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Ultraviolet-C lamp control system designed to estimate deactivation of the coronavirus disease

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ABSTRACT

To prevent the transmission of the coronavirus disease (COVID-19), one approach involves the application of disinfectants containing specific chemical compounds. Nonetheless, an overabundance of chemicals may yield adverse effects on both humans and the environment. Therefore, alternative methods are needed to prevent the spread of the virus without endangering humans and the environment. One method that minimizes the use of chemicals is ultraviolet-C (UV-C) light. The method used in this study is to make a UV-C lamp control system based on the internet of things (IoT). Then conduct experiments on the spread of UV-C radiation using a system that has already been built. Based on the research that has been done, a disinfectant system has been successfully designed using two Philips 30 W UV-C lamps with Wemos D1 mini microcontroller and Blynk application. The results of data collection show that the highest ultraviolet-C radiation irradiation on the intended object is 0.017 mW/cm^2 with a distance between the two is 1.5 m.

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1. INTRODUCTION

After the World Health Organization (WHO) declared coronavirus disease (COVID-19) as a pandemic, governments and individuals worldwide have been collaborating to prevent the spread of the virus and lower the mortality rate it causes [1]. COVID-19 is one type of virus that spreads very quickly. The virus has the potential to infect someone if the person has direct contact with those who have been infected, such as objects/objects around. COVID-19 can survive for a long time on the surface of these objects [2]. While one approach to hinder its transmission involves using specific chemical compounds for disinfectant spraying, it is not advisable [3]. Spraying is carried out on areas that are often touched by people. However, excessive use of chemicals regardless of dosage can also have adverse effects on the health effect for humans and the environment [4], [5]. Spraying is also ineffective in removing contaminants outside the direct spray zone [6]. An eco-friendly alternative disinfection technique, which does not rely on chemicals, involves the use of ultraviolet (UV) decontamination [7], specifically ultraviolet-C (UV-C) light [8], [9]. The International Ultraviolet Association (IUVA) also releases the fact that UV is capable of inactive coronavirus [10].

In an effort to handle this issue, research on the design of a UV-C lamp control system has become increasingly relevant and important. The objective of this research is to develop a remote-controlled UV-C lamp system based on internet of things (IoT). This system will be utilized to analyze and calculate the estimation of COVID-19 virus deactivation rates. Then, the purpose of this research is to design a disinfectant system using IoT-based UV-C lamps and analyze UV light irradiation from the system to inactivate

COVID-19. In this research, we used the mathematical method for estimating of spreading dose of UV-C lamps. Before we calculate, a UV-C lamp control system based on the IoT should be built. A disinfectant system is designed using several electronic devices such as two UV-C lamps, Wemos D1 mini microcontroller, relay, electronic ballast, inverter, lead-acid battery, and Blynk software will be used. The implementation of UV-C lamp technology aims to combat the COVID-19 virus. Various aspects will be explored, including the design of the control system using electronic devices, data collection, and performing calculations to estimate the deactivation of the COVID-19 virus using the developed system.

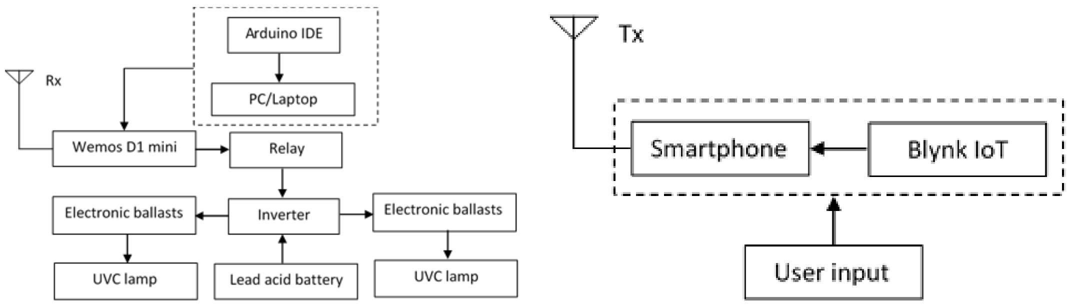
Welch *et al.* [11] conducted experiments involving UV-C light to inhibit the airborne transmission of influenza A/H1N1 viruses. They utilized UV-C light at a wavelength of 222 nm, applying a targeted dose of 2 mJ/cm^2. The outcomes revealed that virus development was significantly hindered, with effectiveness exceeding 95%, leading to a gradual reduction in virus numbers over time [11]. The study is one of several studies that support the development of UV-C light technology in previous years [12]. At present, technology is extensively utilized to address the containment and transmission of COVID-19, particularly for the sterilization of hospital rooms [13], [14], and medical equipment such as masks [15], [16]. The mentioned research employs a technique involving the measurement and installation of UV-C technology to achieve the necessary dosage. Simulations were conducted to assess the distribution of UV-C light within a room or space and identify areas not exposed to UV-C lamps. Then, Ropathy *et al.* [17] used simulation techniques to assess UVC light intensity in various room layouts to aid in the evaluation of the effectiveness of a surface disinfection system comprising UVC lamps. The benefit is that it can assist in designing UVC room disinfection systems, especially in hospital settings [17]. An additional simulation involving the dispersion of UV-C light was conducted, using an aircraft cabin as a case study. This study examined three methods of dose distribution, one of which involved a fixed-lamp system [18].

On the electronic side, a control system for light has been conducted by another researcher. They use NodeMCU ESP8266 as a microcontroller so the system worked based on the IoT [19]. Then, the Blynk application is proven to be used to control lights remotely in the internet connection [20] and the application also can be used for monitoring systems [21]. In another study, a room disinfection device based on UV-C radiation was presented using a program remotely using an Android mobile device. In the study, the cost of making the device was analyzed, but no time estimation was analyzed to disable the virus [22].

Based on previous research, it can be known that lamp control has been done before, but not yet for UVC lamps. In addition, calculation analysis for the estimated time until the COVID-19 virus turns off based on UV-C lamp irradiation emission. So, the state of the art in this study is to design a UV-C lamp control system. The data collected will help in analyzing the estimated time until the COVID-19 virus is inactive.

2. METHOD

UV-C lamp-based disinfectant systems work using IoT technology that can communicate between devices wirelessly. The system works when the Blynk button on the smartphone device is ON. The transmitter system (Tx) will send the signal to the receiver (Rx) in the form of a microcontroller device equipped with ESP8266 Wi-Fi. Microcontrols are connected to a relay that functions as an automatic switch. This switch is driven by the electromagnetic force of a coil. The inverter connected to the relay and 12 V battery will function as a 12 to 213 V DC voltage converter. After the voltage has been converted into AC, it will then be connected by a ballast equipped with a lamp fitting. The light will be ON if data transmission goes smoothly with this IoT technology. The block diagram of the system is shown in Figure 1, where Figure 1(a) is for the transmitting system and Figure 1(b) is for the receiving system.



(a) (b)

Figure 1. Disinfectant control system block diagram using IoT-based UV-C lamps (a) the transmitter system and (b) the receiver system

After the prototype is successfully designed as shown in Figure 2. The program is also successfully run. Data will be taken to determine the maximum level of irradiation that can be emitted by the two UV-C lamps. Figure 2(a) shows the prototype of the UV-C lamp control system when the lamps are off. This means that the button in the Blynk application is in a state that has not been pressed so the status is still OFF. Figure 2(b) is when the light is on which means that the button on the Blynk application has been pressed so that it changes its status to ON. The instrument that is used for data retrieval is the Lutron UVC-254 UV light meter. The data obtained were then substituted into a mathematical equation to determine the UV-C irradiation dose to kill 90% of coronaviruses.

(a) (b)

Figure 2. The prototype of UV-C lamp control system (a) if the lamps are off and (b) if the lamps are on

3. RESULTS AND DISCUSSION

In this section, it is explained the results of the research. Several topics will be discussed, such as the prototype and data analysis. In the prototype, we will describe the electronic devices used and also the schematic diagram. In the data analysis section, we will provide a visualization of the data collected. In addition, we will provide a mathematical calculation analysis related to the estimated time to inactivate the COVID-19 virus based on UV-C irradiation generated by lamps. The average D90 dose required to eliminate coronaviruses which is used in this study is based on the previous research.

3.1. Prototype

The schematic of the system circuit is shown in Figure 3. The system was built using microcontrollers of the Wemos D1 Mini type. This is an Arduino-compatible microcontroller development board. The board is based on the ESP8266EX chip, which offers integrated Wi-Fi connectivity. Relays which are electromechanical components are used to control electrical circuits by using smaller electrical signals. Relays allow microcontrollers to control devices and systems automatically. Then there is the inverter which refers to the electronic circuit used to change the logic of the signal. The function of the inverter in a microcontroller is to change the logical state of the signal between the high logic level and the low logic level. The lead acid battery is used as a backup power source or energy storage related to inverter and microcontroller systems. Electronic ballasts connected to lamps regulate the electric current that can turn on lamps with higher efficiency when compared to conventional ballasts. The electronic ballast will convert the mains voltage from the main power source into the voltage required by the lamp.

3.2. Data analysis

From the results of measurements taken, data is taken every second emitted by two UV-C lamps. The measuring distance between the UV-C meter and the table as the object to be sterilized is about 1.5 meters as shown in Figure 4. Figure 5 is a graph of the results of data collection every second read by a UV-C meter from the radiation of two 30 W UV-C lamps brand Philip. The graph shows the transition of rise when the UV-CC meter begins to sense radiation. The highest value is 0.017 mW/cm^2. The number 0.017 mW/cm^2 will be substituted as an irradiance in mathematical (1) and (2).

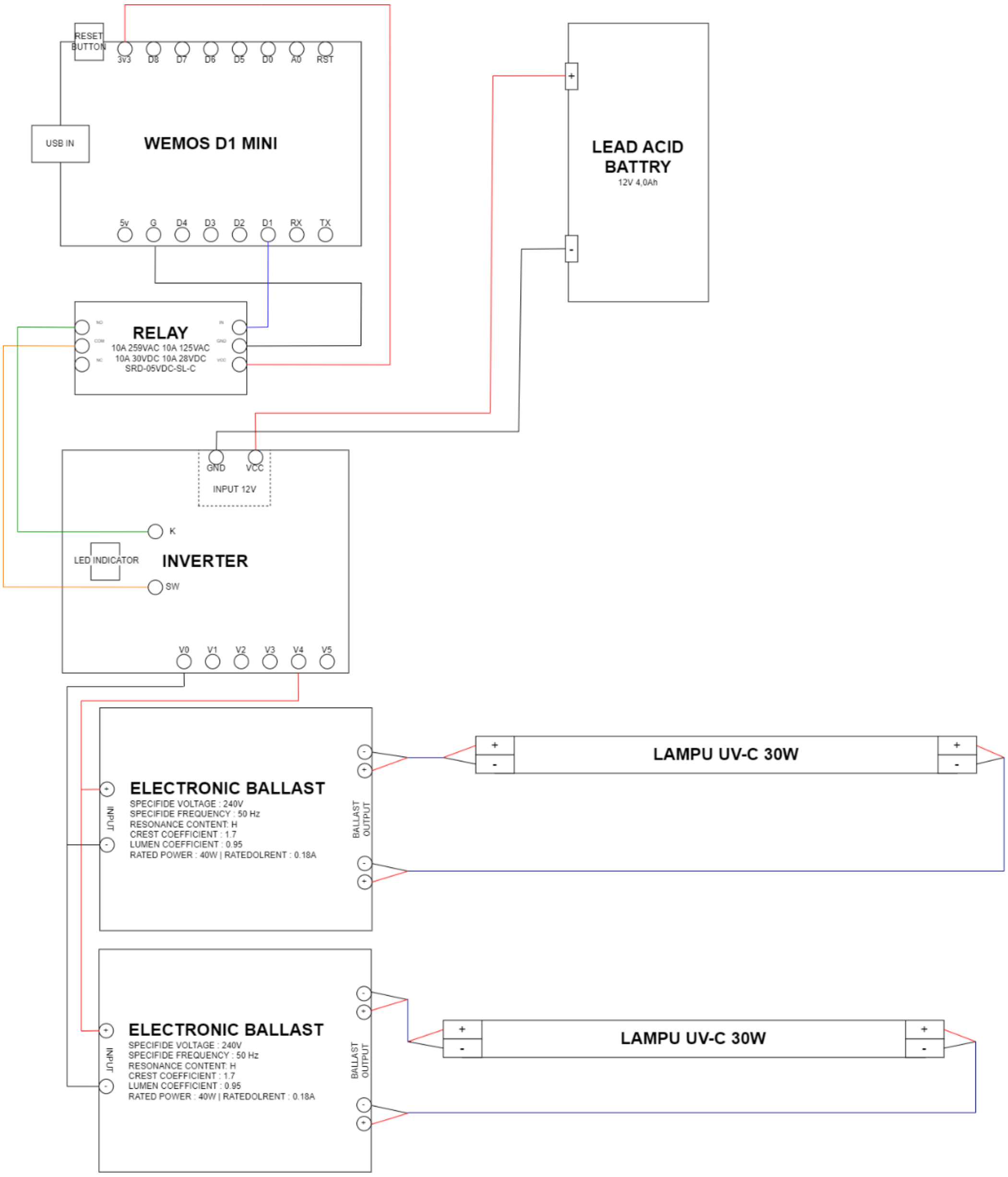


Figure 3. The schematic electronic circuit of a disinfectant control system using an IoT-based UV-C lamp

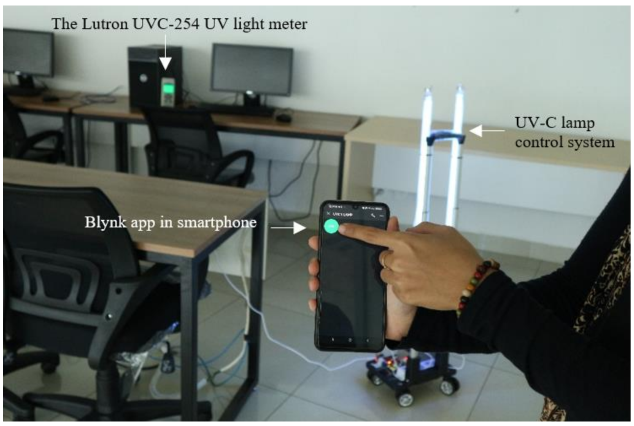


Figure 4. Set up data retrieval using the Blynk application and pre-built prototypes

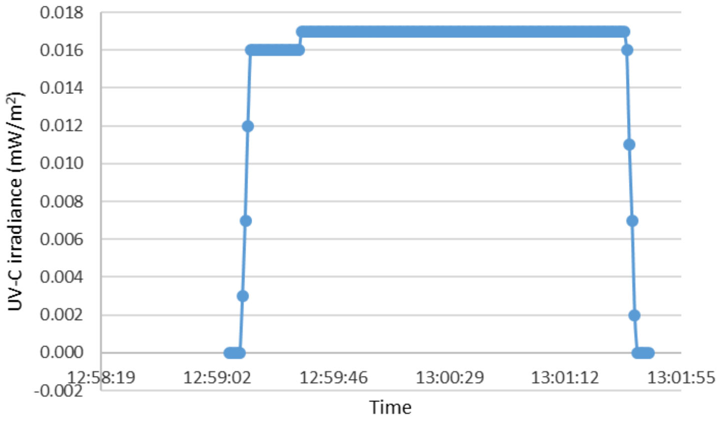


Figure 5. UV-C Radiation data from two UV-C 30 W lamps

For estimating the dose of UV-C for inactive coronavirus we use the data in Table 1. It is a summary of the results of previous studies on coronaviruses in ultraviolet light exposure, with specific species shown in each case [23]–[25]. Where the value of D90 is the ultraviolet dose for the inactivation of 90% of the microbial population [25], [26]. The range of the necessary UV-C light for inactivation is 7 to 241 J/m^2 [27]. Then, the average D90 dose required to eliminate coronaviruses is 67.08 J/m^2. The number 67.08 J/m^2 which is the average D90 dose required to eliminate coronaviruses is used for calculation analysis in mathematical (1) and (2).

Table 1. The previous UV light study on coronaviruses

Microbe	D90 dose required	Source
Murine Coronavirus (MHV)	15 J/m^2	Hirano 1978
Berne virus (Coronaviridae)	7.2 J/m^2	Weiss 1986
Canine Coronavirus (CCV)	28.5 J/m^2	Saknimit 1988
Murine Coronavirus (MHV)	28.5 J/m^2	Saknimit 1988
SARS Coronavirus CoV-P9	40 J/m^2	Duan 2003
Murine Coronavirus (MHV)	103 J/m^2	Liu 2003
SARS Coronavirus (Hanoi)	133.9 J/m^2	Kariwa 2004
SARS Coronavirus (Urbani)	241 J/m^2	Darnell 2004
Coronavirus	6.6 J/m^2	Walker 2007
Total	603.7 J/m^2	
Average	67.08 J/m^2	

If we have known the data of UV-C radiation from two UV-C 30 W lamps, we can obtain the exposure time of UV-C irradiance on a surface or object that can be calculated using (1) and (2) [28]–[30]. This mathematical equation is used to find the exposure time in units of seconds s. But to get it, it takes dose data in units of J/m^2 and UV-C lamp irradiance in units of W/cm^2.

$$dose\ \left(\frac{J}{m^2}\right) = irradiance\ \left(\frac{W}{m^2}\right) \times time\ (s) \tag{1}$$

$$time\ (s) = \frac{dose\ \left(\frac{J}{m^2}\right)}{irradiance\ \left(\frac{W}{m^2}\right)} \tag{2}$$

Based on the data retrieval the highest irradiance from the system that we built is 0.017 mW/cm^2. The average D90 dose required to eliminate coronaviruses is 67.08 J/m^2. Then, the exposure time of UV-C irradiance required for the inactivation of 90% of the coronavirus using a UV-C lamp system that has been built at a distance to the object of 1.5 meters is (3) and (4).

$$time = \frac{67.08\ \left(\frac{J}{m^2}\right)}{0.017\left(\frac{mW}{cm^2}\right)} \tag{3}$$

$$time = 394.59\ s \tag{4}$$

By substituting 0.017 mW/cm^2 and 67.08 J/m^2 to (2), finally, the value of 294.59 seconds is obtained. So, the time for the inactivation of 90% of coronaviruses takes 294.59 seconds with irradiation of 0.017 mW/cm^2 from two 30 W UV-C lamps brand Philip. The determination of the inactivation time for the coronavirus is based on mathematical calculations that utilize specific radiation and energy data. These values indicate that the radiation level produced by two 30 W Philip UV-C lamps at an intensity of 0.017 mW/cm^2 is needed to achieve a 90% inactivation rate. The use of UV-C lamps and mathematical calculations like these can be crucial tools in efforts to maintain cleanliness and safety in environments vulnerable to virus transmission.

4. CONCLUSION

This study concludes that it has been successfully designed to build a disinfectant control system using IoT-based UV-C lamps using Wemos D1 mini and the Blynk application. Using the system that has been designed, we succeeded in taking and analyzing data related to the inactivation of 90% of the coronaviruses with irradiation of 0.017 mW/cm^2 and the distance between objects and UV-C lamps estimated as far as 1.5 meters. The results showed that the UV-C lamp control system designed was able to operate effectively and efficiently. For a duration of 294.5 seconds, the system was able to provide precise irradiation for the estimated nonactivation of the coronavirus.

The application of UV-C lamp technology has great potential in combating the spread of the Coronavirus, especially in closed environments with a high risk of transmission. With the results obtained from this study, it is hoped that the UV-C lamp control system can be an effective solution in fighting the pandemic and reducing the risk of Coronavirus infection. While we acquired our aims of estimating the nonactivation of the coronavirus, we recognize that this study has some limitations. Some of them are limitations on the level of accuracy in measuring the distance between objects with UV-C lamps. Further research is expected to take data with several variations related to the distance between objects and lights.

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