Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Research article

Disinfection chain: A novel method for cheap reusable and chemical free disinfection of public places from SARS-CoV-2

Sushanta Debnath a, *, Mohiul Islam b

a Department of Electrical Engineering, Gomati District Polytechnic, Udaipur, Tripura, 799013, India
b Department of ECE, CMR College of Engineering & Technology, Hyderabad, Telangana, 501401, India

A R T I C L E   I N F O

Article history:
Received 30 July 2020
Received in revised form 21 February 2021
Accepted 26 March 2021
Available online 29 March 2021

Keywords:
Virus
Pandemic
Ultraviolet (UV) ray
Disinfection chain
Social distance

A B S T R A C T

Recently, Governments of several countries are taking steps to unlock their countries from the lockdown state to avoid the adverse effect on economy. Disinfection chains of Ultraviolet (UV)-Clamps supported by holding stands have been placed between the space of object columns for exposure-based disinfection. These chains can be folded easily for carrying purpose. Also, the length of the system can be varied depending upon the requirement. This simple system may be used for cheap, reusable and chemical free disinfection of public places. This system is also suitable to destroy the airborne viruses. But the process of disinfection must be performed in absence of human to avoid the harmful effect of UV rays on skin.

© 2021 ISA. Published by Elsevier Ltd. All rights reserved.

1. Introduction

In the first two decades of 21st century, deleterious viruses have infected the human being several times. The Influenza type A virus, Middle East Respiratory Syndrome (MERS), Severe Acute Respiratory Syndrome (SARS) are few notable cases of such viral infections [1]. In the recent days, COVID-19 pandemic has come into sight in the month of December 2019. Although the death rate of patients due to this SARS-CoV-2 virus is comparatively lesser, yet the transmission ability is found to be very high. Till October end, more than 35 million people got infected across the globe in the rapidly growing COVID-19 pandemic among which 1 million people have lost their lives as per the statistics [2]. Now a days, almost 50,000 or more people get infected per day in a largely populated country like USA, India and Brazil. Though the total figure is small in less populated countries like Qatar, Bahrain, French Guiana, yet more than 30,000 people got infected per million of population. Again, in many countries like Belgium, Peru, Spain, UK, San Marino, more than 600 people per million of population has already died due to this disease. It has become very challenging to control the spread of SARS-CoV-2 especially in the countries having very large populations. Researchers are working hard to find a solution to slow down the transmission rate of infection in the pandemic situation [3–5].

After passing through a lockdown over a period of few months, various Governments are planning to move slowly towards the usual life to keep the proper balance between economy and COVID-19 pandemic. Many Governments have issued some Standard Operating Procedure (SOP) in post lockdown scenario. The virus can be spread from person to person or from the places where COVID-19 affected patient has already visited. It is seen that the elderly people as well as the people already suffering from severe diseases are more prone to this deadly virus. During unlock process of the countries, various public places such as schools, college, offices as well as travelling medium like Air, Rail, by road are likely to be opened in phased manner. So, there is a high chance to transmit the virus through these public places and consequently it may results in a community spread in a particular region. In South Asian countries like India, Pakistan, Bangladesh, the society consists of mostly 3-generation family structure where grandparents, parents and children live together. To prevent the spread of this virus in such type of societies it is extremely necessary to disinfect the various public places like isolation rooms, offices, school, colleges as well as public transports like aeroplane, trains etc. frequently in post lockdown scenario.

The most common way to decontaminate the public places is to use the disinfection spray over the surfaces. However, there is some undesirable consequences of excessive use of disinfectants like generation of chemical residue which are harmful or toxic to human being. Apart from that, extreme cautions need to be taken at the time of preparations of the disinfectant spray. Under this circumstances, the matter of cheap and chemical free disinfection of public places against SARS-CoV-2 virus becomes very important to reduce the transmission of infection. In the existing research work, UV light has been utilized to disinfect the
clinical equipment [6] as it does not produce chemical residue. Due to this reason, the UV ray based method may be utilized to decontaminate the clinical rooms as well as various public places. In this work, a UV-C light based portable disinfection chain system has been proposed to destroy the virus present in the various public places including clinical rooms. Depending upon the requirement of public places, the number of portable disinfection chain may be adjusted or changed. UV-C light is also found to be effective to destroy the airborne viruses during passing through the air [7]. The main contributions of the work has been presented as follows:

- In this work, a simple alternative method based on UV-C light exposure has been developed for a chemical free and cheap disinfection of the public places including the public transport system. So, the method is suitable to decontaminate the clinical rooms too.
- A flexible system is designed for disinfecting the public places or transport systems of different sizes. Depending upon the necessity, the number of portable disinfection chains may be varied.
- This model can disinfect any place in a very short interval of time (3 min). Based on the necessity, this time duration can also be reduced further by increasing the intensity of the UV-C light. Apart from that, it minimizes the requirement of human effort to a large extent.
- It has the ability to destroy the airborne viruses unlike the conventional disinfection system. UV-C light destroys the airborne viruses during passing through the air.

Section 2 describes the related work regarding the recent developments made in order to combat COVID-19 spread. Section 3 depicts the methodology adopted to develop the chemical free disinfection system. The performance of the proposed model has been discussed in Section 4. The Section 4 also presents the comparative analysis and applications of the developed system. Section 5 concludes the work presented in this paper.

2. Related work

In the midst of novel coronavirus outbreak, several researchers have proposed different methods in order to reduce the spread of SARS-CoV-2 virus. The advancement in order to control the COVID-19 spread has been done both in social form [8–14] as well as through technical aspects [7,15–20]. To combat the COVID-19 outbreak, it is very much essential to use face masks and maintain social distancing in public places. However, for effective control, it is extremely necessary to disinfect the public places frequently apart from maintaining the social distancing and use of face shields or face masks. Recently, Cobb et al. [4] have examined the effect of social distancing upon the growth of COVID-19 cases in the USA. In this work, the prediction of COVID-19 compound growth has been made using a random forest machine learning model. It suggests that the shelter-in-place (SIP) order can help to reduce the spread of COVID-19. However, this stay-at-home policy may not be feasible to implement for longer period as it has opposing effect on Economy. Surbhi Khurana et al. [21] have developed an inexpensive hand rubs and face shield especially suitable for the developing countries to fight against the virus. Both in-house developed hand rubs and face shields are found to be effective as it can be developed at minimal cost. All these measures to prevent the spread of the pandemic may not become fruitful if public places are not decontaminated properly from time to time.

The most important measures to be taken is the infection control. To achieve that, frequent disinfection of public places is required in the current scenario. Along with the public places, it is also necessary to decontaminate all the personal protective kits (PPE). In this regard, Li Daniel et al. [15] have proposed a system to decontaminate N95 respirators and face mask rapidly using steam treatment. However, there is a necessary to understand the filtration efficiency of this system in case of short cycles of steam treatment. Now, the decontamination of air and surfaces may be done using chemical based disinfection spray or by using chemical free disinfection system.

Current research trends show some chemical free disinfection methods using Ultraviolet (UV-C) ray which have been developed for various purposes [16–19]. S. Deb Nath [16] has developed a UV-C ray based wooden box that can disinfect any food items kept inside it. However, any small size commodity like hand watch, wallet etc. can also be decontaminated using this method. Yue Ren et al. [17] has discussed the necessity of medical air disinfection using UV-C light to reduce the transmission of airborne SARS-CoV-2 virus. It has been observed that people living within UV ray circulated air area were free from the effect of this virus. Apart from food items, chemical based disinfection is not suitable in clinical applications. Armellino et al. [6] have proposed the usefulness of UV ray based disinfection method to disinfect clinical instruments. Furthermore, telemedicine can play a vital role to reduce the transmission of the virus through the healthcare workers [20]. This is because of the fact that doctors remain free from the contact of the virus infected patients.

3. Methodology

This section illustrates proposed methodology and the technical background of the work in details. Firstly, the background of the proposed technique has been explained. Later, the proposed approach has been discussed in this section.

3.1. Conceptualization

UV ray is found to be effective to disinfect the surfaces, objects and food items against various categories of virus and other microorganisms [6,22,23]. It has been seen that the UV light has the capability to disinfect the clinical equipment [6] without producing any chemical residue. Due to this reason, the UV ray based disinfection method can be applied to decontaminate the clinical rooms or any other public places. Three categories of UV rays (UV-A, UV-B, UV-C) are there [5]. Wavelength range of UV-A light is 315 nm to 400 nm. Wavelength of UV-B ray lies between the range 280 nm to 315 nm in the spectrum. While, the wavelength range of UV-C light is 100 nm to 280 nm. Fig. 1 shows the position of UV rays in electromagnetic spectrum.

It has been experimentally observed that the concentration of active microbes gets reduced with the exposure of UV-C rays in the surfaces. The concentration of survival of virus on any surface depends on the intensity of UV light as well as the exposure time. This relation can be formulated as [23],

\[ N_{uv} = N_0 e^{-Kt} \]  

(1)

where, \( N_{uv} \) is the concentration (PFU/mL) of virus survived on an surface after exposure to UV light for a time \( t \) (s).

\( N_0 \) is the virus concentration (PFU/mL) on a surface which is not exposed to UV light.

\( I \) is Intensity of UV light (\( \mu \)W/cm²).

\( K \) is a constant related to microorganism susceptibility (cm²/[µJ]).

Ratio between concentration of virus after exposure to the concentration of virus before exposure is called Survival fraction. It can be mathematically expressed by Eq. (2).

\[ \text{Survival fraction} = \frac{N_{uv}}{N_0} \]  

(2)
Table 1
Relationship between Survival fraction and time.

| Serial No. | Time (s) | Intensity = 1 mW/cm² | Intensity = 3 mW/cm² | Intensity = 5 mW/cm² |
|------------|----------|----------------------|----------------------|----------------------|
| 1          | 0        | 1                    | 1                    | 1                    |
| 2          | 1        | 0.686                | 0.323                | 0.152                |
| 3          | 2        | 0.470                | 0.104                | 0.023                |
| 4          | 3        | 0.322                | 0.034                | 0.003                |
| 5          | 4        | 0.221                | 0.011                | $5 \times 10^{-4}$   |
| 6          | 5        | 0.152                | 0.003                | $8 \times 10^{-5}$   |
| 7          | 6        | 0.104                | 0.001                | $1 \times 10^{-5}$   |
| 8          | 7        | 0.071                | $3 \times 10^{-4}$   | $2 \times 10^{-6}$   |
| 9          | 8        | 0.049                | $1 \times 10^{-4}$   | $3 \times 10^{-7}$   |
| 10         | 9        | 0.034                | $4 \times 10^{-5}$   | $4 \times 10^{-8}$   |

Table 2
Relationship between Survival fraction and intensity.

| Serial No. | Survival fraction | Intensity (mW/cm²) |
|------------|-------------------|-------------------|
|            |                   | Time = 1 s | Time = 5 s | Time = 10 s |
| 1          | 0.01              | 12.2       | 2.4       | 1.2       |
| 2          | 0.02              | 10.4       | 2.1       | 1.0       |
| 3          | 0.03              | 9.9        | 2.0       | 0.9       |
| 4          | 0.04              | 8.5        | 1.7       | 0.8       |
| 5          | 0.05              | 7.9        | 1.6       | 0.7       |

Fig. 1. Position of UV rays in electromagnetic spectrum.

Decontamination is dependent upon the value of microorganism susceptibility (cm²/mJ). For a microorganism with less susceptibility value, more time and higher intensity rays are required for disinfection. The decontamination can be done with a low intensity UV-C light by exposing it for a longer period. Apart from that, the same work can be performed in lesser time by introducing higher intensity UV-C rays in operation. UV-C light also destroys the airborne viruses during passing through the air [7].

3.2. Proposed methodology

Chains of UV-C lamp are prepared in order to disinfect the surfaces from this virus. These disinfection chains are fabricated in such a way that they can be folded easily for carrying purpose. Three number of disinfection chain prepared with UV-C lamps are placed in the upper, middle and lower portions through the holding stands as shown in Fig. 2. Series of such system are placed in the space present between the columns of objects. For instance, while disinfecting a class room, the proposed system may be kept in between the benches. While in case of shopping malls, it may be placed in between the object racks. Depending upon the requirement of public places, the number of portable disinfection chains may be changed or adjusted. In this prototype system, there are a total of 9 chains. Each chain having a length of 90 cm consists of 3 number of UV-C lamp. The length of each UV-C lamp is 30 cm. The distance between two holding stand is 100 cm or 1 m after considering the length of lamp holders. The structure is having a height of 180 cm while the distance between the each row of chains is kept 80 cm. The structure is designed to ensure the presence of UV-C light in all surfaces where the virus can reach. This measurements may be varied accordingly based upon the necessity and size of the disinfection room or chamber.

In order to place the system, it is essential to supply the power in absence of human being for maintaining the safety criteria. After connecting this network of systems with the power supply, close all the entry doors and put the MCB switch ON for 3 min. This system may be extended with the holding stands depending upon the size and requirement of the public place. Also, a small system may be used repeatedly with spatial variation to disinfect a large place, but it requires more time compared to the previous case.

4. Results and discussions

This section reports the performance of the proposed system. It compares the performance of this approach with the conventional disinfection method. The necessary precautionary measure to be taken while handling the disinfection system has also been discussed in this section. Moreover, this section describes about applications of the developed system.

4.1. Performance analysis

Effectiveness of the system has been analysed for various intensity of light at multiple instants of time. Relationship between Survival fraction and time has been presented in Table 1. Table 2
Table 3
Strategy for disinfection of various public places from SARS-CoV-2.

| Serial No. | Area of disinfection                  | Strategy                                      | Is absence of Human ensured |
|------------|--------------------------------------|-----------------------------------------------|----------------------------|
| 1          | Shopping mall                        | Disinfection using disinfection chains during lunch period and after closing | Yes                        |
| 2          | Classrooms or Office rooms           | Disinfection using disinfection chains during lunch period and after closing | Yes                        |
| 3          | Public transport systems (Aeroplane, train, bus) | Disinfection using disinfection chains after reaching to the destination and before starting a new journey | Yes                        |

Table 4
Comparison of the proposed method with traditional disinfection approach.

| Serial Number | Parameter                        | Proposed technique | Traditional approach |
|---------------|----------------------------------|--------------------|----------------------|
| 1             | Reusability                      | Present            | Absent               |
| 2             | Chemical free disinfection       | Yes                | No                   |
| 3             | Deactivation of airborne virus    | Present            | Absent               |
| 4             | Time requirement                 | Less               | More                 |
| 5             | Human effort                     | Required in less amount | Required in more amount |

shows the characteristics between Survival fraction and light intensity. These relations are also presented graphically using Figs. 3 and 4. Strategy for disinfection of these public places has been described in Table 3.

Following data reveals that the disinfection quality can be improved in two ways. These are as follows:

- For a particular intensity of ray, quality of disinfection gets enhanced by increasing the duration of decontamination.
- Likewise for a particular period of time, disinfection quality can be improved by increasing the intensity of light.

4.2. Precautions and applications

Since UV-C ray is very harmful to human skin, it becomes important to carry out the disinfection process in a closed domain so that the UV light cannot fall directly in the body of any human being. To meet this essential safety criteria, users are advised to supply power to the network externally by putting the electrical power switch ON from outside the disinfection place. This requirement can be satisfied by operating the electric switches from a place where the UV-C light cannot reach i.e., by using the MCB switch placed outside the room.
This proposed method is suitable to disinfect the public places of various size like Shopping mall, Classrooms including the public transport systems such as Aeroplane, Train, Bus after each operational phase due to its flexible structure.

4.3. Comparative analysis

Several features of this disinfection system are as follows.

- It is a simple system which can be designed with little technical knowledge.
- This system is reusable. Hence, the expenditure of disinfection gets reduced considerably.
- This disinfection system is a chemical free decontamination method. It does not produce any chemical waste.
- This is a flexible and portable system as the chain of UV lamp can be folded easily for carrying purpose.
- This technique destroys airborne virus when it passes through the air.

Performance of the proposed technique has been compared with the conventional disinfection system using Table 4.

5. Conclusion

In the recent COVID-19 pandemic situation, a cheap and flexible disinfection system can play a vital role to control the infection of SARS-CoV-2 virus. Considering the need of frequent disinfection of various public places and the barrier of economic constraints, reusability becomes an important parameter of decontamination specially for the developing countries or those countries having large population. Another aspect is that chemical disinfection is not suitable to use in various applications such as decontamination of clinical room, food shop etc. To tackle these issues, a low cost and simple disinfection chain based system has been suggested for chemical free disinfection of public places including the public transport system from SARS-CoV-2 during this pandemic period. The UV-C ray exposure based disinfection chains are reusable and flexible to carry due to its foldable structure. This technique is also suitable to destroy the airborne virus. Proposed system requires minimal human effort and less duration (3 min) compared to the conventional disinfection process. However, precautionary measure must be taken to avoid the harmful effect of UV-C light on human skin.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] da Costa VG, Moreli ML, M.V. Saivish. The emergence of SARS MERS and novel SARS-2 coronaviruses in the 21st century. Arch Virol 2020;165:1517–26. http://dx.doi.org/10.1007/s00705-020-04628-0.
[2] https://www.worldometers.info/coronavirus. [Accessed on 30 Sep 2020].
[3] Castillo RC, Staguhn ED, Weston-Father E. The effect of state-level stay-at-home orders on COVID-19 infection rates. Am J Infect Control 2020;48:958–60.
[4] Cobb JS, Seale MA. Examining the effect of social distancing on the compound growth rate of SARS-CoV-2 at the county level (United States) using statistical analyses and a random forest machine learning model. Public Health 2020;185:27–9.
[5] Hasan A, Putri ERM, Susanto H. Data-driven modeling and forecasting of COVID-19 outbreak for public policy making. ISA Trans 2021. http://dx.doi.org/10.1016/j.isatra.2021.01.028.
[6] Armellino D, Walsh TJ, Petratis V. Assessment of focused multivector ultraviolet disinfection with shadowless delivery using 5-point multisided sampling of patient care equipment without manual-chemical disinfection. Am J Infect Control 2019;47(4):409–14.
[7] Welch D, Buonanno M, Grilli V, et al. Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases. Sci Rep 2018;8:2752.
[8] Yang MC, Hung PP, Wu YK, et al. A three-generation family cluster with COVID-19 infection: Should quarantine be prolonged? Public Health 2020;185:31–3.
[9] Mandal CC, Panwar MS. Can the summer temperature drop COVID-19 cases? Public Health 2020;185:72–9.
[10] Ippolito M, Gregoretti C, Cortegiani A, et al. Counterfeit filtering facepiece respirators are posing an additional risk to health care workers during COVID-19 pandemic. Am J Infect Control 2020;48(7):853–4.
[11] I. Devrim, Bayram N. Infection control practices in children during COVID-19 pandemic: differences from adults. Am J Infect Control 2020;48:933–9.
[12] Woodruff A, Walsh KL, Knight D, et al. COVID-19 infection: Strategies on when to discontinue isolation, a retrospective study. Am J Infect Control 2020;48:1032–6.
[13] Huynh TLD. Does culture matter social distancing under the COVID-19 pandemic? Saf Sci 2020;130:104872.
[14] Patrinley JR, Berkowitz ST, Zakria D, et al. Lessons from operations management to combat the COVID-19 pandemic. J Med Syst 2020;44(7):1–2.
[15] Li DF, Cadnum JL, Redmond SN, et al. Steam treatment for rapid decontamination of N95 respirators and medical face masks. Am J Infect Control 2020;48:853–8.
[16] Deb Nath S. Low cost homemade system to disinfect food items from SARS-CoV-2. J Med Syst 2020;44:126.
[17] Ren Y, Li L, Jia Y. New method to reduce COVID-19 transmission—the need for medical air disinfection is now. J Med Syst 2020;44:119.

[18] Takagi H, Kuno T, Yokoyama Y, et al. The higher temperature and ultraviolet, the lower COVID-19 prevalence—meta-regression of data from large US cities. Am J Infect Control 2020;48(10):1281–5.

[19] Buonanno M, Welch D, Shuryak I, et al. Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses. Sci Rep 2020;10(1):10285.

[20] Hau YS, Kim JK, Hur J, et al. How about actively using telemmedicine during the COVID-19 pandemic? J Med Syst 2020;44:108.

[21] Khurana S, Singh P, Sinha TP, et al. Low-cost production of handrubs and face shields in developing countries fighting the COVID19 pandemic. Am J Infect Control 2020;48(6):726–7.

[22] Guerrero-Beltran JA, Barbosa-Cnovas GV. Advantages and limitations on processing foods by UV light. Food Sci Technol Int 2004;10(3):137–47.

[23] Tseng CC, Li CS. Inactivation of viruses on surfaces by ultraviolet germicidal irradiation. J Occup Environ Hyg 2007;4(6):400–5.