understand how the viruses, bacteria, and other particles could be disabled through ultraviolet radiation.

Given that the study focuses on the application of deep-UV illumination on cabinets, there is a limit to the dimension and volume of the object that can be sterilized or disinfect based on the cabinet dimensions. Evaluating the prototype with an object that carrier coronavirus or any cultured bacterial microorganism will not be included in the study, however, the hypothesis will be assessed based on a related standard for deep-UV sterilization designs and testing procedures. Nevertheless, the study will be conducted in a home environment and such imperfections in the performance will be present.

II. REVIEW OF RELARED LITERATURE

The deep UV (DUV) region occupies wavelengths between 280 nm ~ 200 nm and DUV optics is the backbone of many critical applications such as nano-fabricating technologies that include the following: high-density data storage, high-energy laser applications, laser eye surgery, nano-meter scale photolithography for semiconductor patterning, and sterilization [3]. Other practical uses of UV light sterilization or disinfection are on water, vegetables, fruits, utensils, and surface areas of different objects. Although UV is known to be used for sterilization, only the UVC have sufficient energy to effectively disable or kill microorganisms specifically the 254nm UVC is effective against all microbiota, molds, foodborne pathogens, and viruses since different microorganisms have different sizes and shapes which affects the required UVC exposure time depending on their UV absorption rate [4]. UV Germicidal Irradiation (UVGI) is a method of disinfection to kill or disable viral, bacterial, and fungal organisms using UV energy which is by breaking down chemical bonds and scrambling the structure of RNA, DNA, and proteins, causing a microorganism to be unable to multiply. UVGI is convenient and no chemicals are needed as well as it can kill most kinds of microorganisms, including drug resistant bacteria. However, UVC is dangerous to humans which is why UV sterilization is usually done while avoiding direct exposure to UVC, especially skin and eyes. UV only works in its light path and can be blocked by obstacles; thus, it is common to place an object in direct line of the UV or use of multiple UV sources at different angles.

A. UV Lamp vs LED

Deep-UV LEDs have a superior advantage compared to mercury lamps, such as small size, high efficiency, and zero warm-up time as well as possess many excellent features over conventional mercury lamps, but at present the output is much lower. The light output of mercury lamps is usually 1 W or more, while for deep-UV LEDs amounts only to dozens of milliwatts. Although UV disinfection is generally considered safer than chemical disinfection, all conventional UV lamps typically use between 5-200 mg of mercury per lamp. These UV lamps require routine replacement and are susceptible to breakage during transportation, handling, and operation. UV LEDs are mercury-free and provide a safer alternative [5].

B. UV-C Against Microorganisms

UV-C dose at 254 nm (displayed in J/m2) required to achieve a 90% (1 log reduction).

UV dose (J/m2) = UV irradiance (W/m2) x exposure time (seconds)

- D90 multiplied by 2 could provide with a 99% (2 log) reduction
- D90 multiplied by 3 could provide with a 99.9% (3 log) reduction
- D90 multiplied by 4 could provide with a 99.99% (4 log) reduction
- D90 multiplied by 5 could provide with a 99.999% (5 log) reduction
- D90 multiplied by 6 could provide with a 99.9999% (6 log) reduction

A dose of 50 J/m2, resulting in a reduction of the SARS-CoV-2 virus of 99%. Based on the data, it was determined that a dose of 220 J/m2 will result in a reduction of 99.9999%.[6]

C. UV-C and Banana

A study shows that the effects of anti-fungal induced from ultraviolet C irradiation control the rotting disease from the postharvest crown, establishing quality maintenance for fruits and the effects of antioxidant capabilities of banana during the ripening period 25 ± 2°C, which reduces the disease intensity significantly. However, except for the level of 0.01 kJ m2, the administration of UVC in different doses resulted in severe browning damage to the fruit skin. Compared to the other treatments and the control, this dosage reduced postharvest crown growth by 46.25 percent and had no detrimental effects on respiration rate, ethylene generation, weight loss, firmness, color changes, and soluble solids concentration, titratable acidity, and pH in banana.[7]

D. UV-C Banana Testing

According to research [8] The banana color initially started as green due to chlorophyll characteristics, after which turn into yellow then black because of carotenoids and polyphenols. Moreover, there is an observation from bananas that are exposed to ultraviolet light which turns the peel glow into blue color. It is when the fluorescent chlorophyll catabolites (FCCs) rise over coming chlorophyll leading to banana ripening peels. The UVC banana testing was confirmed and tested by a video illustration [9]. For which the banana is exposed directly to the UVC source making its skin darkened.

E. UV Radiation and Disinfection

1) *Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light [10]*

Researchers found that UVC light at 222-nm light can kill MRSA compared to other conventional germicidal UV lamps at 254 nm. In a 3D human skin model, it makes essentially insignificant premutagenic UV-related DNA harm and is not destructive to bare mammalian skin.

2) *UV-C Lamps and Sars-Cov-2 [11]*

UVC or 'germicidal' lights have been utilized in the medical clinic and different settings for quite a long time to obliterate microbes (for example, TB) or infections in the air (inside light-close air pipes) and to disinfect drinking water. SARS-Coronavirus has been exhibited to be inactivated by UVC radiation. The low-pressure mercury fume light, which creates over 90% of its radiation at 253.7 nm, has generally been the most well-known UVC light being used. Fresher lights available generally produce at 222 nm and seem, by all accounts, to be less harmful to skin and eye exposure. However, these lights are not yet broadly open, and care is exhorted because there is proof that a few models might create unassuming discharges at more extended frequencies that are more unsafe.

UVC lights have likewise been placed in the upper bits of cleaned rooms, albeit the lights should be pointed vertically to lessen the chance of people being uncovered. There have been reports of skin and eye consumption resulting from the unseemly establishment of UVC lights in individuals' rooms. This type of establishment is proposed in rooms with high roofs and introduced by talented specialists. Likewise, there are more current assortments of UVC lights intended to clean purge places, like those found in emergency clinics. UVB radiation could likewise be utilized for sterilization, yet it is less productive and possibly riskier for individuals than UVC radiation. Subsequently, safety measures should be taken to avoid inadvertent human openness.

3) *Germicidal Ultraviolet (GUV) [12]*

a) How does germicidal ultraviolet differ from Ultraviolet Germicidal Irradiation?

Using bright radiation light to inactivate microscopic organisms, shape spores, parasites, or infections is alluded to as germicidal UV (GUV). When applied in a particular locale, it is generally alluded to as UV—light utilizing germicidal specialists (UVGI). Because of the public's feeling of dread toward ionizing radiation (e.g., X-beams and gamma beams), the word GUV eliminates any excessive worries about a relationship with that kind of radiation. Another non-specialized word is germicidal light, but "light" alludes exclusively to noticeable radiation.

b) Is it efficient to kill bacteria and viruses using UV-C?

Yes, Individual, serious UV-C photons photochemically collaborate with the RNA and DNA atoms in an infection or bacterium to deliver these microbes non-irresistible. The phenomenon all happens at the minuscule level. Infections have a size short of one micrometer (m, or one-millionth of a meter), and for the most part, microbes range in size from 0.5 to 5 m.

c) As COVID response does UV-C deactivate SARS-COV 2 virus?

Indeed, if the infection presents to UV-C at the level of robust measurement, UV-C can be helpfully related to a different method for sanitization, but people must be covered to keep away from UV threats to the eyes and skin. UV-C light ought not to be used to sanitize hands.

d) Is there a significant effect between the sunlight and Germicidal Ultraviolet?

Indeed, particularly in pre-summer and late spring, the UV record is high when the sun is sparkling splendidly. At a UV Index of 10, the time to kill somewhere around three logs of microscopic organisms (99.9% dead) expecting it to be short of 60 minutes.

4) *Far-UVC Light (222nm) Efficiently and Safely Inactivates Airborne Human Coronaviruses [13]*

A direct approach to restricting viral transmissions in the air is to inactivate them when created. Far-UVC light (207-222 nm) annihilates microorganisms proficiently and, maybe without harming, uncovered human tissues. Sprayed Covids 229E and OC43 were inactivated separately at low doses of 1.7 and 1.2 mg/cm2. Because of the equivalent genomic sizes of all human Covids, far UVC radiation would expect to have comparable inactivation viability against SARS-CoV-2. Long-haul openness would bring about 90% viral inactivation, 95% quickly, and 99% inactivation at the ongoing administrative breaking point.

5) *The Effect Of 222-Nm UVC Photo Testing on Healthy Volunteer Skin: A Pilot Study [14]*

UVC gadgets, similar to some other sterilization frameworks, should be utilized accurately to be protected.) UVC radiation with frequencies going from 200nm to 280nm. This UVC radiation is fundamentally "more grounded" than average daylight, and it can deliver a genuine sun-related burn-like response on the skin and harm the eyes. Whenever uncovered, the retina of the human eye. Some gears make ozone a component of its cycle, while others, like a circular segment welder, produce light and intensity and move during their cycles. Subsequently, generally machine-human wellbeing all sterilization innovations should be in-depth understand, and these elements should within the activities handbook, client preparation, and appropriate wellbeing consistency.

6) *A Study on The Perceived Marketability of Shoevid-19 as an Effective Disinfecting Shoe Rack [15]*

Many examinations have uncovered that the soles of our shoes can hold onto microorganisms and infections, for example, COVID-19, presenting wellbeing worries to ourselves and other people. The analysts formulated an answer for the issue by fostering a more modest, compact, and affordable shoe rack that cleans and aerates shoes. Likewise chosen was the apparent attractiveness of the proposed shoe rack, assigned as "Shoevid-19," when it becomes available on the lookout. To layout assuming the item is OK and genuine, 251 respondents efficiently distributed with an understanding of the study.

Underlying Equation Modeling (SEM) decides the connection and acknowledgment of the outcomes toward the suggested satisfactory qualities given by the boundaries and the Technology Acceptance Model (TAM). The outcomes show that the ShoeVid-19 shoe rack and its advancements have received positive input from the respondents as the qualities acknowledged considering the boundaries given. Hence, it tends to be reasoned that this item can have high attractiveness and a promising interest once it is accessible on the lookout.

F. UV-C Lamp Compared to other UV LED

Mercury UV lights work well in persistent mode, giving incredible power at a sensible expense [16]. Warm-up time is expected for lights before water can be administered. Since on-off cycling is challenging, the light's assistance life may be decreased to under a year. Moreover, UVC LEDs, then again, give speedy, focused energy UVC light results that might be cycled here and there to permit moment apportioning while at the same time saving broadened life (usually, north of 5-10 years in most shopper point-of-purpose items). Representing this life expectancy contrast is essential for growing long-haul cost-of-possession models for new things. UV lights give advantages to constant long-haul activity in ceaselessly streaming water. UVC LEDs benefit from delaying upkeep free item life expectancy and conveying speedy client response for on-request water pouring.

UV lights can offer advantages in giving the best answer for end clients if the application is a more powerful, higher stream framework in continuous activity. When contrasted with UV lights, UVC LEDs empower less expensive proprietorship costs and more unusual arrangements with plan goals in little, place of-purpose devices and purifiers.

While UV lights and reactors have become market normalized, not all UVC LEDs and reactors are something very similar, so originators ought to broadly research various potential outcomes to pick the one that best matches their goals

G. Types of Lamps that can Produce UV-C Radiation

1) Low-pressure mercury light: Historically, the most famous light used to produce UVC radiation was the low-pressure mercury light, which emanates most of its light (>90 percent) at 254 nm. This kind of bulb may likewise produce different frequencies. Different lights are accessible that radiate a wide range of UV frequencies and apparent and infrared light.
2) Excimer light or Far-UVC light: A kind of light with a pinnacle outputs frequency of about 222 nm.
3) Beat xenon lights: These lights, which create a short beat of expansive range (UV, apparent, and infrared) light, have been sifted to transmit UVC radiation principally and are incidentally utilized in emergency clinics to treat natural surfaces in medical procedure rooms or different areas. These are many times utilized when there are no people nearby.
4) Light-emitting diodes (LEDs): UV-emitting diodes (LEDs) are also becoming more accessible. LEDs typically produce light with a reasonably narrow wavelength range. UV LEDs with peak wavelengths of 265 nm, 273 nm, and 280 nm are now available. LEDs have one benefit over low-pressure mercury lamps in that they do not contain mercury. On the other hand, LEDs may be less effective for germicidal applications due to their tiny surface area and increased directionality. [17]

H. UV-C Uses and Application

Lighting industry specialists consider second-story room germicidal UV the most proficient way to deal with forestall infection and bacterium transmission. Upper-air units continually clean air in a room by creating UV-C over individuals' heads. Second story room UV gadgets are ok for consumed spaces since the UV-C beams are not coordinated straightforwardly at people. [18]

Applying UVC to industrial HVAC system aids to prevent air contamination through disinfection process halting human exposure The type of UV light required for the product varies depending on the system you have. On coil ultraviolet systems focus on the drain pans and cooling pans. The duct ultraviolet systems are installed within the ducts to establish filtering as it goes through the system.

The developed new technology is called far-UVC, that disinfects the air and surfaces which is claimed to be safe to humans. Many other methods of fixtures are still being enhanced and innovated.

Portable ultraviolet – C units that are flexible since they are mobile. The disinfectant can be move from one space to another. The portable ultraviolet germicidal device have wide spread applications that usually found in hotels to disinfect PPE in the hospital to optimize the supply usage.

I. UV Sensor

This sensor is excellent for Arduino projects in that device will expose to UV light. These are fundamentally open-air duties, such as weather stations or a simple gadget that alerts you to the current UV file [19].

You may also use the Raspberry Pi with this similar UV Sensor. The Raspberry Pi and Arduino are both fantastic tools for the VEML6075.

Illuminance is estimated using a photodiode-type UV sensor. When light reaches the photodiode, it activates the electrons, causing an electric flow. Because of the brighter light, the electric flow will be more grounded. After that, the electrical flow transforms into a computerized or straightforward result.

J. Reed Switch

Reed switch in real-world applications, such as beautiful entryway switches, desktops, cell phones, etc. This tutorial will learn about Reed Switches and show you how to interface one with an Arduino. [20]

Reed switches are electrical switches that operate when an attractive field is close to them. The reed switch created by W. B. Ellwood at ringer research centers in 1936. It comprises two small metal parts that are vacuum sealed within a glass tube. Two metal parts of a typical reed switch are constructed of a ferromagnetic substance and coated with rhodium or ruthenium to ensure long life. When there is an appealing field around the switch, the switch will be activated.

K. UVC Effect on Materials

UVC affects the atomic bonding of the material which can easily categorized to what materials are affected by UVC. Ceramics that use ionic covalent bonding are unaffected by UVC as well as metals which uses metallic bonding. However, polymers which uses weak covalent bonding are susceptible to degradation by UVC [21][22]. In the glass material, only the UVA wavelengths can pass through while UVB and UVC are blocked [23]. Although light is known to reflect on some reflective materials, UV lights which are below 400nm are typically absorbed into the surface of the materials which does not reflect the UVC light as much as visible light [24]. Although some are absorbed into the material, there are still UVC light that are reflected which is directly proportional to the reflectivity of the material. As the material’s reflectivity increases, the amount of UVC light that can be reflected also increases. A good material for an enclosure of UVC lights is metals, ceramics, glass, or reflective materials.

L. *Adverse Effects of UVC on Humans*

UVC light can cause a short-term effect on human skin that results in redness or ulceration of the skin. However, at high levels of exposure to UVC, it could lead to serious skin burns such premature aging of the skin or skin cancer due to long-term exposure to UVC. Additionally, direct exposure of UVC light to eyes can causes cornea injury or sometimes referred to as “welder’s eye” but heals in a couple of days [25]. Furthermore, UV-V (Vacuum) with wavelength at 185nm will generate ozone which damages lungs when inhaled however, UV lights in 240-315nm wavelengths breaks the atomic structure to convert it back to simple oxygen gas. A UVC lamp that emits 254nm light actually destroy ozone which does not have an adverse effect on the lungs but can still significantly cause eye or skin injury [26].

M. *UVC Disinfection of Bags*

The UVC disinfection of bags are determined by the material used or type of the bag. As other materials may have different outcomes depending on the process, it is just based on how the material itself is disinfected. As an example, a disinfecting procedure that used chemical may affect the color or the bag. Additionally, a steam cleaner could also shrink the material that makes up the bag. A UVC that does not require direct contact other than the light illuminated is one possible solution. Although there are different types of materials that are used in bags, most materials that are polymers are the only susceptible material to UVC degradation [21]. Some examples of polymer materials are papers, rubbers, PVC, wood, wool, nylon, and plastic polymers. The exposure of such materials to UVC does not show degradation immediately but only when it is overexposed to UVC light. Thus, for polymer materials, it is suggested to exposed in UVC light at the minimum time while following the proper procedures.

III. DESIGN PROCEDURES

This chapter includes the procedures for the development and creation of the prototype from its concepts to system design to program code and to its hardware implementation and physical construction.

A. *Hardware Implementation*

The conceptual framework of this study consists of the features as its inputs such as the functions of the push button, reed switch, and UV sensor for their respective detection or state classification. The process is fully autonomous once the desired exposure time is set and the necessary requirements are met such as the cabinet door state, the UVC light detection, and the push button 3 state. As it is an autonomous process, the output of the design is a UVC disinfected object as well as buzzer sounds that have a corresponding sequence based on the current state of the system. This sequence is used to easily identify the next step in the process and for troubleshooting the prototype design.

Table 3.1: Conceptual Framework of the Study

Input	Process	Output
Object for disinfection Push Buttons state Cabinet Door state UVC light detection	Setting the Exposure time based on the button pushed Initiating the UVC exposure based on the Cabinet door state Terminating UVC exposure based on the cabinet door state, UVC light detection, and pressed buttons	UVC disinfected object Buzzer sound sequence depending on the current state of the system

Supporting the concept of the design is the design for the connection of the components in the system which includes the following: the printed circuit board (PCB), the UV sensor, the UVC lamps, the Microcontroller (Gizduino), the buzzer, and the switches as the main control of the system.

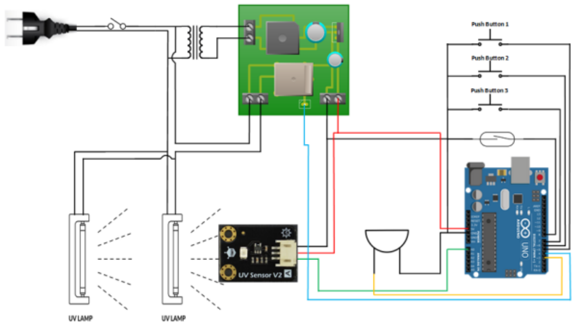

Fig 3.1: System Component Connections

Fig 3.1 describes the specific connections of each component in the system which includes pin configurations in the microcontroller and its respective connected component.

The UVC lamps are parallel to each other however, it is in series with a 5V relay that is in the PCB. The PCB have a 12V input after the step-down transformer. The output of the PCB is a regulated 5V DC supply for all the external components using the LM7805, capacitors, and full-bridge rectifier diodes. Each switch are grounded while connected to a specific digital pin in the microcontroller for a controlled input using the internal pull-up resistor. The buzzer is controlled by the microcontroller for the specific sound sequence. The UV sensor is directly powered by the PCB, but it outputs the analog data to the analog pin of the microcontroller for processing. As this design utilizes 220V AC, it uses a plug and a main switch to start the whole system.

B. *Software Implementation*

The system as shown in the flow chart describes how the prototype program works. When the main switch is pressed, the system starts which can only proceed whenever push button 3 is pressed after setting the UVC exposure time with push buttons 1 and 2. Each push buttons have their own respective functions such that PB1 set the time to 30 minutes while PB 2 set the time to 60 minutes. On the other hand, PB3 is used to start or terminate the UVC exposure. While in this process, it will repeat to output 1 short buzzer sound until PB3 is pressed. Afterwards, the door cabinet state is monitored for the UVC lamps to turn on. While the cabinet door is open, it will repeatedly output 1 long buzzer sound. Once the door is closed, the UVC lamps are turned on and that the last loop will start. In this part, the microcontroller monitors the UV sensor reading, the cabinet door state through reed switch, the PB3 state, and the current timer value of the UVC exposure. Whichever one condition is satisfied, the UVC lamps are turned off and the system outputs a specific 3 short then 1 long sequence through the buzzer that indicates ending the current process of the system. As this is a repeating system, it restarts to selecting the exposure time once again after some time.

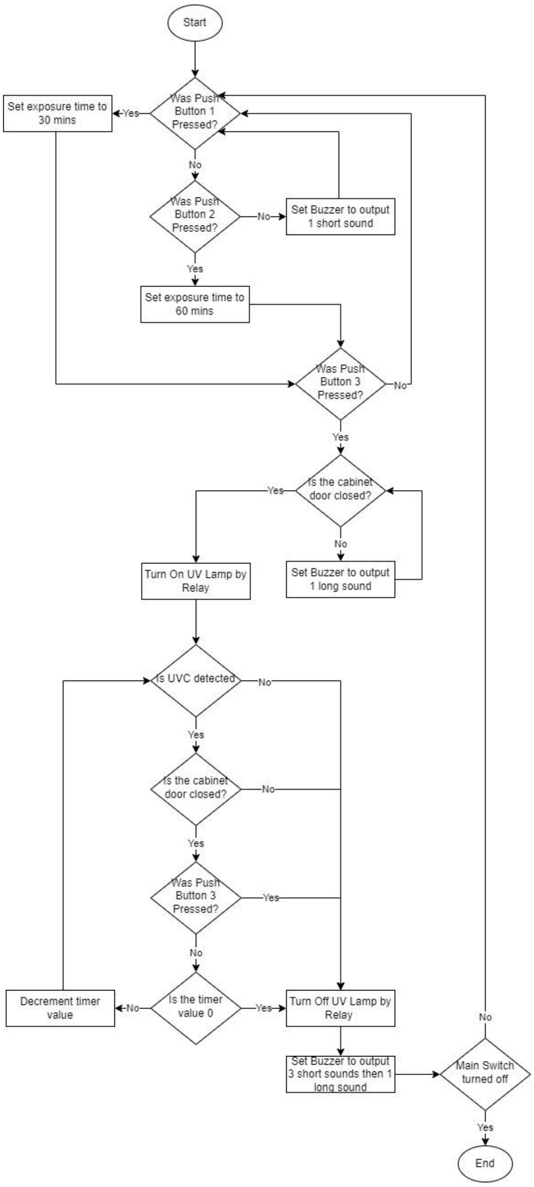

Fig 3.2: System Process Flowchart

Fig 3.2 illustrates the process of the system or specifically how the microcontroller process the information and decide the outcome based on certain conditions.

C. *Prototype Development*

Once the system design has been approved, the PCB is developed to create a copper path depending on the electrical wiring and components needed. The design is printed in a reflective paper which is then transferred to a copper board through heat. In case that ink was not fully transferred, a marker was used to trace the lines. The following step is by etching the copper board with ferric chloride acid that gradually removes copper from the surface of the board. The last part is just drilling the necessary holes then soldering the components. A separate hole was made for the mount to stabilize and avoid grounding in the components.

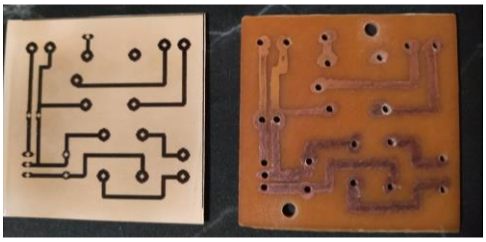

Fig 3.3: PCB design for the Prototype

Fig 3.3 shows the PCB design used in the prototype which have been drilled for component pin slots and board mount. It also shows the copper connection that will electrically conduct the components.

The program code for the system is coded through the Arduino IDE which follows the system flow or process as shown in appendix A.

Physical construction step-by-step process shown in appendix B starts with cutting the angle bar to the design length of the cabinet which will be welded to form a rectangular prism. A separate frame is created to hold the glass window which was sealed with silicon. The metal sheets are then added to the remaining surface faces of the rectangular prism. Once the PCB components was completed, it will be installed together with the remaining materials such as the UVC lamps, UV sensor, reed switch, push buttons, buzzer, main switch, transformer, and microcontroller through gauge 12 or 18 wires in the transparent acrylic casing. If the initial test indicates that there are no incorrect placements or connections, the prototype will be finished with the glass tint.

Fig 3.4: Completed Prototype

Fig 3.4 shows the actual and completed working prototype which has been tinted and polished for testing and presentation.

D. Design Constraint

Table 3.2: Design Constraint, Trade Offs, and its Alternative Solution

Design Constraint	Trade Offs	Alternative Solution
The time duration for exposure is fixed for each push button	Some users and application to specific object will require to manipulate the time of exposure	Digital keypad Graphical user interface or analog
Measuring the bad bacteria, viruses, fungi, and unwanted microorganism during and after the UVC exposure	To ensure that the sanitation process is successful and monitored	Implementing electronic instrument that can measure microorganisms to the object without physical interaction

Table 3.2 differentiates the design with its constraints, trade-offs, and possible alternative solutions. One of its design constraints is the fixed time duration which can be selected through the push buttons. As some users prefer specific time for different objects, a solution could be the use of digital keypad or any other graphical user interface (GUI) to manipulate the time variable. The other design constraint is a feature that could accurately measure unwanted microorganism for monitoring the effectiveness of the UVC cabinet. To implement this method is through an external electronic instrument that has the ability to measure microorganisms without physical interaction to the object.

E. Impact Design Solution

Design impacts global factors such as the economy and environment establishing sustainable well-being of the ecosystem. Instead of using conventional processes that may cost a large amount of capital for the instrument and labor of sanitation processes, the technological application will provide countless situational implementations. The implementation may largely vary according to the context that may require the technology. The context may be in hospitals, households, industrial plants, offices, and transportation. This may significantly affect further research and development of sanitation techniques using technology.

F. Engineering Standards, Principles, and Tools

1) *Engineering Standards*

Table 3.3: Engineering Standards

Element/System	Engineering Standards	Description
Mobile sterilization Deep UV Cabinet	UL 73 with ANSI RP-27 standards	The UL 73 is accounted for the electrical investigation of the element/component, which includes the ANSI RP-27 standard for photobiological personal injury requirement assessment
Germicidal components	UL 8802 and IEC 62471 protocols	The UL 8802 standard is for the outline of investigation, while IEC 62471 is for Photobiological assessments'
Testing and calibration	ISO/IEC 17025:2017	ISO/IEC 17025:2017 is for the requirements and competence of calibration and testing

The table above shows the engineering standards considered in creating the prototype of the deep UV cabinet. The table consists of three columns: element/system, engineering standards, and descriptions. The first element is the sterilization UVC cabinet which is governed by the engineering standards of UL 73 with ANSI RP-27 standards, indicating that the UV is contained in a single space with its source of UVC comes within enclosed box. The door will switch off the UV source if the entry way is opened. Testing would ensure that any UV "spillage" is under satisfactory dose levels. Another component/element is the germicidal components governed by engineering standards UL 8802 and IEC 62471 protocols, indicating for all time mounted, for example, extremely durable hardware intended for the establishment and use in non-private settings. UVC regulation has achieved the result of insurance, prepared staff, and site precautionary measures. Finally, the calibration of the system engineering standard of ISO/IEC 17025:2017 the license ensures that the lab is equipped to guarantee that an item meets indicated rules and has the essential confirmations of quality administration framework.

2) *Principle, Goal and its Implementation*

Table 3.4: Engineering Principles

Principle	Goal	Implementation
Smart interaction	Provide selection for desired outcome and action to conduct	Select time viable for efficient sanitation following best practices
Affordances	Optimizing intuitive	Accessible starter developer electronic components.

Efficient acquired space	Provide a specified space that will allow optimal exposure	Measuring the distance of the UVC radiation

Table 3.4 describes the principles and goals as well as its implementation for the design of the UVC cabinet system prototype.

3) *Tools and Instruments Used in Design*

This section of the paper consists of the items and electronics used to construct the proposed design governing the objective of implementing the prototype. The objects are listed and described as follows

Fig 3.5 gizDuino LIN-UNO

The figure above is a gizDuino Lin-UNO, an arduino made by the e-gizmo mechatronics central store. The microcontroller specifications are ATA6614Q (Automotive-grade Atmega with integrated LIN interface), a memory of 32kilobytes flash, 2 kilobytes SRAM, 1 kilobyte EEprom, Input/Output pins of 20, SPI, I2C, Timers, UART and USB bridge of PL2303. LIN stands for Local Interconnect Network is a one-of-a-kind hardware and software serial network used to establish links and communication with automotive components of the gizduino. The microcontroller's USB port is compatible with any major Operating system such as Windows, IOS and Linux.

Fig 3.6 8W Ultraviolet Germicidal Light T5 Tube with Fixture UVC Disinfection Kill Dust Mite

The figure above shows a sanitation device that emits Ultraviolet- C rays, killing microorganisms. The device's specifications are as follows color emitted is violet with blue combination, aluminum bracket for voltage, voltage input 220VAC, power rating of 6W, the shape and bulb type is a cylindrical tube with a length of approximately 235 mm/310mm, disinfection area approximately 9 meters squared. The suggested time exposure for sterilization and sanitation ranges from 30 to 60 minutes three times a week.

Fig 3.7 Printed Circuit Board

Printed circuit boards are the foundation of organized networks and systems of electronics that create a device that can compute, analyze, store, and manipulate numerical and logical data. As shown from the figure above, the board is mostly composed of copper sheet mounted to nonconductive material to uphold the electronics placed. The PCB is drilled with the holes according to the designed pattern. Thus, the hole is where the through-the-hole soldering process is initiated.

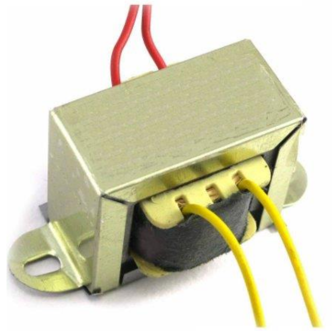

Fig 3.8 220V-12V Step-down Transformer

The device above is a step-down transformer that reduces the sinusoidal AC voltage from 220 V to 12 V amplitude. This occurs because the primary winding has more turns than the secondary winding. The primary winding is where the 220 V is connected, while the output is where the 12V AC is induced.

Fig 3.9 1N4007 Rectifier Diode

The 1N4007 Rectifier Diode is a piece of electronic component that acts as an automated logical switch that converts AC signal into Full-wave AC signal. This occurs when the polarization of the diode cannot be breakover voltage by the input voltage to force it on a forward bias condition. The output from the rectifier circuit is a positively full-wave sinusoidal signal. The main purpose of this electronic implementation is to convert Alternating Current to a Steady Direct Current.

Fig 3.10 10uF and 1000uF Capacitor

The capacitor component is basically used as a filtering circuit that utilizes clamping signals from the rectifier circuit output. The output from the filtration capacitor circuit is a sawtooth signal relative to the original full-wave positively induced signal. This makes the signal closer to the desired steady direct current signal.

Fig 3.11 LM7805 5V DC Voltage Regulator with Heat Sink

The regulator circuit, as shown above, helps the rectifier and capacitor circuit to retain an ideal fixed voltage output in respective to the input signal. It holds the voltage supply within a range, making the circuit compatible in supplying important electronic devices requiring minimal voltage and direct current. The heatsink component used was to eliminate intense heat-induced from the regulator, preventing malfunction and other electronic hazards.

Fig 3.12 220V 5V DC Relay Arduino Module

As shown from the figure above, the relay electronic circuit is also used for advance switching and control at a certain amount of voltage required and with the output. The relay varies depending on its application. This may normally come open or closed. The switch's actuation depends on the electromagnetic phenomenon, similar to the reed switch. It activates whenever a current passes, creating a magnetic field to actuate.

Fig 3.13 Momentary Push Button and On/Off Rocker Switch

The pushbuttons used are similar to the figure above, which was used to switch the whole system on, placed explicitly at the power supply. It is essential when the device is not being used currently. Electronic devices may have this, but it varies according to their uses and ergonomics.

Fig 3.14 UV Sensor Module

The UV sensor GRAVITY series V2 can detect the levels of radiation present in any light source with ultraviolet rays. The application of this device varies widely for monitoring, DIY project lamp monitoring, and environmental supervisory. The UV wavelength it detects ranges from 200 – 370 nm.

Fig 3.15 Reed Switch

Finally, as shown above, the reed switch is an electronic component usually used for advanced switching applications, specifically on automated appliances and devices. The concept is through the electromagnetic concept, which depends on the current or electricity flow on the circuit. This acts as a false trigger for doors or cabinet that uses electronic devices.

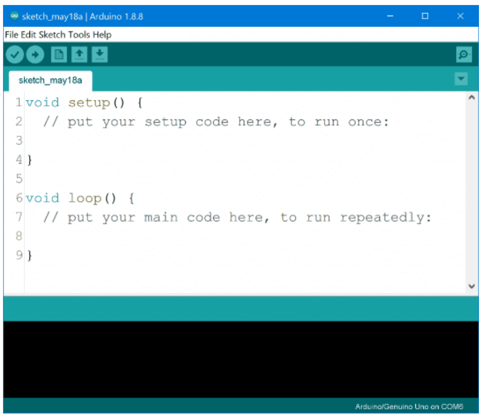

Fig 3.16 Arduino Integrated Development Environment (Gizduino)

The figure above shows the editor text for code writing, message area, and a text console. It also has a toolbar that consists of common functions and menus. The program Arduino IDE also has a compiler, which then communicates with the Arduino by uploading a universal serial bus. The language it uses is C/C++ and JavaScript for syntax and scripting.

4) *Nearest Similar Design Differentiation*

This part encompasses the nearest similar design that is compared with the designed prototype.

Fig 3.17 Ultraviolet Germicidal Irradiation

The nearest design to the designed prototype is shown in the fig 3.17 that can sanitize up to three (N95) masks at once for complete disinfection without congestion. Viruses, bacteria, and mold spores are all killed by this product.

Table 3.5: Design Differentiation

	Design Prototype	**Nearest Similar Design**
Technology	Deep Ultraviolet cabinet UV- C	Ultraviolet germicidal irradiation UV-C
Functionality	Sanitation and disinfecting objects killing microorganisms and germs	Full disinfecting without overcrowding killing microorganisms and germs
Specifications	• Gizduino microcontroller • UVC Germicidal light • UV sensor module	• Programmable Microprocessor calculating irradiation time-based dosage energy entry • EMI protection • Constructed anodized aluminum

The table above shows the difference between the designed prototype and the nearest similar design. It is categorized into three distinct parts such as the technology, functionality, and specifications. The technology contains the actual tech that is compared with each other. The designed prototype is deep ultraviolet cabinet with UV-C bulb for sanitation and disinfecting objects. While the nearest similar design technology is an Ultraviolet irradiation UV-C. The functionality for both technologies are the same which focuses on sanitation and disinfection of objects. Finally, the specifications differ significantly in terms of electronics implemented. The Designed prototype uses conventional electronics where it uses gizduino as microcontroller, UVC germicidal light and UV sensor. However, the similar design uses a single chip microprocessor for irradiation time-based dosage energy entry, EMI protection and constructed anodized aluminum for casing.

G. Laboratory Set-up

Cabinet setup in a laboratory is a simple ratio of one cabinet to one table. The tables in the laboratory must have at least 22 inch by 40 inch by 25 inch space below it. Furthermore, a 220V AC outlet must also be nearby to power on the UVC cabinet. In case that it is not possible to place the cabinet in the ground, the base of the structure should be able to hold a weight of 25 kg. As the design utilizes UVC light, the laboratory room must be ventilated to avoid exposure to ozone once the UVC exposure is completed. With all these requirements, the UVC cabinet should not be installed in some laboratories. It was not designed for any computer laboratories that have a crowded arrangement of tables to occupy as many computers as possible or an airconditioned room for the student's comfortability.

IV. TESTING, PRESENTATION, AND INTERPRETATION OF DATA

A design of a system is accompanied by tests to ensure its functionality and features are working as well as if it is up to standards. For this study, four tests was conducted on the basis to answer the objective of the study.

A. Prototype Testing

The first test for the prototype is the prototype feature test which is for validating the output of the system based on specific conditions that was indicated as a feature of the prototype of the designed system.

Table 4.1: Prototype Features Test

Feature	Test	Result
Reed switch for detecting door cabinet state	Door is open before UV lamp start	UV lamp does not start and Buzzer outputs sequence 2
	Door opens while UV lamp is on	UV lamp turns off and Buzzer outputs sequence 3
UV Sensor for detecting UVC light	UV cabinet UVC exposure with UV lamps	UVC exposure continues with the set time
	UV cabinet UVC exposure without UV lamps	Buzzer outputs sequence 3
Push Button 3 for initiating and force ending UVC exposure	Start UVC exposure after pressing Push Button 3	UV lamps are turned on
	End UVC exposure after pressing Push Button 3	UV lamps are turned off
Push Button 1 for 30 minutes UVC exposure	Record 30 minutes of UVC exposure	Continues UVC exposure for 30 minutes
Push Button 2 for 60 minutes UVC exposure	Record 60 minutes of UVC exposure	Continues UVC exposure for 60 minutes
Buzzer Sequence	Buzzer sound while selecting UVC exposure time	1 short sound loop (sequence 1)
	Buzzer sound when Door is open before UV exposure time	1 long sound loop (sequence 2)
	Buzzer sound when UVC exposure ends	3 short and 1 long sound loop (sequence 3)

Table 4.1 shows the results when each feature of the prototype of the designed system is tested which shows that the prototype functions and operate properly as the design of the system that was proposed to develop and build and UVC cabinet. However, only one feature was still not tested which was the UVC illumination of the cabinet which was fulfilled in the following banana tests. From this first test, it is possible to conclude that the prototype is working properly but still have not satisfied the objective of the study.

Table 4.2: Prototype Voltage Readings

Component Input/Output	Prototype Mode Standby	UVC Exposure
Transformer Input	221V AC	221V AC
Transformer output	11.2V AC	11.5V AC
PCB regulated output	5.00V DC	5.02V DC
Top UVC Lamp input	3V AC	228V AC
Back UVC Lamp input	3V AC	229V AC

An additional test was conducted for the prototype feature or specifically the voltage specifications of the prototype design. As proposed, the transformer inputs 220V AC and step down the voltage to 12V AC however, when the prototype is in actual usage, there is a slight discrepancy between the ideal and real voltage readings. This also applies to the PCB regulated output and the UVC lamps input for both standby and UVC exposure mode. Although there is a slight discrepancy, the voltage readings are still in the range of the working voltage without affecting the components.

B. Banana Test

The banana test is a known method for determining a UVC germicidal lamp if it outputs UVC. As the UVA and UVB does not have enough energy to kill or disable cell, UVC have been proven to be effective in it which is also identifiable in banana skin. For this test, it was conducted to evaluate the UVC illumination feature of the UVC cabinet whether it outputs real and sufficient UVC light or just a normal UV not in the range of UVC. As the product description of the UVC lamp that it outputs

254nm with 8W, it is expected that there should be browning effect in the banana skin since the output is in the range of UVC. The procedure that was conducted was to pick 5 almost ripe (Yellowish) banana which will be placed in five different locations or positions and will be exposed to UVC lamp for 60 in one side and 30 mins in the other side for comparison. As there was no available colorimeter, the result will be classified based on the visibility of the change in the banana color. These classification are as follows: visible, faded or slightly visible, and no visible color change. The five different locations are categorized if it is located in the front, back, center, left, or right in the cooling rack.

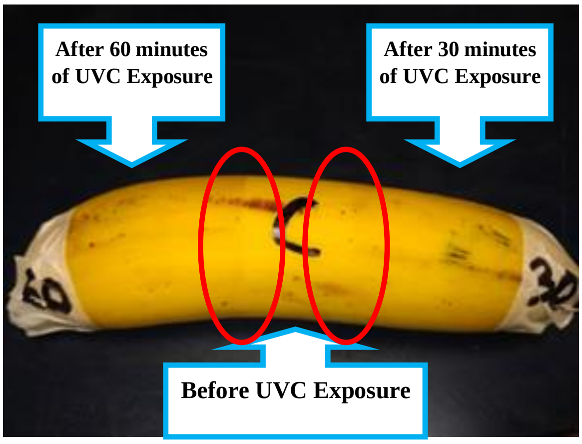

Fig 4.1: Sample Banana after UVC exposure

Fig 4.1 shows the result of the banana test for 30 and 60 minutes UVC exposure and five different locations which are front-left, front-right, center, back-left, back-right. For a more focus image of each banana, refer to the Appendix B

Table 4.3: Ripe (Yellow) Banana Test Results for Varying Locations in the UVC Cabinet

Location/Position in the Cabinet	UVC Exposure Time 30 minutes	60 Minutes
Center	Visible color change	Visible color change
Back-Left Corner	Faded or slightly visible color change	Visible color change
Back-Right Corner	Faded or slightly visible color change	Visible color change
Front-Left Corner	Faded or slightly visible color change	Visible color change
Front-Right Corner	Faded or slightly visible color change	Visible color change

Table 4.3 shows the tabulated result of banana test for varying locations and exposure time. At any locations, a 60 minutes UVC exposure resulted in a visible change of color. On the other hand, for 30 minutes UVC exposure, only in center position was it visible. For the other locations, there are still changes in the color however, it was only slightly visible like a faded color unlike a sudden change in color that can be observed after 60 minutes UVC exposure. From this test, it is possible to conclude that the cabinet truly outputs UVC light however, its effective and optimal location is in the center of the cabinet. From a standard UVC exposure, it is estimated to sterilize for 30-60 minutes a $12m^2$ area to completely sterilize its surface. On the other hand, the prototype sterilizes a $3.87m^2$ area for either 30 or 60 minutes about 18cm away from the source. As it was computed based on the power describe in the UVC lamp specifications, it may actually output lower power than expected. The UVC cabinet sterilizer functions properly and illuminate UVC light however, it is suggested to expose an object for 60 minutes to ensure a complete disinfection.

C. 5 Common Things of a Student in Mapua

As the optimal location and illumination of the UVC light has been evaluated in the banana test, the last test is to examine if there will be a detrimental effect of the UVC illumination to the five common objects that was introduced in the objectives. Given that UVC light only affects microorganisms, there should be no effect to the objects as it has a different composition than a cell. The test procedure will be conducted so that the sample object is placed in the center for optimal exposure and set for the maximum of 60 minutes of UVC exposure to test if the maximum set in the system will have a negative effect on the objects.

Table 4.4: Common Objects Mapuan Bring to Laboratory

Object	Type	Change after 60 minutes UVC exposure
Bag	Leather Backpack	No fading of color however with slightly warm surface
	Nylon Shoulder Bag	No shrinking of bag however with slightly warm surface
	Denim String Bag	No fading of color or shrinking of fabric however with slightly warm surface
Documents	Letter Size	No fading of written or printed inks or change in the color or texture of the paper
Gadgets	Mobile Phones	No effect to electronic components, plastic casing, or the screen
Pens	Blue, Black, Red…	No particular change or damage done to the pens as it can still write properly
Calculators	Sharp	No particular change or damage done to the calculator as it is still fully functional

Table 4.4 shows the result for testing five common things mapuan bring to laboratory with 60 minutes UVC exposure. Although there was heat generated as the objects somewhat felt warm, overall, the UVC light does no detrimental effect to those objects. Although there are different types of bags based on materials such as leather, nylon, cordura, denim, rubber, fabric, etc. or sizes such as backpacks, handheld bags, waist bag, shoulder bags, and string bags, the suggested UVC exposure

will be determined on the material of the object. For polymers, it is suggested to expose in UVC light for the minimum time which is 30 minutes. Since the test was conducted to determine if there will be a detrimental effect on the object, the UVC exposure was set to 60 minutes. Although there was heat generated as the objects somewhat felt warm, overall, the UVC light does no detrimental effect to those objects. As there is no detrimental or harmful effect or damage to objects, it is safe to say that the UVC cabinet is applicable for practical use as a UVC sterilizing cabinet.

V. Conclusion and Recommentation

Disinfection and sterilization have been an integral part of our modern community especially with the emergence of the covid-19 global pandemic. To avoid the spread of virus and other microorganism, disinfection with deep UV range or UV-C light is one of the popular methods in killing or disabling microorganisms. A design of a disinfection cabinet that utilizes UVC light was proposed in this study. Although there have been present design and products that have the same function, the proposed design utilizes UV sensor reading and reed switch to determine the state of the cabinet at all times. Four test procedures were conducted to determine the functionality of the UVC cabinet for each features and specifications, as well as to classify the optimal location and UVC exposure time using banana test and five common objects that Mapua students bring to the laboratory class. The results showed that the optimal location is in the center of the cabinet which is about 18cm from the top UVC lamp source. Additionally, to ensure disinfection of the object, it is suggested for a 60 minutes UVC light exposure. Although the results indicates that 30 minutes UVC light exposure is also sufficient, but only when the object is at the center location. Furthermore, the UVC illumination to the five common objects have no detrimental effect to its functions aside from generating slight heat in the surface. As heat was not considered in the design, the researchers recommend developing a UVC cabinet disinfection that utilizes thermocouple or any temperature sensor to consider the effect of UVC in other objects that are sensitive to heat. It is suggested to test a UVC application with actual UV meter or dosimeter as well as cultured bacteria to for an actual observable effect of disinfection. Overall, the prototype for the design of a UVC cabinet system can now be considered for a practical use in the Mapua laboratories as it has been functional and operational.

VI. Acknowledgement

The researchers would like to thank the support of their family and friends as well as the adviser, Engr. Febus Reidj Cruz as the study would not be possible without them. Furthermore, for the Mapua University (MU) in providing the topic of the study that would not only benefit the institution but also all other future study of UVC applications.

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VIII. APPENDICES

A. *Operation’s Manual*

1) System Requirements
   a) 220V AC Source
   b) At least 22in x 40in x 25in space
   c) Ventilated room
   d) Base that can hold 25kg weight

2) Installation Procedures
   a) The UVC cabinet must be placed in a ventilated area and a flat base.
   b) Only 1 cabinet must be installed for every 1 table in the laboratory.
   c) The tray must be placed only after when the base stability is secured to avoid scratching and bents in the metal sheets.
   d) The UV lamps must be installed as the last piece to avoid damaging the glass.

3) User’s Manual
   a) The user must properly install the UVC cabinet, please refer to the *System Requirement* and *Installation procedures*.
   b) Connect the plug to an AC outlet for a supply of 220V AC source.
   c) Turn on the main switch located in the side of the casing.
   d) 1st Sequence: Selecting UVC Ligh Exposure Time.
      a. While buzzer outputs repeating 1 short sound, configure the time using the buttons.
      b. Press PB1 (left button) for a 30-minutes UVC light exposure.
      c. Press PB2 (middle button) for a 60-minutes UVC light exposure.
      d. Press PB3 (right button) to proceed with the UVC light exposure.
   e) 2nd Sequence: Ensuring a Closed UVC Door Cabinet
      a. While buzzer outputs repeating 1 long sound, close the door of the UVC cabinet.
   f) 3rd Sequence: Disinfecting by UVC Light Exposure
      a. While UVC lamp is on, avoid suddenly opening the UVC door cabinet. If accidentally opened, the system will automatically terminate the UVC disinfection.
      b. Press PB3 (right button) to terminate the UVC disinfection.
   g) For disinfecting longer than 60 minutes, repeat from the 1st sequence
   h) When buzzer output 3 short and 1 long sound, it is suggested to slightly open the cabinet for a few minutes to ensure that there is the least amount of ozone to the user, but it is encourage to switch off and unplug the UVC cabinet.

4) Troubleshooting Guides and Procedures
   a) Cabinet does not output any buzzer sound:
      a. Check the plug connection, ensure that the supply is 220V AC.
      b. Check the main switch state, ensure that it is “ON” state when symbol “1” is pressed.
      c. If the buzzer does not output any sound after the Gizduino internal LED turns on, check the wiring connection. Red wire should be connected to Gizduino pin 3 while black wire is grounded together with every black wire.
   b) Buzzer output sequence 1 (repeating short sound):
      a. The user is in the time selection state, to successfully proceed to the next step, either press PB1 then PB3 or PB2 then PB3.
      b. If the system does not proceed even after pressing the PB3, check the wiring connection in the casing. PB3 red wire must be connected to Gizduino digital pin 7 while the black wire is grounded with all the other black wires.
   c) Buzzer output sequence 2 (repeating long sound):
      a. The user is in the second state of the system where the system registers that the cabinet door is still open.
      b. Close the door and the buzzer sound should stop then the UVC lamps should turn on.
      c. If the buzzer sound still does output 1 long sound, check the reed switch connection near the top-left front of the cabinet. The red wire should be connected to Gizduino pin 8 while the black is grounde.
   d) Buzzer output sequence 3 (3 short then 1 long sound):

a. If the system outputs buzzer sequence 3 immediately, check the UVC lamps if it still outputs UVC light or already dimmed. The system will automatically terminate UVC exposure when the UV sensor no longer detect UVC light inside the cabinet.
b. If the system still outputs buzzer sequence 3 after checking that UVC lamps works properly, check the connection of PB1 and PB2. It may be the case that even when pressed in the 1st sequence, the system did not register the selected time. PB1 red wire must be connected to Gizduino pin 5 while PB2 red wire is in pin 6. The black wires should be grounded together with every other black wires.
c. In case that the door was slightly opened, the system will output buzzer sequence 3 which will automatically terminate the UVC light exposure.

e) Dangling wire in the casing:
   a. The wiring connection to the gizduino microcontroller was purposedly connected using connector wires rather than soldered with solid wires. This was to ensure an easy troubleshooting for each component since it can be connected with a computer or laptop for serial monitoring. Just follow the pin configuration or wiring connection of the system presented in chapter 3.

5) Gizduino Microcontroller Code

```
//MAPUA UNIVERSITY (MU)
//ECEA120D PROJECT
//ABEL, LALAINNE ANE JARABE
//MOREDO, MICHAEL JULIUS
//UV-C CABINET ARDUINO CODE
const int UV = A0; //UV Sensor
const int Buzzer = 3; //Buzzer
const int Relay = 4; //Relay
const int PS1 = 5; //Push Button 1
const int PS2 = 6; //Push Button 2
const int PS3 = 7; //Push Button 3
const int Reed = 8; //Reed Swtich
int Exposure_Time; //Exposure Time set by Push Buttons
int Cabinet_State; //Indicate if Cabinet will continue or end
void setup() {
  Serial.begin(9600);
  pinMode(UV, INPUT);
  pinMode(Buzzer, OUTPUT);
  pinMode(Relay, OUTPUT);
  pinMode(PS1, INPUT_PULLUP);
  pinMode(PS2, INPUT_PULLUP);
  pinMode(PS3, INPUT_PULLUP);
  pinMode(Reed, INPUT_PULLUP);
}
// the loop function runs over and over again forever
void loop() {
//For Configuring the UV Exposure Time with Push Buttons
Serial.println("Loop 1: UV Exposure Time Selection");
while (digitalRead(PS3) == HIGH)
{
  digitalWrite(Relay, HIGH);
  digitalWrite(Buzzer, HIGH);
  delay(100);
  if (digitalRead(PS1) == LOW)
  {
    Exposure_Time = 30;
    Serial.println("30 minute UV Exposure");
  }
  delay(100);
  digitalWrite(Buzzer, LOW);
  delay(100);
  if (digitalRead(PS2) == LOW)
  {
    Exposure_Time = 60;
    Serial.println("60 minute UV Exposure");
  }
  delay(100);
}
//To Start UV Exposure if the Cabinet Door is Closed
Serial.println("Loop 2: Cabinet Door Indicator");
while(digitalRead(Reed) == HIGH)
{
  Serial.println("Cabinet Door is still Open");
  digitalWrite(Buzzer, HIGH);
  delay(1000);
  digitalWrite(Buzzer, LOW);
  delay(1000);
}
//Control Relay to Start UV Lamps
delay(500);
digitalWrite(Relay, LOW);
delay(1000);
Serial.println("Start UV Exposure!");
delay(2000);
//UV Exposure Loop
Cabinet_State = 1;
Serial.println("Loop 3: UV Exposure");
Exposure_Time = Exposure_Time * 60;
while (Cabinet_State == 1)
{
  Serial.print("UV Exposure Time: ");
  Serial.print("\t");
  Serial.print(Exposure_Time);
  Serial.print("\t");
  Serial.print("\t");
  Serial.print("UV Sensor Reading: ");
  Serial.print("\t");
  Serial.println(analogRead(UV));
  Serial.print("\n");
  //Check if UV Sensor Still Detect UVC
  if (analogRead(UV) > 28)
  {
    Cabinet_State = 0;
    digitalWrite(Relay, HIGH);
    Serial.println("UV Sensor does not Detect UVC!");
```

```
        }
        //Check if the Door is Still Closed
        if(digitalRead(Reed) == HIGH)
        {
          Cabinet_State = 0;
          digitalWrite(Relay, HIGH);
          Serial.println("Cabinet Door was Opened!");
        }
        //Check if Push Button 3 was Pressed
        if(digitalRead(PS3) == LOW)
        {
          Cabinet_State = 0;
          digitalWrite(Relay, HIGH);
          Serial.println("Exposure Forced Stop!");
        }
        //Check the Current Exposure Time Left
        if(Exposure_Time == 0)
        {
          Cabinet_State = 0;
          digitalWrite(Relay, HIGH);
          Serial.println("Done UV Exposure!");
        }
        delay(985);
        --Exposure_Time;
      }
      //End Buzzer Sequence
      digitalWrite(Buzzer, HIGH);
      delay(300);
      digitalWrite(Buzzer, LOW);
      delay(100);
      digitalWrite(Buzzer, HIGH);
      delay(300);
      digitalWrite(Buzzer, LOW);
      delay(100);
      digitalWrite(Buzzer, HIGH);
      delay(300);
      digitalWrite(Buzzer, LOW);
      delay(400);
      digitalWrite(Buzzer, HIGH);
      delay(1000);
      digitalWrite(Buzzer, LOW);
      delay(100);
      Serial.println("End UV Exposure");
      delay(2000);
    }
```

B. *Physical Construction of the Prototype*

Cutting angle bar into the designed lengths (dimension of the cabinet).

Welding the angle bar to form rectangular prism.

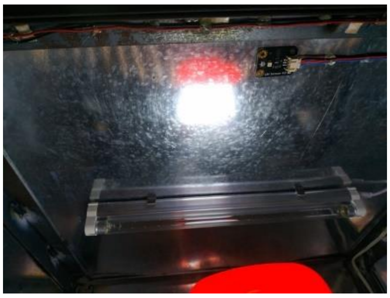
Welding a separate rectangular frame to hold the glass window after sealing with silicon.

Welding the metal sheets to the remaining surface face of the prism.

Create the design PCB and solder the necessary components.

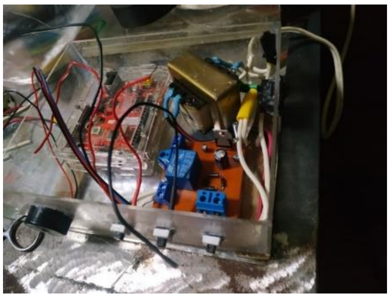
Install the UVC lamps and cooling rack.

Install the UV sensor and reed switch.



Reed switch to detect if the door is closed or open.

Complete the electrical and electronic wirings.



Trial Testing in the breadboard before soldering.

Cabinet view while UVC lamps are on.

Finished UVC cabinet with glass tint.

C. *Pictures of Experimental Testing*

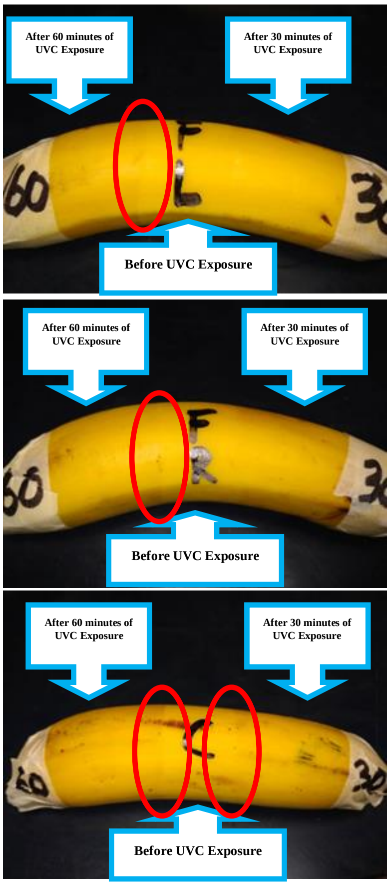
1) Banana Test

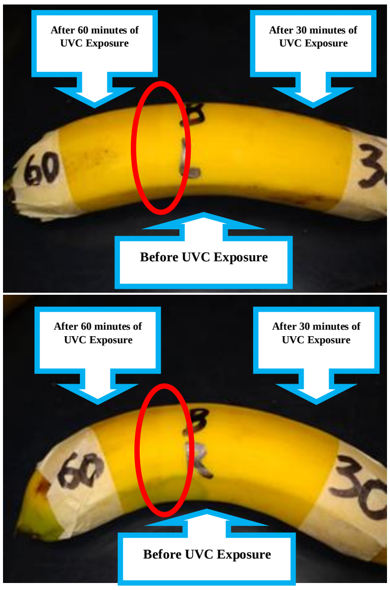
Setting up Banana for UVC exposure.

Banana Test: Placing Banana setup in the experimental locations/placements/position.

Banana Test after 60 and 30 minutes UVC exposure.

Banana test setups at different locations (F = Front, B = Back, L = Left, R = Right, C = Center).

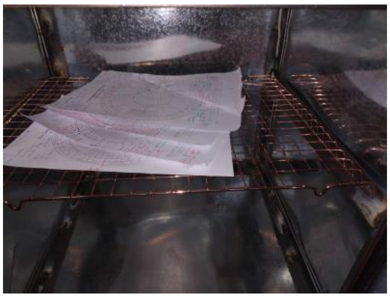




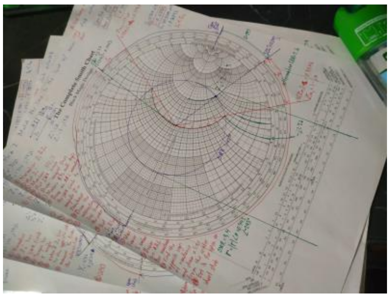
2) Tests on five common objects of mapua students

Testing of different bags for UVC exposure.

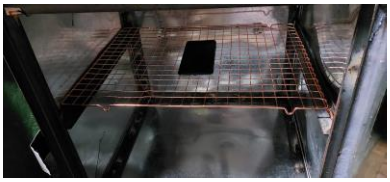
Testing of letter size documents for UVC exposure.



Results shows no fading of written or printed ink.

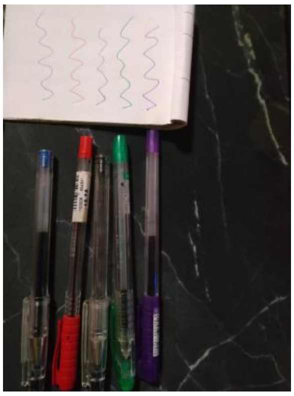


Testing of gadgets for UVC exposure which had no effect afterwards.



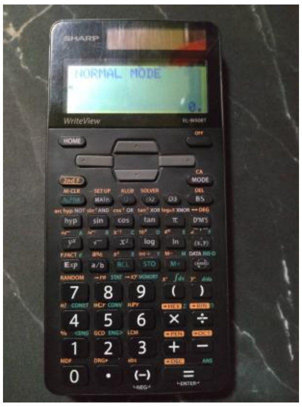
Testing of pens for UVC exposure

Results shows no effect in the ink.



Testing of calculator for UVC exposure.

Results shows no damage or detrimental effect to the function of the calculator.



D. IEEE Paper (Article)

Deep-UV Cabinet-Enhancement of Bag Cabinets in MAPUA Laboratory with Gizduino

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Abstract*—With the emergence of the novel coronavirus (Covid-19) pandemic, disinfecting or sterilizing objects has become more essential in our daily lives as part of the new normal to avoid the spread of the virus and other microorganisms. The UVC is known for killing or disabling such microorganisms, which is the main technology in this study's design of a disinfecting cabinet system. Aside from known features of available UVC cabinets, the proposed system utilizes a UV sensor and reed switch to determine the state of the cabinet at all times. Three tests were conducted to determine and classify the functionality of each feature of the UVC cabinet which the results of the banana test show the optimal location, that is, in the center, and time at 60 minutes to ensure complete disinfection of the object's surface. Overall, the Prototype for designing a UVC cabinet system can be considered for practical use in the Mapua laboratories as it has been functioning without any significant negative effect on five everyday objects of Mapua students.

***Keywords*—Covid-19, UVC, cabinet, Mapua, Laboratory, banana test.**

I. Introduction

Cleanliness is one of the major aspects that contribute to a better environment, creating a healthy environment. A clean environment does not only measure the objects that are visible to our naked eye, but it can also include microorganisms and particles that are not visible to the naked eye. With the recent surge of the Coronavirus or Covid-19 Pandemic, it is evident that a clean environment against this virus and its variants are a must that can be provided through disinfection and sterilization. Through small particles, the virus can spread as it attaches to surfaces that had contact from an infected person [1]. Some schools now allow face-to-face classes as communities become more resilient to these viruses. Mapua being one of the most prestigious and top schools, limited face-to-face classes have begun, including laboratory classes for a more in-depth learning experience. Students traveling from various places may have been in contact with an infected person, which in turn they become carriers; thus, it is important to disinfect their belongings. A cabinet disinfectant for Mapua laboratories would be one of the methods to achieve this together with ultraviolet radiation, specifically the deep-ultraviolet range or the UV-C, whose wavelengths range from 200 to 280nm [2].

The study will incorporate an electronics design aimed to develop a deep-UV cabinet-enhancement of bag cabinets in the MAPUA laboratory with deep-UV illuminations to disinfect 5 (five) different objects, specifically: (1) school bags, (2) letter size documents, (3) gadgets, (4) pens, and (5) calculators. The specific objectives are: (1) To build and develop a cabinet that emits ultraviolet lights ranging from 200-280nm (UVC). (2) To characterize the optimal location in the cabinet for exposure to UV-C lamp. (3) To evaluate the disinfecting performance for the five different objects specified above.

The study will significantly benefit students, faculties, and the institution of Mapua University, such that cabinet disinfection will be available for students in laboratory classes. Furthermore, a UVC cabinet could also be incorporated into other facilities such as healthcare sectors, bio-facilities, research facilities, and even homes or apartments. It could also contribute to further understanding of how viruses, bacteria, and other particles could be disabled through ultraviolet radiation.

Given that the study focuses on applying deep-UV illumination on cabinets, there is a limit to the dimension and volume of the object that can be sterilized or disinfected based on the cabinet dimensions. Evaluating the Prototype with an object that carrier coronavirus will not be included in the study. However, the hypothesis will be assessed based on a related standard for deep-UV sterilization designs and testing procedures. Nevertheless, the study will be conducted in a home environment, and such imperfections in the performance will be present.

II. Review of Related Literature

The deep UV (DUV) region occupies wavelengths between 280 nm and ~200 nm, and DUV optics is the backbone of many critical applications such as nano-fabricating technologies that include the following: high-density data storage, high-energy laser applications, laser eye surgery, nano-meter scale photolithography for semiconductor patterning, and sterilization [3]. Other practical uses of UV light sterilization or disinfection are on the water, vegetables, fruits, utensils, and surface areas of different objects. Although UV is known to be used for sterilization, only the UVC has sufficient energy to effectively disable or kill microorganisms specifically, the 254nm UVC is considered to be effective against all microbiota, molds, foodborne pathogens, and viruses since different microorganisms have different sizes and shapes which affects the required UVC exposure time depending on their UV absorption rate [4]. UV Germicidal Irradiation (UVGI) is a method of disinfection to kill or disable viral, bacterial, and fungal organisms through the use of UV energy which is by breaking down chemical bonds and scrambling the structure of RNA, DNA, and proteins, causing a microorganism to be unable to multiply. UVGI is convenient, and no chemicals are needed, as well as it can kill most kinds of microorganisms, including drug-resistant bacteria. However, UVC is dangerous to humans, so UV sterilization is usually done while avoiding direct exposure to UVC, especially to the skin and eyes. UV only works in its light path and can be blocked by obstacles; thus, it is common to place an object in a direct line of the UV or use multiple UV sources at different angles.

A. *UV Lamp vs. LED*

Deep-UV LEDs have a superior advantage compared to mercury lamps, such as small size, high efficiency, and zero warm-up time and possess many excellent features over conventional mercury lamps. However, at present, the output is much lower. The light output of mercury lamps is usually 1 W or more, while deep-UV LEDs amount only to dozens of milliwatts. Although UV disinfection is generally safer than chemical disinfection, all conventional UV lamps typically use between 5-200 mg of mercury. These UV lamps require routine replacement and are susceptible to breakage during transportation, handling, and operation. UV LEDs are mercury-free and provide a safer alternative [5].

B. *UV-C Banana Testing*

According to research [6], the banana color initially started as green due to chlorophyll characteristics, turning yellow and black because of carotenoids and polyphenols. Moreover, there is an observation from bananas that are exposed to ultraviolet light, which turns the peel glow into blue color. When the fluorescent chlorophyll catabolites (FCCs) rise over coming chlorophyll, leading to banana ripening peels. A VIDEO ILLUSTRATION CONFIRMED the UVC banana testing was confirmed and tested by a video illustration [7]. The banana is exposed directly to the UVC source making its skin darkened.

C. *UV Radiation and Disinfection*

1) *Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light [8]*

Researchers found that UVC light at 222-nm light can kill MRSA compared to other conventional germicidal UV lamps at 254 nm. In a 3D human skin model, it makes essentially insignificant premutagenic UV-related DNA harm and is not destructive to bare mammalian skin.

2) *UV-C Lamps and Sars-Cov-2 [9]*

UVC or 'germicidal' lights have been utilized in the medical clinic and different settings for quite a long time to obliterate microbes (for example, TB) or infections in the air (inside light-close air pipes) and to disinfect drinking water. SARS-Coronavirus has been exhibited to be inactivated by UVC radiation. The low-pressure mercury fume light, which creates over 90% of its radiation at 253.7 nm, has generally been the most well-known UVC light being used. Fresher lights available generally produce at 222 nm and seem, by all accounts, to be less harmful to skin and eye exposure.2 However, these lights are not yet broadly open, and care is exhorted because there is proof that a few models might create unassuming discharges at more extended frequencies that are more unsafe.

UVC lights have likewise been placed in the upper bits of cleaned rooms, albeit the lights should be pointed vertically to lessen the chance of people being uncovered. There have been reports of skin and eye consumption resulting from the unseemly establishment of UVC lights in individuals' rooms.3 This type of establishment is proposed in rooms with high roofs and introduced by talented specialists. Likewise, there are more current assortments of UVC lights intended to clean purge places, like those found in emergency clinics. UVB radiation could likewise be utilized for sterilization, yet it is less productive and possibly riskier for individuals than UVC radiation. Subsequently, safety measures should be taken to avoid inadvertent human openness.

III. Design Procedures

This chapter includes the procedures for developing and creating the Prototype from its concepts to system design to program code and its hardware implementation and physical construction.

A. *Hardware Implementation*

The conceptual framework of this study consists of the features as its inputs, such as the functions of the push button, reed switch, and UV sensor for their respective detection or state classification. The process is fully autonomous once the desired exposure time is set and the requirements are met, such as the cabinet door state, the UVC light detection, and the push button three states. As it is an autonomous process, the output of the design is a UVC disinfected object and buzzer sounds that have a corresponding sequence based on the current state of the system. This sequence is used to easily identify the next step in the process and troubleshoot the prototype design.

Table 3.1: Conceptual Framework of the Study

Input	Process	Output
Object for disinfection	Setting the Exposure time based on the button pushed	UVC disinfected object
Push Buttons state		Buzzer sound sequence
Cabinet Door	Initiating the UVC exposure	depending on the current state of

state UVC light detection	based on the Cabinet door state Terminating UVC exposure based on the cabinet door state, UVC light detection, and pressed buttons	the system

Supporting the concept of the design is the design for the connection of the components in the system which includes the following: the printed circuit board (PCB), the UV sensor, the UVC lamps, the Microcontroller (Gizduino), the buzzer, and the switches as the main control of the system.

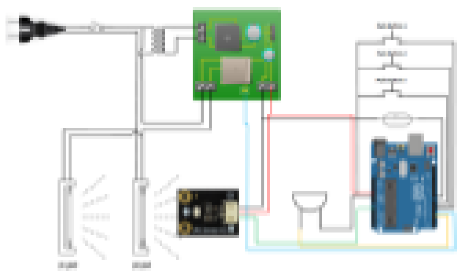

Fig 3.1: System Component Connections

Fig 3.1 describes the specific connections of each component in the system, including pin configurations in the microcontroller and its respective connected component.

The UVC lamps are parallel to each other. However, it is in series with a 5V relay in the PCB. The PCB has a 12V input after the step-down transformer. The output of the PCB is a regulated 5V DC supply for all the external components using the LM7805, capacitors, and full-bridge rectifier diodes. Each switch is grounded while connected to a specific digital pin in the microcontroller for a controlled input using the internal pull-up resistor. The buzzer is controlled by the microcontroller for the specific sound sequence. The PCB directly powers the UV sensor, but it outputs the analog data to the analog pin of the microcontroller for processing. This design utilizes 220V AC, it uses a plug and the main switch to start the whole system.

B. Software Implementation

As shown in the flow chart, the system describes how the prototype program works. When the main switch is pressed, the system starts, which can only proceed whenever push button three is pressed after setting the UVC exposure time with push buttons 1 and 2. Each push-button has its functions, such that PB1 sets the time to 30 minutes while PB 2 sets the time to 60 minutes. On the other hand, PB3 is used to start or terminate UVC exposure. While in this process, it will repeat to output one short buzzer sound until PB3 is pressed. Afterward, the door cabinet state is monitored for the UVC lamps to turn on. While the cabinet door is open, it will repeatedly output one long buzzer sound. Once the door is closed, the UVC lamps are turned on, and the last loop will start. In this part, the microcontroller monitors the UV sensor reading, the cabinet door state through the reed switch, the PB3 state, and the current timer value of the UVC exposure. Whichever one condition is satisfied, the UVC lamps are turned off, and the system outputs a specific three short then one long sequence through the buzzer that indicates ending the current process of the system. As this is a repeating system, it restarts selecting the exposure time once again after some time.

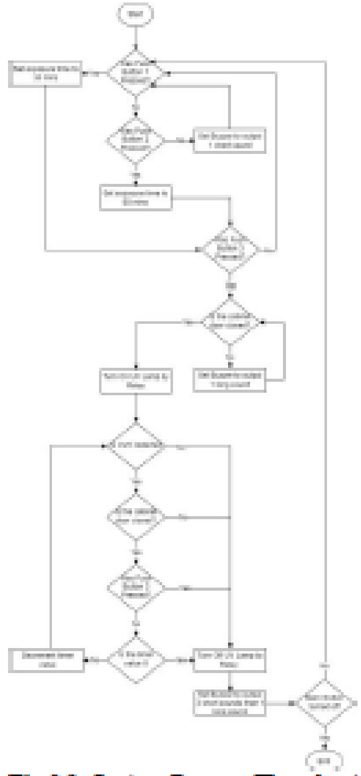

Fig 3.2: System Process Flowchart

Fig 3.2 illustrates the process of the system or specifically how the microcontroller process the information and decides the outcome based on certain conditions.

C. Prototype Development

Once the system design has been approved, the PCB is developed to create a copper path depending on the electrical wiring and components needed. The design is printed on a reflective paper which is then transferred to a copper board through heat. In case the ink was not fully transferred, a marker was used to trace the lines. The following step is by etching the copper board with ferric chloride acid that gradually removes copper from the board's surface. The last part is just drilling the necessary holes and then soldering the components. A separate hole was made for the mount to stabilize and avoid grounding in the components.

The program code for the system is coded through the Arduino IDE, which follows the system flow or process.

The physical construction step-by-step process starts with cutting the angle bar to the cabinet's design length, which will be welded to form a rectangular prism. A separate frame was created to hold the glass window which was sealed with silicon. The metal sheets are then added to the remaining surface faces of the rectangular prism. Once the PCB components are completed, they will be installed together with the remaining materials such as the UVC lamps, UV sensor, reed switch, pushbuttons, buzzer, main switch, transformer, and microcontroller through gauge 12 or 18 wires in the transparent acrylic casing. If the initial test indicates no incorrect placements or connections, the Prototype will be finished with the glass tint.

Fig 3.3: Completed Prototype

Fig 3.3 shows the actual and completed working prototype which has been tinted and polished for testing and presentation.

IV. Testing, Presentation, and Interpretation of Data

A system's design is accompanied by tests to ensure its functionality and features are working as well as if it is up to standards. For this study, three tests were conducted to answer the objective of the study.

A. Prototype Features Test

The first test for the Prototype is the prototype feature test, which is for validating the system's output based on specific conditions indicated as a feature of the Prototype of the designed system.

Table 4.1: Prototype Features Test

Feature	Test	Result
Reed switch for detecting door cabinet state	Door is open before UV lamp start	UV lamp does not start, and Buzzer outputs sequence 2
	Door opens while UV lamp is on	UV lamp turns off, and Buzzer outputs sequence 3
UV Sensor for detecting UVC light	UV cabinet UVC exposure with UV lamps	UVC exposure continues with the set time
	UV cabinet UVC exposure without UV lamps	Buzzer outputs sequence 3
Push Button 3 for initiating and force ending UVC exposure	Start UVC exposure after pressing Push Button 3	UV lamps are turned on
	End UVC exposure after pressing Push Button 3	UV lamps are turned off
Push Button 1 for 30 minutes of UVC exposure	Record 30 minutes of UVC exposure	Continues UVC exposure for 30 minutes
Push Button 2 for 60 minutes of UVC exposure	Record 60 minutes of UVC exposure	Continues UVC exposure for 60 minutes
Buzzer Sequence	Buzzer sound while selecting UVC exposure time	One short sound loop (sequence 1)
	Buzzer sound when Door is open before UV exposure time	One long sound loop (sequence 2)
	Buzzer sound when UVC exposure ends	Three short and one long sound loop (sequence 3)

Table 4.1 shows the results when each feature of the Prototype of the designed system is tested, which shows that the prototype functions and operates properly as the design of the system proposed to develop and build and UVC cabinet. However, only one feature was still not tested, which was the cabinet's UVC illumination, which was fulfilled in the following banana tests. From this first test, it is possible to conclude that the Prototype is working properly but still has not satisfied the study's objective.

Table 4.2: Prototype Voltage Readings

Component Input/Output	Prototype Mode: Standby	Prototype Mode: UVC Exposure
Transformer Input	221V AC	221V AC
Transformer output	11.2V AC	11.5V AC
PCB regulated output	5.00V DC	5.02V DC
Top UVC Lamp input	3V AC	228V AC
Back UVC Lamp input	3V AC	229V AC

An additional test was conducted for the prototype feature or specifically the voltage specifications of the prototype design. As proposed, the transformer inputs 220V AC and step down the voltage to 12V AC however, when the prototype is in actual usage, there is a slight discrepancy between the ideal and real voltage readings. This also applies to the PCB regulated output and the UVC lamps input for both standby and UVC exposure mode. Although there is a slight discrepancy, the voltage readings are still in the range of the working voltage without affecting the components.

B. Banana Test

The banana test is a known method for determining a UVC germicidal lamp if it outputs UVC. As the UVA and UVB do not have enough energy to kill or disable a cell, UVC has been proven effective, which is also identifiable in a banana skin. This test was conducted to evaluate the UVC illumination feature of the UVC cabinet and whether it outputs real and sufficient UVC light or just a normal UV not in the range of UVC. As the product description of the UVC lamp that it outputs 254nm with 8W, it is expected that there should be a browning effect in the banana skin since the output is in the range of UVC. The procedure was to pick five almost ripe (Yellowish) bananas, place them in five different locations or positions and expose them to a UVC lamp for 60 on one side and 30 mins on the other side for comparison. As there was no available colorimeter, the result will be classified based on the visibility of the change in the banana color. These classifications are visible, faded, or slightly visible, and no visible color change. The five different locations are categorized if it is in the front, back, center, left, or right in the cooling rack.

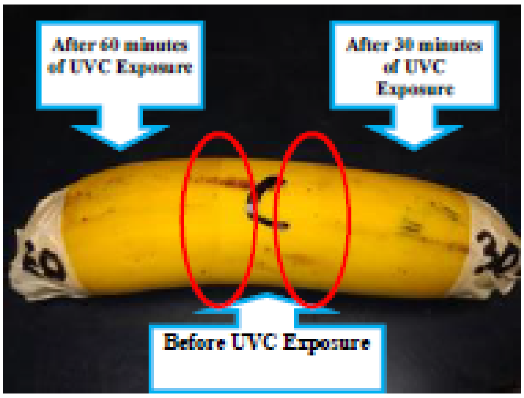

Fig 4.1: Sample Banana after UVC exposure

Fig 4.1 shows the result of the banana test for 30 and 60 minutes UVC exposure and five different locations which are front-left, front-right, center, back-left, back-right. For a more focus image of each banana, refer to the Appendix B

Table 4.3: Ripe (Yellow) Banana Test Results for Varying Locations in the UVC Cabinet

Location/Position in the Cabinet	UVC Exposure Time 30 minutes	UVC Exposure Time 60 Minutes
Center	Visible color change	Visible color change
Back-Left Corner	Faded or slightly visible color change	Visible color change
Back-Right Corner	Faded or slightly visible color change	Visible color change
Front-Left Corner	Faded or slightly visible color change	Visible color change
Front-Right Corner	Faded or slightly visible color change	Visible color change

Table 4.3 shows the tabulated result of the banana test for varying locations and exposure times. A 60-minute UVC exposure at any location resulted in a visible change of color. On the other hand, for 30 minutes of UVC exposure, it was only visible in the center position. There are still changes in the color; however, it was only slightly visible, like faded color, unlike a sudden color change that can be observed after 60 minutes of UVC exposure. From this test, it is possible to conclude that the cabinet truly outputs UVC light; however, its effective and optimal location is in the cabinet's center. From a standard UVC exposure, it is estimated to sterilize for 30-60 minutes a $12m^2$ area to sterilize its surface completely.

On the other hand, the Prototype sterilizes a $3.87m^2$ area for either 30 or 60 minutes, about 18cm away from the source. It was computed based on the power described in the UVC lamp specifications; it may output lower power than expected. The UVC cabinet sterilizer functions properly and illuminates UVC light; however, it is suggested to expose an object for 60 minutes to ensure complete disinfection.

C. 5 Common Things of a Student in Mapua

As the optimal location and illumination of the UVC light have been evaluated in the banana test, the last test is to examine if there will be a detrimental effect of the UVC illumination on the five common things that were introduced in the objectives. UVC light only affects microorganisms, so there should be no effect on the objects as it has a different composition than a cell. The test procedure will be conducted to place the sample object in the center for optimal exposure and set it for 60 minutes of UVC exposure.

Table 4.4: Common Objects Mapuan Bring to Laboratory

Object	Type	Change after 60 minutes UVC exposure
Bag	Leather Backpack	No fading of color however with slightly warm surface
	Nylon Shoulder Bag	No shrinking of bag however with slightly warm surface
	Denim String Bag	No fading of color or shrinking of fabric however with slightly warm surface
Documents	Letter	No fading of written or printed inks

	Size	or change in the color or texture of the paper
Gadgets	Mobile Phones	No effect to electronic components, plastic casing, or the screen
Pens	Blue, Black, Red…	No particular change or damage done to the pens as it can still write properly
Calculators	Sharp	No particular change or damage done to the calculator as it is still fully functional

Table 4.4 shows the result for testing five common things mapuan bring to laboratory with 60 minutes UVC exposure. Although there was heat generated as the objects somewhat felt warm, overall, the UVC light does no detrimental effect to those objects. Although there are different types of bags based on materials such as leather, nylon, cordura, denim, rubber, fabric, etc. or sizes such as backpacks, handheld bags, waist bag, shoulder bags, and string bags, the suggested UVC exposure will be determined on the material of the object. For polymers, it is suggested to expose in UVC light for the minimum time which is 30 minutes. Since the test was conducted to determine if there will be a detrimental effect on the object, the UVC exposure was set to 60 minutes. Although there was heat generated as the objects somewhat felt warm, overall, the UVC light does no detrimental effect to those objects. As there is no detrimental or harmful effect or damage to objects, it is safe to say that the UVC cabinet is applicable for practical use as a UVC sterilizing cabinet.

V. Conclusion and Recommentation

Disinfection and sterilization have been an integral part of our modern community especially with the emergence of the covid-19 global pandemic. To avoid the spread of virus and other microorganism, disinfection with deep UV range or UV-C light is one of the popular methods in killing or disabling microorganisms. A design of a disinfection cabinet that utilizes UVC light was proposed in this study. Although there have been present design and products that have the same function, the proposed design utilizes UV sensor reading and reed switch to determine the state of the cabinet at all times. Four test procedures were conducted to determine the functionality of the UVC cabinet for each features and specifications, as well as to classify the optimal location and UVC exposure time using banana test and five common objects that Mapua students bring to the laboratory class. The results showed that the optimal location is in the center of the cabinet which is about 18cm from the top UVC lamp source. Additionally, to ensure disinfection of the object, it is suggested for a 60 minutes UVC light exposure. Although the results indicates that 30 minutes UVC light exposure is also sufficient, but only when the object is at the center location. Furthermore, the UVC illumination to the five common objects have no detrimental effect to its functions aside from generating slight heat in the surface. As heat was not considered in the design, the researchers recommend developing a UVC cabinet disinfection that utilizes thermocouple or any temperature sensor to consider the effect of UVC in other objects that are sensitive to heat. It is suggested to test a UVC application with actual UV meter or dosimeter as well as cultured bacteria to for an actual observable effect of disinfection. Overall, the prototype for the design of a UVC cabinet system can now be considered for a practical use in the Mapua laboratories as it has been functional and operational.

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