An IoT based UV-C disinfection method against COVID-19: implementation experiences

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***Abstract*—Since the SARS-CoV-2 transmission can occur by contact with surfaces contaminated with respiratory secretions and other fluids like faeces or saliva, the superficial disinfection has been one of the main problems during the COVID-19 pandemic. Cross-contagion has been observed between health personnel and cleaning staff from hospitals attending COVID-19 patients. The aforementioned problem was solved through the implementation of a contact-less disinfection system that reduces the COVID-19 exposition of sanitation workers from healthcare facilities. This work presents the results observed from the implementation of an Ultraviolet-C (UV-C) disinfection method controlled and monitored using an Internet of Things (IoT) scheme. Also, implementation experiences obtained from the application of the proposed solution at the *Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán* (INCMNSZ) are discussed in this article. The main contribution of this work relies in the fulfillment of a disinfection proceeding that helps reducing the cross-contagion between the cleaning staff of hospitals attending the COVID-19 pandemic.**

***Index Terms*—COVID-19, SARS-CoV-2, Internet of Things, Ultraviolet-C disinfection**

I. Introduction

The emergent pathogen SARS-CoV-2 has provoked an acute health crisis due to the COVID-19 disease that this virus causes [1]. In fact, healthcare systems have collapsed in many countries because the disease is hard to diagnose if a Polymerase Chain Reaction (PCR) test is not done. But in order to reduce the number of infections, some protective measures have been taken. These include sneezing into a handkerchief, keeping a safe distance between people and frequent hand washing [2], [3]. The two most usual ways by which the virus is spread throughout the body are inhaling droplets or aerosols suspended in the air that were produced by the respiration and speech of asymptomatic individuals [3] and being in contact with surfaces that are contaminated by respiratory secretions or other bodily fluids like mucus, saliva, faeces, etc. One factor to take into account is that although the most common symptoms of COVID-19 are fever, dry cough and tiredness [4], [5], in most of the cases the subject starts gradually presenting mild symptoms [6]. Other factors are at-risk groups, such as elder people [7] or patients with chronic conditions like high blood pressure, cancer, diabetes or heart or lung conditions [8], because they are more predisposed to present severe symptoms which include pneumonia, organ failure, heart problems, blood clots, among others which may complicate the patient's situation [9], [10] or lead to death [11]. One of the challenges that the countries are facing is that they think that with the measures taken (social distancing [12], isolation [13], travel restrictions [14], obligatory quarantine [15], etc.), the COVID-19 has been controlled. However, with the outbreak of new cases [16] it has been shown that there are ~ 20 viral variants of the virus [17]. And even with the creation of numerous SARS-CoV-2 vaccines, the rate of the population vaccinated is low. An even more, the balance that occurs between the vaccine doses to be produced versus the people to be vaccinated is negative. Additionally, the World Health Organization (WHO) has reported that in spite of the safety protocols implemented, around 10% of the worldwide infection rate correspond to medical staff [18]. And along with the increasing demand for hospital's beds due to COVID-19; these situations have produced the closure of healthcare facilities [19] and laboratories [20] in all regions of the world. Therefore an alternative solution, alongside with vaccines, must be implemented to contain the contagion. And given that most cases occur because the person is in contact with surfaces that are infected [21] or with droplets that contain infected mucous secretions [22], then the solution must be directly related to disinfect environmental surfaces. An effective method to do so is UV-C radiation, which consists on a high energy type of UV with a short wavelength that allows to disinfect water, air and non-porous surfaces [23]. Moreover, UV-C can kill divers types of bacteria, destroying the outer protein membrane of several viruses and changing their genetic material to induce their inactivation. The wavelength of this type of radiation is in the interval between 200 and 280 nanometers (nm) [24], but the highest efficiency against COVID-19 occurs when the value is 254 nm [25]. In addition, the vast majority of germicidal lamps also work at this value of wavelength because of its efficiency [26]. But this does not necessarily imply that longer or shorter wavelengths cannot be used to disinfect surfaces [27].

A. Structure of the paper

This paper presents an Internet of Things based solution for the surface disinfection inside hospitalization rooms of healthcare facilities attending COVID-19 patients. Disinfection is carried by using UV-C lights allocated in the ceiling of highly transit areas without the necessity of costly or complex installations. The proposed disinfection strategy was carried out at the INCMNSZ in Mexico City, where its implementation protocols were also met. This article is organized as follows: section II explains the problem of disinfecting several hospital areas during turn shifts. Section III describes materials and methods used to solve the disinfection problem. Section IV explains how the system was implemented, focusing in the challenges, and experiences obtained at the INCMNSZ. Section V presents the results, while in section VI the conclusions reached from this project are presented.

II. Problem Statement

One of the most common transmission routes for COVID-19 is throughout the contact with contaminated surfaces and later contact with body parts such as the eyes, nose and mouth. Among the most vulnerable health personnel are the caretakers and cleaning personnel who are in charge of cleaning and disinfecting areas and surfaces that have been in contact with patients. The reason is that these infected areas represent a great risk of contagion and transmission for the staff and others. That is why it is proposed a method of disinfection without contact with surfaces and areas, by means of UV-C and IoT lamps that are remotely controlled. The UV-C works at a certain wavelength which is capable of inactivating COVID-19 virus, according to several studies.

III. Materials and Methods

This section describes the materials and methods established for the implementation of the proposed disinfection system. In order to define the adequate materials the following requirements were stated:

- The proposed materials must be available in the Mexican market.
- The system has to implement low-cost and easy replaceable components.
- The device needs to have different connectivity options, such as, Wi-Fi or Ethernet.
- The system should be able to remain connected to the cloud for remote monitoring, as well as to have enough computing power to analyse and to save usage information.
- If needed, the system has to be able to connect with external peripherals.
- The system must be user friendly.
- The UV-C range must be effective against COVID-19.

A. Raspberry Pi

Using a Raspberry Pi (RPi) 3 model B+ as the core element of the proposed IoT system, brought several benefits to the project. First of all, the capability to work under an open-source Operating System (OS) like the *Raspbian* GNU/Linux OS. Secondly, the remote accessibility to the system records through the Secure Shell (SSh) protocol, which allows the user to keep the system updated, but also to look after the system status, ensuring the correct functionality of every element connected to the network.

The selected RPi board model features a 1.4 GHz 64-bit quad-core ARMv8 CPU and a RAM memory of 1 GB, which is sufficient to process the information from several disinfection nodes. Also, its CPU is coupled with a Wireless LAN and Bluetooth 4.1, which can host multiple sensors connected simultaneously. In addition, it has a 40 General Purpose Input/Output pins that allows the interfacing with external sensors. The RPi will serve as a local server, which will maintain a record on the state of each element contained in the disinfection network. Also, it will help sensing whenever a patient room is occupied or not throughout the activation of a passive infrared sensors (PIR). The implementation of this sensors will also serve as one of the main security stages of the system, since the disinfection through the radiation of UV-C requires that the rooms are isolated during the process. Figure 1 shows the RPi node functionality by taking advantage of the Google Spreadsheets API to communicate the state of each element in the network to each other.

B. Switch

The implementation of smart switch is necessary to trigger the variation on the states sensed by the RPi. This element facilitates the implementation of the system, since it counts with a pre-built operation band-width of 2.4 GHz that requires a power source of 90-250 V AC. When connected to the RPi, it allows the creation of a local server, becoming a node, as it will also contain the movement sensor (PIR) and the UV-C light bulbs attached to it. Thus, each bulb in the hospitalization area must have one of this switches, so it can be remotely operated to avoid exposing the medical personnel or the cleaning staff.

C. UV-C light bulbs

As aforementioned, UV-C light working in the range of 253.7 nm [25] is effective to sanitize surfaces in contact with the SARS-CoV-2 virus [28], among others pathogens. Derived from the effectiveness of this method, the commercialization of light bulbs emitting different ranges of UV-C light became accessible in the Mexican market. As a main requirement, the usage of E39 to E27 adapters were required, this to comply

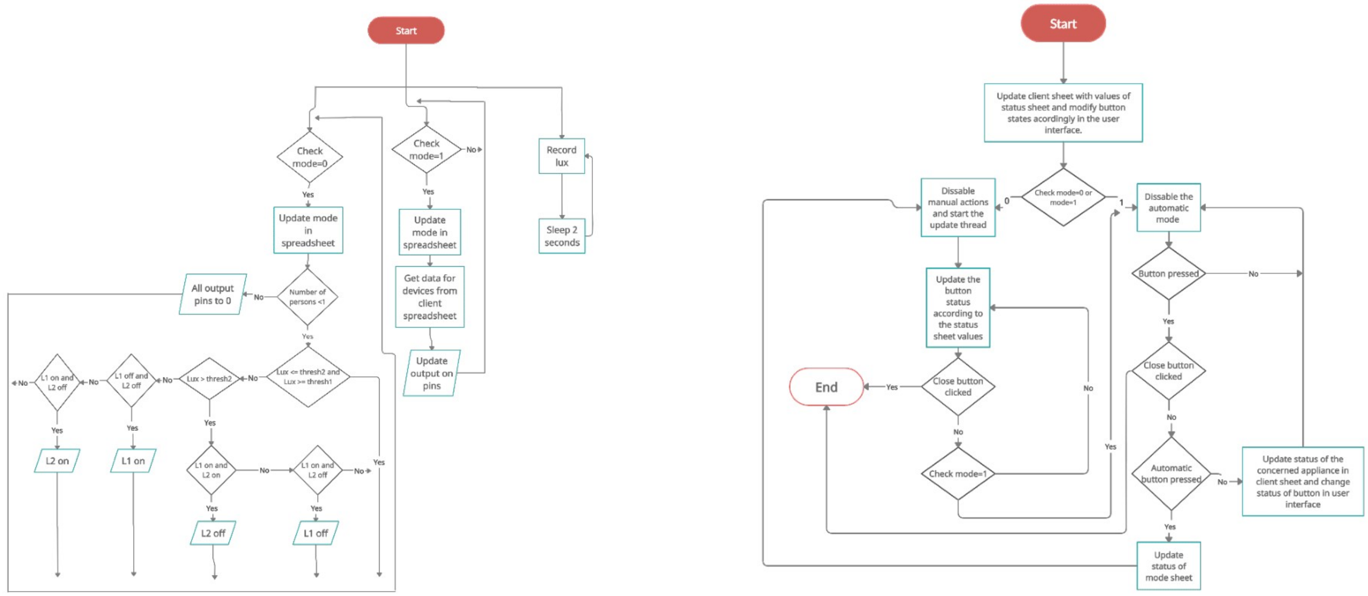

Fig. 1. Systems core node contains 2 modes, at the spreadsheet, which will sense the operative mode of the system. Mode 0 or automatic mode, sends a message to the RPi to control rooms when data is provided from the sensors. Mode 1 refers to manual mode which lets the user control rooms according to customized needs. The user will then verify if the system is in manual mode and if this is true, the user can control particular elements in order to turn them on/off. This information is then sent into a "Client" sheet on the cloud, enabling the RPi to accurately fetch this "Client" sheet and read, from there, what it has to do and control the system accordingly. Also when in automatic mode, the user should know which devices are on or off. Hence, RPi will update values/status in the "Status" sheet and the user will gain access to that sheet through the application. The RPi will then get the data from the sensors and according to that data and without any human interaction, the algorithm will find out which devices should be in which state.

with the standards established by the Mexican Health Council. Also, as a requirement, the power of the bulbs needed to obtain an efficient luminescence of 80 W. It is worth mentioning that the bulb posses a quartz tube as protection, which is filled with vaporized mercury gas. And along with the PIR sensors that are attached in the upper zone of the light bulbs to ensure its maximum operational range, which is 6 m with a 360 degree range of coverage, the system can detect variations on an infrared scale and the sterilization process is aborted.

D. Mobile interface

A tablet running Android OS will function as a user interface allowing the user to monitor the nodes as their status get updated through the spreadsheets, enabling the operator to remotely modify the UV-C light states from the hospitalization areas. This tablet will be located in the nurse station or command center and it will be connected permanently to the local network, as a result of the RPi connection with the smart switch connection.

IV. Disinfection system

Since one of the most vulnerable sector is the health worker, the proposed system was implemented at the INCMNSZ. It is intended to be allocated at the nurse station, where the team in charge can turn on and off the UV-C light in each of the patient's rooms even during night-shifts, with the purpose of cleaning COVID-19 out. For instance, if a patient leaves the room, the person responsible of cleaning the patient's room can turn on the disinfecting lights for a predetermine time. The system seeks to minimize the contact of the health worker with the areas previously used by confirmed or potentially positive COVID-19 patients. Additionally, it consists on a series of independent smart switches hosted by a RPi. Also, the complete system is allocated in a private wireless local network that allows the whole system to interact and to establish a set of previously defined setups based on the actual states of each component in the system. On other related matters, the UV-C light bulbs are controlled by the smart switches and supervised by a set of three PIR sensors connected to the light bulbs. Finally, the tablet is used as an interface that lets the user monitor the modifications or it provides him privileges to access manually to the state of each light bulb. Figure 2 presents the general operation scheme of the proposed system.

A. Implementation Challenges

The INCMNSZ has been one of the hospital that dedicated most of their rooms to treat COVID-19 cases in Mexico, and it remains almost at its full capacity. Nonetheless, due to the gradual reopening of services for non-COVID-19 patients, such as medical consultations given at the Outpatient Unit, radiology therapies, amongst others, the influx of people inside the institute has increased and this has also occurred in common areas or other areas like the waiting rooms. Within the groups of people that attend the institute for other services not related with the treatment for COVID-19, there has been some cases in which the patients were asymptomatic. The above represents a potential risk to the health personnel and

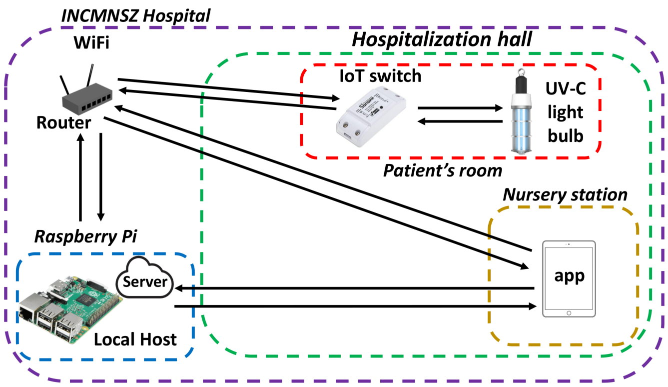

Fig. 2. Operation scheme of the proposed system.

the rest of the patients of the hospital. Therefore, it arose the need at INCMNSZ to quickly and efficiently disinfect different surfaces and areas that are in contact with patients, either in COVID areas or areas where other services are provided. One of the challenges for this type of IoT disinfection system with UV-C light, is the necessity to reconstruct structures and facades of the desired areas, because it is necessary to install elements such as IoT switches and E39 sockets. Due to the high influx of patients, the constant occupation of the areas that nurse the patients with COVID-19 and the high levels of ozone (as a result of the disinfection process) in the disinfected spaces, it was seen that the rooms with the installation of the IoT disinfection system needed a good ventilation plan. At the same time, it was shown that the air-stream would not contribute to the aerosol volatilization of the the virus of COVID-19. In addition, appart from the IoT sensors that the lamps already have, more security measures must be considered to avoid sensor failure and because the UV-C can be unhealthy. With the above, the safety of the patients and the medical staff is assured. Other challenge was that the shadows produced by the lighting may provoke that the system does not cover these areas. Therefore, to solve this issue the bulbs must be placed in a way that the production of shadows is minimal and with this it can be guaranteed the disinfection of the area.

Moreover, other factor that needs to be assured is that the UV-C light is capable of eliminating diverse viruses and bacteria, because there is a constant influx of patients that may present COVID-19 or other contagious diseases. Table I shows the doses of UV-C needed to reach the Log inactivation of different bacteria, spores and viruses.

These considerations were taken into account when the system was installed. The two pilot areas of the INCMNSZ in which the UV-C desinfection method was implemented were the Biomedical Engineering and Nuclear Medicine Departments. The reason why the fist one was a candidate, was because it does preventive and corrective maintenance of medical devices and these instruments may contain pathogens. On the other side, the Nuclear Medicine area was chosen since in this place patients receive treatment with radiopharmaceuticals. And in most of the cases, these patients carry other affections and need other treatments, that is why in the INCMNSZ these therapies were not suspended. In this area another two challenges that were presented were the architectural design and the fact that this area is restricted to COVID-19 patients on the grounds that when it happens, the cleaning staff needs about a day to completely disinfect the Nuclear Medicine Department. This not only produces delays on programmed treatments, consultations and other services, but also it is a risk factor for the healthcare personnel.

Furthermore, since the system requires a permanent network connection to function correctly, this could represent a problem to reach the network in the radiological units. The reason for that is due to the radiological protection that the units need for their safely operation. During several tryouts of the system in a leaded room, the signal of the transmitter reached the receptor all the way through; ensuring the correct operation of the IoT system.

TABLE I
UV-C DOSE TO ACCOMPLISH A LOGARITHMIC REDUCTION WITHOUT PHOTO-REACTIVATION ON SPORES, BACTERIA AND VIRUS.

	UV-C dose for Log reduction (mJ/cm^2)				
	1*	**2***	**3***	**4***	**5***
Spores					
Aspergillius niger	132	-	-	-	-
Bacillus subtilis	20	39	60	81	-
Bacteria					
Escherichia coli	4.4	6.2	7.3	8.1	9.2
Pseudomonas stutzeri	100	150	195	230	-
Staphylococcus aureus	3.9	5.4	6.5	10.4	-
Compylobacter jejuni	1.6	3.4	4	4.6	5.9
Salmonella spp.	<2	2	3.5	7	14
Mycobacterium tuberculosis	10	12.2	-	-	-
Streptococcus faecalis	6.6	8.8	9.9	11.2	-
Shigella sonne	3.2	4.9	6.5	8.2	-
Legionella pneumophila	1.9	3.8	5.8	7.7	9.6
Klebsiella pneumoniae	12	15	17.5	20	-
Virus					
SARS-CoV-2	3-3.75	3-3.75	3-3.75	3-3.75	3-3.75
Influenza	6.6	6.8	-	-	-
Poliovirus Type 1	5.7	11	17.6	23.3	32
Coxsackievirus B3	8	16	24.5	32.5	-
Coxsackievirus B5	9.5	18	27	36	-
Rotavirus	20	80	140	200	-
Hepatitis A	5.5	9.8	15	21	-
Echovirus I	8	16.5	25	33	-
Reovirus-3	11.2	22.4	-	-	-

* The values of the UV dose required to accomplish a logarithmic reduction without photo-reactivation, were retrieved from [29].

V. Results

The proposed system was implemented and tested at the Biomedical Engineering Department (Figure 3), as well as the Nuclear Medicine Department at the INCMNSZ. One of the main findings of this paper is the validation that when the system has a well established Wi-Fi network, the high lead concentration shield walls do not affect the data transmission between the Wi-Fi network, server and interface.

Another highlight of this paper is the implementation of a system based on an IoT model which is highly proficient in an implementation state. Specially it is efficient as a disinfection system, since not only do the processes becomes efficient, but they also allow to reduce human error and to increase the security levels during the implementation.

Last but not least, the disinfection time for the Biomedical Engineering Department, where the devices that are in contact with COVID areas are stored, was 30 minutes. The surface area of this place was 60 m^2. On the other hand, for the case of the Nuclear Medicine Department, the system was tested in the rest rooms (3 rooms) that have dimensions of 4 m^2 and it took a disinfection time of only 3 minutes.

Fig. 3. Disinfection system being implemented at the INCMNSZ Biomedical Engineering Department.

VI. Conclusions

The disinfection system using IoT and UV-C light proved to be functional for the Biomedical Engineering and Nuclear Medicine Departments. Also, the Wi-Fi connection proved to be effective during tests carried out in both departments, specifically in the Nuclear Medicine Department whose walls and doors are lead-shielded and have a considerable thickness. Finally, the time needed to disinfect an area had a direct relation with the value of the surface area.

A. Future Work

The future work of this system is to take it to the different attention areas that the INCMNSZ has. Nonetheless, this requires a change in the network connections of each of the specialty areas, as well as a change in the structure for the placement of disinfection lamps.

Likewise, interconnection tests between each of the switches need to be carried out, depending on the amount of lamps required by area or department, since this is the one that will determine the workload received by each of the routers that they propose.

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