Chemical based disinfectant robot end effector

Csaba Vass
University of Plymouth
Plymouth, United Kingdom
csaba.vass@postgrad.plymouth.ac.uk

Chinonso Egejuru
University of Plymouth
Plymouth, United Kingdom
chinonso.egejuru@postgrad.plymouth.ac.uk

***Abstract*—The CoVID-19 pandemic has brought about a set of new problems where robotic applications can be useful. We propose a CoVID-19 disinfecting robot that can carry out the disinfection of communal areas of public transport as well as the confined environments of coaches. These kinds of robots are in use today by for example, St. Pancras train station in London and by the Mass Transit Railway in Hong Kong. The robot uses a chemical based approach for disinfection. It has a removable spinning brush for an end effector that can clean flat, circular, or angled surfaces. This paper is focusing on exploring the use of such an end effector for the above-mentioned purposes.**

Keywords—disinfection, robot, chemical.

I. Introduction

The Covid 19 pandemic highlighted the issue of how fast a virus can spread in our increasingly connected world. After the first reported Covid 19 death in Wuhan, China in just over 3 weeks there were 171 deaths were reported in 18 countries [1]. The World is more connected by public transport than any other time in history. The tenacity with which this disease could spread, caught many countries by surprise and forced all the major powers in the world into nationwide lockdowns. Covid 19 caused almost 3.3 million deaths [2] worldwide from January 2020 until May 2021, economic pressures on governments and mental health issues.

It is clear that slowing the spread of such a virus by cheap, regular disinfection of public transport areas can be highly beneficial. Today's cleaning method is to use human power which is expensive. Robots can be a cheap and reliable solution. There are a lot of example of such robotic systems that have been developed recently, mainly using UV-C type disinfection methods for its fast and cheap operation. This paper explores the use of a motorized chemical-based cleaning brush to disinfect hard to reach areas in an environment such as a train car. UV-C lights has to be handled carefully because they can be very harmful to Humans if exposed. A chemical based device could be deployed in during the day when people are about more safely. Alcohol-based solutions are tuberculocidal, bactericidal and virucidal. [3]

II. Literature review

As mentioned in the introduction there are several examples of disinfectant or helper robots that are in use today or under research. In this part of the paper, we introduce some of those exploring their advantages and disadvantages.

A. *Centralized Multi-agent Mobile Robots SLAM and Navigation for COVID-19 Field Hospitals[4]*

This paper explores the use of a hexapod robot in a field hospital environment. It is using a decentralised control and mapping for autonomous navigation. The advantages of a hexapod base for a robot are the ability to navigate on steep or rugged, irregular terrain and over high obstacles.

The disadvantages of such a system includes, increased complexity of control due to complex kinematics.

Such a base would not justify the extra complexity in a public transport environment. Easier and less complex wheeled or tracked solutions exist that are capable of navigating most of the obstacles the trains or train stations pose.

B. *Evaluation of an Ultraviolet C (UVC) Light-Emitting Device for Disinfection of High Touch Surfaces in Hospital Critical Areas [5]*

This paper evaluates the use of UVC light for disinfection. A cross-over study was conducted in a 1158 bed hospital in Italy to evaluate the effectiveness of pulsed xenon-based ultraviolet light (PX-UVC) disinfection method.

The paper states that due to the inverse square law that doubling the distance between the light and the surface will quadruple the amount of time needed for disinfection, so the device need to be close to the surface and not further than 2m. In an average hospital room, the device would need 5 minutes on either side of the bed and 5 minutes for the private bathroom (if applicable) while in an operation theatre it needs 10 minutes on either side of the bed. We can conclude from this that in an environment where high hygienic standards are needed the device is able to disinfect the room in approximately 15-20 minutes.

The paper also states that the device should operate in unoccupied rooms due to the high-intensity UVC light.

In conclusion while UVC light can enhance the cleaning process it should operate in seclusion making it less effective in highly crowded areas.

III. Design process/implementation

The purpose of this design is to provide a possible alternative disinfection method to the UVC light, to be used in more crowded areas. This paper focused mainly on the mechanical design of such an end effector (EF).

A. *Mechanical/System design*

The design was carried out with the use of Fusion 360 Computer Aided Design (CAD) program.

The EF uses a detachable microfiber glove with microfibre 'bristles' attached. That spins around on a hard meshed inner core to provide the cleaning action. The top end of the microfiber glove is attached to the core by screws. To avoid it slipping around.

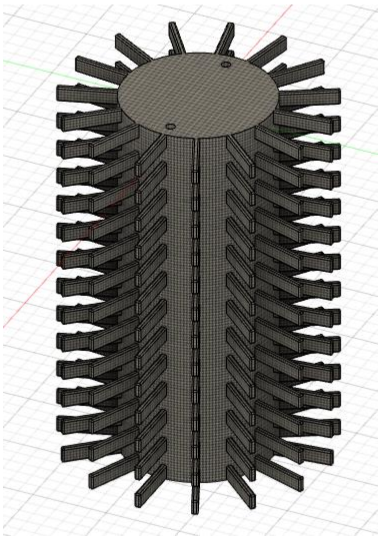

Figure 1 – Microfiber glove

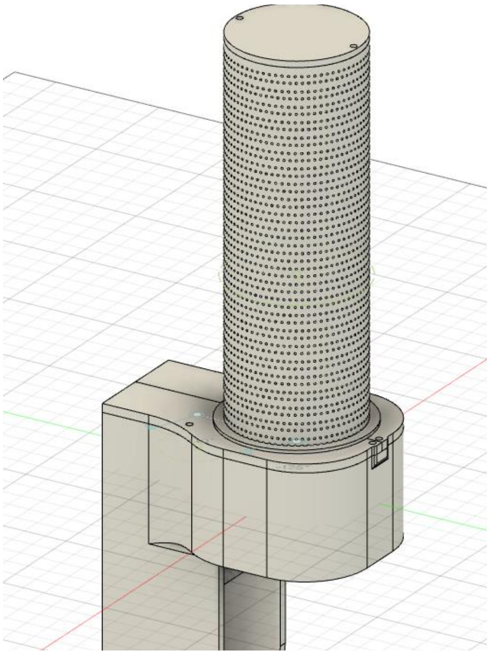

Figure 2 – End Effector

An alcohol-based solution that is a water-soluble chemical compounds of ethyl alcohol and isopropyl alcohol between 50% to 90% concentration for optimum bactericidal effect [3]. This solution is sprayed on the inside surface of the hard core via a flexible rubber pipe. The solution is pumped from a tank with the use of a peristaltic pump.

A stepper motor spins the motion of the hard inner core providing the cleaning action and the centrifugal force to carry the cleaning liquid through the core and into the microfiber glove. The motor was displaced from the main axis of the core to provide space for the rubber pipe carrying the cleaning solution. A gear mechanism with the gear ratio of 1:2, was used to transfer the motor rotation to the core. The motor was chosen based on the torque required to spin a fully saturated microfibre cloth and the rpm required for the cleaning effect.

Microfibers can retain liquids 4 times their weight [6]. Titre is the linear mass of a strand. The titre in Decitex (dTx) represents the weight in grammes of 10km of thread. We speak of microfiber when the titre of the thread is less than 1 dTx [7].

The microfiber glove is 17 cm long cylindrical shape with 6.5cm diameter and has 195 bristles each 19 mm * 4 mm. This adds up to a surface area of 460 cm2 that roughly equals to a 21 cm * 21 cm square textile. 23 cm * 35 cm dishcloth contains 1300km of thread [7]. Using this as baseline the microfiber glove has 740 km of thread that equals to 74 g of weight with a 1dTx microfiber textile. It is able to retain 4 times its weight in liquid so the glove weighs 296 g when saturated with water.

The rpm of the brush can be calculated as below:

$$\omega e = \omega m * \frac{1}{Gear\ ratio} \tag{1}$$

Where ωe is the speed of the EF and ωm is the speed of the motor and the Gear ratio is equal to the number of driven gear teeth over the number of drive gear teeth. The torque curve of stepper motors often given in grams times centimetre against pulse per second (pps). To calculate the torque of a motor for a given speed the following equation can be used along with the motor's torque curve:

$$pps = \frac{\omega m * 360}{Step\ angle * 60} \tag{2}$$

Where the step angle refers to the degree the motor shaft turns for each step. From the value of pps the torque expressed by the motor (τm) can be seen from the torque curve. Since we are using a gear train the driver gear expresses,

$$\tau g = \tau m * driver\ gear\ radius \tag{3}$$

The torque expressed by the core (τe) can be calculated as below:

$$\tau e = \tau g * Gear\ ratio \tag{4}$$

Using equations (1), (2), (3) and (4) and the torque curve of the stepper motor like for example the Soyo *SY42STH38-0806A* τe equals to 2500 gcm which is about 8.5 times the stall torque with fully saturated microfiber glove. Even after adding the weight of the core which is made of plastic the motor would still have enough torque to spin the brush with sufficient force.

The gears and stepper motor are held in a housing where measures were taken to prevent the moisture getting to the motor as seen in Figure 3.

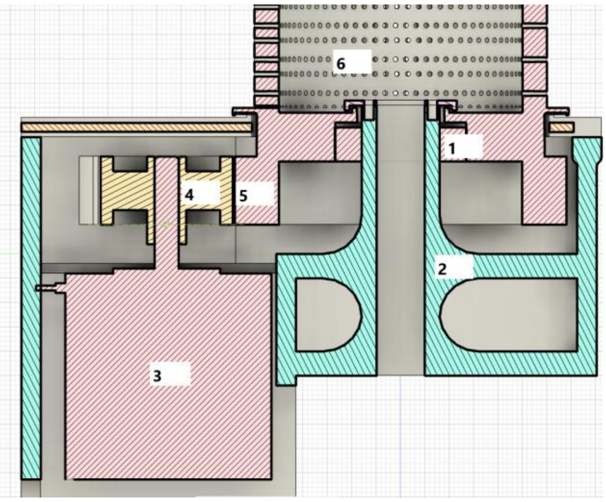

Figure 3 – Housing parts I.

The numbers in Figure 3 are denoting the parts of the EF.

1. Ball bearing - Ceramic to be able to withstand the relatively high rotation. On the image this is displayed as a solid ring.
2. Housing – This can be attached to a manipulator and serves as the base on which the meshed core spins.
3. Stepper motor.
4. Driver gear.
5. Driven gear that is part of the meshed core.
6. Meshed core.

The housing leads into the meshed core and has a detachable lid (8.). It is visible on Figure 3 and that this lid has a rim that together with the rim on the meshed core serves as protection against the cleaning liquid seeping into the ball bearing. There is a similar solution on the outside base of the meshed core (11.)

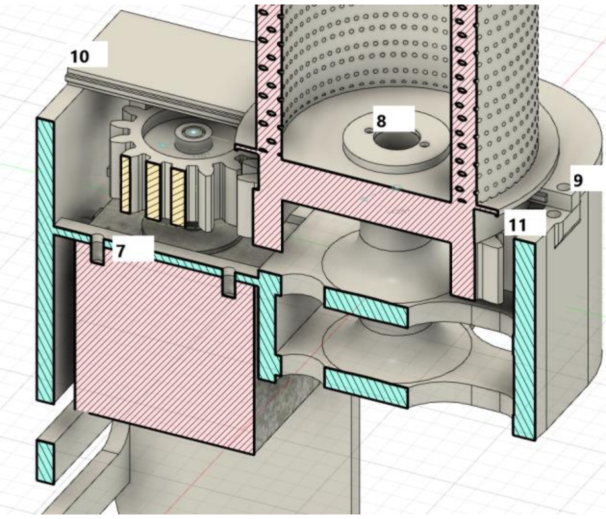

Figure 6 – Housing parts II.

7. Screw holes on housing to hold stepper motor.
8. Detachable lid on pipe entrance.
9. Screw holes for housing lid.
10. Housing lid.
11. Rim to protect motor from water.

The housing lid has 2 parts, one of them has a ridge and the other has a groove. When they are fitted together this prevents water leaking through.

As discussed in previous sections the cleaning liquid will be delivered from the inner side of the meshed core to the outside by centripetal force. This is calculated by equations 5 and 6. Where Fc is the centripetal force ac is the acceleration, r is the radius of the meshed core and ω is the angular velocity of the meshed core.

$$Fc = m * ac \tag{5}$$

$$ac = r * \omega^2 \tag{6}$$

The cleaning liquid is delivered to the inside of the meshed core with the use of a peristaltic pump. The flow rate of the pump is controlled by the speed at which the pump is being turned. By controlling the speed of the motor we can control the amount of liquid reaching the core. Typical motor speed for a pump ranges between 0 – 400 revolutions per minute [10]. A brushless DC motor would be able to provide the necessary speed and torque.

B. Finite element structural analysis

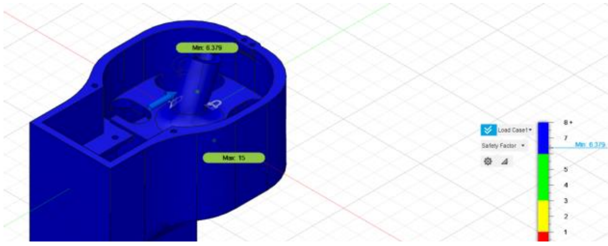

Figure 4 – Fusion 360 FEA simulation – Safety factor

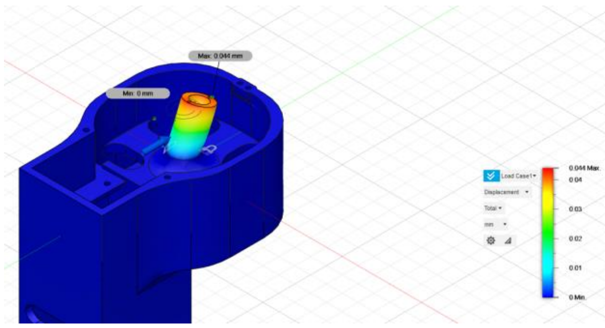

Figure 5 – Fusion 360 FEA simulation - Displacement

The weakest point of the structure is where the housing protrudes into the meshed core. Finite element analysis was conducted on this part to investigate the durability of it against a linear external force. Fusion 360 simulation tool was used to carry out the analysis.

A 100 N of external force was simulated on the core's shaft. It is reasonable to assume that higher external force is unlikely to act on the shaft. The results showed a maximum of 15 safety factor when solid ABS material was used. This is deliberately high to allow for the weakening effect arising from the infill. A design with such a safety factor allows for as low as 45-50% infill which would lower the young's modulus of the material to about 18-20 MPa which is about half of a solid ABS part [8]. This still allows a safety factor of 6. The low amount of infill increases the print time and more cost effective.

Name	**Minimum**	**Maximum**
Safety Factor		
Safety Factor (Per Body)	6.379	15
Stress		
Von Mises	4.871E-08	3.135 MPa
1st Principal	-0.5729 MPa	3.738 MPa
3rd Principal	-3.762 MPa	0.7955
Normal XX	-1.432 MPa	1.469 MPa
Normal YY	-1.353 MPa	1.46 MPa
Normal ZZ	-3.516 MPa	3.501 MPa
Shear XY	-0.3892 MPa	0.4153
Shear YZ	-0.1577 MPa	1.514 MPa
Shear ZX	-0.7126 MPa	0.7076
Displacement		
Total	0 mm	0.044 mm
X	-0.001014 mm	9.736E-04
Y	-4.224E-04	0.04254
Z	-0.01169 mm	0.01166
Reaction Force		
Total	0 N	23.7 N
X	-2.775 N	3.098 N
Y	-10.48 N	0.5228 N
Z	-20.61 N	21.17 N
Strain		
Equivalent	3.582E-11	0.002155
1st Principal	2.351E-11	0.001894
3rd Principal	-0.001899	-2.66E-11
Normal XX	-5.718E-04	5.671E-04
Normal YY	-6.769E-04	7.046E-04
Normal ZZ	-0.001331	0.001321
Shear XY	-4.796E-04	5.117E-04
Shear YZ	-1.943E-04	0.001866
Shear ZX	-8.78E-04	8.719E-04

Figure 7 – Fusion 360 analysis results

C. *Materials*

Since the project only explores an alternative way of cleaning method to the UVC light we only used 3D printing material to be able to quickly go through iterations if necessary.

Two of the most used materials were considered and compared with each other.

Porperties	ABS	PLA
Yield stress	43.3 MPa	44.8 MPa
Part accuracy	Printing details down to 0.8 mm	Printing details down to 0.8 mm
Strength	• Improved ductility • Higher flexural strength • Bigger elastic region	
Biodegradability	Non biodegradable	Biodegradable (under correct circumstances)
Price	~ £25.00/ 1kg of 1.75mm Spool	~ £25.00/ 1kg of 1.75mm Spool

Figure 8 – 3D printing material comparison table [8],[9]

Most of their properties are similar, but ABS has a higher strength for similar price.

IV. Experiments

Simulation was carried out by Chinonso Egejuru.

Conclusion

The project shows that the EF can be built from cheap easily available materials. Due to the lack of field testing the feasibility of the EF was not tested sufficiently.

For supporting files please visit https://github.com/Csaba1988/ROCO507_Disinfectant_robot github repository.

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