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ORIGINAL ARTICLE

Development of Autonomous Advanced Disinfection Tunnel to Tackle External Surface Disinfection of COVID-19 Virus in Public Places

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Abstract
This paper describes a robust autonomous disinfection tunnel to disinfect external surfaces of COVID-19 virus such as clothes and open body sections in public places such as airports, office complexes, schools, and malls. To make the tunnel effective and highly efficient, it has been provided with two chambers with three disinfection processes. Due to the multiple processes, the possibility of neutralizing the virus is quite high and higher than other solutions available at this point for this purpose. Chamber 1 sprays the solution of a disinfectant on the person. This solution can be either a dilute solution of approved chemical or any Ayurvedic/herbal disinfectant. Once the person enters chamber 2, he/she is exposed to hot air at 70 °C along with far-ultraviolet C rays (207–222 nm). Both chambers function autonomously by detecting a person in a chamber using ultrasonic sensors. The proposed tunnel is developed under industry–academia collaboration jointly by Technopark@iitk and ALIMCO under the ambit of the Ministry of Human Resources Development and the Ministry of Social Justice and Empowerment, respectively. The tunnel is referred to as the 'Techno Advanced Disinfection Tunnel' (TADT).

Keywords Covid19 · Disinfection tunnel · Disinfectant spray · Far-UVC radiations · Automated tunnel

Introduction

The outbreak of the COVID-19 virus has affected countless people all over the world. Controlling this real-time pandemic is now a major priority of the scientific community. People can get infected from this virus in many ways, mainly from person to person contact via the spread of contaminated droplets originating from the oral and nasal passages, or by touching a contaminated surface (Zhang 2020). In the current scenario, there is no vaccine available, which can treat the COVID-19 virus infection.

Inadequate cleanliness and hygienic practices can lead to an increase in the infection rate during this outbreak. The virus is active for up to three hours in aerosols, up to four hours on copper surfaces, up to three days on steel and plastic surfaces, and up to twenty-four hours on cardboard surfaces (Van Doremalen et al. 2020). This indicates that without proper disinfection, the virus can spread rapidly through contact surfaces and air. Effective surface and air disinfection can ensure an early containment and prevention of further viral spread. The literature suggests that COVID-19 virus infection can be arrested effectively with 0.1% sodium hypochlorite solution within 1 min (Kampf 2020). High temperature and high humidity can also reduce and dampen the coronavirus transmission (Wang et al. 2020; Jithin Krishan and Subash 2019).

'Social distancing' amongst people has emerged as a useful tool for slowing down the virus spread. In public places, however, it is hard to maintain social distancing. Hence,

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taking precautions is the only way to tackle the virus. For dampening the spread of the COVID-19 virus outbreak, when the economy limps back to normalcy, a robust disinfection system is required to break the chain of the virus from spreading in public places, irrespective of the hygiene condition of people. An automatic disinfection system can perform contactless disinfection of the exterior surfaces to arrest further infection if one gets contaminated while moving/ working, and it will be an effective deterrence to the spread of infection. It would effectively help and manage people's movement once lockdown is phased out systematically. Therefore, the disinfection tunnel should be autonomous and without any human intervention for arresting the virus on the exterior surfaces of people. Sree Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST), Trivandrum, used two processes and designed an electronically controlled disinfection gateway/disinfection tunnel. The gateway generated hydrogen peroxide mist to disinfect the person's body. Afterward, UV light was used for disinfection purposes. However here, the choice of the wavelength of UV radiation is extremely critical. If an informed choice is not made, it could be deleterious to human health, skin, and eyes.

The proposed disinfectant tunnel developed by Technopark@iitk and ALIMCO is named as the 'Techno Advanced Disinfection Tunnel' (TADT), which has two chambers. The first chamber automatically detects a person and delivers a disinfectant solution through the spray nozzle array, which could be a sodium hypochlorite solution of a concentration approved by authorities, a herbal disinfectant, or any other solution suggested by health agencies such as the Indian Council of Medical Research (ICMR) or World Health Organisation (WHO). After the first treatment, the person enters the second chamber. Here, the sensors detect the presence of the person and deliver a thermal shock (heat) for a few seconds. Along with the thermal shock, the person is also exposed to ultraviolet rays (in the safe wavelength range). These processes can effectively reduce the virus contamination on clothes, skin, and any other exposed body surface getting treated. The tunnel incorporates automatic guidance and dynamic movement system through universal lighting symbols. It can direct people's movement effectively without any human intervention and is autonomous.

Techno Advanced Disinfection Tunnel

Structural Design

In this section, the design and the material of the proposed tunnel are discussed. Figure 1 shows the tunnel's side and isometric views. The tunnel chambers are made of mild steel structural members.

The floor of the chambers is made of wooden ply covered with a thick rubber sheet. The floor of the sanitization chamber (chamber 1) is adequately sloped to drain out the excess solution sprayed. Figure 2 shows the dimensions of each structural member used for fabricating the structure of the tunnel.

Functioning

The first chamber is the sanitization chamber (chamber 1), which sprays a mist of herbal disinfectant solution or sodium hypochlorite solution, a chlorine compound often used as a disinfectant or a bleaching agent. The mist is generated by a suitable arrangement of nozzles as the person passes through the chamber. A suitable fan is used for directing the uniform distribution of mist over the person. Sodium hypochlorite is a component of commercial bleaches and cleaning solutions and used as a disinfectant for drinking and wastewater purification systems and swimming pools in very mild concentrations. However, a slightly high concentration of sodium hypochlorite could lead to mild to extremely serious side effects, ranging from skin and eye irritation to severe burns; therefore, the concentration should be used as per the government/ ICMR guidelines. Any other chemical recommended by leading health agencies could also be used in approved concentrations.

The second chamber is a hot air and far-ultraviolet C (far-UVC) chamber (chamber 2). The ultraviolet rays are known to destroy the DNA of the virus (Kowalski 2020). Hence, they are very effective in viral disinfections, specifically in the medical domain. The radiations from the far-UVC warp the structure of the genetic material of the virus and prevent the viruses from making more copies of themselves. In chamber 2, an exhaust fan and heating coil arrangement are used to maintain the temperature at 65–70 °C. Chan et al. (2011) suggested that the infectivity of the virus is lost at a temperature above 57 °C. In this chamber, an exhaust fan is used to blow the hot air from the heating coil (1.5 kW) on to the chamber occupant. Figure 3 shows the TADT. The tunnel dimensions are such that several of these tunnels can be used in parallel at places, where there is a largely expected footfall.

The entire system is modular and portable. It has four wheels in all corners as shown in Fig. 2 and can be easily moved from one place to another. The disinfectant tank is placed on a separate trolley, and the pump is also housed in this trolley. The trolley is portable and placed beside the tunnel such that adding disinfectants is rather easy. One of the main advantages of this design is that it uses two low-slope ramps on either side of the tunnel so that persons with disability/ wheelchair-bound individuals do not face any challenges in using this tunnel. The ramps are visible in Fig. 3.

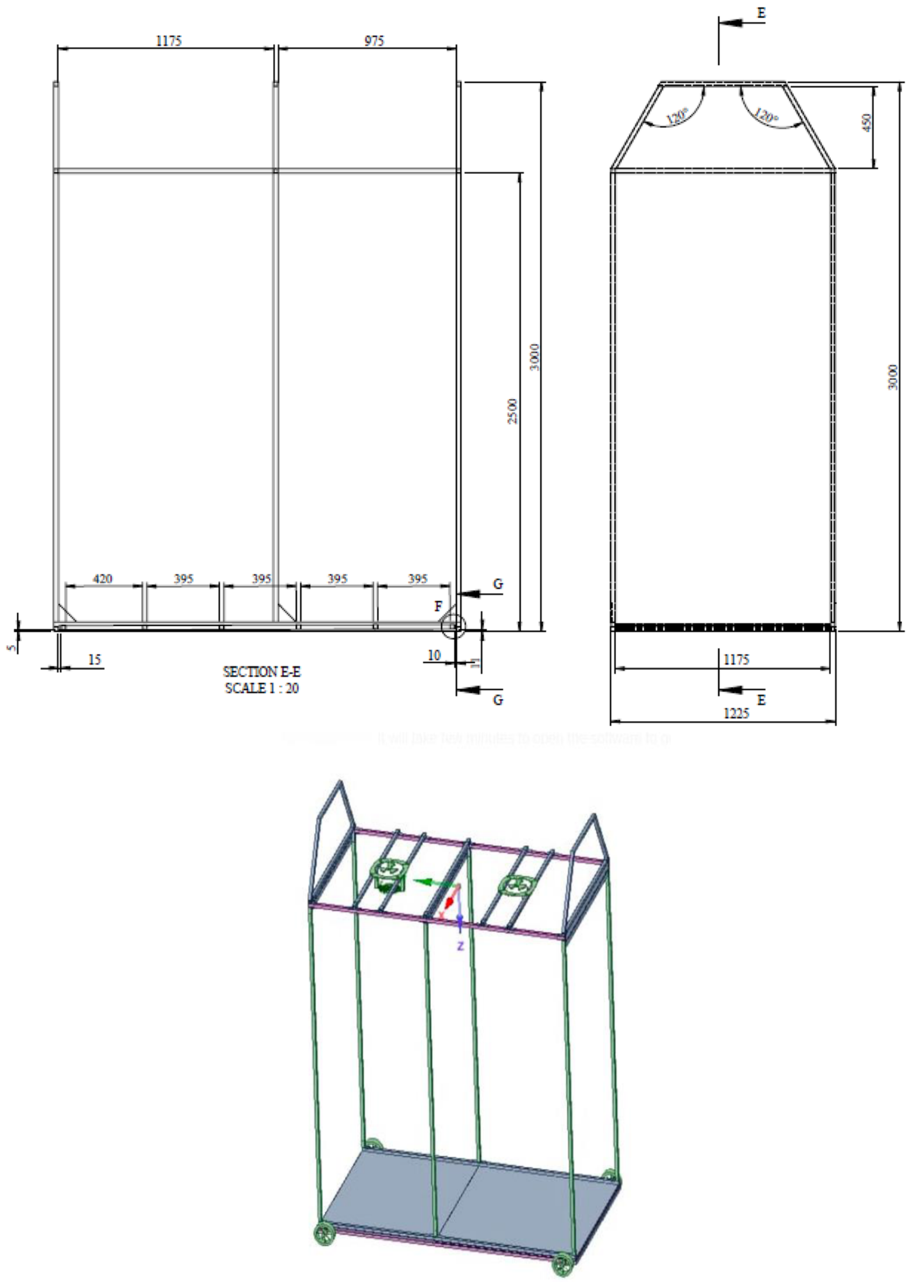
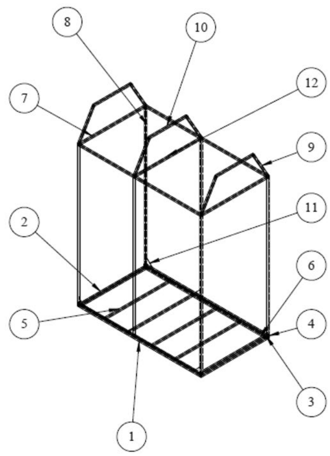


Fig. 1 A side view and an isometric view of the TADT structure

Disinfectant Spraying Mechanism

The first chamber of the disinfectant tunnel consists of a spray mechanism for a disinfectant solution. The various components used in the spray mechanism include low flow rate high-pressure pump, mist fan, electrostatic nozzles, disinfectant fluid, fluid tank, pipes, electrical components, and microcontroller. This chamber is fully automated with various sensors and actuators. No manual operation is required, which reduces the chances of virus spread and makes the whole disinfection process more efficient. It has the potential to kill (or neutralize) the virus if used properly. A major objective was to develop a user-friendly spray chamber with full effectiveness against the coronavirus.

For this application, an ultra-fine spray of droplet size < 30 microns is generated so that the spraying is uniform with minimal use of a disinfectant. To achieve this, electrostatic nozzles are used, which can produce such small-sized droplets from the fluid using the "Electrostatic Atomization" process (Fig. 4). In this process, an intense electric field is applied around the atomizer by using a special kind of charged electrostatic nozzle. Due to the electric charge, repulsion forces are created between the atomizer and the spray fluid. These repulsive forces are responsible



ITEM No.	Quantity	Dimensions of cross-section (mm)	Length (mm)
1	1	PIPE 25*25*1.5	2175
2	1	PIPE 25*25*1.5	1200
3	3	PIPE 25*25*1.5	2200
4	2	PIPE 25*25*1.5	2225
5	6	PIPE 25*25*1.5	1171.27
6	2	PIPE 25*25*1.6	2171.08
7	2	PIPE 25*25*1.5	1225
8	6	PIPE 25*25*1.5	2449.7
9	6	PIPE 25*25*1.5	5333.47
10	3	PIPE 25*25*1.5	705.38
11	6	SHEET 100*100*3.15	2171.08
12	2	PIPE 25*25*1.5	1175

Fig. 2 Dimensions of the structural members used to fabricate the tunnel structure

for the atomization of fluid film into ultra-fine droplets. The droplet size depends upon three main factors: the strength of the electric field applied, fluid flow rate, and fluid properties (Pratama et al. 2020). The electrostatic spray also increases the spray angle to cover a higher surface area (Kumar Patel et al. 2017).

Controller Design

The functionality of the tunnel is very good because of the high degree of automation and the use of a microcontroller and several sensors. Arduino Mega 2560 Rev3 microcontroller is used to control the processes in both the chambers automatically. The block diagram of the controller is shown in Fig. 5.

In the tunnel, the entry and the exit of a person are sensed by the ultrasonic sensors represented by S1, S2, and S3 (Fig. 5). The sensors can detect the presence of a human from a 2–450 cm distance. Here, LGe, LG1, and LG2 represent the green light at the entry of the tunnel, chamber 1, and chamber 2, respectively. Similarly, LRe, LR1, and LR2 represent the red light at the entrance of the tunnel, chamber 1, and chamber 2, respectively. The red and green lights indicate that the user must stop or move forward, respectively. The complete operational layout and logic map of the controller is shown in Fig. 6.

When a person enters chamber 1, the disinfectant is sprayed on them from the spraying system for approximately 20 s. The spraying system consists of fan and spray nozzles that will spray the disinfectant in the form of an atomized ionized mist. The ionization of the mist increases the neutralizing efficiency of the virus.

Afterward, the person enters chamber 2. In chamber 2, the person is provided additional safety against the virus by exposing him/ her to safe far-UVC radiations and hot-air flow simultaneously. The UV lights are turned on for approximately 15 s, and the exposure to hot air is approximately 20 s. The temperature in the chamber 2 is ~ 65–70 °C. The UV Lamps used here emit far-UVC of 207–222 nm wavelength, which is safe for human skin and eyes (207–222 nm Far-UVC Light Can Slow Spread of Novel Coronavirus COVID-19 2020). The switching on/off of all these devices and the red/green lights in each chamber is controlled by the

Fig. 3 TADT (techno-advanced disinfection tunnel)

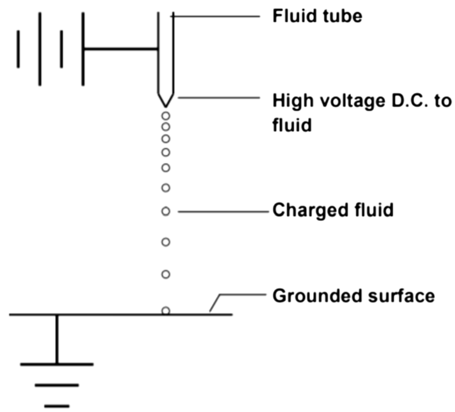


Fig. 4 Electrostatic atomization

microcontroller, which gets triggered by the sensors in each of the chambers based on people's presence. The sequential operation of TADT is shown pictorially in Fig. 7.

Summary

This paper discusses the design and development of a fully automatic, modular, and portable tunnel that has two chambers and uses three processes to disinfect people with high neutralizing efficiency of the COVID-19 virus. In the first chamber, the person is disinfected by the spraying of the ionized mist of an approved disinfectant solution for 20 s. The electrostatic nozzles used in the chamber

Fig. 5 Controller block diagram

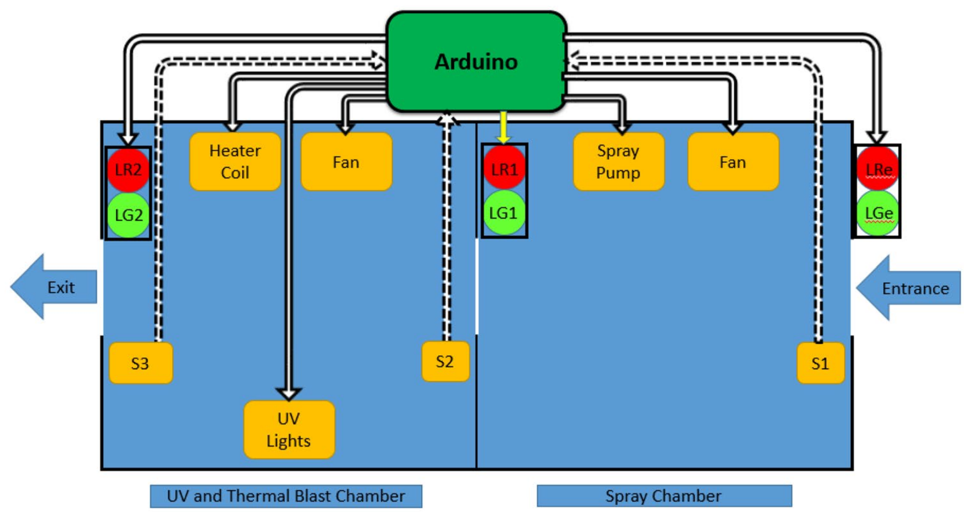
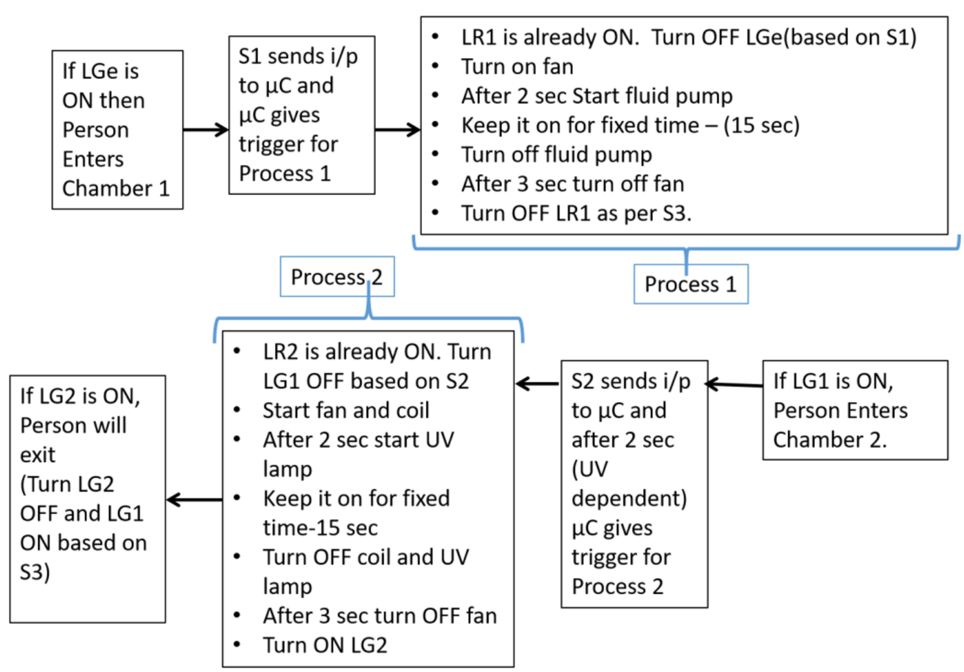


Fig. 6 Controller operational layout and logic map



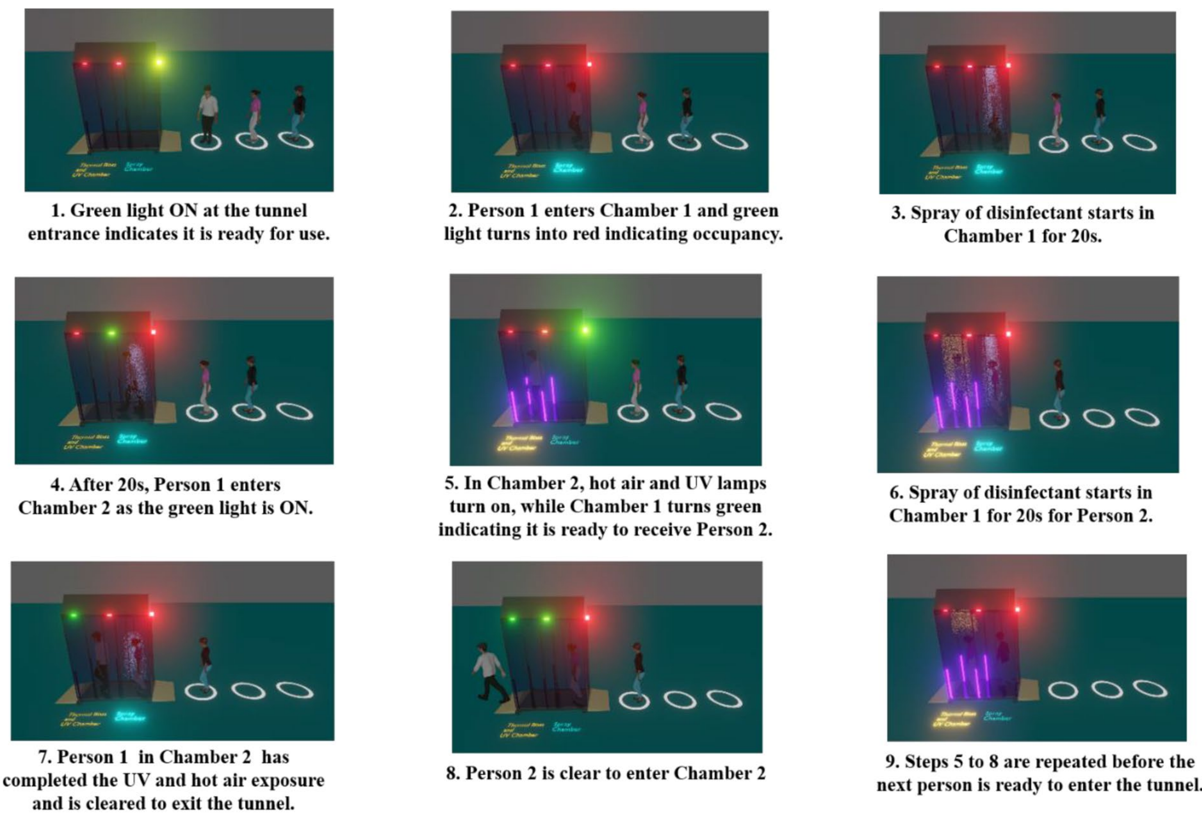


Fig. 7 Sequential operations of TADT

produce ultra-fine droplets of size < 30 microns allowing minimal use of a disinfectant. In the second chamber, the person is exposed to hot air for approximately 20 s and a safe wavelength of far-UVC radiations for 15 s simultaneously. All these processes are performed autonomously, where the presence of a person is detected using ultrasonic sensors. This 'Techno Advanced Disinfection Tunnel' is successfully developed under industry–academia collaboration at IIT Kanpur. This work can be extended to mobile disinfection tunnels for vehicles/two-wheelers and for lightweight chambers at airports, schools, and office complexes, once India reopens its economy.

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