# General Purpose Reusable Mechanical Glove

Kenneth Lee Wen
*School of Engineering*
*Asia Pacific University of Technology and innovation (APU)*
Kuala Lumpur, Malaysia
TP053285@mail.apu.edu.my

Low Yee San
*School of Engineering*
*Asia Pacific University of Technology and innovation (APU)*
Kuala Lumpur, Malaysia
yee.san@staffemail.apu.edu.my

Raed Abdulla
*School of Engineering*
*Asia Pacific University of Technology and innovation (APU)*
Kuala Lumpur, Malaysia
raed@staffemail.apu.edu.my

***Abstract*-This project is aimed at developing a general-purpose reusable glove that allows users to freely don gloves in a moment's notice when coming in contact with contaminated surfaces in this COVID-19 pandemic. The mechanical glove is composed of three major linkages in the housing, the palm and the four long fingers fully 3D printed. The mechanism implemented to tackle the retraction and extension of the glove relies on two distinct actuation techniques: cable-driven retraction for the palm and belt-driven shafts for the fingers. The dexterity of the user while the glove is equipped is evaluated with the Kapandji test and Feix's Grasp Taxonomy whereas the performance of the gloves is tested through a grip force setup as well as a retraction and extension mechanism time testing. The prototype developed is a product of low cost with sufficient functionalities and comfort paired with a highly reproducible retraction and extension mechanism.**

***Keywords— Reusable Mechanical Glove, COVID-19, 3D printed, cable-driven retraction, belt-driven shafts***

## I. INTRODUCTION

The one word that strikes fear into everyone's hearts in the year 2020 – COVID19. The pandemic started out as reports of a series of pneumonia cases with unknown origin in Wuhan, China on 31st December 2019. (World Health Organization [WHO], 2020) Before the Chinese government and the WHO were able to assess the situation and enforce necessary protocols, the disease had begun spreading worldwide. COVID19 was able to spread so quickly and silently due to its unique spreading pattern. According to the WHO (2020), 80% of COVID19 patients are asymptomatic or have mild symptoms consisting of fever, dry cough and fatigue. Severe patients will be plagued with breathing difficulties, lack of appetite, discomfort in the chest area and high fever, all of which are symptoms of pneumonia. (National Health Service [NHS], 2019) The symptoms may emerge anywhere between a day to two weeks upon exposure with COVID19, averaging at 5-6 days. The combination of inconsistent symptoms manifestation and symptoms that are commonly found in other simple sicknesses became the simple recipe for effective transmission. By the time COVID19 was declared a worldwide pandemic, the local transmissions have already begun, leading to incidents such as the Sri Petaling Cluster. According to the WHO's (2020) research based on current evidence, COVID19 is a strain of coronavirus that spreads through respiratory fluids and contact with contaminated surfaces. The primary recommendation by the Ministry of Health Malaysia (KKM) during the recovery movement control order (RMCO) is to practice 3Ws: Washing of hands, wearing of masks and warning others to take precautionary steps. It is also recommended to avoid 3Cs: crowded places, confined spaces and close conversations. By diligently adhering to the 3Ws and 3Cs and avoiding unnecessary excursions, the chances for contracting COVID19 is heavily reduced. As the scientists and medical professionals fight their way to a vaccine, COVID19 continues to lurk in the shadows of our daily lives. However, the routines and necessities of the common folks have to be maintained. Instead of feeling anxiety upon coming in contact with door handles, grocery shelves and various unknown surfaces, "General Purpose Reusable Mechanical Gloves" intends to eliminate any uneasiness while interacting with public facilities. The project aims to create a working prototype of a retractable and comfortable mechanical glove, allowing wearers to perform their duties with little to no disruption.

On a separate note, the Centers for Disease Control and Prevention (CDC, 2020) and the WHO (2009) outlines that the usage of gloves for the general public in dealing with the pandemic and other similar infectious diseases are unnecessary. These guidelines consider the general population's lack of knowledge on appropriate glove donning and doffing techniques. Furthermore, Freeman et al. (2014) states that only 19% of the world population wash their hands with soap after toilet usage. The importance of handwashing in preventing the transmission of COVID19 is further proven in Pogrebna and Kharlamov's (2020) study. In the study, countries with lack of handwashing habits are reflected in their initial spike of COVID19 cases per population as of 8th March 2020, namely: China, South Korea and Italy.

The use of disposable gloves not only poses an issue due to donning and doffing, but also in terms of the method of disposal. Personal Protective Equipment (PPE), including disposable gloves are an environmental hazard when they're littered or when they're not disposed properly. As a matter of fact, single-use masks and synthetic polymer gloves are not biodegradable and require additional steps for recycling. (Tan, 2020) When the gloves are used, they're also possibly contaminated and can pose a risk for cross-contamination for garbage collectors or even passers-by.

Not only that, but the supply of disposable gloves should also be prioritized for health-care workers (HCW) as well as front-liners. This is primarily because they are strongly advised against the reuse of gloves due to close contact with bodily fluids, mucous membranes as well as other potentially infectious materials. (WHO, 2006). Double gloving is also a common practice as a precaution and identification of glove degradation, alternatively serving as an easy-removal layer post-contamination.

According to WHO (2009), the potency of gloves against contamination and transmission of pathogens is proven is multiple clinical studies. However, proper glove usage and disposal stand in the way of making gloves a viable solution to be implemented alongside other preventive measures such as social distancing, frequent handwashing and wearing of masks. Therefore, a mechatronic engineering approach in “General Purpose Reusable Mechanical Gloves”, a reusable and mechanical glove that has contactless retraction is required to resolve the problems presented.

Therefore, the main aim of this project is to create a retractable mechanical glove that is comfortable and does not disrupt the user’s abilities, reusable and does not require contact for removal.

As recommended by the WHO and the KKM, the steps in preventing COVID19 transmission are primarily through the washing of hands before and after touching your face, the proper usage of masks and most importantly, social distancing. Although the usage of gloves can further reduce COVID19 transmission, its effectiveness is suppressed by human error. Even with social distancing and avoiding contact with unnecessary surfaces in public, door handles, lift buttons and groceries cannot be evaded.

For the duration of the pandemic, only a handful of products and ideas have been developed to tackle the problem of contact. Among the three of them, the first is a 3D printed part attached to a door handle, allowing people to open door handles with their forearm. (Simplify3D, 2020) The second and third ones share similar intentions as the proposed project whereby one is a fabric glove with a retractable cord and the other differs slightly in that it is a silicon oven mitt-style glove, also with a retractable cord. (However, the contact area for both gloves are not fully concealed and pose a risk for cross-contamination.

Unlike both glove products, the proposed project aims to provide a complete solution that does not place the user or the community at any risk of cross-contamination. Through the application of compliant mechanism, the mechanical glove will have minimal part-count and less wear compared to a rigid-body mechanism. (Shuib, Ridzwan & Kadarman, 2007) Through the usage of sensors and a microcontroller, the retraction and extension mechanism can be activated contactless. By using 3D printed parts, the project’s sustainability is improved, and users can easily obtain component replacements by 3D printing it or locating their nearest 3D printing service.

Lastly, due to the lack of research on mechanical gloves for the purpose of contact protection, the proposed project will be a pathway for future research. In particular, research on mechanical gloves for different applications such as contact with extreme cold or heat and contact with toxic materials.

Shimawaki et al. (2019) proposed a technique to determine flexion angles of the fingers using X-ray imaging. The 10 human test subjects has a mean hand length of 185.8 mm, mean palm length of 107.7 mm and mean hand width of 86.3 mm. The study indicated a lack of significant difference between the coupling ratio (ratio of flexion angles of the DIP and PIP) for all four long fingers. Shimawaki et al.’s research was limited by the 2-dimensional analysis of CT imaging, thus angles of thumb joints could not be measured accurately. Furthermore, prolonged exposure to X-ray is not recommended.

Allahyari, Khanehshenas & Khalkhali’s (2015) investigation, a sample of 30 university students were tested on their hand and finger dimensions as well as their gross and fine dexterity with the usage of disposable gloves using a Purdue pegboard test. The mean value for the thumb length, index finger length, middle finger length and thumb width were 66.56 mm, 94.56 mm, 103.17 m and 18.1 mm respectively. The results from the Purdue pegboard test indicated a mean score of 31.1, 33.9 and 31.02 for fine finger dexterity and a mean score of 10.00, 10.46 and 10.33 for gross dexterity using both hands. Allahyari, Khanehshenas & Khalkhali indicated that the Purdue pegboard test may be unsuitable to accurately assess the dexterity and the performance of human hands. Moreover, the test utilized unstandardized anthropomorphic hand dimensions which complicates the data comparison with other similar researches.

Preece, Lewis & Carre (2020) evaluated the efficiency of medical professional in donning and doffing four types of disposable medical examination gloves, namely: chlorinated (CL) latex, polymer coated (PC) latex, chlorinated nitrile and polymer coated nitrile. The study highlighted a tendency amongst the participants to select gloves of a larger size compared to the recommended sizes (based on middle finger length and palm circumference). However, the research is limited by the unrealistic testing of the doffing process as typical medical examination settings would involve prolonged usage which may lead to sweat. Not only that, there is insufficient information provided by glove manufacturers regarding the details of the manufacturing process. The study was also done based on the participants perceived best fit instead of the recommended best fit, which may cause significant changes in the results.

In the process of designing a hand exoskeleton for haptic applications, Nguyen and Tran (2016) proposed two different kinematic models, a 2-link and a 3-link model. Using Grubler’s formula, the 2-link and the 3-link systems have two and three degrees of freedom respectively. The forward and inverse kinematic equations were applied to determine the fingertip position and joint angles for both systems in the flexion and extension positions. A Monte Carlo approach was applied to resolve the multi-objective optimization process to determine the optimal geometry of the mechanism. A very similar focus compared to Nguyen and Tran’s research is the design and optimization of haptic glove mechanism developed by Ma & Ben-Tzvi (2015). The development of the haptic glove mechanism was further applied in the Sensing and Force-feedback Exoskeleton (SAFE) glove: a haptic exoskeleton with integrated sensing and actuation system (Ma & Ben-Tzvi, 2014). The haptic glove mechanism is lightweight, weighing at a total of 310 grams and is attached to the dorsum of the hand via the support pad, with secondary attachments at the tip of each finger.

Similar to Nguyen and Tran, the haptic glove mechanism and SAFE glove developed by Ma and Ben-Tzvi applied forward and inverse kinematic equations as well as geometry optimization in order to determine the optimal link lengths. Furthermore, the constraints due to mechanical design, kinematic modelling and collision of linkages are shared as well. However, two optimization techniques were utilized: numerical optimization and second derivate Lagrangian method with brute force global search (BFGS) formula. The index finger mechanism link lengths were optimized and resulted in 73.88 mm, 47.23 mm and 19.1 mm for each linkage beginning from the support pad (around 140 mm in total) compared to the normal values for the finger joints, MCP (48.3 mm), PIP (28.2 mm) and DIP (28.2 mm). Such a solution also increases the adaptability of the glove for users with varying hand sizes.

Secciani et al. (2019) focused on the three-step development of a novel under-actuated single phalanx rigid-body mechanism. Key design features that remained the same across all three prototypes are the housing of the actuator and electronics which are fixed on the dorsum of the hand. The primary concept of utilizing a motor to actuate the exoskeleton through a cable-driven mechanism remains unchanged as well. The development process for all three processes employed forward and reverse kinematics and different optimization algorithms to determine the geometry of the mechanism while 3D printing was used to fabricate the mechanism.

Gerez et al. (2020) proposed a fabric-type glove with semi-rigid parts and actuators. The actuation features of the glove is separated into four categories: flexion/extension, abduction/adduction, thumb opposition and telescopic thumb. The flexion for all fingers in addition to the thumb's opposition function are cable-driven. The proposed glove utilizes laminar jamming to increase stiffness during flexion while acting as a passive extension. Laminar jamming is a technique to compress and morph soft and flexible materials into rigid structures by applying a vacuum and in an enclosed pocket. The abduction/adduction of the long fingers are carried out by controlling the air pressure in the pneumatic chambers between the fingers. The telescopic thumb feature is also inflated similarly.

Similar to Gerez et al.'s exoskeleton glove, Rose and O'Malley (2018) proposed the SeptaPose Assistive and Rehabilitative (SPAR) fabric-type glove with metal fittings and vertebrae. The SPAR glove maintains a focus on the baseline of achieving functional grasps commonly used in ADLs and minimum ROM for healthy fingers while maximizing grasp force transmission. As the SPAR glove is primarily fabric, there is insufficient stiffness to maintain proper force transmission and path of the tendon-driven actuation. As such, an ergonomically designed palm bar is placed across the palm, redirecting and guiding the tendon's path. The glove also incorporates four sets of vertebrae-like mechanisms on the dorsal side of the thumb, pointer, middle and ring fingers to counteract excessive extension of the tendon actuation. The flexion and extension of the thumb and pointer are actuated individually whereas the remaining three fingers are combined.

Internet of things, or IoT, is one of the biggest advancements made in recent technological times (Abdulla et al., 2020; Al-Gumaei et al., 2018; Eldemerdash et al., 2020; Haziq et al., 2022; Hon et al., 2020; Kalilani et al., 2021; Katemboh et al., 2020; Lakshmanan et al., 2020; Murugiah et al., 2021; Nazrin et al., 2021; Rasheed et al., 2021; Samson et al., 2020; Singh et al., 2021; Yong et al., 2020). Smart IoT device with training algorithm performs the operation with lower power consumption (Priyadharsini. K et al.)

## II. SYSTEM IMPLEMENTATION

As shown in Fig1., the control system of the General-Purpose Reusable Mechanical Glove is split into three sections. The first section is the power supply which consists of a 3.7V Lithium Ion (Li-ion) 18650 battery and an XL6009 switching regulator. The battery is rated at 3800 mAh with recommended discharge of 0.2C (760mA) and maximum discharge of 1C at 3.8A. The battery feeds voltages of 3 to 4.2V depending on capacity to the voltage regulator. The voltage regular then steps up the voltage to approximately 5V. This is necessary to power the servo motors with a minimum functioning voltage of 4.8V. The microcontroller is powered by the regulated voltage via the $V_{IN}$ port which can withstand up to 30V.

The Maker Uno microcontroller contains the code whereby the system will continuously run as long as it is powered up. The microcontroller is a part of the mechanism activation and the actuation system. The Infrared sensor is powered through the 5V pin from the microcontroller and feeds data to it. The microcontroller processes the data receives and controls the three servo motors via pulse width modulation (PWM). The extension and retraction mechanism is split into the palm and the finger sections.

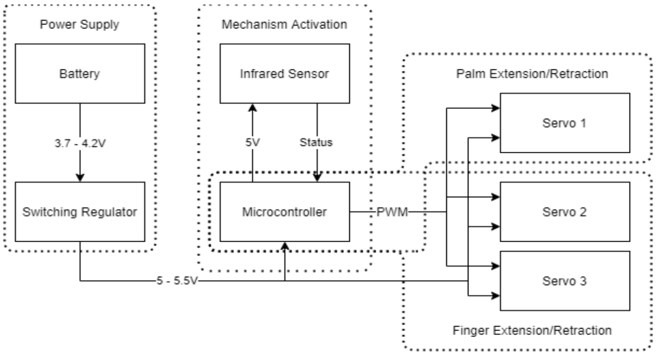

Fig. 1. System block diagram.

As shown in Fig 2., all the components share the same ground. The PWM inputs of the motors in connected to the digital pins 9, 10 and 11 on the microcontroller. The Infrared sensor is connected to digital pin 7. The printed circuit board (PCB) schematic is designed with such a shape such that the top right corner is emptied out to accommodate for a servomotor; the two blacked out portions on the schematic are actually holes for the protruding features on the housing unit. The traces on the PCB were designed to have a minimum gap of 30 mils or 0.762mm. The connections with lower currents were designed to have a trace width of 10 mils. The connections entering and exiting the voltage regulator directly have a trace width of 15 mils to be able to better sustain the larger currents flowing through.

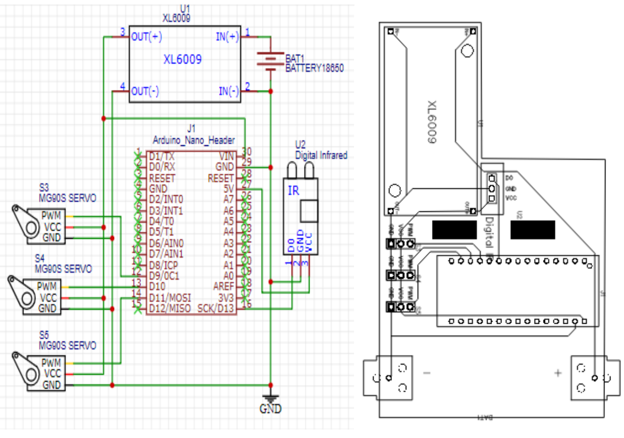

Fig. 2. Wiring diagram (left) and pcb schematic (right).

Upon system activation, the microcontroller is initialized with the glove status of false or retracted. The system continuously runs until the infrared sensor detects an obstruction. Rather than the infrared being connected to the analog inputs of the microcontroller to measure distance of obstruction, it is connected to a digital pin whereby the status of the infrared sensor momentarily true and thus the extension or retraction mechanism commences. If the glove status is true or extended, the system runs the retract() function whereby it contains instructions for the activation of the servo motors performing the retraction motion. The system will instead run the extend() function if the glove status happens to be false or retracted. At the end of each function or the completion of the either mechanism, the glove status is inversed. A short delay is introduced before the main code loops again to ensure all data is registered in the system.

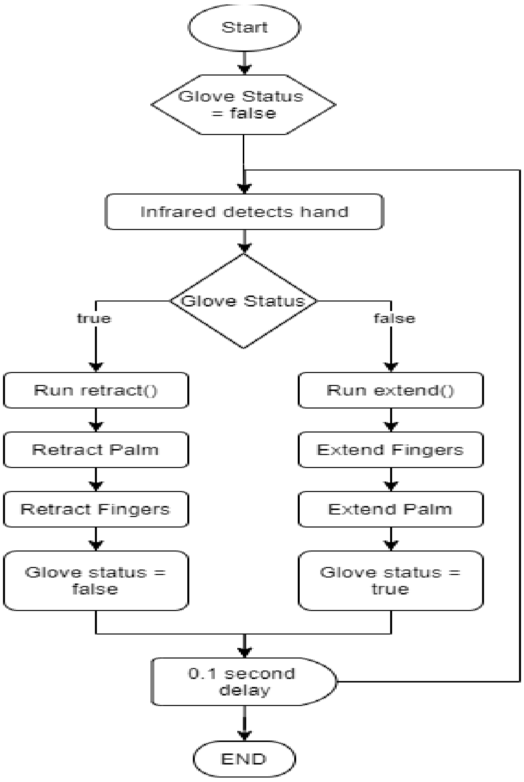

Fig. 3. Flowchart for System Working Principle.

The structure of the mechanical glove is split into three parts. The first part is the housing which is fixated on the wrists of the user. The palm and thumb section is a separate part whereby it is retractable via a tendon-driven mechanism powered by the servo on the far right in Fig 4. The fingers are retractable via a combination of two beams connected to the two servos on the left in Fig 4. via belt mechanism. The electronics and battery are designed to be attached to a PCB and positioned on the far right of the housing. Fig 5. shows the glove in its partially extended position on the left and fully retracted position on the right. The figures also show the location of the servos on the housing piece. The step-by-step finger extension and retraction belt mechanism is shown in Fig 6.

The retraction and extension mechanisms are designed with special features to allow for snap fits and modular printing. The fingers and palm are connected with a cylindrical joint. The finger and palm sections are printed separately and can be attached via a snap-fit mechanism. This allows not only printing separate pieces due to small build volumes on 3D printers, but also allow customization with respect to the modular capabilities. The palm and housing sections are connected with a partial cylindrical joint that allows the palm to move horizontally with respect to the housing unit and also allows flexion and extension of the user's palm when the palm piece is fully extended. The joint piece on the housing unit is printed separately to allow proper positioning setup of the palm and housing before the joint is attached. The joint piece also incorporates a snap-fit design to allow easy replacement of the palm portion when it is worn out or broken.

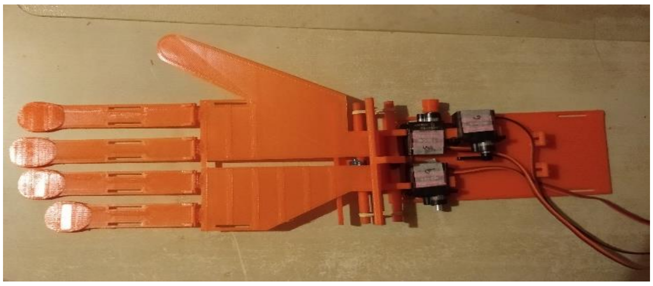

Fig. 4. Fully extended mechanical glove.

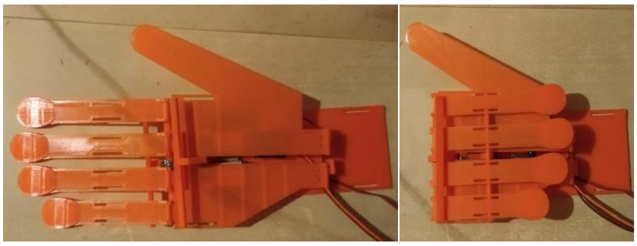

Fig. 5. Partially extended (left) and fully retracted (right) mechanical glove.

Fig. 6. Finger retraction/extension mechanism.

The retraction and extension mechanism of the fingers were actuated via 2 separate shafts with a fixed linkage and fits into the holes on the housing piece. Each shaft is 3D printed into two pieces and attached together upon fitting them through the holes. The shafts were designed as two detachable pieces rather than a single shaft due to the restrictions of the housing design along with the interactions between the housing, palm and finger parts as a single assembly. Grooves were designed on both ends of the shafts for placement of the belt drive.

The retraction and extension mechanism of the fingers were actuated by a single servo motor through the use of cables connected and fastened to two small holes located at the edge of the palm piece. Two strings or cable is connected from the servo to the palm piece, one for retraction and the other for extension. The working principle behind this mechanism is such the motor will rotate clockwise or counter-clockwise, reducing the length of one string while simultaneously increasing the length of the other. The shortened string will be under tension whereas the lengthened string will be slacking. As a result of this, the palm piece will align itself along the housing unit whereby the string or cable under tension will take the shortest path possible.

The mechanical glove without the electrical, electronic components and retractable mechanisms were fitted with elastic straps to display and test the fittings and functionality of the gloves. The position of the joints on the mechanical gloves are slightly different compared to the surface area of the palm. This is to ensure that the finger-palm joint is parallel to the MCP joint whereas the palm-housing joint is placed much lower than the wrist to allow for fully flexion capabilities.

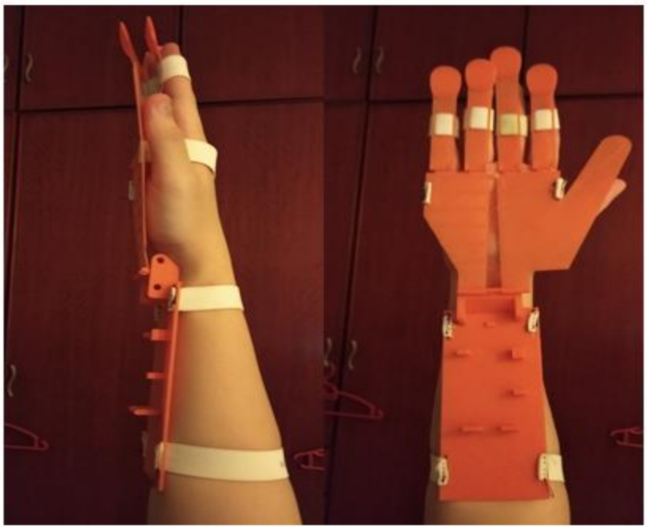

Fig. 7. Mechanical glove fitted with elastic straps.

## III. TESTING OF THE PROPOSED DESIGN

### A. *Kapandji Test*

The Kapandji test was created by Kapandji (1986) to assess the dexterity of the thumb, especially the opposition and reposition motion without the need of any external equipment. Using only the hand of the subject, scores were given based on the ability of the subject to reach certain areas of the hand with the tip of the thumb. The scoring system ranges from 0 to 10 based on Fig 8.

Fig. 8. Kapandji scores (left) and evaluation of the mechanical glove (right).

The test was performed using the mechanical glove that does not contain any electronics on it as the functionality of the mechanisms and the mass of the components are not relevant. The elastic straps as shown in Fig 7. was used to secure the glove to the hand while the evaluation was under way.

Based on the evaluation, the mechanical gloves were able to achieve a Kapandji score of 6. The rigidity of the palm and thumb piece around the carpometacarpal joint area as well as the inability for the thumb to perform abduction and adduction motion prevented the full opposition motion of the thumb in order to perform the positions of 7 till 10.

### B. *Feix GRASP Taxonomy*

The Feix taxonomy was developed by Feix et al. (2015) to be a reference for terminology related to human hand configurations in various biomedical and robotic applications. The GRASP taxonomy was a compilation of existing grasp taxonomy and classification and naming standardization of grasp techniques into 33 grasp types which can be further reduced into 17 if the shape and size of the object is omitted. Feix's taxonomy is used to evaluate the user's dexterity to perform ADLs while equipped with the General Purposed Retractable Mechanical Glove. The setup of this test is similar to that of the Kapandji test as the actuation and electronic components are not vital in evaluating the dexterity.

The ability to achieve a grasp will be evaluated based on 4 criterias. The first criteria lies in the comfortability while the posture is held, such that the score of 0 indicates a severe disruption and discomfort resulting from the glove and 5 indicating no discomfort. The second criteria is the effectiveness of the grasp, such that a score of 0 indicates that the object being grasped cannot be maintained in the position for longer than 5 seconds whereas a score of 5 indicates no difficulty in maintaining the grip for longer than 30 seconds. The third criteria is ease of replication of the grasp such that 0 indicates the need for external support to recreate the grasp and 5 indicate a short and simple replication process. The fourth and final criteria is contact avoidance whereby a binary result hand coming in contact with the object directly.

Most grasps are able to be completed comfortably with the exception of Light Tool which scored a 2 out of 5 for criteria 1. Based on criteria 2, most grasps which are catered to large objects can be maintained for an extensive period of time. Smaller objects that require a tight grasp such as Light Tool, Stick, Palmar, Fixed Hook and Ventral which scored 3 or below is difficult to maintain due to the lack of joints present in the glove structure, in which excessive bending beyond the elastic limit is required. Precision and prismatic grasps are also difficult to maintain on smooth objects due to the lack of friction on the glove structure. The lack of friction is also a big factor in the difficulty to achieve the grasp (criteria 3).

In certain cases, the limitations of the glove structure combined with the opposition motion from the thumb caused the palm section to be detached. Out of the 33 grasp types, 10 managed to be completed without contact. The main causes of contact during the 23 other grasps is due to the inability for the thumb to abduct/adduct and certain grasps utilizing the side of the fingers and thumbs such as the adduction grip. 4 grasps obtained an average score below 3, which is a sign of necessary improvement.

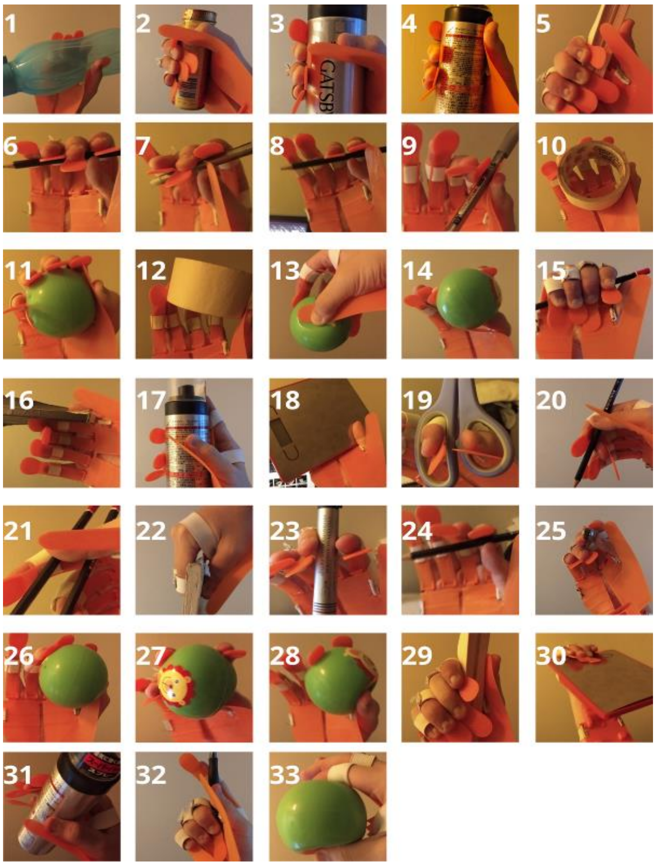

Fig. 9. Feix GRASP taxonomy results.

### C. *Grip Force Testing*

The grip force test was performed for the mechanical glove to be evaluated in terms of performing a singular gripping action between the flexion motion of the four long fingers and the palm similar to the motion of squeezing a stress ball. The grip force was evaluated under three different conditions with the first being bare handed as a controlled variable. The two other condition being tested is the fully strapped glove with and without the housing unit. The gripping force is measured through a calibrated load cell displaying readings in terms of grams on the serial monitor of the Arduino client. A single set of values is defined as the average value of ten consecutive readings and was repeated for four times for each of the conditions.

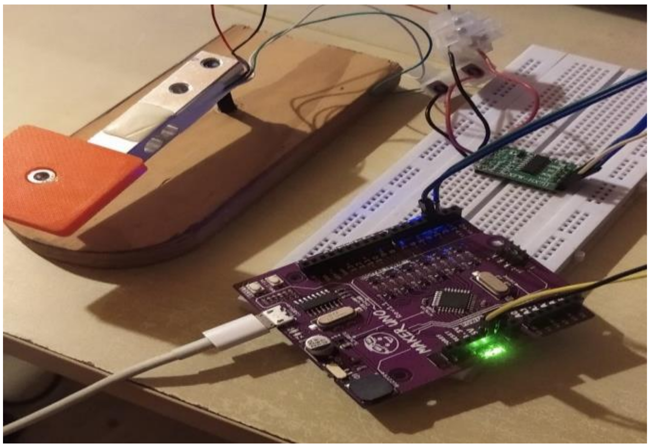

Fig. 10. Grip force testing load cell setup.

TABLE I. TABLE OF CRITERIA-BASED RESULTS FOR FEIX GRASP TAXONOMY

| Grasp Name | Grasp No | Criteria 1 | 2 | 3 | Average | 4 |
|---|---|---|---|---|---|---|
| Large Diameter | 1 | 5 | 4 | 1 | 3.3 | 0 |
| Small Diameter | 2 | 4 | 4 | 3 | 3.7 | 0 |
| Medium Wrap | 3 | 5 | 5 | 4 | 4.7 | 0 |
| Adducted Thumb | 4 | 5 | 5 | 5 | 5 | 1 |
| Light Tool | 5 | 2 | 3 | 1 | 2 | 0 |
| Prismatic 4 Finger | 6 | 4 | 4 | 4 | 4 | 0 |
| Prismatic 3 Finger | 7 | 4 | 4 | 4 | 4 | 0 |
| Prismatic 2 Finger | 8 | 4 | 3 | 4 | 3.7 | 0 |
| Palmar Pinch | 9 | 4 | 2 | 3 | 3 | 0 |
| Power Disk | 10 | 5 | 5 | 5 | 5 | 1 |
| Power Sphere | 11 | 5 | 5 | 4 | 4.7 | 1 |
| Precision Disk | 12 | 5 | 4 | 5 | 4.7 | 1 |
| Precision Sphere | 13 | 5 | 5 | 5 | 5 | 1 |
| Tripod | 14 | 5 | 5 | 4 | 4.7 | 1 |
| Fixed Hook | 15 | 5 | 2 | 4 | 3.7 | 1 |
| Lateral | 16 | 4 | 4 | 4 | 4 | 0 |
| Index Finger Extension | 17 | 5 | 5 | 5 | 5 | 0 |
| Extension Type | 18 | 5 | 5 | 3 | 4.3 | 0 |
| Distal | 19 | 4 | 3 | 1 | 2.7 | 0 |
| Writing Tripod | 20 | 5 | 5 | 5 | 5 | 0 |
| Tripod Variation | 21 | 5 | 5 | 2 | 4 | 0 |
| Parallel Extension | 22 | 4 | 5 | 3 | 4 | 0 |
| Adduction Grip | 23 | 5 | 5 | 5 | 5 | 0 |
| Tip Pinch | 24 | 4 | 3 | 4 | 3.7 | 0 |
| Lateral Tripod | 25 | 4 | 4 | 3 | 3.7 | 0 |
| Sphere 4-Finger | 26 | 5 | 5 | 5 | 5 | 1 |
| Quadpod | 27 | 5 | 5 | 4 | 4.7 | 1 |
| Sphere 3-Finger | 28 | 5 | 5 | 5 | 5 | 1 |
| Stick | 29 | 4 | 2 | 2 | 2.7 | 0 |
| Palmar | 30 | 5 | 5 | 4 | 4.7 | 1 |
| Ring | 31 | 5 | 5 | 5 | 5 | 0 |
| Ventral | 32 | 4 | 1 | 1 | 2 | 0 |
| Inferior Pinch | 33 | 5 | 5 | 2 | 4 | 0 |
| | Total Average | 4.54 | 4.15 | 3.61 | 4.11 | |

TABLE II. DATA FROM GRIP FORCE TESTING.

| Condition | Bare-handed | Glove with housing | Glove without housing |
|---|---|---|---|
| Lower Limit | 4678.36 | 3807.12 | 3769.11 |
| Upper Limit | 6416.5 | 5783.07 | 6514.74 |
| Range | 1738.14 | 1975.95 | 2745.63 |
| Mean | 5510.772 | 4918.018 | 5021.353 |
| Standard Deviation | 419.893 | 536.4242 | 648.6301 |

Based on the data collected, the average grip force (mean) and standard deviation was calculated using Excel. Based on the compiled data in TABLE II, the average grip force exerted while the gloves with housing are worn was calculated to be 10.8% lower than the average bare handed grip force. The average grip force for gloves without housing increased by a small margin compared to the gloves with housing at 8.9% lower than the bare handed grip force. The standard deviation for the bare-handed, gloved with housing and gloved without housing are 7.62%, 10.91% and 12.92% respectively when expressed as a percentage. Furthermore, bare-handed force exertion indicate data with less variation, whereas the standard deviation for both gloved data sets are higher when expressed as absolute or percentage. Based on the upper limits of all three conditions, it is reasonable to assume that the gloves without housing does not limit the gripping force. However, the presence of the housing seem to affect the gripping ability of the user by a significant margin. The large discrepancy in the range of values of the gloves without housing indicate the inability to maintain gripping force. The difference in mean gripping forces and standard deviation can be attributed to the glove structure disrupting the user's ability to apply a consistent gripping force.

## IV. CONCLUSION

Research surrounding upper-limb assistive technology is increasingly prevalent in the past decade. However, the COVID19 pandemic brought awareness to the need for effective contact prevention for the general public. Hand sanitizers, frequent handwashing and disposable gloves are partial solutions to a larger problem. Through the integration of compliant material and mechanisms with conventional actuation techniques such as cable-driven and belt driven mechanisms. The mass of the gloves with all the electronic and electrical components is measured to be at 142 grams which is significantly higher compared to a disposable glove but not enough to adversely affect the user's experience. The gloves scored a 6 on the Kapandji test and 4.1 average score for the Feix's GRASP taxonomy based on three criteria: comfortability, grasp effectiveness and ease of replication.

## References

ALLAHYARI T., KHANEHSHENAS F. AND KHALKHALI H. R. (2015). An Investigation of the Impact of Using Latex and Nitrile Gloves on Hand Dexterity. International Journal of Occupational Hygiene. 7(1) p. 22 – 26. Available at: (PDF) An Investigation of the Impact of Using Latex and Nitrile Gloves on Hand Dexterity (researchgate.net) [Accessed: 29 December 2020].

Abdulla, R., Eldebani, A. A., Selvaperumal, S. K., & Abbas, M. K. (2020). IoT based Pet Feeder. Test Engineering & Management, 83(March-April 2020), 269–279.

Al-Gumaei, W., Selvaperumal, S. K., Abdulla, R., & Nataraj, C. (2018). Smart Tree Care System with Internet of Things. Research Journal of Applied Sciences, Engineering and Technology, 15(9), 328–336. https://doi.org/10.19026/rjaset.15.5923.

CENTERS FOR DISEASE CONTROL AND PREVENTION (2020). Wearing Gloves – When Gloves Are and Aren't Needed. Available from: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/gloves.html [Accessed: 12 November 2020]

FEIX T., ROMERO J., SCHMIEDMAYER H., DOLLAR A. M. AND KRAGIC D. (2015). The GRASP Taxonomy of Human Grasp Types. *IEEE Transactions on Human-Machine Systems.* 46(1) p. 1 – 12. DOI: 10.1109/THMS.2015.2470657 [Accessed: 1 May 2021]

FREEMAN M. C., STOCKS M. E., CUMMING O., JEANDRON A., HIGGINS J. P. T., WOLF J., PRÜSS-USTÜN A., BONJOUR S., HUNTER P. R., FEWTRELL L. AND CURTIS V. (2014). Systematic review: Hygiene and health: systematic review of handwashing practices worldwide and update of health effects. Tropical Medicine & International Health. 19(8) p. 906 – 916. DOI: https://doi.org/10.1111/tmi.12339 [Accessed: 29 November 2020]

GEREZ L., GAO G., DWIVEDI A. AND LIAROKAPIS M. (2020). A Hybrid, Wearable Exoskeleton Glove Equipped With Variable Stiffness Joints, Abduction Capabilities, and a Telescopic Thumb. IEEE Access. Vol 8. DOI: 10.1109/ACCESS.2020.3025273 [Accessed: 27 December 2020]

Haziq, M. I., Noor, I. M. B. M., & Abdulla, R. (2022). Smart IoT-Based Security System for Residence. Journal of Applied Technology and Innovation, 6(1), 18–23.

Hon, F. S., Abdulla, R., Selvaperumal, S. K., Nataraj, C., & Ratnadurai, D. (2020). Wheelchair-Person Fall Detection with Internet of Things. Solid State Technology, 63(1S), 911–922.

Kalilani, M., Lai, N. S., & Abdulla, R. (2021). IoT Based Neonatal Incubator for the Developing World and Conflict zones. Journal of Applied Technology and Innovation, 5(4), 44–50.

KAPANDJI A. (1986). Clinical Test of Apposition and Counter-Apposition of the Thumb. *Annales De Chirurgie De La Main : Organe Officiel Des Societes De Chirurgie De La Main.* 5(1) p. 67 – 73. DOI: 10.1016/s0753-9053(86)80053-9 [Accessed: 12 May 2021]

Katemboh, E. M., Abdulla, R., Jayapal, V., Selvaperumal, S. K., & Ratnadurai, D. (2020). Integrated Animal Health Care Using IoT. International Journal of Advanced Science and Technology, 29(01), 42–56.

Lakshmanan, R., Djama, M., Selvaperumal, S. K., & Abdulla, R. (2020). Automated Smart Hydroponics System Using Internet of Things. International Journal of Electrical and Computer Engineering, 10(6), 6389–6398.

Ma, Z., & Ben-Tzvi, P. (2015). Design and optimization of a five-finger haptic glove mechanism. Journal of Mechanisms and Robotics, 7(4).

NATIONAL HEALTH SERVICES (2019). Pneumonia Overview. Available from: https://www.nhs.uk/conditions/pneumonia/ [Accessed: 18 November 2020]

NGUYEN T. AND TRAN V. (2016). Kinematic Modelling and Geometric Optimization of a Cable-driven Hand Exoskeleton for Haptic Applications. In 5th World Conference on Applied Sciences, Engineering & Technology. Vietnam and 2nd – 4th June 2016. [Accessed: 23 December 2020]

POGREBNA G. AND KHARLAMOV A. A. (2020). The Impact of Cross-Cultural Differences in Handwashing Patterns on the COVID-19 Outbreak Magnitude. To be published in Regulation and Governance. Advance Online Publication. 22 [Preprint] DOI: 10.13140/RG.2.2.23764.96649 [Accessed: 20 November 2020]

PREECE D., LEWIS R. AND CARRE M. (2020) Efficiency of Donning and Doffing Medical Examination Gloves. *International Journal of Ergonomics,* 10 (1). p. 1 – 17. Available at: http://eprints.whiterose.ac.uk/163531/ [Accessed: 30 December 2020].

Priyadharsini, K., Kumar, J. D., Deepakkumar, A., Chandran, S., & Babu, C. G. (2021, February). A Novel System for Surgical Gloves Removing and Reusing-IoT Approach. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1059, No. 1, p. 012071). IOP Publishing.

ROSE C. AND O'MALLEY M. K. (2018). A Hybrid Rigid-Soft Hand Exoskeleton to Assist Functional Dexterity. *IEEE Robotics and Automation Letters.* 4(1) p. 73 – 80. DOI: 10.1109/LRA.2018.2878931 [Accessed: 26 December 2020]

Rasheed, W. M., Abdulla, R., & San, L. Y. (2021). Manhole Cover Monitoring System Over IOT. *Journal of Applied Technology and Innovation*, *5*(3), 1–6.

Samson, A. M., Dhakshyani, R., & Abdulla, R. (2020). IoT Based Sustainable Wallet Tracking System. *International Journal of Advanced Science and Technology*, *29*(1), 1301–1310.

SHIMAWAKI S., MURAI T., NAKABAYASHI M. AND SUGIMOTO H. (2019). Measurement of Flexion Angle of the Finger Joint during Cylinder Gripping Using a Three-Dimensional Bone Model Built by X-Ray Computed Tomography. *Applied Bionics and Biomechanics*, vol. 2019. Available at: https://doi.org/10.1155/2019/2839648 [Accessed: 5 January 2021]

SECCIANI N., BIANCHI M., RIDOLFI A., VANNETTI F., VOLPE Y., GOVERNI L., BIANCHINI M. AND ALLOTTA B. (2019) Tailor-Made Hand Exoskeletons at the University of Florence: From Kinematics to Mechatronic Design. *Machines.* 7(2). DOI: 10.3390/machines7020022 [Accessed: 23 December 2020]

Singh, H., Abdulla, R., & Selvaperumal, S. K. (2021). Carbon Monoxide Detection Using IoT. *Journal of Applied Technology and Innovation*, *5*(3), 7–12.

TAN P. T. (2020). Face Masks, Gloves and PPE: A New Breed of Plastic Pollution. Available from: https://codeblue.galencentre.org/2020/08/03/face-masks-gloves-and-ppe-a-new-breed-of-plastic-pollution/ [Accessed: 23 November 2020]

WORLD HEALTH ORGANIZATION (2006). Glove Use (Technical). Available from: https://www.who.int/gpsc/tools/Infsheet6.pdf [Accessed: 25 November 2020]

WORLD HEALTH ORGANIZATION (2009). Glove Use Information Leaflet. Available from: https://www.who.int/gpsc/5may/Glove_Use_Information_Leaflet.pdf [Accessed: 13 November 2020]

WORLD HEALTH ORGANIZATION (2020). Coronavirus Disease (COVID-19). Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19#:~:text=symptoms [Accessed: 10 November 2020]

WORLD HEALTH ORGANIZATION (2020). Timeline: WHO's COVID-19 Response. Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/interactive-timeline?gclid=CjwKCAiA5IL-BRAzEiwA0lcWYoPZhvmpbg1VDM2HG4FDfDPGno83cuRr0IL-j39bapmGEfQy7_DRjRoCA2UQAvD_BwE#! [Accessed: 15 November 2020]

Yong, L. Y. I., DHAKSHYANI, R., & Abdulla, R. (2020). Intelligent Book Returning and Sorting System Using IoT. *Solid State Technology*, *63*(1S), 899–910. http://www.solidstatetechnology.us/index.php/JSST/article/view/780