REVIEW ARTICLE

Can Autonomous UV Disinfection Robots Sterilize a Room? A Review

Cantika Nurcahyani Kiai Demak[1], Nonik Siti Ayati[1], Dita Ayu Mayasari[1] , Aripin[1], Alfian Pramudita Putra[2,3]

1 Biomedical Engineering, Faculty of Engineering, Universitas Dian Nuswantoro, Semarang, Indonesia
2 Biomedical Engineering Study Program, Department of Physics, Faculty of Science and Technology, Universitas Airlangga, Surabaya, 60115, Indonesia
3 Biomedical Signals and Systems Research Group, Faculty of Science and Technology, Universitas Airlangga, Surabaya, 60115, Indonesia

ABSTRACT

The coronavirus disease 2019 pandemic has forced us to improve hygiene. Sterilizers have been widely used in public and private homes. Ultraviolet (UV) robots with different designs, biological interactions, and features have been widely used as sterilizers. The dose issued is only based on theoretical calculations under optimal conditions without considering other environmental factors. This ideal condition is unsuitable to apply in real conditions. Factors such as room temperature and room airflow could affect the effectiveness of UV sterilizers. This review aims to propose an ideal design for UV sterilizer robot by adding a feedback system to minimize external disturbances. The development of UV robots is necessary for future design improvements to be effective and efficient.

Keywords: COVID-19, UV disinfection, robot sterilizer, UV robot

Corresponding Author:
Dita Ayu Natasari, PhD
Email: mayasari.dita@dsn.dinus.ac.id
Tel: +6281340328007

INTRODUCTION

Several local health facilities reported a cluster of pneumonia cases with unknown causes in the end of December 2019 in Wuhan, China. The Chinese Center for Disease Control and Prevention (Chinese CDC) sent a rapid response team to help Hubei Province and Wuhan City perform epidemiological and etiological investigations on December 31, 2019. They were tasked to report the investigation results, identify the source of the pneumonia cluster, and describe the new coronavirus detected in the patients whose specimens were tested by the Chinese CDC in the initial outbreak (1).

A month later, WHO declared the outbreak due to coronavirus. The new coronavirus outbreak is currently examining an unfortunate record with the number of deaths officially outstanding that of the severe acute respiratory syndrome (SARS) outbreak. This outbreak started in Wuhan, China, but then also identified in many East and Southeast Asian countries, the United States, Australia, the Middle East, and Europe. In addition, Vietnam, Japan, Germany, Indonesia, and the rest of the world have reported transmission within the country (2).

In mid-April 2020, more than 2 million cases of infection by COVID-19 had been reported worldwide, and more than 160,000 people reportedly died from the disease. This virus has had a significant impact on many aspects in a month. Various government policies have heavily influenced the entire tourism sector to suppress the surge in the number of patients with COVID-19 worldwide. Some of the implemented policies were lock-down (only in certain countries), social distancing, large-scale social restrictions, and orderly patrols by all police units and other relevant officials (3).

In carrying out this policy, each individual is encouraged to apply regulations based on the new normal, which is in line with the provisions of the health protocol. Maintaining hygiene is essential in carrying out health protocols. Treatment of a surface likely exposed to various bacteria and viruses can eradicate or even kill bacterial and viral colonies. However, given the size of bacteria and viruses, special tools are needed to assist humans in detecting and eradicating these microorganisms. Technological advances, such as using a sterilizer that can eliminate bacterial and viral colonies on the surface of objects, are vital during a pandemic. The installation of the main component in the sterilizer is emitted from the spectrum of ultraviolet type C (UV-C). UV-C radiation, which is bactericidal, is defined as practical and capable of destroying bacterial and viral colonies (4).

CORONAVIRUS STRUCTURE

Coronavirus has four structural proteins, namely, spike protein (S), envelope protein (E), membrane protein (M), and nucleocapsid protein (N) (Fig.1) (5). Each of these proteins have an essential role in viral activity. The N-protein that binds to +ssRNA allows the virus to enter the host cell and functions in replication and transcription. The M protein is the most abundant protein on the virus's surface and is the regulatory center for coronavirus assembly. The S protein on the virus's surface acts as a mediator of virus attachment to host cell receptors and facilitates virus entry into host cells. Protein E plays an essential role in viral assembly, permeability of host cell membranes, and interactions between virus and host cells (6).

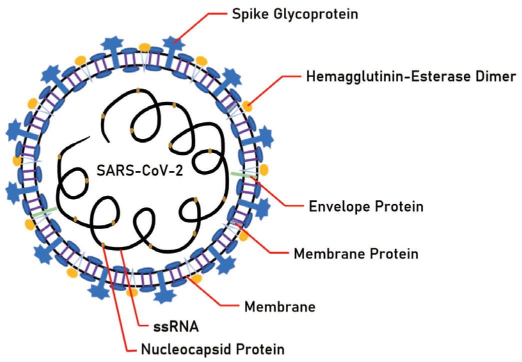

Figure 1: SARS-CoV Structure (6)

The genetic material of the coronavirus is positive single-stranded RNA (+ssRNA) approximately 26–32 kb in size. The initial 2/3 of the coronavirus genome occupies replicase genes called open reading frames 1a and ab (ORF1ab), which encode non-structural proteins, whereas 1/3 of the coronavirus genome includes genes encoding structural gene proteins (7). Currently, the genetic material of COVID-19 has undergone mutations. Mutations often occur in the spike protein, whereas the genes encoding the E, M, ORF6, ORF 7a, ORF7b, and ORF 10 proteins are stable (8).

UV LIGHT

UV light is an electromagnetic wave with a wavelength of 100–400 nm. The wavelength of UV light is between visible light and X-rays. UV rays are divided into four types: vacuum UV, UV-C, UV-B, and UV-A (9). These four types of UV have different wavelengths. UV-A, UV-B, and UV-C rays are emitted by sunlight, but the ozone layer prevents 99% of the radiation from reaching the earth's surface. Each type of UV light has a different effect. UV-A ray cause sun tanning; UV-B causes sunburn, which can trigger skin cancer; and UV-C is absorbed by RNA, DNA, and proteins that trigger cell damage, mutations, cancer, and cell death (9).

Natural UV rays that can be absorbed by cells and genetic material can be used for sterilization. UV light has been widely used to sterilize water and air in a room. Sterilization using UV light is effective if the correct dose is applied. Several factors, including UV lamp power, exposure duration, and distance between the lamp and the object, determine the dose of UV exposure. UV dose (J/m^2) is used to achieve viral inactivation of 90% of a virus population in a particular environment "D(90)" (10).

The UV dose can be determined using the following simple equation:

$$\text{UV Dose} = \frac{\text{UV Energy}}{\text{Area}} = \frac{\text{UV Power} \times t}{4\pi d^2},$$

where UV power (watts) is the power generated by UV radiation, t (s) is the length of exposure time, and d (m) is the distance between the lamp and the object to be sterilized. This equation is used with the assumption that the room is spherical. This equation is applied to optimal conditions that ignore air flow and room temperature.

UV–VIRUS INTERACTION

Several studies have shown the effectiveness of UV light for the inactivation of various pathogens, including bacteria, fungi, and viruses (11). UV-C can inactivate DNA viruses, including those with single-stranded and double-stranded DNA (11). Darnell et al. (12) showed that exposure to UV-C light with a wavelength of 254 nm is more efficient in inactivating the SARS-CoV virus than exposure to UV-A. This study was carried out by exposing UV light to 2 mL aliquots of virus placed on 24-well plates at a distance of 3 cm from the UV light source with a dose of 4016 W/cm^2 (where W = 10^6 J/s). This result is in line with the study by Bedell et al. (13), who used UV-C exposure to the MERS-CoV virus placed on a coverslip at a distance of 1.22 m. The results of this study indicate that UV-C only takes 5 min to reduce MERS-CoV by 5.91 $\log_{10}$.

UV radiation can cause several types of RNA damage, including photochemical modification, cross-linking, and oxidative damage. Photoproducts form according to the general principle of photo-reactivity of RNA. ssRNA is more prone to form photoproducts than dsRNA (14). In RNA viruses, inactivation occurs due to changes in the cross-linking between the uracil nucleotides and the formation of uracil dimers (15). The uracil dimers formation causes extensive RNA contact with proteins in the nucleocapsid (16).

Enveloped viruses exhibit photoprotection mechanisms in the form of scattering and absorption (Fig. 2). The absorption spectrum shows the absorption of a molecule at a particular electromagnetic frequency range. The absorption of UV light by molecules produces electron

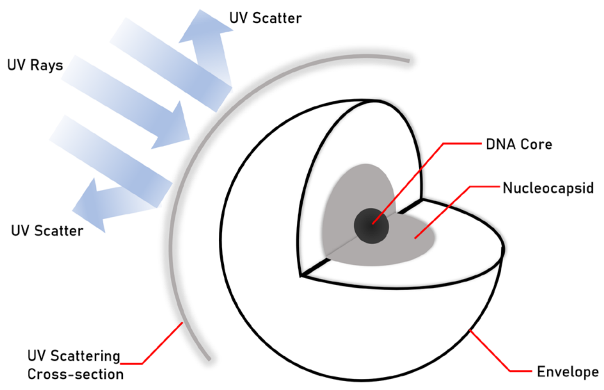

Figure 2: Photoprotection of an Enveloped Virus (17)

configurations, which are transformed into radiant, rotational, and vibrational energy. When this energy level is in the ground state, the energy obtained from UV absorption produces an excitation. Therefore, the molecule's capacity to absorb UV energy above the wavelength band is called the absorption spectrum (17).

COMMON UV ROBOT STERILIZERS

Many UV disinfection robots are being developed. Various techniques are used to reduce contact with humans as operators. Some of these techniques employ a line follower robot to direct the UV robot, an android so that a remote operator in real time can control it, and a room mapping program to be sterilized immediately at the beginning of using the robot (18), (19). These robots can only be used in an empty room without any humans. When in contact with humans, the danger of UV rays is the reason for developing a UV disinfection robot that can detect human presence (20). The UV robot that can detect the presence of humans can turn off automatically. This method can reduce the performance of the UV lamp because the lamp may turn off. After all, humans are passing by even though the exposure time has not met the predetermined standard.

How to make UV sterilizers work in the presence of humans in the room is challenging. However, this method can be performed through two approaches: designing a closed UV robot that is sucked in from the room and combined with a high efficiency particulate air (HEPA) filter. This robot will suck the air in the room to be sterilized in a closed UV chamber, passed through the HEPA filter, and then released back into the room. The second approach is to adjust the layout of UV lamps and ventilation patterns to control the transmission of airborne diseases (21). For example, Hasan (22) showed that UV lamps as radiation in mechanical ventilation systems can minimize virus survivability.

Several factors, such as air temperature, airflow rate, lamp design, and ballast design, must be considered because they can affect the performance of UV light as a sterilizer. The performance of UV rays can be optimal when considering various environmental conditions and heat transfer rates, especially air temperature and airflow rate temperature (23). Various materials from an item in the room can also affect the performance of UV radiation because of the optical properties of the material. Examples of materials that can affect the performance of UV radiation are stainless steel, aluminum foil, e-PTFE, and porous PTFE. These materials can have a boosting UV power of 0.38–10 to increase the performance of UV rays (24), (25).

Despite using air decontamination kits, fighting airborne pathogens remains a challenge due to the absence of aerobiology test facilities that comply with a robust and scientifically valid experimental protocol (26). In addition, the absence of a feedback system on the UV robot that can state that the room is sterile makes this tool work in an open loop. A disadvantage of the open-loop control system is that the system's output does not affect the control system. Therefore, an external disturbance can cause the system output to be disturbed not to match the target.

One feedback system that can be used in this robotics is the electronic nose (eNose). Some research showed that eNose could detect several pathogens, including viruses (27), (28). eNose analyzes volatile organic compounds produced by the pathogen (28). Several technologies that use eNose for COVID-19 screening are Aeonose (Maastricht University, The Netherlands) and Genose (Universitas Gadjah Mada, Indonesia) (28), (29).

The proposed model for robotic UV is displayed in Fig. 3. The robotic UV is adapted from laminar airflow system, which uses some filters, including pre-filter and HEPA filter. It also has two turbines for airflow inlet and outlet. The important part of this robotic UV has a feedback system by using eNose. eNose is added in between the UV chamber and outlet turbines. This system is added to ensure that the air is sterilized properly before it is

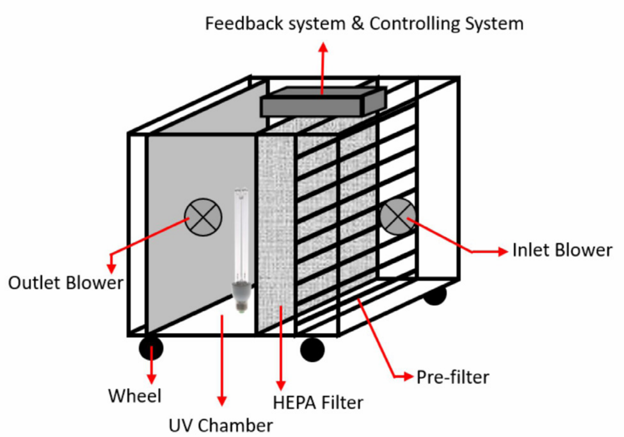

Figure 3: Proposed Model of a UV Robot

distributed into the room.

CONCLUSION

Various UV sterilizer robots have been developed to inactivate the virus to minimize airborne disease transmission. However, the dose issued is only based on theoretical calculations under optimal conditions without considering environmental factors, which could lead to sterilization failure. The effectiveness of a UV sterilizer robot can be increased by adding a feedback system that is unaffected by external disturbances.

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