

## RESEARCH ARTICLE



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# Design of compliant mechanism for self-sanitizing glove to prevent spread of COVID-19 during mass gatherings

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## Abstract

**Background/Objectives:** COVID-19 outbreak already has millions of confirmed cases worldwide, making religious gatherings like Hajj and Umrah or places like hospitals susceptible as one person can affect hundreds. It caused a rapid increase in the number of infections. Without any vaccine, quick and easy safety measures need to be taken to prevent mass exposure. This article proposes designing a compliant mechanism for self-sanitizing gloves to inhibit the virus spread through touch. **Methods:** Simulation of design for spray compliant mechanism is carried out. The gloves are made through the polymer, which is a low-risk material. Sanitizing liquid is contained inside the device, and as pressure is applied, the liquid is sprayed. A compliant mechanism for spraying is developed. It consists of two main parts, the middle part and the joints. The middle part acts as a reservoir while the ends act as disposal units. The kinematic synthesis equations are derived from the Pseudo-Rigid-Body method to model the compliant mechanism. **Findings:** The simulation for the modeling approach to design the spray mechanism was carried out successfully. The specification allows the user to reproduce the spray compliant mechanism's design by inputting the total desired length ( $L_f$ ) to generate all the required parameters. **Novelty:** Self-sanitizing gloves are a relatively new idea, and the spray mechanism can be further applied to other articles of clothing and promote a cleaner and healthier environment. **Application:** These gloves can sanitize themselves along with the surface in contact. So, the increased use can help curb the infection by providing rapid sanitization and a cleaner environment.

**Keywords:** Pandemic; Coronavirus; Self sanitizing glove; Compliant mechanisms; Religious gatherings (Hajj & Umrah)

## 1 Introduction

This study will provide a solution in preventing the spread of the coronavirus outbreak. The spread of coronavirus is now classified as a pandemic, and the whole world is affected. The outbreak's damage has greatly affected the global economy, and all humanity will suffer the outcomes. By the end of September 2020, Covid-19 cases have crossed 34 million in which present active cases are only 7.8 million, and deaths crossed

over one million globally<sup>(1,2)</sup>. If the spread continues, the damage will be catastrophic, and it will take years to overcome the sequences. Therefore, solutions must come to stop/slow down its spreading.

It is confirmed that coronavirus's fast spread is passing through our hands<sup>(3,4)</sup>. When a single person gets infected, symptoms may take 14 days to appear, and during this time, the infected patient may practice normal activities, which gives the virus a footprint everywhere this patient goes<sup>(3,5,6)</sup>. In other words, every surface the patient touches have a high chance of containing the virus, which means many people will have a high rate of getting infected if they touch the same surfaces<sup>(7,8)</sup>. It is essential to sanitize all surfaces in the infected area to minimize infections<sup>(2,3,9)</sup>. The proposed idea here is to invent self-sanitizer gloves that allow the user to sanitize all the surfaces they touch. This will protect the user from passing the virus into the person's face (the most sensitive area to be infected) or other surfaces and places. Moreover, it sanitizes every surface and objects it touches.

This work will introduce self-sanitizer gloves that prevent the virus's spread and sanitize the surfaces that it touches. The self-sanitizer glove will protect the user as the glove sanitizes itself every time the user grabs a surface. Moreover, the self-sanitizer glove will wipe down the virus from many surfaces in the infected area. With the increasing number of glove users, getting infected will eventually decrease as the more surfaces get sanitized repeatedly by users.

Although this project's need seems only applicable to this pandemic, the need for such a solution is a desire for many clients. In hospitals, doctors, nurses, administrations and workers, patients, and visitors are vulnerable to many contagious diseases, not only coronavirus COVID-19. Security and police are also in need of protection as they are in the first line of contacting the diseases. Besides, Hajj and Umrah are the most critical time as many people come from around the globe, bringing many infections those need to be controlled.

## 2 Methods and materials

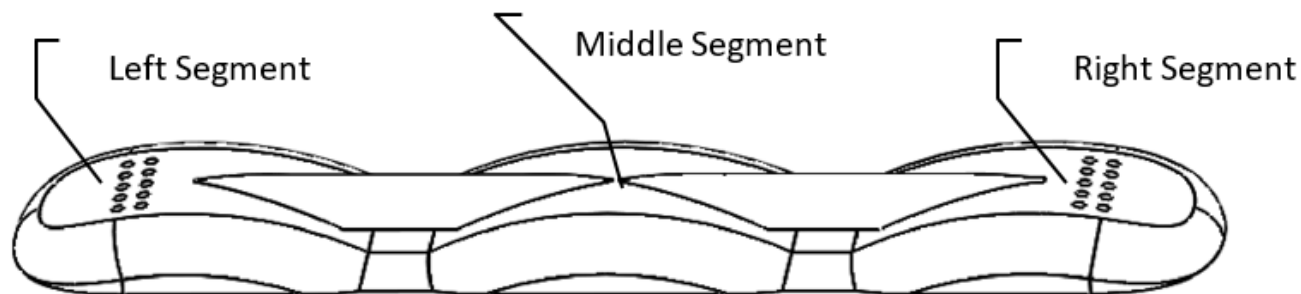
The glove is made of polymer material that should prove the virus does not live on it for a long time<sup>(10)</sup>. It is suggested to use materials that can be fabricated monolithic processes (single part) such as PLA (polylactic acid), Hysoll 9361, and polydimethylsiloxane (PDMS)<sup>(11)</sup>. A compliant spray mechanism that contains the sanitizing liquid is embedded in the palm-side of the glove as shown in Figure 1. The compliant spray mechanism will spray as it compresses every time the hand's grip somethings. The compliant spray mechanism consists of three segments (left, middle, and right). The left and right segments are the disposal units where the sanitizing liquid is coming out. The middle segment contains the sanitizing liquid. Tiny tubes are connected to the middle segment to refill the liquid as needed. The schematic of the compliant spray mechanism is shown in Figure 2.



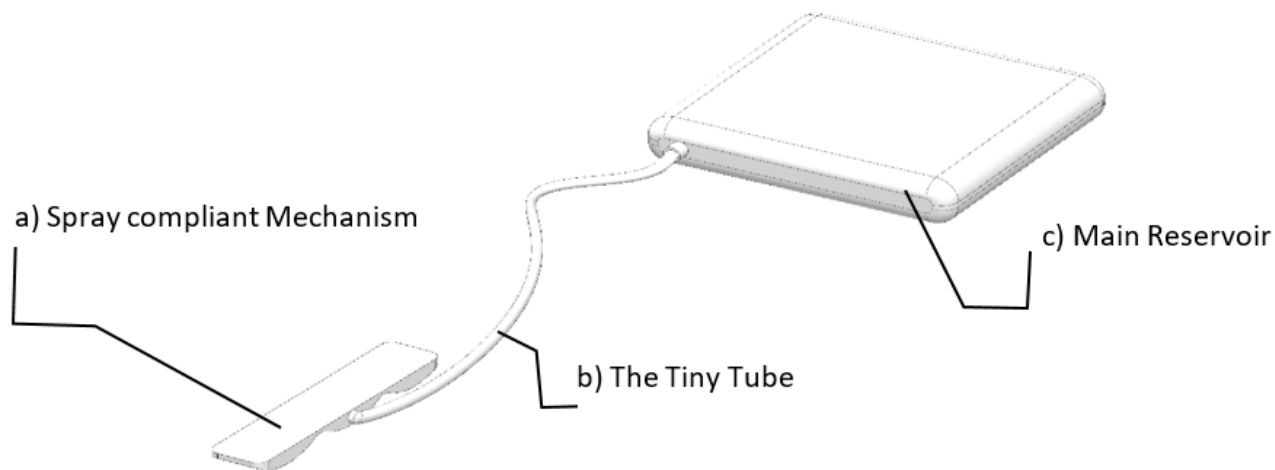
**Fig 1.** A schematic assembly of the self-sanitizer glove. The spray mechanism is only attached to the glove fingers as a proof of concept.

The main components of the self-sanitizing glove as shown in Figure 3 :

1. Spray compliant mechanism.
2. The main reservoir of sanitizing liquid.
3. Feeding tube that connects the main reservoir with the mechanism.



**Fig 2.** The compliant spray mechanism in a flat configuration. In this configuration, the sanitizing fluid is stored in the middle segment.



**Fig 3.** Different components of the self-sanitizer device. a) the spray compliant mechanism. b) the tiny tube that connects the spray mechanism to the main reservoir. c) the main reservoir of the sanitizing liquid.

## 2.1 Spray mechanism design

The entire of the spray mechanism meant to be fully compliant for manufacturing advantages. It can be fabricated in a 3D printer as one piece from one flexible material as a stereolithography (STL) 3D printer<sup>(12)</sup>. Generally, 3D printing of small-sized objects becomes very cheaper compared to large-sized objects. Spray mechanism can be produced with very high dimensional accuracy and with intricate details of mechanisms. SLA components offer a very smooth surface finish. SLA substances are readily accessible, produce transparent, flexible, and castable resins. Prices go up exponentially as the object size increases. These offer resistance to sanitizer containing alcohol in small quantities. Therefore, they are suitable for the fabrication of storage containers<sup>(13)</sup>. It can be fabricated using the casting process with the conventional method. Still, these cast components may increase the weight, decrease the spray mechanism's flexibility and smooth surface, etc.

The left and right segments contain the spray nozzle where it sprays out the pressured liquid (coming from the middle segment when it compressed) to the air. The nozzle works as a conventional nozzle except it is embedded inside the segment and made in the same material which does not require any assemble as shown in [Figure 4](#).

The nozzle is located in the center of the left and right segments and oriented 45 degrees from the base plane where it spouts out toward the sides as shown in [Figure 5](#). This allows the spray mechanism to ensure targeting the gripped object and cover most of the area. To elaborate, the following [Figure 6](#) shows how the 45° angle of the nozzle will cover more area at 90° and 180°.

## 3 Results and Discussion

The main concepts of the spray compliant mechanism are mainly covered in the following two factors:

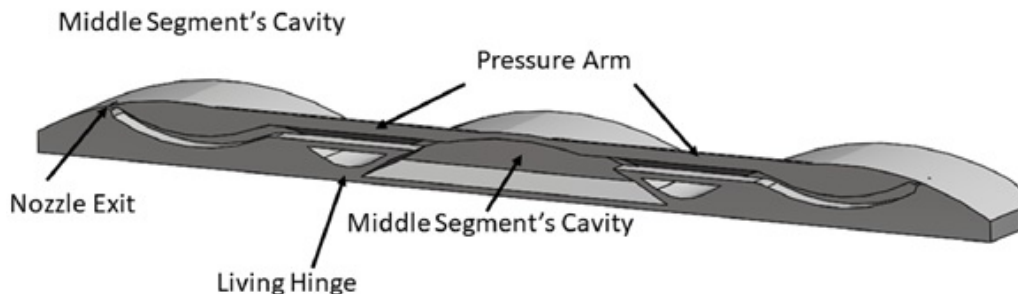


Fig 4. A section cut that exposes the interior components of the mechanism.

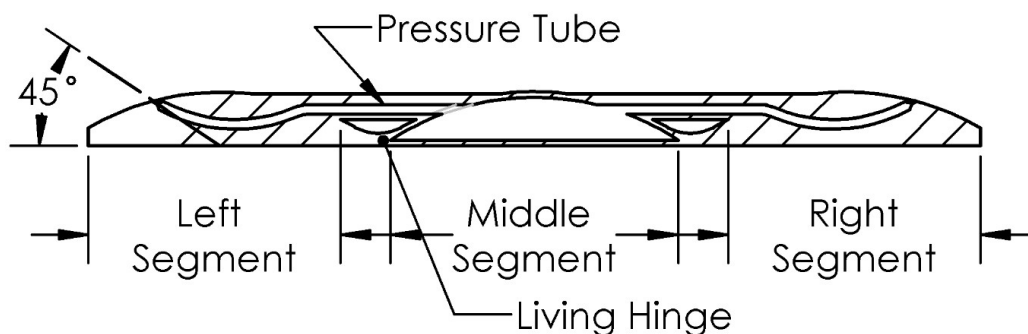


Fig 5. A section cut of the spray compliant mechanism showing the pressure arm's location and the spouts angle of the nozzle.

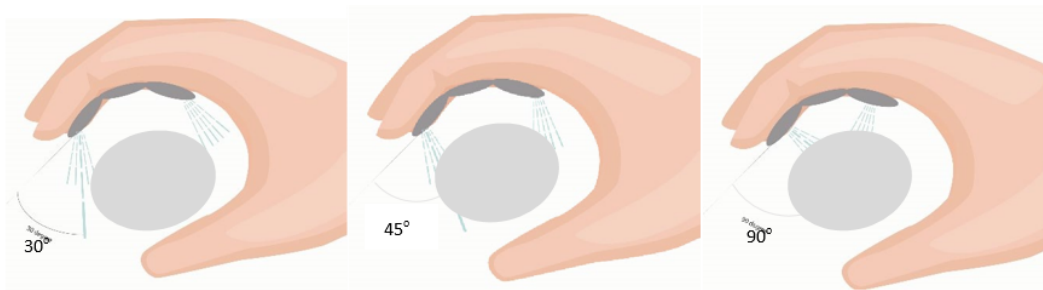


Fig 6. Nozzle angle from the spray mechanism's base. The angle is oriented at 30°, 45°, and 90° to illustrate the total coverage when gripping an object.

#### 1- The Middle segment (storage of the sanitizing liquid).

The middle segment contains only the liquid ingredient: there is no pressurized content at all. When the joint connections compress it, the liquid will escape to the nozzle tube (pressure arm) to the nozzle as shown in Figure 7. In this configuration, the middle segment is compressed, and the inside fluid is pushed to the spray exits at the left and right segments. The mechanism works to increase pressure in the middle segment, which forces the liquid to escape. Once pressure is left up, meaning the mechanism will return to its original shape (flat shape), a low pressure will be created inside the middle cavity, which will fill up the storage again feeding form the main reservoir on the gloves.

A tiny tube is connected to the middle segment to feed the mechanism every time the liquid level is reduced. The tube is made to allow only on direction flow to the middle segment. The tube is hidden within the glove material. The tube connects the middle segment with the main reservoir located on the top of the glove side as shown in Figure 3. The volume of Liquid sanitizer released is 0.75mL to 3ML depending on the gripping position, which may be sufficient for a medium and large-sized

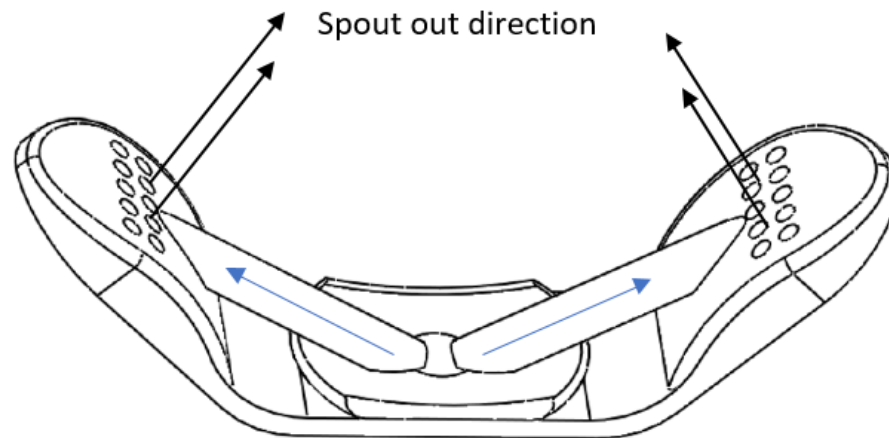


Fig 7. Compliant spray mechanism in the deformed configuration.

hand sanitizer.

2- The joints connecting the left to middle segments and right to middle segments.

The left and right joints connecting the segments are compliant links that are embedded in the spray mechanism. The compliant mechanism consists of two important aspects, the pressure tube and the small-pivot flexural as shown in Figure 8.

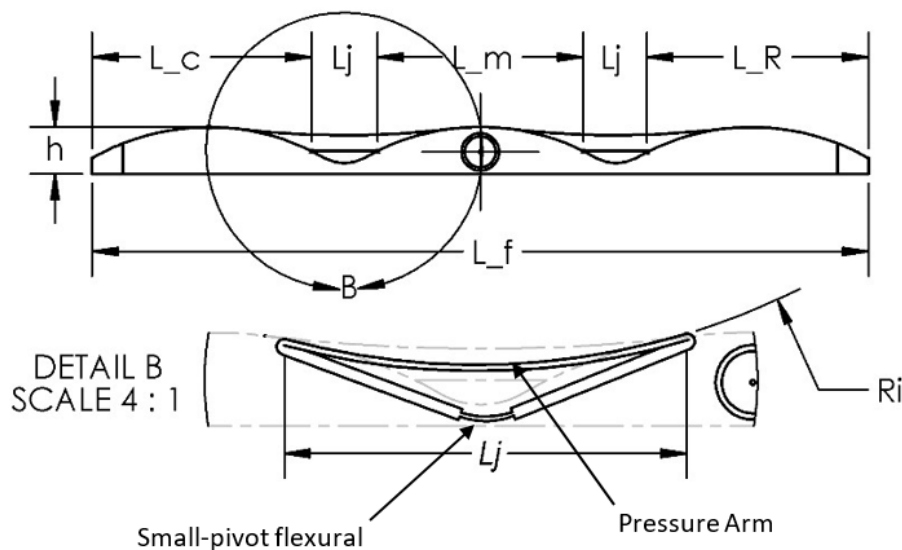


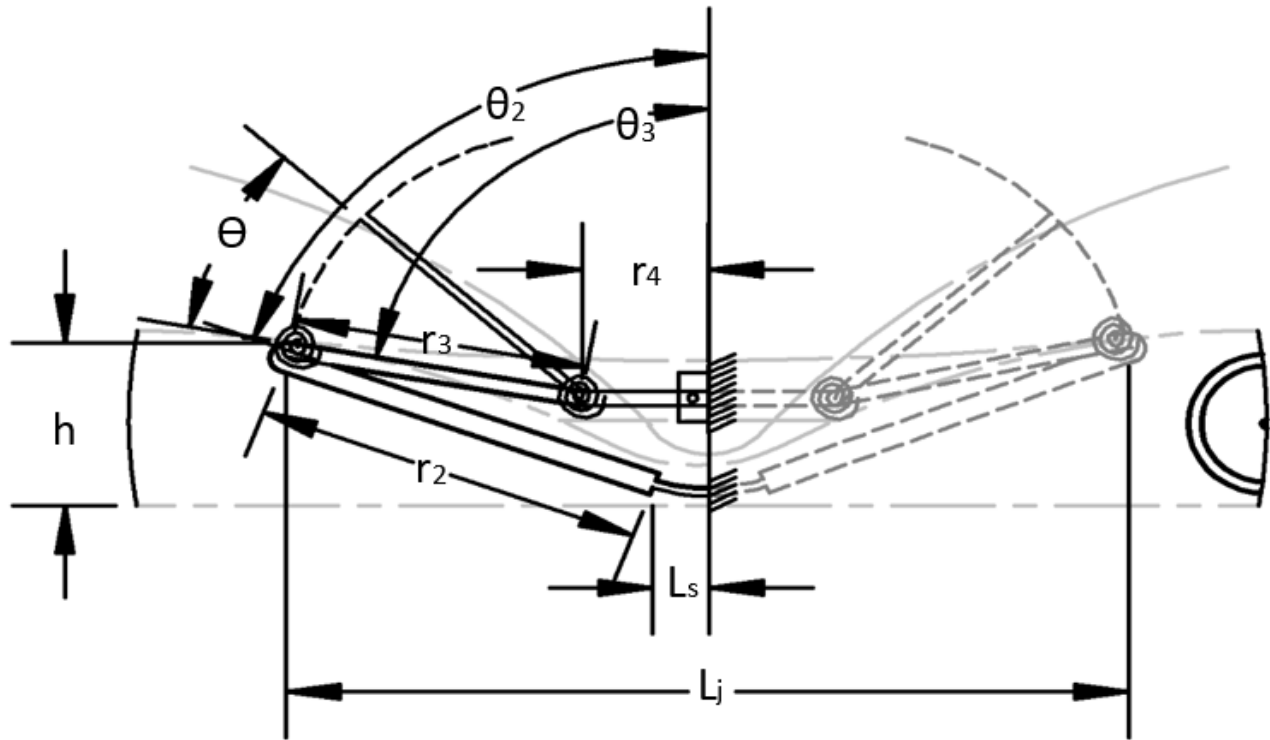
Fig 8. A zoom-in between the left and middle segments and detail B shows the joint's skeleton mechanism.

The pressure tube is a flexible link with a hollow semicircular cross section that will dominate the spray mechanism's stiffness characteristic. The hollow cross section allows the liquid to transfer from the middle segments to the nozzle when the middle segment is compressed. As the left and right segments move, the pressure arm's rigidity will cause it to press on the middle segment and push out the liquid inside of it. Once the pressure arm presses on the middle segment and reaches the base, the pressure arm will buckle if the load keeps increasing. The pressure arm is fixed at the right end at this stage, and the load is increasing at the other end.

The connecting joints between the left and right segments can be designed as a fully compliant mechanism considering the pressure arm and small-pivot flexural as one system, as shown in Figure 9. The full compliant mechanism can be modeled as a slider mechanism considering the fully compliant mechanism's symmetry using Pseudo-Rigid-Body Model. The stiffness of

the pressure tube link is modeled as torsional springs that are placed on the link. The link has an initial curve characteristic that guided the deflection path.

The pressure arm and the small-pivot flexural are modeled using the Pseudo-rigid-body model (PRBM) approach. The PRBM was early developed by Howell to approximate the large deflection of compliant beams<sup>(14)</sup>. Different types of loading and conditions can have a different type of PRBM models. The pressure arm link is considered as a pinned-pinned beam with grip force at its end.



**Fig 9.** The fully compliant mechanism where the symmetry is representing a slider mechanism. The center of the fully compliant mechanism is considered the ground where the slider slides vertically.

The kinematics synthesis of the mechanism is referred to as rigid-body replacement synthesis, where the modeling approach approximates the compliant links as two rigid links joined by torsional springs. The torsional spring, which the material properties decide its stiffness coefficient  $K$ , is assigned at the calculated location representing the resistance as the link deflecting. The angle of the deflection of pseudo-rigid-link is referred to as the angle of the pseudo-rigid-body  $\Theta$ . This PRBM considers homogenous material properties. The fully compliant mechanism's links lengths are specified as a function of the finger's length ( $L_f$ ). The equations Equations (1), (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13) and (14) representing this model are pseudo-rigid body:

$$L_c = L_R = L_m = 0.3 L_f \quad (1)$$

$$L_j = 0.05 L_f \quad (2)$$

$$h = 0.1 L_f \quad (3)$$

$$r_2 = \sqrt{h^2 + \left(\frac{L_c + L_j}{2}\right)^2} \quad (4)$$

$$r_3 = \frac{L_c + L_j}{2} \quad (5)$$

$$r_4 = \frac{L_j}{2} \quad (6)$$

$$r_1 = r_3 \cos \theta_3 + r_2 \cos \theta_3 \quad (7)$$

$$\theta_3 = \text{asin}\left(\frac{r_4 - r_3 \sin \theta_2}{r_3}\right) \quad (8)$$

$$\theta_{2o} = \frac{\pi}{2} - \text{acos}\left(\frac{h}{r_2}\right) \quad (9)$$

$$F \text{ asin} \theta_2 = K_2 ((1 + H) (\theta_2 - \theta_{2o}) - (1 + 2H) (\theta_3 - \theta_{3o})) - K_1 (\theta_2 - \theta_{2o}) \quad (10)$$

$$K_2 = \frac{2\gamma k_\theta E I_3}{r_3} \quad (11)$$

$$K_1 = \frac{E I_s}{L_s}, L_s = \frac{0.15 L_j}{2}, I_s = \frac{wt^3}{12} \quad (12)$$

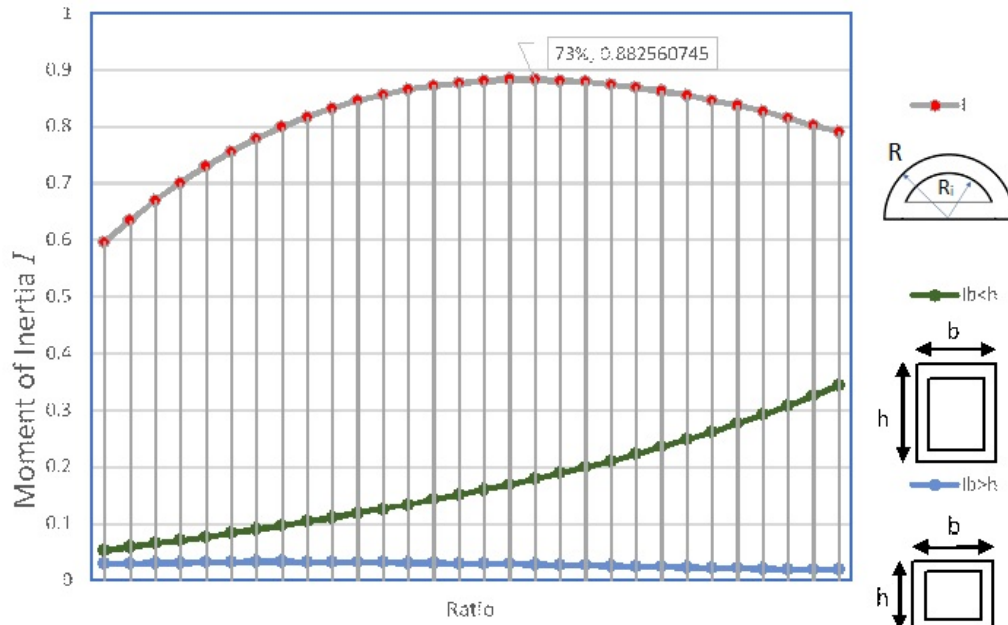
$$H = \frac{r_2 \cos \theta_2}{r_3 \cos \theta_3} \quad (13)$$

Where  $a$  is equal to  $r_2$ ,  $k_\theta$  is a stiffness coefficient that equals 2.65 as recommended by Howell<sup>(14)</sup> and  $t$  is the thickness of the small pivot flexural that equals 10% of the width. The width  $w$  of the spray mechanism equals 10% of the total length of the spray mechanism. The vertex angle  $\theta_2$  is the range of left segment's movement after reaching the base, which will be detected from the finger's movement. Equation (10) is the governor equation of the mechanism. The average grip force is known from Equation (15) and can be estimated based on the gender and age of the user. The output from Equation (10) is the geometry schematic, which will define the dimensions of the pressure arm based on the moment of inertia of the cross section  $I_3$ :

$$I_3 = \frac{9\pi^2 - 64}{72\pi} R_o^4 (1 - \xi) + 2R_o^2 \xi (1 - \xi) \quad (14)$$

Where  $R_o$  of Equation (14) is the outer radius as shown in Figure 10 and  $\xi$  is the ratio between the inner area  $R_i$  and the outer radius  $R_o$ . The ratio is examined for a range between 90% to 60% of  $R_o$ . Figure 10 shows the effect of the change in the ratio over the moment of inertia for different cross-sections. This experiment of studying different cross-sections on a range is aimed to show which cross section gives more stiffness of the pressure arm and at what ratio.

The Figure 10 shows that the semicircular cross section provides a higher moment of inertia, leading to higher torsional springs' stiffness. Also, it shows that the semicircular cross section maintains at larger  $I$  and which ratio leads to larger  $I$ . It also shows that  $I_3$  is max at  $\xi = 73\%$  which will be used as constant ratio  $\xi = \frac{R_i}{R_o}$ .



**Fig 10.** Graphs show the relationship between the moment of inertia of different hollow cross-sections with a range of ratios of the inner and outer dimensions.

The load acting on the left and right segments is the grip force for individual fingers. The load should be bigger than the pressure force acting inside the tube to guarantee the spraying action. The pressure force can be calculated using Bernoulli equations (Equation (15)) where the required parameter for the spray mechanism is the orifice diameter (nozzle exit,  $R_e$ )<sup>(15)</sup>:

$$q = A_2 \left[ \frac{2(p_1 - p_2)}{\rho \left( 1 - \left( \frac{A_2}{A_1} \right)^2 \right)} \right]^{\frac{1}{2}} \quad (15)$$

Where  $q$  is the flow rate inside the pressure arm,  $p_2$  and  $A_2$ ,  $p_1$  and  $A_1$  are the pressure and the cross-section area of at the orifice and the pressure arm, respectively. From the Bernoulli equation, the orifice radius can be found based on the ratio ( $\beta$ ) of the orifice radius ( $R_e$ ) to the pressure arm inner radius ( $R_o$ ).

$$\beta = \frac{R_e}{R_o} \quad (16)$$

The ratio ( $\beta$ ) of (Equation (16)) has a typical value that ranges from 0.3 to 0.75 depending on the required exit velocity<sup>(16)</sup>. For the spray mechanism, the exit velocity should be in range to ensure spraying action, which does not require high speed. So, the ratio ( $\beta$ ) is chosen to be 0.4. Since the compliant mechanism is easily activated by different gripping positions by a light movement of fingers, the load remains small on linkages and the assembly. It exhibits good endurance strength of the mechanism due to the low amount of induced stress. Hence, its life expected can be more<sup>(17)</sup>. It is beyond millions of a number cycles irrespective of plunging the sanitizer/ liquid or holding in a particular gripping position. They are economical in mass production, as a 3D printer can produce the compliance mechanism. The glove setup's overall cost comes to USD 75 when produced single, and in mass production, a piece may cost come up to USD 15 to 20 for 10000 pieces and USD 2 to 3 for 1000000 pieces and so on.

## 4 Conclusion

We report the invention of self-sanitizer gloves that can defend the user because the glove sanitizes itself when the user grabs a surface. When the user touches a surface, the glove sanitizes itself. Besides, the Self-sanitizer glove will wipe the virus off multiple surfaces within the infected region. This work provides a step-by-step procedure to develop the spray compliant mechanism. The specification allows the user to reproduce the spray compliant mechanism's design by giving the total desired length (Lf) to generate all the required parameters.

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### Conflict of interest

The authors declare that there is no potential conflict of interest concerning research, authorship, and/or publication of this article.

## References

- 1) Sanu M. Impact of novel Coronavirus (COVID-19) pandemic on travel pattern: A case study of India. *Indian Journal of Science and Technology*. 2020;13(24):2491–2501. Available from: <https://doi.org/10.17485/IJST/v13i24.958>.
- 2) W H Organization. Coronavirus disease 2019 (COVID-19): situation report 59. 2020. Available from: <https://apps.who.int/iris/handle/10665/331597>.
- 3) Zhang X. Epidemiology of Covid-19. *N Engl J Med*. Available from: <https://doi.org/10.1056/NEJMc2005157>.
- 4) Zu ZY, Jiang MD, Xu PP, Chen W, Ni Q, Lu G, et al. Coronavirus Disease 2019 (COVID-19): A Perspective from China. *Radiology*. 2020. Available from: <https://doi.org/10.1148/radiol.2020200490>.
- 5) Zhang Y, FAAN, Sun Z, Latour J, Hu B, Qian J. Hospital response to the COVID-19 outbreak: the experience in Shanghai. *China J Adv Nurs*;2020(7):1483–1485. Available from: <https://doi.org/10.1111/jan.14364>.
- 6) Zhou Z, Zhao N, Shu Y, Han S, Chen B, Shu X. Effect of gastrointestinal symptoms in patients with COVID-19. *Gastroenterology*. 2020;158(8):2294–2297. Available from: <https://dx.doi.org/10.1053/j.gastro.2020.03.020>.
- 7) Zhonghua IZ. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) in China. *CPERE*. 2020;41(2). Available from: <https://doi.org/10.3760/cma.j.issn.0254-6450.2020.02.003>.
- 8) Anedda J, Ferreli C, Rongioletti F, Atzori L. Changing gears: Medical gloves in the era of coronavirus disease 2019 pandemic. *Clinics in Dermatology*. 2020. Available from: <https://dx.doi.org/10.1016/j.clindermatol.2020.08.003>.
- 9) Yuen KS, Ye Z, Fung S, Chan C, Jinet D. SARS-CoV-2 and COVID-19: The most important research questions. *Cell Biosci*;10. Available from: <https://doi.org/10.1186/s13578-020-00404-4>.
- 10) Webmd. WebMD. Coronavirus and Surfaces: How Long Does COVID-19 Live on Surfaces?. 2020. Available from: <https://www.webmd.com/lung/how-long-covid-19-lives-on-surfaces>.
- 11) Lateş D, Căşvean M, Moica S. Fabrication Methods of Compliant Mechanisms. *Procedia Engineering*. 2017;181:221–225. Available from: <https://dx.doi.org/10.1016/j.proeng.2017.02.377>.
- 12) Formlabs material properties – flexible: photopolymer resin for form 2 3d printers. 2017. Available from: <https://formlabs.com/materials/engineering/#flexible-resin>.
- 13) Taormina G, Sciancalepore C, Messori M, Bondioli F. 3D printing processes for photocurable polymeric materials: technologies, materials, and future trends. *Journal of Applied Biomaterials & Functional Materials*. 2018;16(3):151–160. Available from: <https://dx.doi.org/10.1177/2280800018764770>.
- 14) Howell LL. Compliant mechanisms;vol. 459. New York. Wiley. xvii. 2001.
- 15) Menon E. Transmission pipeline calculations and simulations manual;vol. 599. Waltham, MA. Elsevier/Gulf Professional. xii. 2015.
- 16) Upp EL, LaNasa P. Fluid flow measurement: A practical guide to accurate flow measurement;vol. 264. 2nd ed. Boston. Gulf Professional Pub. x. 2002.
- 17) Alfattani R, Lusk C. Shape-Morphing Using Bistable Triangles With Dwell-Enhanced Stability. *Journal of Mechanisms and Robotics*;2020(5):51003–51003.