# An Ultra-violet sterilization robot for disinfection

Pacharawan Chanprakon
Biomedical Engineering Department
Faculty of Engineering King Mongkut's
Institute of Technology Ladkrabang
Ladkrabang Bangkok 10520, Thailand
Email: Pacharawan.chan@gmail.com

Tapparat Sae-oung
Biomedical Engineering Department
Faculty of Engineering King Mongkut's
Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, Thailand
Email: Tapparattip@gmail.com

Treesukon Treebupachatsakul
Biomedical Engineering Department
Faculty of Engineering King Mongkut's
Institute of Technology Ladkrabang
Ladkrabang, Bangkok 10520, Thailand
Email: treesukon.tr@kmitl.ac.th

Pimkhuan Hannanta-anan
Food Engineering Department
Faculty of Engineering King Mongkut's
Institute of Technology Ladkrabang
Ladkrabang Bangkok 10520, Thailand
Email: pim.hannan@gmail.com

Wibool Piyawattanametha
Biomedical Engineering Department
Faculty of Engineering King Mongkut's
Institute of Technology Ladkrabang
Ladkrabang Bangkok 10520, Thailand
Institute for Quantitative for Health Science and Engineering, Michigan State University
Michigan 48824, USA
Email: wibool@gmail.com

***Abstract*—Ultraviolet (UV) sterilization technology is used to aid in reduction of microorganisms that may remain on the surfaces after a standard cleaning to the minimum number. Our research team developed a UV robot or UV bot for sterilization in an operating or a patient room. Our UV bot has three 19.3-watt of UV lamps mounted on top of the UV bot platform covering 360° direction. Our UV bot employed an embedded system based on a Raspberry Pi to aid in navigation to avoid obstacles. In addition, we tested the effectiveness of eliminating Staphylococcus Aureus bacteria sample plates located 35 cm away from our UV bot to be within 8 seconds after UV light exposure.**

***Keywords*— Ultra-violet Sterilization, Robot, Disinfection**

## I. INTRODUCTION

The goal of environmental control in the operating room (OR) or a patient room setting is to keep microorganisms including drug-resistant bacteria to an irreducible minimum in order to provide a safe environment for the patient and healthcare worker. At present, there are as many as 14-17% of infections in operating, and 38% of hospital infections occur in patients who have surgery [1]. Therefore, both daily perioperative and terminal cleaning of the OR environment is one of the most effective infection control methods used to accomplish the goal in minimizing the number of microorganisms, dust, and organic debris present in the environment.

However, a standard cleaning procedure via cleaning solutions by human alone cannot reduce the number of these microorganisms as there are many blind spots or unreachable areas such as walls and ceiling. Recently, a type of ultra-violet (UV) could aid hospitals in ongoing battle to keep microorganisms from lingering in patient rooms and causing new infections [2]. That particular wavelength range which can eradicate microorganisms is in the range of 200-280 nm, also known as C band of UV light (UV-C). This wavelength range is effective in inhibiting bacteria, viruses, and fungi. In addition, it can be used to sterilize in air, in water, on the surface, and very effective when using disinfection in the OR.

Currently, fixed UV sterilization system has many limitations in use. For instance, a UV exposure is harmful to users if they are exposed for a long time or in a very large quantity. It can cause redness of the skin and eye infections (conjunctivitis) or ceiling lamp types. Furthermore, it cannot be used to disinfect in some areas hidden under the shadow of the object.

To eliminate all the aforementioned issues, our research team designed a UV robot or UV bot that can either manually or autonomously (using machine learning or ML) navigate around a room including avoiding obstacles enabling it to thoroughly sterilize the entire OR with or without human intervention.

## II. BACKGROUND

### A. Ultraviolet disinfection

Light wavelength (Figure 1) for germicidal irradiation is a technology that utilizes a UV light in the range between 100 - 400 nanometers. UV-C radiation (200 – 280 nm), which is considered the most germicidal wavelength range due to the fact that UV-C can inactivate microorganisms.

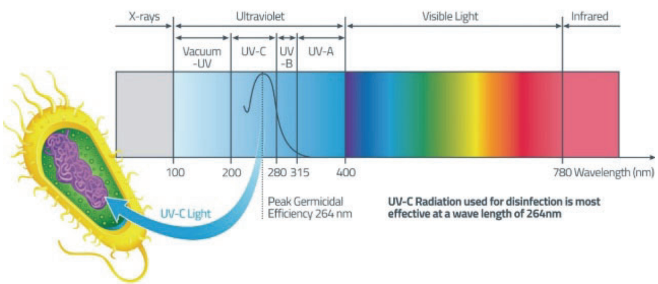


**Fig. 1** The Spectrum of Light (www.uvguard.com/knowledge-centre/).

The light is absorbed by the DNA and RNA of microorganisms resulting in the dimerization of adjacent molecules (particularly thymine). This occurrence in the DNA and RNA of viruses and bacteria makes it impossible for the microorganisms to replicate and infect as shown in Figure 2 [4].

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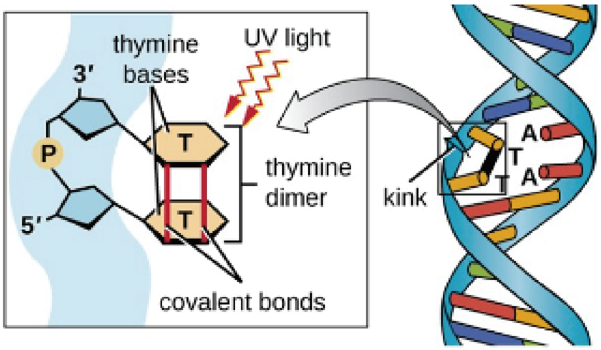


**Fig. 2** Thymine dimer phenomenon (courses.lumenlearning.com/microbiology/chapter/mutation/).

### B. *Surgical site infections*

Surgical site infections (SSIs) remain one of the most common causes of serious surgical complications. they account for 14 - 17% of all hospital-acquired infections and 38% of nosocomial infections in surgical patients. Approximately 20 - 30% of surgical-site infections are caused by *Staphylococcus aureus* (*S. aureus*) as shown in Figure 3 [1].

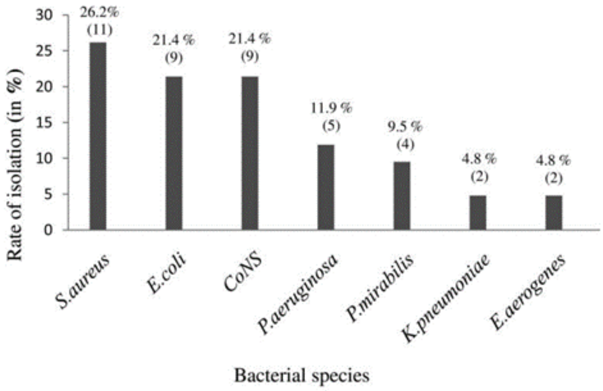


**Fig. 3** Bacteria that cause infection in the operating room. [5]

### C. *Exposure time required for inactivation of bacteria*

In order to know the traveling speed of our UV bot, the exposure time for bacteria inactivation needs to be calculated. As individual UV lamps purchased commercially emit a different amount of UV energy. It is necessary to measure it via a power meter. The unit of brightness is typically expressed in microwatt per centimeter squared ($\mu W/cm^2$) and the exposure time employed for UV sterilization is directly proportional to a UV dosage, which is the amount of UV dose per brightness as described below in (1) and (2) [3], respectively

$$\text{Brightness} = \frac{Luminosity\ (w)}{4\pi \times Distance^2\ (cm^2)} \qquad (1)$$

$$Time = \frac{UV\ Dose\ \left(\mu W \cdot \frac{sec}{cm^2}\right)}{Brightness\ (w/cm^2)} \quad . \qquad (2)$$

## III. Methods

### A. *UV bot designing*

Key designs for our UV bot are in both a small form factor and in free of electrical control wires (battery operated) in aiding navigation around the OR. Essential components of our UV bot (Figure 4) are: 1) a robot platform or frame 2) three UV lamps 3) a controller box 4) a power source equipped with 12 volts battery 5) a driving terrain (2 controlled wheels and 4 free wheels) 6) two ultrasonic sensors, and 6) control software. Our UV bot height is 143.5 cm with its base size of 60x60x30 cm.

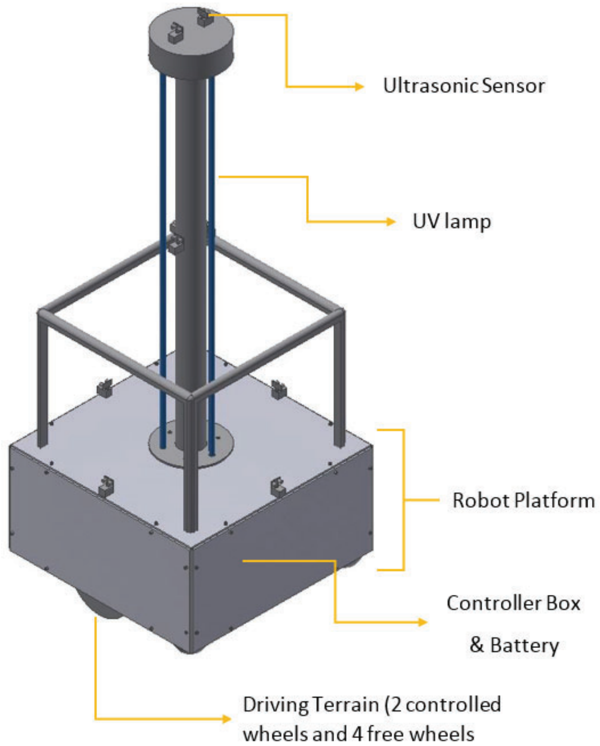


**Fig. 4** Design of UV sterilization robot.

The heart of the system is a microcontroller. That is a central command center of the UV bot. It is programmed to accept inputs to sense obstacles around it and navigate the robot around the room to avoid any collisions as shown in Figure 5. There are 6 ultrasonic sensors mounted on the UV bot. Those locations are front, left, right, and back of the robot platform. The remaining 2 sensors are mounted on the head of robot. If there is an obstacle in the pathway, two controlled wheels will help steer around that obstacle according to processed signals received from ultrasonic sensors In case of an obstacle, or a potential collision, the microcontroller controls the wheels of the robot by a motor driver to avoid collision. The controller block diagram and the flow chart of our control software are shown in Figure 6 and 7, respectively.

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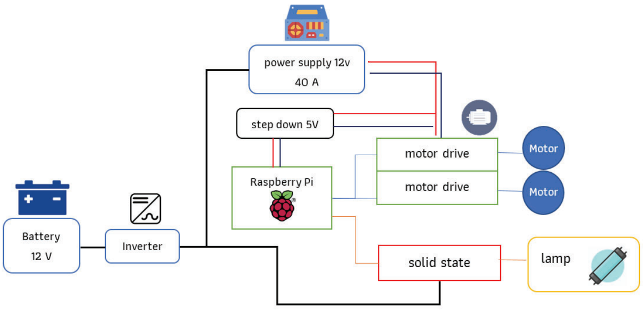


**Fig. 5** Block diagram of controller box.

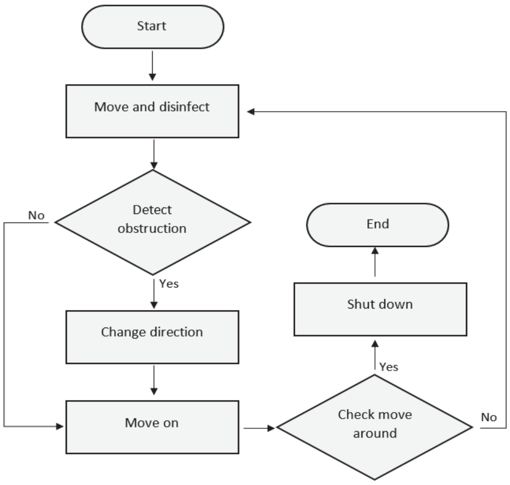


**Fig. 6** A flow chart of a UV bot control software.

*B. Calculated time for disinfection*

Our UV bot utilized 3 UV lamps mounted in a circular pattern with 120° apart. Each lamp has a 19.3-watt output (as listed on a UV lamp datasheet). The amount of brightness in with a certain distance away (35 cm) can be calculated below as:

$$\text{Brightness} = \frac{19.3 \times 3\ (w)}{4\pi \times 35^2\ (cm^2)} \tag{1}$$

$$= 0.00376\ w/cm^2 = 37.6\ \mu w/cm^2.$$

In order to calculate the amount of exposure time received at sample plates, our team selected UV dose require for inactivation of *S. aureus* to be 6,600 μW·sec /cm$^2$ [7]. Hence, the minimum time required to eradicate germs is expressed below

$$Time = \frac{6{,}600\ \left(\mu W \cdot \frac{sec}{cm^2}\right)}{37.6\ (\mu w/cm^2)} \tag{2}$$

$$= 1.75\ sec.$$

*C. Counting of bacterial colony*

Ultraviolet sterilization test *S. aureus* TISTR 746 in nutrient broth (0.35%Yeast extract, 0.5%Peptone, 0.5%NaCl) was cultivated in nutrient agar (0.35%Yeast extract, 0.5%Peptone, 0.5%NaCl, 1.5%agar) using a spread plate technique onto 5 culture plates. The first plate was used a reference sample with no UV exposure. The other 4 plates were exposed to the UV light for 2, 4, 6 and 8 s, respectively. Each plate was placed at 35 cm away from the UV bot. Then, each plate was incubated at 37°C for 24 h. After that, the total number of colonies forming units on each plate was enumerated.

## IV. Results

*A. Ultraviolet sterilization Bot*

Our fabricated UV bot is shown in Figure 7. The ability of the robot is user can control it via website by connect with same Wi-Fi network. User can control movement, speed motor and turn on-off lamp. Can observe environment by watching through the camera. With the collaboration of webcam camera and ultrasonic sensors allow the robot to avoid obstacles and move around the room. Maximum speed of our UV bot is 0 - 1.4 meter/sec and can operate via a battery is 30-45 minutes or connect to an electrical outlet.

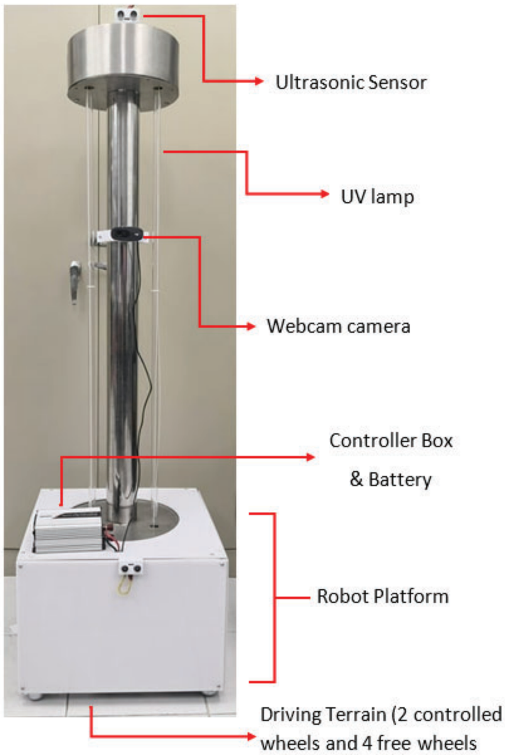


**Fig. 7** UV sterilization robot.

*B. Ultraviolet sterilization test*

The number of bacteria colonies on the reference plate (without the disinfection by UV bot) and the samples plate under the various disinfected time are shown in Table 1 and Fig. 8.

**Table 1.** Comparison results from reference and UV disinfection

| Time (s) | ***Staphylococcus aureus* colony counts** | |
|---|---|---|
| | ***Reference*** | ***UV disinfect*** |
| 2 | 23 | 7 |
| 4 | 23 | 8 |
| 6 | 23 | 1 |
| 8 | 23 | 0 |

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From the results, the sample plate placed under a UV exposure of our UV bot for only 2 second will significantly see the reduction of *S. aureus* to 7 colonies from the starting colonies of 23 in the reference plate. Further increment in UV exposure time as shown in Table 1 will lead to a complete eradication of *S. aureus* in 8 seconds.

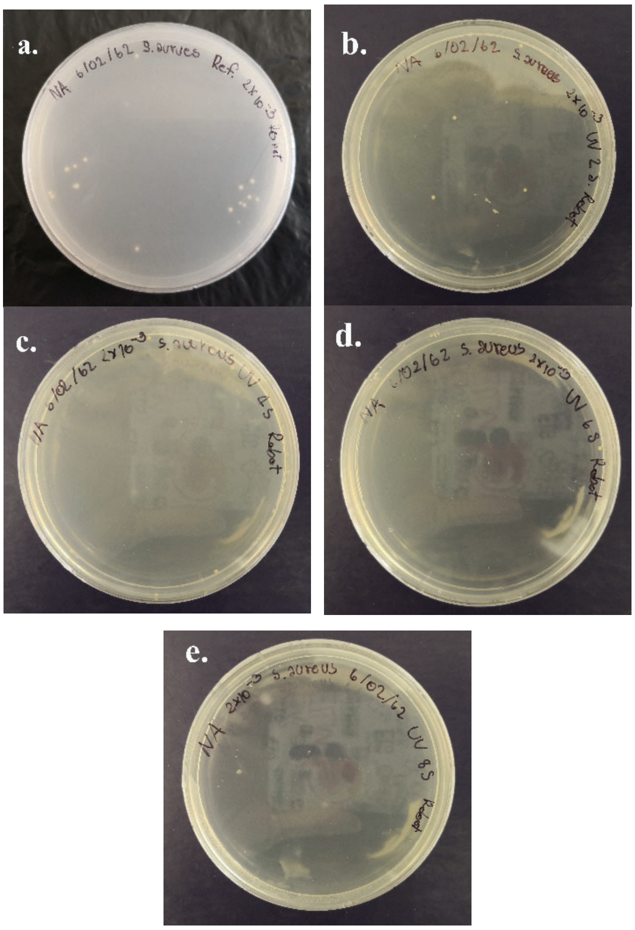


**Fig. 8** Photos of cultured plates with different exposure time: a) a reference plate, b) 2 seconds, c) 4 seconds, d.) 6 seconds, and e) 8 seconds.

## V. Discussion and Conclusions

From the experimental results of disinfection test, the UV bot requires at least 8 seconds in order to completely eradicate the *S. aureus* colonies. This number is over 4 times larger than the theoretically calculated value. Some of the main reasons can be explained as follows. Firstly, there is a large discrepancy between the listed output power (19.3 W) by the UV lamp manufacturer and the actual output power (5.3 W). Secondly, transparency of our culture plates could affect the amount of UV light exposure onto *S. aureus* colonies. Currently, our UV bot can only navigate manually via a wireless remote control. The autonomous navigation of the UV bot is underway.

Our UV robot has demonstrated a great potential to aid sterilization by keeping microorganisms including drug-resistant bacteria to an irreducible minimum in order to provide a safe environment for the patient and healthcare worker. In addition, our UV bot will be able to move around a room and avoiding obstacles by using a wireless control system via the website by connecting through the same Wi-Fi network. enabling it to thoroughly sterilize the entire operating rooms

## Acknowledgment

This work is supported in part by grants from KMITL Research Fund, Thailand Research Fund, National Research Council of Thailand, Newton Fund from British Council United Kingdom, and the Fraunhofer-Bessel Research Award from the Alexander von Humboldt Foundation, Germany.

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