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An Ultraviolet Germicidal Irradiation Autonomous Robot

Bir Ultraviyole Antiseptik Işınlama Otonom Robotu

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Abstract

Utilization of UV light for disinfection and sterilization has increased as a result of its germicidal properties; nevertheless, due to its adverse effects on the skin and eyes, this poses a risk to individuals. The demand for autonomous UV robots originates from the requirement that UV disinfection must occur without human intervention in order to minimize health risks and take advantage of UV light as a disinfection mechanism. This study focuses on the development of a UV disinfection robot that navigates autonomously via obstacle detection and avoidance using Raspberry Pi 4 model B interfaced with UV light and YOLOv4 for high touch object detection. The UV disinfection robot uses object detection to find objects that come into touch with hands frequently and successfully cleans them with UV light. The robot uses an embedded system with a Raspberry-Pi controller, motion sensors, and detects human presence because UV radiation may be harmful to humans. Without human intervention, the autonomous UV disinfection system was effective in cleaning surfaces. Based on the findings in this study, the dosimeter showed a very faint purple tint at 10, 20, and 30 minutes that ranges from 0 to 25 mJ/cm^2. Between 45 and 60 minutes, and between 25 and 50 mJ/cm^2, the dosimeter exhibited a vivid purple color. These results showed that even though different bacteria require different exposure durations to become inactive, a minimum disinfection time of 10 minutes is required to conduct any type of disinfection.

Keywords: Autonomous robot, Convolutional network, Germicidal irradiation, LED, Ultraviolet light

Özet

UV ışığının antiseptik özelliklerinin bir sonucu olarak dezenfeksiyon ve sterilizasyon amacıyla kullanımı artmıştır; ancak cilt ve gözler üzerindeki olumsuz etkileri nedeniyle bireyler için risk oluşturmaktadır. Otonom UV robotlarına olan talep, sağlık risklerini en aza indirmek ve bir dezenfeksiyon mekanizması olarak UV ışığından yararlanmak için UV dezenfeksiyonunun insan müdahalesi olmadan gerçekleşmesi gerekliliğinden kaynaklanmaktadır. Bu çalışma, yüksek temaslı nesne tespiti için UV ışığı ve YOLOv4 ile ara yüzlenen Raspberry Pi 4 model B'yi kullanarak engel tespiti ve kaçınma yoluyla otonom olarak hareket eden bir UV dezenfeksiyon robotunun geliştirilmesine odaklanmaktadır. UV dezenfeksiyon robotu, ellerle sık temas eden nesneleri bulmak için nesne algılamayı kullanır ve bunları UV ışığıyla başarılı bir şekilde temizler. Robot, Raspberry-Pi denetleyicisi ve hareket sensörleri içeren gömülü bir sistem kullanıyor ve UV radyasyonu insanlara zararlı olabileceğinden insan varlığını tespit ediyor. Otonom UV dezenfeksiyon sistemi, insan müdahalesi olmadan yüzeylerin temizlenmesinde etkili oldu. Bu çalışmadaki bulgulara göre dozimetre, 10, 20 ve 30. dakikada 0 ile 25 mJ/cm^2 arasında değişen çok soluk bir mor renk tonu gösterdi. 45 ile 60 dakika arasında ve 25 ila 50 mJ/cm^2 arasında dozimetre canlı mor renk sergiledi. Bu sonuçlar, farklı bakterilerin inaktif hale gelmeleri için farklı maruz kalma sürelerine ihtiyaç duymalarına rağmen, herhangi bir dezenfeksiyon türünün gerçekleştirilmesi için minimum 10 dakikalık bir dezenfeksiyon süresinin gerekli olduğunu gösterdi.

Anahtar kelimeler: Otonom robot, Evrişimli ağ, Antiseptik ışınlama, LED, Ultraviyole ışık

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1. Introduction

The quest for proper hygiene has piqued global interest since the last global public health emergency occasioned by the COVID – 19 pandemic [1]

Effective measures to maintain hygiene while disinfecting contaminable surfaces has ever since attracted enormous research attention [2] [3] [4]. According to [5], to prevent the transmission of diseases, pathogens, such as bacteria, prions, viruses, fungus and other microbes could be removed, destroyed or rendered inactive by the decontamination procedure. This procedure is usually categorized as cleaning, sterilization and disinfection [6]. It is to be noted that both sterilization and disinfection may be carried out by utilizing UV Radiation among other methods, while cleaning requires vacuuming, mopping or scrubbing [6] [7].

Because viruses can spread through the air or by direct contact, the risk of disease transmission rises when surfaces are contaminated. To reduce the probability of disease transmission, it is pertinent to carry out proper routine disinfection of surfaces. This plays an important part in the prevention of disease transmission and ensures healthier living. This study explores the use of one of the most effective methods of disinfection and sterilization; Ultraviolet Germicidal Irradiation (UVGI) [8]. UV light, which was discovered in 1801, was used to treat and sterilize water before it was used as a disinfection method [9]. After the end of World War II in 1945, germicidal UV lamps were made commercially available and utilized to disinfect the air [9].

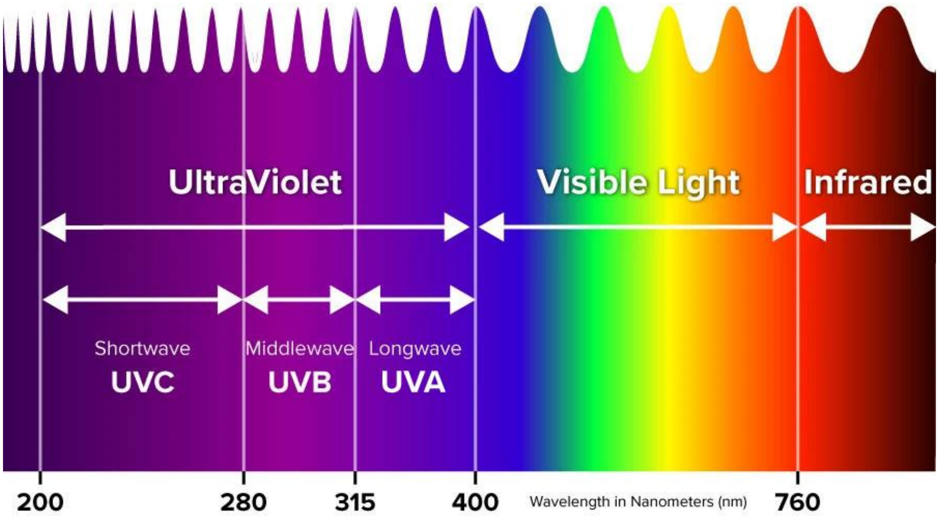

Figure 1. A section of the electromagnetic wave spectrum [10]

As shown in Figure 1, three sections of UV light are identified on the spectrum: UV-A, with a spectrum of 315–400 nm, UV-B, with a spectrum of 280–315 nm, and UV-C, with a spectrum of 200–280 nm [10] [11]. Out of these, UV-C light has the shortest wavelength (200 to 280 nanometers) and possesses the highest energy. This gives it the ability to eliminate viruses and bacteria, otherwise known as pathogens [8]. UV-C disinfects by breaking up the covalent bonds that hold the DNA of pathogens together, and 'super bugs' that have developed a very strong resistance to antibiotics are not exempt. It is effective against new viral and bacterial strains and it also eliminates the need for toxic chemicals [12].

UV-C light has been instrumental in the sterilization of surgical tools, medical equipment, and hospital rooms. It was found in a study that analyzed 21,000 patients that when combined with traditional cleaning methods, UV light disinfection resulted in a 30% reduction in the transmission of drug-resistant bacteria [12]. UV light disinfection has been deployed as fixed or mobile systems such as wands, boxes, and bottles, but this has certain limitations [8]. The fixed systems are bulky and this makes the navigation of crowded spaces difficult. It is also difficult to reach corners and shadowed areas. In the case of mobile systems, disinfection of a large area may require multiple mobile units; whereas a single unit may require more time to disinfect. The need for human control of the mobile unit is another limitation as this may result in increased cost of hiring operation personnel. Another major problem is the health hazard it presents. Human exposure to UV light has been linked to several diseases as it penetrates the outermost layer of the skin. This leads to cell and tissue damage that could predispose to skin cancer and cataracts. It could also negatively affect the immune system.

According to the work done in [13], it was noted that before the COVID-19 pandemic, businesses and research facilities were developing disinfection robots to improve cleaning and sterilization in areas with a high risk of infection. However, in response to the pandemic, various robotic disinfection systems had been implemented. Some designs are simple combinations of commercial mobile devices with specialized UV lamps, while others are more sophisticated robotic systems that could turn UVC lamps on and off while moving through a facility [14]. For instance, AVA robotics built a movable base for MIT's UV robot that incorporates a controller for the UV light. This UV robot was utilized in food pantries. This robot utilized four UVC lamps and could cover 370 square meters in 30 minutes at a speed of 0.1m/s [15]. Another example is the Building Momentum's UVC robot 2.0, which had a mobile base with UVC lamps on top and utilized six lamps operating at 330 W with a wavelength of 254 nm for disinfection. This robot could navigate using the line-following technique [16] [17].

In the work of [18], Akara Robotics developed Violet, a UV disinfection robot that could detect humans and turn off its mercury UV lamp when humans were present. Violet had a small form factor and could navigate through tight spaces, making it suitable for use in cluttered areas such as hospital rooms with multiple medical devices [19]. To enhance its safety around humans, Violet adopted a reflective shield made of aluminum metal, which enhanced the radiation intensity [18]. It has been demonstrated that the pulsed xenon UV light used by Xenex's Lightstrike robot reduces SARS-CoV-2 on hard surfaces and face respirators [20]. The robot's wide-spectrum UV light was highly toxic to microbes and had a peak power 4300 times greater than a mercury lamp. Xenex's robot had fast disinfection cycles and could disinfect a hospital ward in 10 minutes and an operating theater in about 20 minutes [17].

The UVD Robot was created by Blue Ocean Robotics, a Danish business that specialized in creating robots for cleaning hospitals, trains, and airlines. This robot use 3D sensors to survey the environment, identify barriers, and carry out an algorithm that turns off the UV light when it detects humans or when it approaches an object too closely [17]. Medical facilities in Croatia and Romania have started using Blue Ocean Robotics' autonomous disinfection robots. The UVD robot designed using low pressure mercury (LMP) lamps could disinfect rooms in just 10 minutes [13].

The AIDBOT, developed by Dr. KangGeon Kim of the Artificial Intelligence and Robotics Institute at KIST, is a disinfection robot powered by artificial intelligence. The AIDBOT could independently navigate and disinfect a contaminated room using both disinfectants and UV light simultaneously. The ADIBOT-A, developed by UBTECH, is an autonomous UV robot that combines UVC technology with UBTECH’s expertise in robotics to create an intelligent UV disinfection system. The robot operates at a UV wavelength of 253.7 nm and could move around medical facilities autonomously. The ADIBOT-A is re-configurable, meaning it is able to modify its UVC power and height for different disinfection applications [21].

Some disinfection robots that are not completely autonomous also utilizes UVC technology. GermFalcon, a UVC airplane disinfection system, requires a human operator for it to be moved into the airplane. The robot protects its operator from UV exposure with its in-built shield [22]. A UVC robot created by Tru D Smart was deployed in a hospital for acute care, and it was able to significantly decrease pathogens like Acinetobacter in rooms of infected patients [15]. Sterilray has begun advertisement for its autonomous disinfection robot that employs excimer lamps producing far-UVC that is set to launch in 2023 [13]. Developed for the sterilization of patients or operating rooms, the UV bot by [23], utilizes three 19.3W UVC lamps, installed on top of a mobile robot base. This robot navigates with the aid of a wireless remote-control technology operated by a human operator [23]. A comparison of UV disinfection robots is depicted in Table 1.

Table 1. Comparison of UV Disinfection Robots (existing and open to research)

Robot/Properties	Autonomous	Cost (USD)	Human safety	UV Source
Aitheon's UVD Robots	Yes	-	No	LPM
Ava Robotics UV Disinfection robot	Yes	-	No	-
BlueBotics's mini UVC	Yes	-	No	-
Blue-Ocean UVD Robot	Yes	90,000	No	LPM
BooCax UV1500	Yes	-	No	Quartz lamp
GlobalDWS's DSR	Yes	-	No	-
Helios UVC System	No	125000	No	Amalgum UVC lamp
Hero21	Yes	-	No	-
Honeywell's UV System	Yes	-	No	LPM
Lumnicleanse's UVC robot	Yes	-	No	-
Prescientx's Violet	Yes	-	Yes	-
Pudu's Puductor 2	Yes	-	No	-
RoverUV	Yes	89,000	No	-
R-Zero Arc	No	-	No	-
Sterilray Far-UV Robot	Yes	90,000	No	LPM
The Badger UV Disinfect Robot	Yes	-	No	LPM
TMiRob's Intelligent Disinfection Robot	Yes	-	No	-
Tru D	No	125000	No	LPM
Violet by Akara Robotics	Yes	-	Yes	Mercury vapor UV lamp
Xenex Lightstrike	No	125,000	No	PXL
ADAMMS UV Robot	No	-	No	LPM and UV Wand
Fetch UV Robot	No	-	No	UV Flashlight
Ultrabot	No	-	Yes	LPM
G-Robot	No	-	Yes	Far-UVC

Data from: [13], [17], [18], and [24].

Table 1 compares UV robots that are existing and still under research based on their cost, autonomous ability, and human safety and UV light sources. By comparing these factors, the essential features of a UV robot could be identified and the areas that requires further research may be determined. In this study, an autonomous UV disinfection system was developed using embedded technology. This was achieved by programming the Raspberry Pi interfaced with the UV light source. To achieve the high touch object detection, You Only Look Once (YOLOv4) machine learning model was programmed to run on the Raspberry Pi microprocessor. The safety mechanism was factored into the design by using an aluminum foil as the lining behind the UV light source. This was to shield the area behind the disinfection system from the effect of the UV light and its reflecting incident light. Hence, simultaneous manual cleaning and UV disinfection could be achieved. To add built-in autonomous navigation capability into the design, the Raspberry Pi was interfaced with a proximity sensor and a motor driver.

2. Materials and Method

A microprocessor, the Raspberry Pi 4 model B, sits at the heart of the autonomous UV disinfection robot. The experimental setup as shown in Figure 2 details the implementation of the autonomous UV disinfection robot. The web camera feeds data into the microprocessor which processes this input and runs it through an object detection model for identifying high-touch surfaces such as door knobs or handles. This object detection model is based on the YOLOv4 architecture, known for the balance it offers between speed and accuracy, to ensure a high degree of precision [25]. Architecture-wise, YOLOv4 is a fully convolutional network. There are 110 convolutional layers in all. 44 of them are 3 x 3 and 66 are 1 x 1, respectively. A 3 x 3 convolution layer with 32 filters is present in the input layer. The output layer is a convolution layer with a size of 1 x 1, stride, and padding. The 33 filters are in the output layer. The head of YOLOv3 is used as the head in YOLOv4, and the backbone is Cross Stage Partial DenseNet (CSPDarknet53). The neck is made up of Spatial Pyramid Pooling (SPP) and Path Aggregation Network (PAN). For optimization, mini-batch gradient descent with momentum is employed. Deep features from the input photos are extracted by CSPDarknet-53. SPP effectively increases the receptive field, PAN retrieves features at various scales, and the heads identify objects [25-27]. For the last layer, a linear activation function is employed. While SPP enables the network to use a variety of image sizes as opposed to the fixed-size input image required by the conventional approach, PAN is a feature pyramid network used in YOLOv4 to increase information for segmentation [28, 29].

Upon detection of a high-touch surface, the robot by employing the use of an ultrasonic sensor computes its distance from any object or obstacle along its path. A 3-wheel robot chassis at the base of the robot, and an L298N motor driver acting as the H-bridge allows the motor rotate both clockwise and anti-clockwise. The Raspberry Pi is connected to the ultrasonic sensor and the motor driver which in turn is connected to the motors. The Raspberry Pi reads data about the surrounding of the robot using the ultrasonic sensor and sends commands to the motor driver based on this. If an obstacle is detected within a 15cm range, the Raspberry Pi instructs the motor to avoid the obstacle.

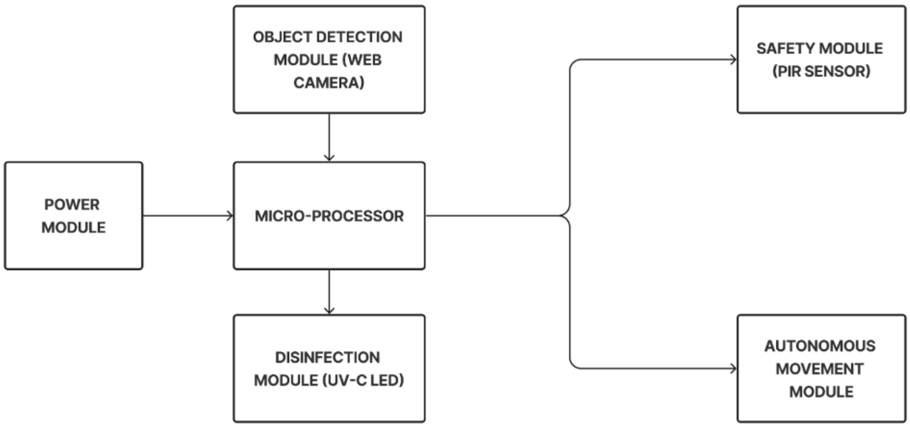

Figure 2. Block diagram of the modular classification of the UV Disinfection Robot

For UV disinfection, the system employs UVC LEDs operating at a wavelength of 275 nm as its ultraviolet light source. With a forward voltage of 5 V and a rated current of 0.1 A, 8 UVC LEDs were connected in parallel to form an LED array which was controlled by a driver circuit consisting of a relay. The UVC LED was attached to the robotic structure hosted a few centimeters above the ground. This module also included an aluminum foil reflective shield that increases the overall output and reflects UV light, boosting the effectiveness of disinfection. As shown in Figure 3, the system uses a PIR sensor with a detection range of 5 m to 12 m to identify human presence and then convey a warning in order to reduce the risks associated with exposure to UV light. When a human is detected, the Raspberry Pi turns off its UV LEDs and sounds a buzzer as a warning until it no longer detects humans.

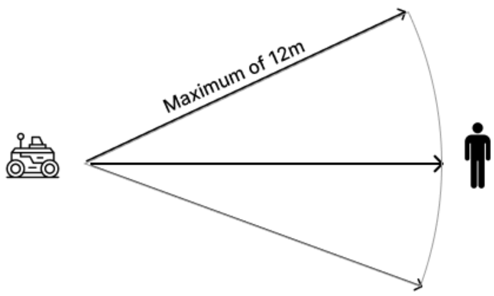

Figure 3. Human detection radius of the UV-C robot

The robot was battery-operated while the Raspberry Pi was powered by a 5 V 2.1 A power bank. A 7.4 V, 2400 mAh lithium-ion battery supplied power to the remaining circuitry. The robot's operational flowchart is shown in Figure 4. The robot moves for three seconds after starting up in an effort to find objects that are prone to contamination. The robot activates a buzzer for 0.5 seconds every 3 seconds after detecting a human until the human is no longer seen. The robot navigated to avoid an impediment that was 15 cm away and kept traveling after detecting it. When a contamination-prone object is successfully identified, the robot advances toward it, stops 20 cm away, and then moves on after disinfecting it for 30 minutes. If the robot does not detect any contamination-prone object in 2 minutes, the robot powers off and stops its operation.

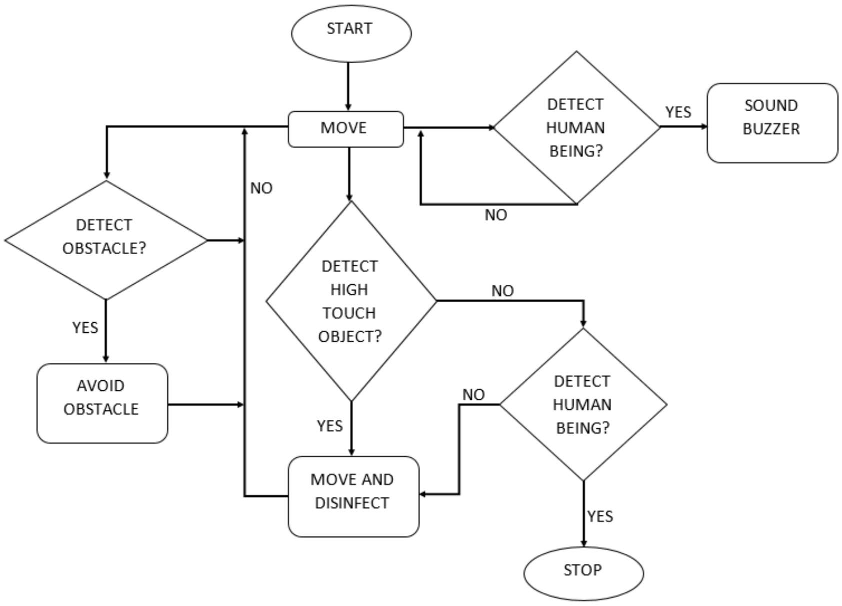

Figure 4. Flow chart of the operation of the UV Disinfection Robot

The schematic diagram of the circuit designed with Fritzing is shown in Figure 5. A voltage divider is connected to the echo pin of the ultrasonic sensor to reduce the voltage level of the echo pin from 5 V to 3.3 V. This is to protect the Raspberry Pi because the GPIO pins have an operating voltage of 3.3 V and can only read voltages up to that level [30]. Two 220 ohms resistors were connected in parallel to form a 110 ohms resistance, which was connected to the positive terminal of the UV LED array - 8 UV LEDs connected in parallel. Since connecting LEDs directly to the power supply causes them to heat up and eventually burn out, this prevents overheating and burnout of the LEDs. Through a 5 VDC relay utilized for electrical switching, the LEDs were connected to the power supply, the 5 V terminal of the L298N motor driver. By sending commands to the relays' IN pin, the raspberry pi may control the UV LEDs and subsequently the disinfection module.

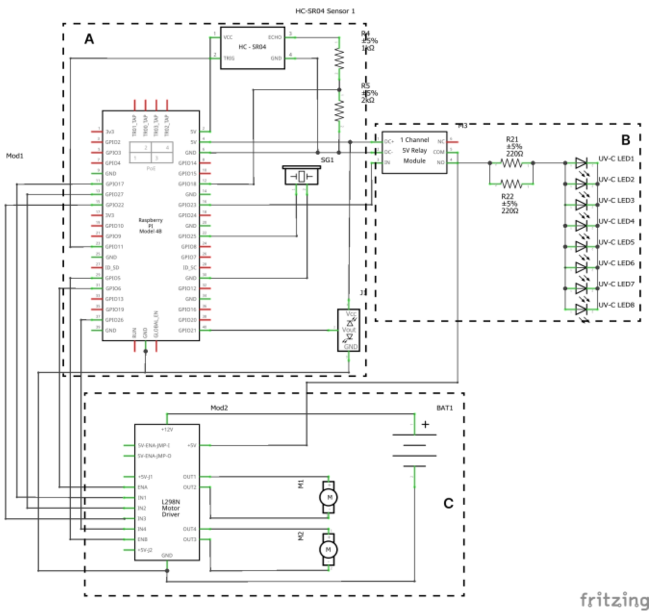

Figure 5. Complete Circuit Schematic of the UV Disinfection Robot

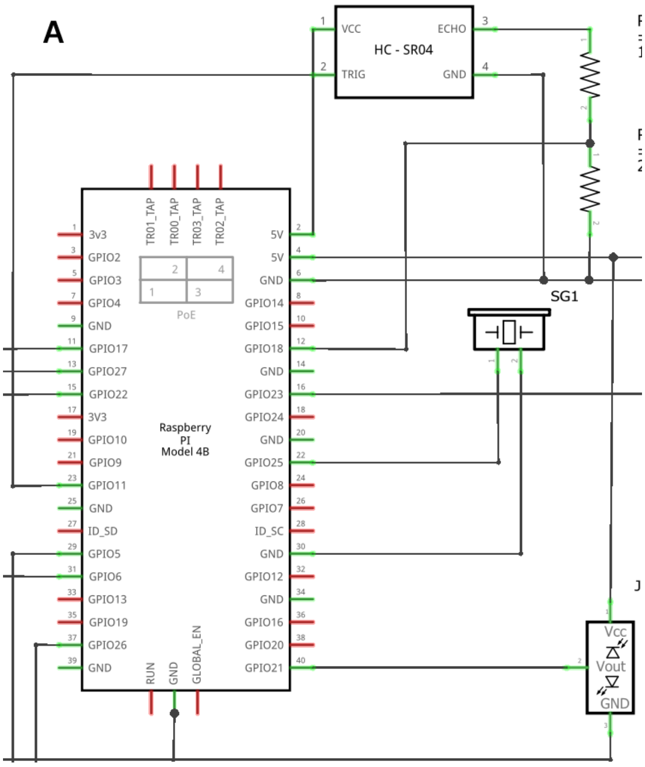

Figure 6. Section A of the UV Robot Schematic

Figure 6 shows the schematic diagram for section A of the UV robot's schematic. In this section, the ultrasonic sensor, HC-SR04 was connected to the pins of the Raspberry Pi. The VCC was connected to the 5V output of the Pi, while the echo pin was connected to GPIO 18 through a voltage divider. The trigger pin connects to GPIO 11 whereas the GND pin connects to the GND of the microprocessor. The buzzer, SG1, also had its positive and negative terminals connected to GPIO 25 and GND respectively. The PIR sensor, located at the bottom right of the image had its VCC and GND terminals connected to the 5 V and GND terminals of the Pi respectively while its Vout terminal was connected to GPIO 21.

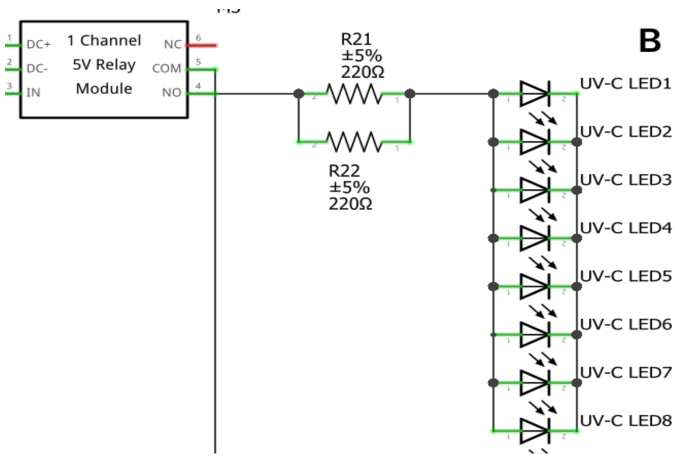

Figure 7. Section B of the UV Robot Schematic

Figure 7 shows the schematic diagram for section B of the UV robot's schematic. This section mainly functions as the UV disinfection module because it contains the UV LED arrangement and its driver circuit. The UV LED array was created by connecting two parallel 220 ohm resistors in series with an arrangement of UV LEDs that were linked in parallel. This LED array was connected to the normally-open terminal of the relay module, while the common terminal of the relay module was connected to the 5V output of the L298N motor driver. The Raspberry Pi supplied power to the relay via its

DC+ and DC- pins, and the Raspberry Pi's GPIO23 was linked to the IN pin, which was used to regulate the relay's switching.

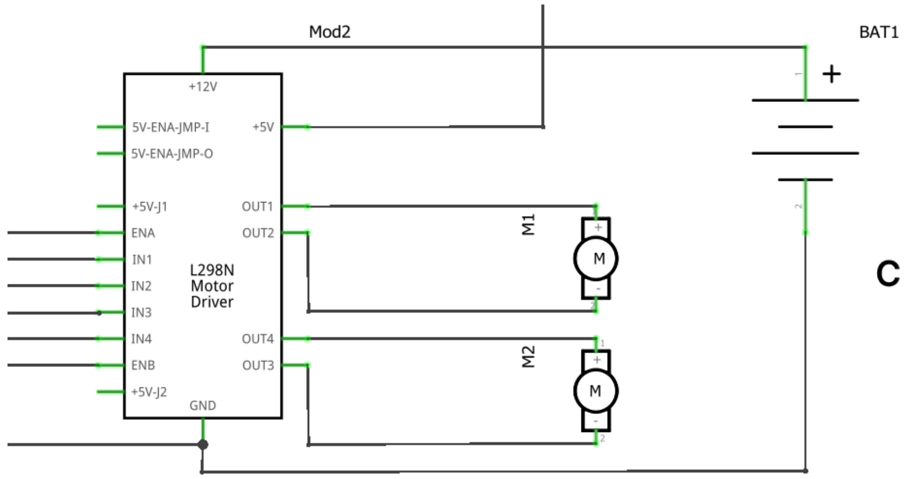

Figure 8. Section C of the UV Robot Schematic

Figure 8 illustrates the schematic diagram for section C of the UV robot's schematic. The primary function of this section is the mobility of the UV robot as both the motor driver and DC motors are connected here. OUT 1 & 2 were connected to motor M1, and OUT 3 & 4 were connected to motor M2. The motor driver was powered through its 12 V pin by the battery, BAT1. The motor was controlled through the IN and Enable pins. Pins IN 1 & 2 were used to control the motor M1 while pins IN 3 & 4 were used to control the motor M2. The enable pins, EN A & B were used to control the speed of the motors M1 and M2 respectively. These control pins were all connected to the Raspberry Pi GPIO pins and the full connection is as shown in Figure 5.

The presence of UVC light and the intensity of the radiation was measured with the aid of a UVC test dosimeter card, shown in Figure 9. The UV dosimeter card visually indicates the light energy or dosage level by 6 different gradient colors with different dosages 25 mJ/cm², 50 mJ/cm², 75 mJ/cm², 100 mJ/cm², 200 mJ/cm², 300 mJ/cm², as shown in Table 2.

Figure 9. UVC Test Dosimeter Card

Table 2 shows the available UV dosage ranges that are detectable by the UV dosimeter card and the colors for each range.

Table 2. UV Dosimeter Ranges

UV Dosimeter Range (mJ/cm^2)	Color
0 - 25	Faint purple
25 - 50	Light purple
50 - 75	Medium purple
75 - 100	Dark purple
100 - 200	Darker purple
200 - 300	Darkest purple

3. Results

The UV LED has two UVA (395–405 nm) and UVC (270–280 nm) LED chips, which together offer a twofold sterilizing effect. The primary purpose of the UVC light, at 275 nm, was to deactivate bacteria, while the primary purpose of the UVA light, at 395nm, was to serve as an indicator. Since UVC is in the invisible range of light, UVA light with a wavelength of 395 nm is used as an indication light to make sure the UVC LED is on. The color change on the dosimeter card shows the UV dosage. To evaluate the effectiveness of the UV disinfection, non-reusable UVC dosimeter cards were used to measure the UV dosage. Positioned 20 cm away from the surface to be disinfected, the dosimeter cards were exposed to UV irradiation for different durations. Figure 10 shows the readings on the UVC dosimeter test cards for the different exposure times.

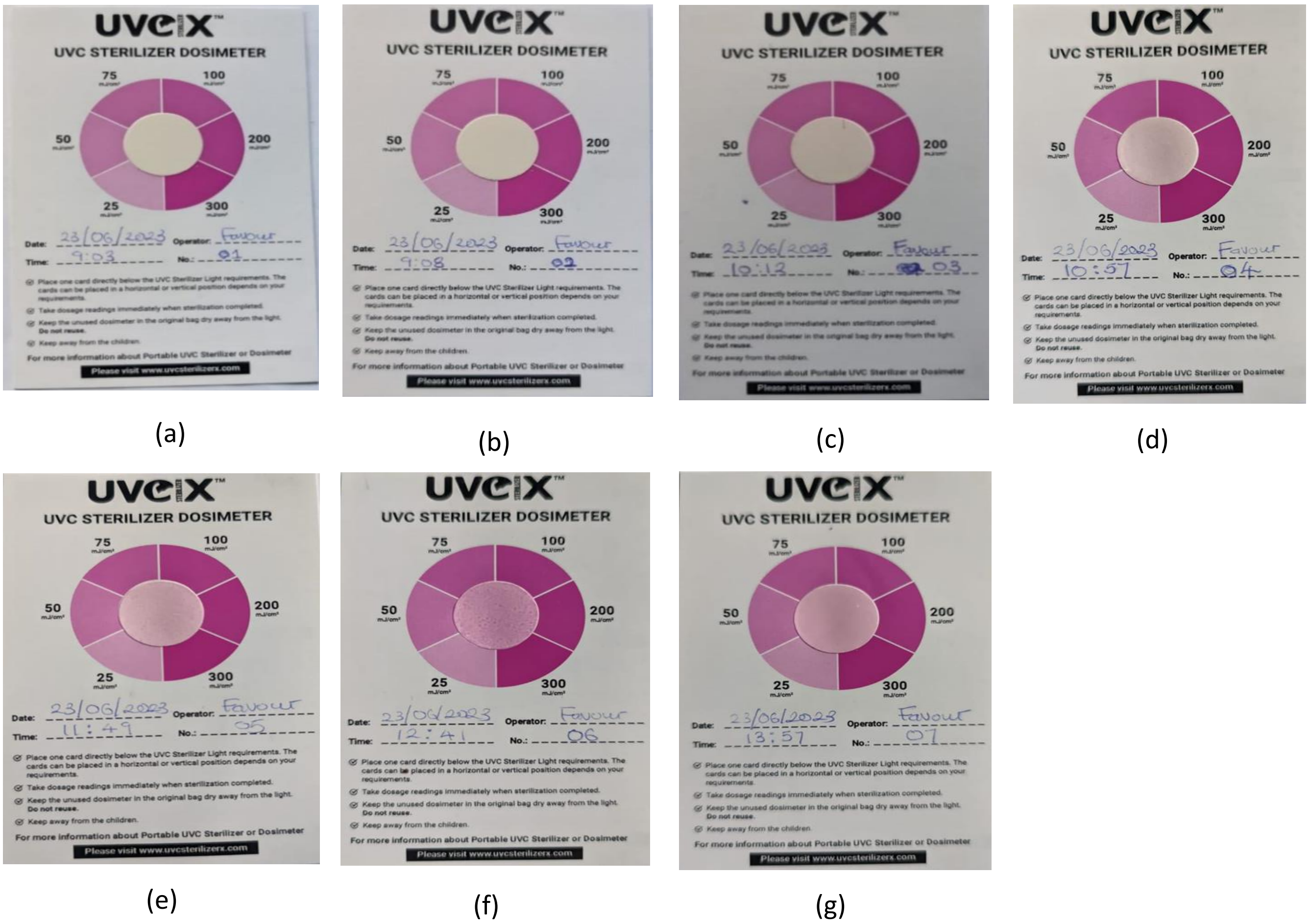

Figure 10. UV Dosimeter reading after (a) 1 minute of exposure (b) 5 minutes of exposure (c) 10 minutes of exposure (d) 20 minutes of exposure (e) 30 minutes of exposure (f) 45 minutes of exposure (g) 60 minutes of exposure

Figure 10 (a) demonstrates that the UV dosimeter card's color remained unchanged after 1 minute of exposure, making it impossible to record a reading. The UV dosimeter card's color was unchanged after 5 minutes of exposure, as shown in Figure 10 (b), and no reading could be taken. Figure 10 (c) demonstrates that the UV dosimeter card exhibits a very faint purple tint within the 0–25mJ/cm^2 range after 10 minutes of exposure. Figure 10 (d) shows that after 20 minutes of exposure, the UV dosimeter card showed a very faint purple color, which fell within the 0-25mJ/cm^2 range. Figure 10 (e) depicts that after 30 minutes of exposure, the UV dosimeter card revealed a very faint purple color, which was within the 0-25mJ/cm^2 range. Figure 10 (f) demonstrates that after 45 minutes of exposure, the UV dosimeter card showed a light purple color, which was within the 25-50mJ/cm^2 range. Figure 10 (g) also revealed that after 60 minutes of exposure, the UV dosimeter card showed a light purple color, which fell within the 25-50mJ/cm^2 range. Upon exposure to UVC light, the circular center of the dosimeter reacted to the irradiation with a color changes, depending on the UV dosage over the duration of exposure. The perimeter of the circular center was surrounded by different shades of purple representing the different ranges of the UV dosage. Upon examination of the circular center on each of the exposed dosimeter cards, the nearest color to the purple shade was recorded as the dosimeter reading for the given exposure time. The UV dosage readings taken from the UV dosimeter cards are shown in Table 3.

Table 3. UV Dosage readings over time

Exposure Time	UV Dosimeter Range	Color
1 minute	-	No detectable change
5 minutes	-	No detectable change
10 minutes	0 - 25	Very faint purple
20 minutes	0 - 25	Very faint purple
30 minutes	0 - 25	Faint purple
45 minutes	25 - 50	Light purple
60 minutes	25 - 50	Light purple

Figure 11 shows a graph of the exposure time against the UV dosimeter readings, which is the graphical representation of the UV dosages shown in Table 3.

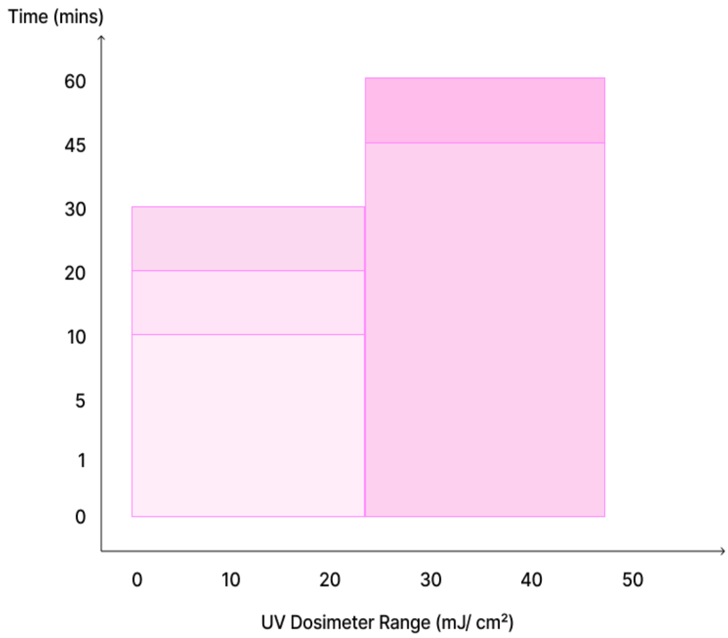

Figure 11. Graph of Time versus UV Dosimeter Readings

Figure 11 illustrates a bar chart that shows the relationship between exposure time and the UV dosimeter readings. The chart illustrates that at 1 and 5 minutes, the dosimeter displays no observable changes and is considered to read a value of zero. The UV dosimeter range is on the x-axis and the exposure period is on the y-axis. The dosimeter displayed a very light purple tint at 10, 20, and 30 minutes that falls between 0 and 25 mJ/cm^2. The dosimeter displays a bright purple tint between 45 and 60 minutes that is between 25 and 50 mJ/cm^2. These findings demonstrate that a minimum disinfection duration of 10 minutes is necessary to perform any sort of disinfection, even if various bacteria require varied exposure times for their deactivation. Different microbes require different UVC energy levels for their effective deactivation, and Table 4 shows some microbes and their respective deactivation dosages.

Table 4. UV Dosage Required to Eliminate Microorganisms

Microbe	Type	Dosage (mJ/cm^2)
Acinetobacter baumannii	Bacteria	1.8
Bacillus megatherium	Bacteria	27.3
Listeria monocytogenes	Bacteria	15.6
Newcastle Disease Virus	Virus	1.6
Poliovirus	Virus	4.4
Adenovirus type 2	Virus	40

Data sourced from: [31].

Tables 3 and 4 show that the UV disinfection robot can successfully get rid of harmful germs while also decontaminating the contaminated surfaces. With the aid of the webcam camera and object detection model, the UV disinfection robot had the ability to detect high-touch surfaces such as door handles, and disinfect them with UV light within the germicidal wavelength. Figure 12 shows different views of the robot prototype. The UV robot avoids obstacles along its path and navigates on its own with the aid of the ultrasonic sensor. The robot shields areas outside of its line of disinfection with an aluminum shield, enabling simultaneous human cleaning, so that after disinfection, cleaning professionals can remove dust and grime. This is important to reduce cleaning time as UV disinfection only destroys microorganisms and does not clean dirt. Objects and surfaces still need to be "cleaned" to get rid of visible dirt, albeit neutralized.

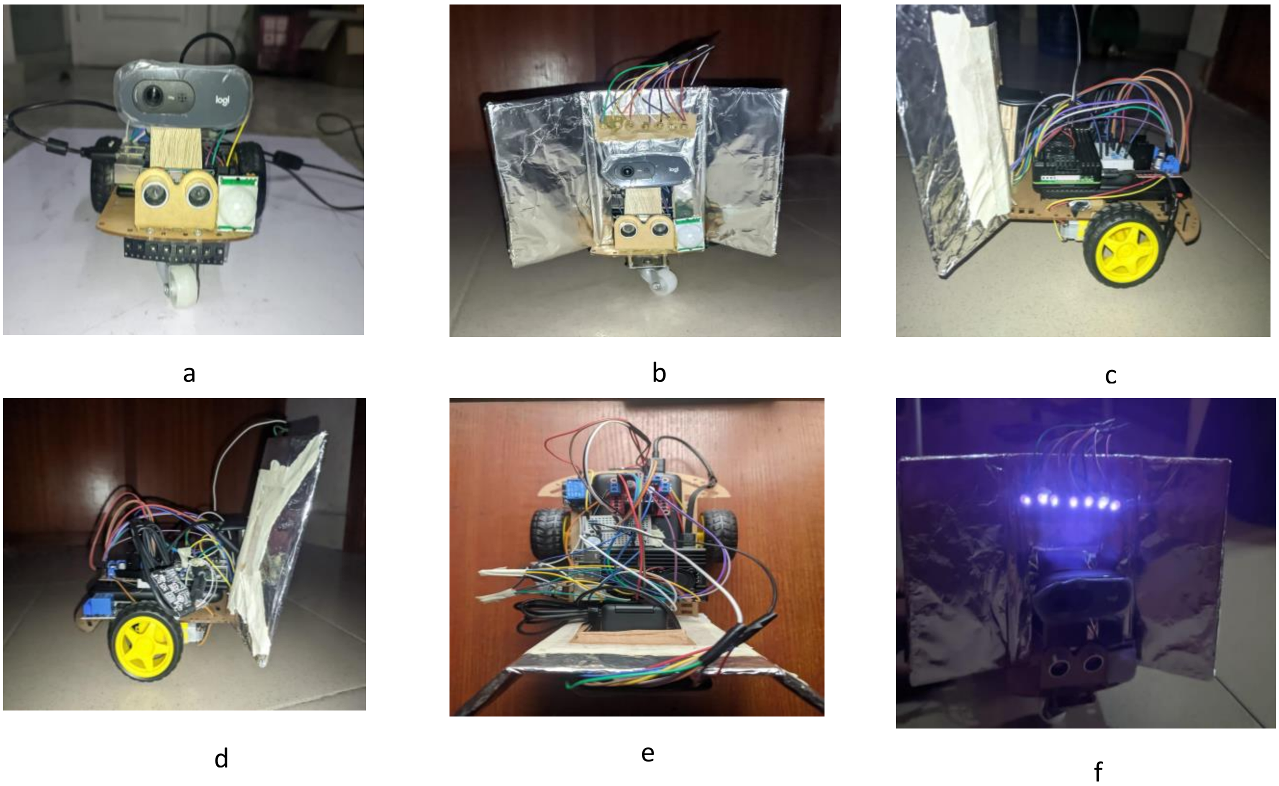

Figure 12. (a) Front view of the robot without the Aluminum shield (b) Front view of the robot with the Aluminum shield (c) Left view of the robot (d) Right view of the robot (e) Top view of the robot (f) Robot prototype with the UVC LEDs turned ON

Figure 12 (a) captures the front view of the 3-wheeled robot without the aluminum shield in view. A wooden cuboid that was affixed to the robot's chassis can be seen supporting the web camera. Along with the PIR sensor, which is placed exactly next to the web camera, the ultrasonic sensor, which is in front of it, was also glued to the robot's chassis. Figure 12 (b) captures the front view of the robot, showing the placement of the aluminum shield on the robot chassis, as well as the location of the UVC LED arrangement. The aluminum shield is affixed to the bottom of the robot chassis and is constructed from cartons covered in aluminum foil. The breadboard, which is connected by the wires that are visible coming out of the LED setup, is shown in other figures. Figure 12 (c) shows the left view of the robot with the Raspberry Pi, power bank, breadboard, motor driver, left DC motor, and wheel in view. The Raspberry Pi, breadboard, and motor driver were all adhered to the top of the power bank, which was bonded to the robot's chassis. The arrangement aimed to maximize the limited space available, while also ensuring that all necessary ports to the Pi remained accessible. The jumper wires used for the connection between the components and the breadboard are shown. Figure 12 (d) shows the left view of the robot with the power bank, relay, motor driver, right DC motor, and wheel in view. The relay was used to control the switching of the UVC LED array and can be seen to be glued to the robot chassis. The cable connecting the web camera to the USB port of the Pi and some other ports on the Pi are equally shown. Figure 12 (e) shows the top view of the UV robot prototype with the majority of the interconnected components in view. As the jumper wires coming out of the Raspberry Pi are linked to the breadboard, relay, and motor driver, it is visible inside the aluminum shell that houses it. It can be seen that the power cable is attached to the power bank that powers the Raspberry Pi. On the breadboard, the jumper wires from the UV LED array in front of the robot are connected in series with a parallel arrangement of two 220 ohm resistors, and the relay is connected after that. On the robot chassis, the left and right wheels are where the jumper cables are shown coming from. Figure 12 (f) shows the UV robot with the LED array powered ON. It should be noted that the reflection angle of this prototype takes a range from 20^o to 25^o on both sides respectively. The Aluminum shield reflects the UV light and prevents it from reaching behind the device. This allows further human activities behind the robot and out of risk. The autonomous UV disinfection robot is a significant achievement in the field of robotics engineering and disinfection technology. It effectively combines obstacle avoidance, UV disinfection, and object detection to create a solution for contamination-prone environments. The use of an Aluminum shield ensures targeted disinfection and increases efficiency while allowing for human activities away from the line of disinfection. A key innovation of this study is the integration of object detection with real-time disinfection, which optimizes the process and makes it environmentally friendly. This robot is particularly relevant in high-risk environments such as hospitals and shared spaces, and its autonomous nature minimizes the need for human interference, reducing potential exposure to pathogens and improving hygiene standards. This robot opens the door to numerous applications in industrial facilities, hospital settings, and public venues.

4. Conclusion

This article has presented an effective and efficient approach for surface disinfection by implementing UVGI with the aid of UVC LEDs and a robot for autonomous navigation. It prioritizes the autonomy of the disinfection robot due to the advantages it has over fixed UV-C systems. The efficiency of the robot's functioning was boosted by the employment of integrated sensors and cameras. The capacity of the robot to function safely in the presence of humans was a key consideration during the design process. Although UV-C effectively inhibits microorganisms, it does not get rid of dust and dirt that may be present on surfaces. Due to this, its applicability in spaces that are not completely vacant was also taken into consideration. The robot allows for simultaneous human cleaning, by shielding the areas that are out of its line of disinfection with an aluminum foil so that cleaning staff could get rid of dust and dirt after disinfection has occurred. This effectively reduces the total sanitization time and optimizes the processes involved. The UV robot could be adopted in places like hospitals or medical centers where sick people are often located. Some of the possible innovations in the future work will be to explore the possibility of improving upon the efficiency of the UV disinfection robot. UV light source at a wavelength of 254 nm could be investigated as well. To improve the accuracy of the autonomous navigation, a more accurate technique such as Lidar sensor or camera-based techniques could be investigated. Since objects beyond the maximum height of the robot are not disinfected because they are beyond the reach of the robot, further research may be carried out in designing a robot that could adjust the height of the UV light sources relative to object detection using AI. The robot may also experience trouble navigating in tight spaces due to its form factor and as such, certain corners and shadow areas may not be captured. The surfaces and surface shapes where microbes and viruses are found could be investigated in future work as well.

5. Author Contribution Statement

In this study, Author 1 contributed to forming the idea, design, manuscript preparation, and critical review; Author 2 contributed to the design and manuscript preparation.

6. Ethics Committee Approval and Statement of Conflict of Interest

"There is no need for an ethics committee approval in the prepared article"
"There is no conflict of interest with any person/institution in the prepared article"

7. List of Abbreviations

AI	Artificial Intelligence
COVID – 19	Coronavirus Disease 2019
CSPD	Cross Stage Partial DenseNet
GND	Ground
GPIO	General Purpose Input/Output
LED	Light Emitting Diode
LMP	Low Pressure Mercury
PAN	Path Aggregation Network
PIR	Passive Infrared
SPP	Partial Pyramid Pooling
UV	Ultraviolet
UVGI	Ultraviolet Germicidal Irradiation
YOLO	You Only Look Once

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