Robotic Applications for Disinfection and Sterilisation

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Abstract— **This research report has presented a new design of the robotic application to facilitate more flexible disinfection and sterilisation of small medical equipment, such as medical drills or mask component of the respiratory machine, and help reduce the risk of indirect spread of COVID-19 via longer contact with potentially contaminated medical equipment while easing the heavy workload among the healthcare workers.**

I. INTRODUCTION

On 12th March 2020, the World Health Organisation (WHO) has announced the outbreak of COVID-19 to be a pandemic[1]. Up to date, there are approximately 2.5 million people dead from COVID-19 and 114 million people infected the deadly virus[2]. Among all, many deaths and infection occur among the healthcare workers who, despite fears of getting infected and potentially infecting others, have dedicated their life trying to reduce the number of deaths in the pandemic[1]. WHO reports have shown that the transmission of COVID-19 is facilitated by the close setting and contact in environments like hospitals, where the medical equipment is potentially contaminated and physical contact with the contaminated environment increases the transmission[2]. Disinfection and sterilisation can effectively reduce the risk of indirect transmission by decontaminating the environmental surfaces [3]. However, exposure to the disinfectants and sterilisation substances can result in increased risk of respiratory or skin diseases among healthcare workers, depending on the methods of disinfection or sterilisation[4][5]. Also, the effect of sterilisation can be influenced by various factors, such as temperature and pH values of the environments or distance from the disinfectants, and so on[5]. Hence, we proposed an autonomous system to control the environment more accurately to increase the effect of decontamination and reduce the risk of exposure of healthcare workers.

II. BACKGROUND

Under normal practice, medical equipment like surgical instruments will undergo two processes that remove the germs on it [6]:

1) First, the equipment was transported to a disinfection process which removes most of the bacteria. The equipment is washed using disinfectants under 90 - 95°C. Finally, the equipment is accessed by well-trained staffs to ensure they are in good condition and free from contamination.
2) Second, is subjected to an airtight environment. Then undergo a heat treatment which typically has a temperature of 134°C to kill any germs on the surface of the instruments. This is typically done in an autoclave with 1N $NaOH$ [7].

Although nowadays much equipment is available in the form of single-use, a significant amount of equipment is still reused. Besides, the trend to cut plastic products in an operation theatre encourages the use of reusable items [8]. In the midst of COVID-19, most hospitals were full of patients and the demand for disinfecting and sterilising the equipment is higher than usual. This means that the supply for sterilized and disinfected equipment may not be able to meet the demand in these medical institutions.

To mitigate the spreading of COVID-19, there has already been a robot created by Times Medical in Hong Kong utilizing UV and gas form disinfectants which include H_2O_2 to sterilize environments such as intensive care units in hospitals, shopping malls and offices [9]. However, this robot only roughly sterilizes a $5\times 5m^2$ area. To further elaborate, albeit this robot is claimed to have the ability to kill 99.99% of germs in a $5\times 5m^2$ area under 10 minutes, it still cannot provide a promising sterilization and disinfection to decontaminate the surgical equipment for the high hygiene standard required in healthcare industry.

The first reason for the robot's limited effect is due to the blocking of objects, resulting in a partial UV treatment across the space. The second reason is that it just has an H_2O_2 concentration sensor [10], which means that it works best with H_2O_2. However, some instruments need more advanced disinfectants such as enzymatic cleaner [11][12]. If we use this kind of disinfectant, equipment must be manually cleaned and rosined afterwards, otherwise the enzymatic materials will harden and coat on the surfaces of the equipment. Besides, the effect of using big UV robots for sterilising the rooms and equipment is not guaranteed due to the varying distance from the robot to various objects, which may reduce the effectiveness due to farther than expected distance. Also, there is possibility for human's exposure to the UV light if the robot does not detect the appearance of human in the environment due to the blind-spot of the visual sensor. In the next section, we will propose a safe and efficient robotic solution that can help us overcome the aforementioned issues to sterilize and disinfect the small-sized equipment.

[1]https://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/news/news/2020/3/who-announces-covid-19-outbreak-a-pandemic

[2]https://www.bbc.co.uk/news/world-51235105

III. PROPOSAL

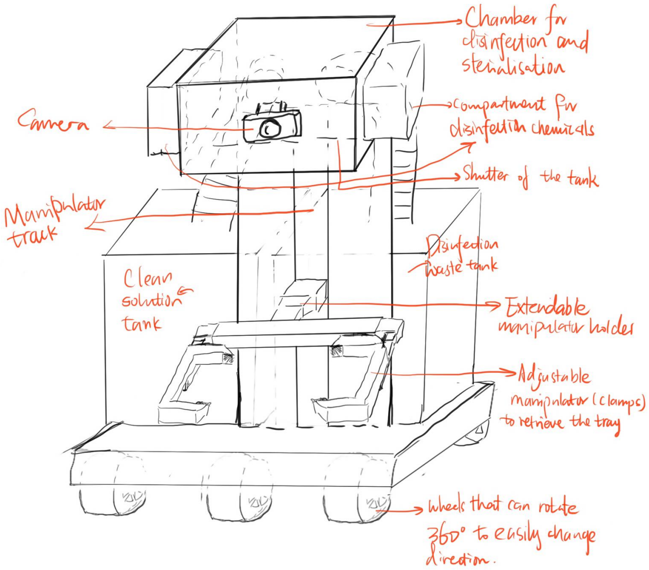

Fig. 1: Design of the robot

We proposed an autonomous robot for disinfection and sterilization of particularly small-sized reusable hospital equipment, such as medical drills for surgeries, for higher efficiency of cleaning and stronger protection of healthcare workers. We believe that UV light is an effective means of sterilisation [13]. In particular, the UVC spectrum has been identified as being significantly detrimental to microbial cells [13]. While microbes are exposed to UVC, the absorption of the photons leads to the destruction of the microbes genetic makeup, inhibiting survival and replication [13].

Current state of the art for UV disinfection robots has UV emitting rods connected to a mobile base to disinfect spaces such as hospital rooms or offices. While this has proven to be fairly effective, there are many limitations, such as that the operation of these robots requires additional time, interfering the busy schedule of hospitals [14]. Moreover, the room must be empty for the robot's operations, as exposure to UV lights is dangerous to humans. The rooms must also be uncluttered as shadowing greatly decreases the efficacy of the sterilization [13].

Our design is a more refined version of the current state of the art. While current UV robots are used to sterilize spaces, the robot being proposed is to be used for disinfecting and sterilizing small-sized hospital equipment. The robot, as illustrated in Figure 1, will have an end effector of clamps to grab trays of used equipment and deliver them into the self contained disinfection and sterilization chamber by moving up along the track on the main board as shown. Once it is inside the chamber, the bottom shutter of the chamber closes, making it air tight. The first process is disinfection, where the robot discharges an enzymatic solution to wash off any blood stain and other physical contamination from the equipment. After disinfection, the enzymatic solution is released into the disinfection waste tank. The equipment is then exposed to the appropriate levels of UVC light to ensure a fully sterile environment has been achieved. This is possible as all sides of the chamber except the bottom are rigged with water-proof UVC emitting rods.

Based on the standard dimensions defined by the International Standard Organisation for the surgical trays, which are 470mm $\times$ 250mm $\times$ 75mm for standard dimension and 560mm $\times$ 300mm $\times$ 75mm for double dimension[3], we designed the robot chamber to be 700mm $\times$ 400mm $\times$ 100mm to accommodate the non-negligible size of the clamps.

To assist the robot in carrying out the tasks, multiple sensors will be required. A camera on the front of the chamber captures the environmental obstacles for route planning, and detect the equipment tray for firm grasping. Temperature, pH and humidity sensors are required as the enzymatic disinfection and UVC sterilization processes have different specific optimal conditions under which they should be carried out to ensure the best efficacy[5]. The sensors and controllers ensure that these conditions are achieved.

For the robot navigation and the booking across different departments to operate, the robot will be using GPS and simultaneous localization and mapping (SLAM) systems. The location data collected from the SLAM systems will then be used for route planning for robots to move across various departments in the hospitals.

A tank of clean solution and a tank of disinfection waste solution are attached at the back of the robot for disinfection process to provide storage for the solutions. Consequently, one or multiple base stations must be set up across the hospital where the clean solution tank can be filled up and the used solution tank can be emptied. The base stations can also act as a charging station for the robot, such that every time it goes to change its fluids, it can also recharge if needed.

Unlike the current robots being utilised, these robots would not require additional time and empty rooms to operate. The idea is for this robot to operate in parallel to ordinary hospital operations. Ideally, the software of the robot enables the hospital staff to book and call the robot, such that the amount of time spent sterilizing equipment can be maximised and more flexible, i.e. whenever the small-sized equipment are ready for cleaning from anywhere. The problem of shadows on UV sterilization will also be largely eliminated as the equipment sterilization will take place in a self contained chamber, where light is emitted from all sides to fully cover the equipment.

Current state of the art robots also only focuses on sterilization, ignoring the disinfection process. This means that the robots only perform an additive role, as the equipment or rooms must be disinfected before usage [14]. The solution

[3]https://www.plymouthhospitals.nhs.uk/download.cfm?doc=docm93jijm4n7762.pdfver=10876

being proposed is a more holistic approach where the robot conducts both steps.

IV. EVALUATION

We believe that our robot has approached the problem from a new perspective and presented an efficient and effective solution to the problem of higher demand for the disinfection and sterilisation of the small-sized equipment. The robot enables a higher frequency of disinfectants and sterilisation of small sized medical equipment, which may need a higher rate of decontamination compared to bigger equipment due to higher use frequency or higher number of usage.

Besides, our robot provides higher flexibility of cleaning the small-sized equipment by allowing more flexible starting time of cleaning, more cycles of cleaning and more flexible scheduling or booking across different department due to the robot's mobility. With the robot, there is no need to wait for the big sterilisation machine to be filled before starting the disinfection and sterilisation process.

Moreover, our robot automates a large proportion of decontamination process of the equipment suitable for use in this case, reducing the amount of time and efforts invested into training the staff to perform the same tasks. Meanwhile more manpower can be dedicated to more complicated and human-needed tasks such as surgical operations or more delicate tasks.

The automation in localisation, navigation and routing of the robot enables easy access of the application across large area, potentially the entire hospital. The compartmentalisation of different solutions and substances for cleaning enables easy replacement and refill of the materials whenever needed.

However, there are limitations of our design. Firstly, the number of cycles of disinfection and sterilisation is limited by the availability of clean solution or the enzymatic disinfectant stored on the robot.

Also, the robot needs to interrupt any current operation and goes to the nearest base station for refill should the decontamination substances run out, resulting in lowered efficiency of cleaning.

The size of the chamber limits the number of medical equipment decontaminated for each cycle.

Moreover, the robot cannot be used for heat sensitive equipment due to the fact that the chamber will be dried using heat after discharging the disinfection solution before the sterilisation process.

One important thing is to ensure that the efficiency of decontaminating the fitting medical equipment is higher than the traditional way apart from all other important robotic performance indicators. As such, we planned experiments to test the performance of the robot by measuring how many pieces of medical equipment the robot can clean across a selection of departments, say 3, across the hospitals, and compare to the number of pieces of medical equipment cleaned using the traditional way, i.e. sending the used equipment from the same 3 departments to the Sterile Processing Department (SPD), for the same given period of time, say from 8am to 6pm. Throughout the experiment, we will look into some key performance indicators (KPIs) for the automated robotic application and traditional manual process of decontamination, such as the number of pieces of equipment decontaminated, the percentage of time of cleaning versus the time of transporting the equipment versus time of waiting for the equipment to be cleaned, amount of exposure of human to the harmful substances used in the process and so on.

In the next section, we introduced some relevant further work we can think of to further improve the current design.

V. CONCLUSION AND FUTURE WORK

A. Conclusion

We have designed a new type of robot that can facilitate a more flexible way of disinfection and sterilisation for the small medical equipment to enable faster iteration for reuse of the equipment. This robot does not only help reduce the risk of potential indirect transmission of COVID-19 among the healthcare workers, but also increase the efficiency of disinfection and sterilisation system, reducing the time and efforts needed for decontamination training[15]. We believe that the robot does not serve to help protect the healthcare workers during the pandemic period more efficiently, but also has the potential of increasing the efficiency of disinfecting and sterilising the small medical equipment in the hospital environment in general in the long run.

B. Future Work

With our proposal described in Section III, there are still rooms for improvement for this robotic solution. For example, we should put effort to develop a chemical filtering process to convert the disinfection waste into reusable clean solution. As such, the robot can lighten up by replacing the two tanks with only one tank to store the reusable liquid, providing more room for bigger volume of liquid storage, enabling more cycles of cleaning each time. Also, the visual information, we can further develop the image recognition models to allow the robot to categorize different kinds of equipment using deep learning techniques [16].

Beyond the current purposes of disinfection and sterilisation, facial recognition can be used so that the robots can be used in some psychiatric hospitals to prevent the patients from escaping from the hospital while moving along the aisles[17]. This will be a quite challenging yet interesting development since the robot have to avoid people during normal transiting but have to take actions when it identify absconding patients such as contacting the security.

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