The University of Sussex
School of Engineering & Informatics

Masters Dissertation

Programme…MSc in ……Robotics and Autonomous Systems………………….…………..……………......

Candidate number …254055………………

Title of Dissertation …Exoskeleton glove for upper limb rehabilitation……………………………………………………
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……………………………………………………………….………...

Approximate number of words ……8000…………

Supervisor(s) ……Yanan Li…………………………………………………………

Date submitted …01/09/2022……………... Time submitted …13：33………………….

Declaration

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I certify that the content of this dissertation is my own work, and that my work contains no examples of misconduct such as plagiarism, collusion, or fabrication of results.

Candidate's signature …Zhihao Zhu………………………………………………………….

Abstract
The project is a rigid exoskeleton glove which aims to work as the power supply part of the hand. It may help people with the symptoms of diseases, injury, or nervous disorders. An external action-supporting device can not only help with the daily support on moving or action but also in rehabilitation. Symptoms can be reduced by training in some situations. The budget can realize one finger of the hand part in the prototype. The prototype focuses on the index finger and gets 3 degrees of freedom for the links. Two of them have the power to assist.

Building this exoskeleton needs some techniques from others. Such as the CAD to design its structure, 3D printing to print out the components, MATLAB as the driving system of the robot, Arduino board as the controller and the breadboard to jump wire. Servo motors drive the assist function and use the fsr sensor to collect the user's feedback.

This research shows that the cost of the action-supporting technique can be acceptable, and its ability is reliable. Increasing the number of people who need this technique, the exoskeleton will bring people a higher quality of life.

Acknowledgements
Many thanks to the lab staff and the teachers who help me with the project. Also, thanks to Kevin Brady, who taught me how to glue the broken parts up, and Dr Hareesh Godaba gave me ideas about controlling the servo motor. Finally, I most appreciate my supervisor Dr Yanan Li who supported and guided the project and allowed patients to discuss details so many times.

Table of Content

Extra documents:

底座.SLDPRT
中指节左.SLDPRT
中指节右.SLDPRT
指头.SLDPRT
后指头左.SLDPRT
组装.SLDASM
servo_drive3.m
fsr.m
main.m

1. Introduction

1.1 problem to solve

humanity always finds their body is not strong enough to solve all the questions they meet. Sometimes not strong enough to draw the bow, maybe too weak to carry the heavy stuff, and perhaps the body structure is not rigid as they imagine that they got a fracture. This is one of the reasons why the ancients often had animal worship. Even nowadays, medical technology is developed, and society is getting more and more humanitarian, people sometimes still find that they need a better limb. It could be because they are working on a construction site and want to enforce their upper limb, or they find they are too old to use their limbs and need other things to support their moving or grabbing. People live longer than before and survive easily after some illness.

More and more people find that the disease's sequelae make it harder to use their limbs. For example, they get a stroke or other motor and functionality impairment caused by a neurological illness or injury. Sometimes they are unable to move, or sometimes they cannot control their muscles correctly. They need an assistive device to help with their daily life and rehabilitation. Research has shown a significant future shortage in health care hospitals and rehabilitation centres because of the increasing number of disabled people[1]. This provides a big necessity for health care and rehabilitation service. The increase in supply is lower than the demand. It makes the cost of the treatment goes higher. The chance of in-house care does not belong to every patient in the future. Perhaps most of them will be sent to a waiting list and wait for a long time to miss the best period for recovery. The first month after the first week of stroke is the best period for rehabilitation. The following two months still have an excellent effect but are not as efficient as before. The treatment after the third month does not work so good anymore [2]. This means that the demand for taking—away rehabilitation services will be considerably more popular.

People have lived longer in the recent century, but the body of a human is not prepared for people to live longer than expected[3]. Many people are getting easier to face the threat of getting a stroke. A stroke is similar to a symptom that disconnects the link between the body and the brain[4]. Finding the port will take time to link the actuators back to the controller. Using the part affected by stroke will stimulate the nerve to link muscle and the brain again. A treatment assist device may help their rehabilitation before getting into the professional rehabilitation centre, so they do not waste the best chance to recover. It may also save the budget for them if they just suffered from a light stroke symptom or some neurological disease.

In the robotic area, the challenge is that it is difficult to simulate the movement of muscles. This project focuses on the hand part. Though the hand only occupy a small amount of mass in the upper limb compared to the arm, its structure is much more complex. The human hand have got 15 joints and 29 skeletal muscles with 21 degrees of freedom[5]. Most of the parts of it can work at the same time. It will be too complicated to modify all the muscles in hand as the link parts. That will be a significant burden on the microcontroller. Even though a processor is powerful enough to control all the robot's actuators, that will be too costly for the patients. So it is essential to design a robotic device that can use the links, sensors and actuators as little as it can but can mobilize most of the muscles on the hands for training. It also needs to function the power supply and the nerve network during the disabled period. The device should also be small enough to be convenient to use—for example, wearable and Ergonomics design. The material also needs to be light enough to avoid the burden of daily use.

1.2 target

This project focuses on the wearable rehabilitation assistance device, which is easy for people to use daily. Reduce the work of the enormous machine. It will save the use of the machine to help more people who need it urgently. This will also keep the maintenance cost of the device to protect the medical social resources. To be a piece of convenient and wearable equipment, the exoskeleton should be easy to use for anyone and easily afford. The device also aims to help with patients' daily use of hand parts, and some others need the assistance device by a bit of reform on shield designing and circuit updating.

The research should contribute to the civilianization of exogenous power equipment after researching.

2. Background research

Before starting the project, researching the background and searching for materials to improve the understanding of neurorehabilitation and the exoskeleton is helpful. This part shows the literature review and the existing prototype for the exoskeleton and rehabilitation device.

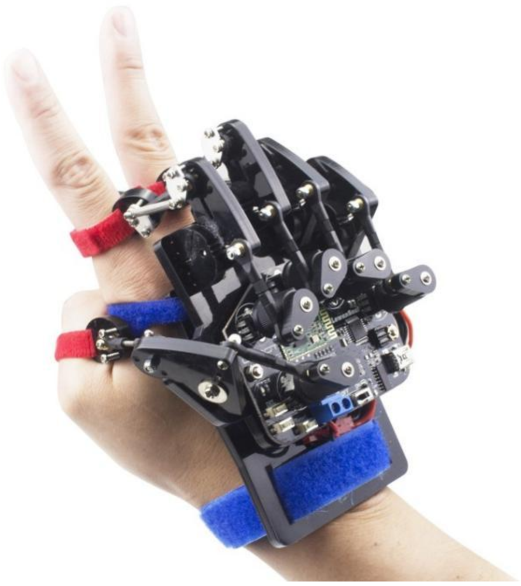
Primates have more adroit palms than other creatures, and people are the foremost rich among them[6]. The hands are the most complex and advanced portion of the upper limb of the human body. It catches things up and down and precisely works with profoundly controlled muscles. So humankind can use very complex tools which other primates cannot. The complex structure and nerves around the hand allow people to use the upper limb precisely. This is also one of the most significant differences between humans and other animals. When something goes wrong with the control of the hands, it will decrease the quality of life. Some research found that the index finger takes control of the precision of the hand's action. This finger plays an essential role in writing and using chopsticks. Some researchers believe that If someone has lost his index finger, the middle finger will play that role [7]. They think the brain's control is mainly focused on the nearest finger of the thumb. If someone hasn't got an index finger, the middle finger will become the nearest one to the thumb. Typical patients with neurological disorders and a stroke have all the fingers. So this project can mainly focus on the device for the index finger because some researchers define that the best target for stroke rehabilitation is restoring daily life skills[8]. Though the grip mainly depends on the little finger[7], the controller of the robotic links does not have the focus tendency and assists. So the rehabilitation of the index finger is more important than other fingers.

With the growing percentage of elders, medical resources will not be enough to meet the demands of society[1]. Automation is the trend in future nursing care. So exoskeleton will be an excellent choice in health care.

The exoskeleton is an active assistance device divided into active and passive[9]. The passive one is to use the structure to sustain the body to save the energy of maintaining the body shape(for example, it is still tiring for people to keep the position when they lift heavy stuff though they do not work with external ones). As the opposite of the passive one, the active skeleton has the power supply by itself to assist the user. During the researchers' research, the active exoskeleton usually does not use self-block to maintain the position because they need to keep the joint flexible for moving[10]. This feature is fit to be applied to the fingers' flexibility.

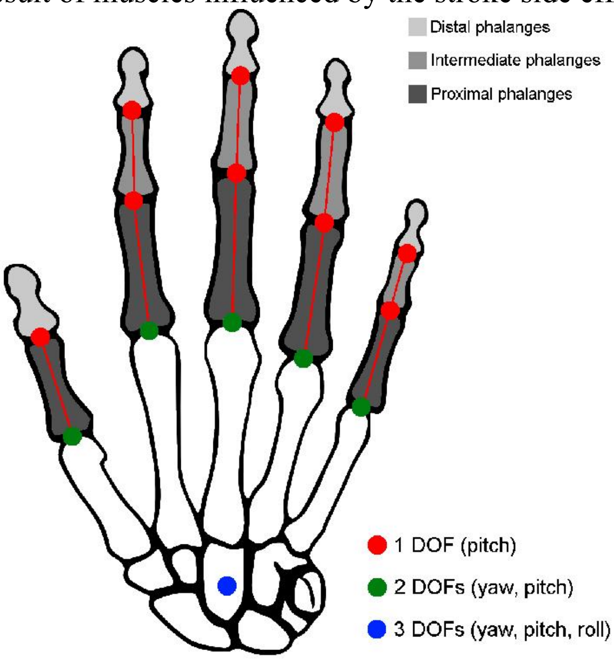
There are two different kinds of an exoskeleton. One is the traditional rigid one, and another is the soft exoskeleton(植入图片). Airbags and springs usually drive soft Design. It is easy to maintain but hard to achieve precise work without very complex Design. For example, use the soft part to simulate the muscles. As a "skeleton", the device also needs to protect the part of the body from external damage, such as the harm caused by itself [11]. Lost control of the finger is dangerous because if the muscles get overwhelming and work towards the wrong against the joint will damage the body. Active exoskeleton benefits finger control and grip support[12]. The solid structure assists limit the part of the body in the designed moving way. Once it assists the daily use of the body part, it protects it and helps with that rehabilitation. Focus on stimulating the nerve network is a critical way of restoration. To give more focus on a body part, some researchers discovered that utilizing the diversion propels the patients to undertake their best to mobilize the muscles of the fingers to total the desired activity[13].

To build an exoskeleton for the upper limb, the work is mainly about how to create an exoskeleton for the hand[1]. So is the relationship between the hand and the finger. Different from the lower limb, the finger is asked for more gestures. Most finger skeletons nowadays are only allowed to have a grab-and-release function. As shown in the picture below, there is only one power drive on each finger. This means that the user can't make the complex gesture and use some tools just driven by the device, such as writing and using chopsticks.



(Picture 1, sourced by aliexpress.com)

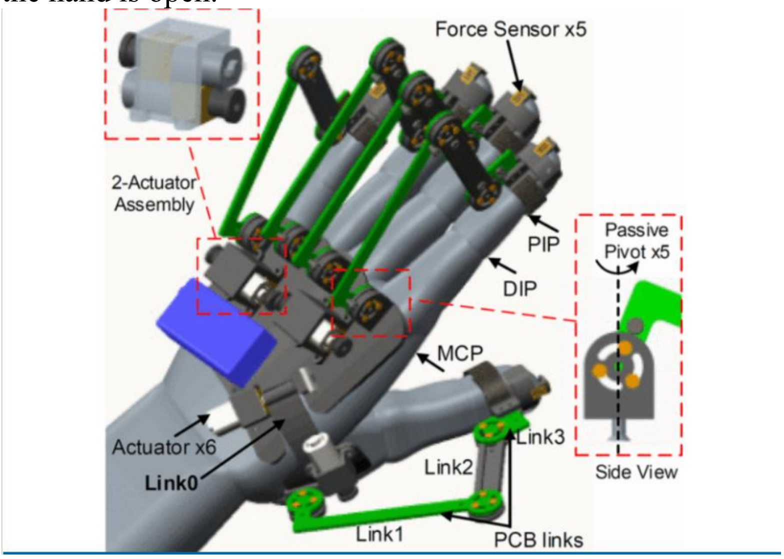
The muscles and nerves on hands are profoundly associated with the sensorimotor brain cortex so that fingers and palms can do complex exercises[14]. They accepted that the muscles of the hands take more put on the engine cortex than the leg. Usually, the foot is two times bigger than the hand, but the hands have 15 moving joints(if the palm is one joint), 29 muscles around the skeleton and 21 degrees of freedom in all[15]. The human hand is a much more complex structure than other creatures. More than 3,000 touch receptors in each fingertip react fundamentally to touching[16]. This allowed the brain to know the touching feeling better to see the subject on touching better. It also helps to give a more precise command to the actuator, like the feed-forward controlling. When a stroke is going on, it usually goes with another symptom called spasm, which makes the part suffering from the stroke feel tightness or stiffness[17]. Those researchers concluded that the connection between the brain and the hand muscles is disrupted. The disconnect between the muscles and the brain affects the hands' grip, strength, and overall function, which usually leaves damage that will impact daily life[17]. This makes the regular errands more complicated and possibly the ability to be independent with functional activities. So the treatment regimen aims to repair the connection between the brain and its actuators. Some researchers believe that the nervous system can be affected by external factors and change its weight and brain control performance, which is called Neuroplasticity [18]. Some of them discovered that the nerves could be reconnected to the brain by the redundancy and consistency of the reflection, like the "memory of the muscles" [19]. This is very the same as people learning how to swim or how to ride a bicycle with two wheels in their childhood. Here using, swimming and riding a bike are these two skills examples. People activate the same part of the brain again and again with the same content in information conduction to fortify the connection so that to use less focus the next time meed the same condition. Then this new action will no longer let people fill challenging tasks and become a new skill of that person. This memory will remain in the brain, and can take it out quickly when the next time necessary. It is to say that more exercise and repetition is an excellent way to reconnect the lost or damaged neurological pathways(or find another way to control the part) in need of repairing the disconnecting caused by stroke. A few dreary and direct activities incorporate picking up little things, and indeed utilizing chopsticks can offer assistance to delicate engine aptitudes[17]. He accepted that the net engine workout ought to be prescribed to patients with minor to no hand work, such as steadying a rolling ball on a table's surface or different extending works to diminish spasticity. A few light resistance training is additionally essential, and it'll re-awaken the result of muscles influenced by the stroke side effects.



(picture 2, sourced by google)

As a rigid exoskeleton, the whole structure can provide a limitation by resistance from other directions and assists in working direction[20]. This Design enables the device back as the control source and engine. Still, more imperatively, it gives security and resistance to the hand muscles to induce freed of fits and issues such as the spasms and the cramps caused by disarranged strengths working [20]. Not only as a treatment device but the exoskeleton ought to moreover offer assistance to support the patient's standard of living to spare the treatment resource, particularly the nursery one. This means that the power supply of the exoskeleton must be more critical than the patient himself in this situation, meaning that the user's feedback should be collected frequently to be helpful in patients' daily lives. Based on polymer thick film technology, this kind of sensor is insensitive to vibration or everyday environmental stresses and holds under long-term usage[21]. FSR innovation is rapidly being coordinated into numerous applications, strikingly machine control, computer input devices, and composite fabrication.

Embedding a lean force-sensing resistor(FSR sensor) between the fingertip and the object makes a difference in the user's command. Some researchers think that the request for a reasonable, rough constraint sensor of subjective exactness was driven to improve the FSR sensor[21]. They are delicate, so the sensor recognizes a tiny bit of weight, making them friendly to stroke patients. The target clients cannot provide an exact frequent command, so nonlinearity, drift, saturation and hysteresis, the most drawbacks of FSR sensors, are acceptable[22]. The learning material has already appeared to utilize the Arduino Uno, breadboard and various motors. They are supportive and low-cost. As a classic exoskeleton glove, the CyberGrasp is one of the foremost effective sorts accessible on the showcase[23]. The straightforward plan, as it were, weighs 350g for the hand and can have 12N on each finger, even though it still has a shortage of utilitarianism and delays and is redundant when the hand is open.



(Picture 3, sourced from CyberGrasp)

To diminish the redundant connect when open hands and let the development of finger gotten to be assorted, the equipment plan will generally be based on the comparable sort of Cempini et al.[20] continuously cover the finger firmly. They also utilize an encoder to calibrate the exactness so that the fingers can move quickly.

Matlab and Arduino are the recommended options for controlling the exoskeleton. Arduino is a company famous for its microcontroller and software both for the new and the pro user in robotic[26]. Its software is the programming software mainly used in their hardware. Both of them are open-sourced. The Arduino integrated development environment (IDE) is the programming assist software which works as a cross-platform application for the hardware. It is based on the Java programming language[26]. This software is famous for its convenience on the executable cyclic executive program with the GNU toolchain between the engineers. So as the embedded systems. The hardware of the Arduino microcontroller can save one programme inside its memory so that it does needn't to connect with the computer when the users want to use it. For example, in this research, Abdallah et al. used the Arduino board and its embedded function to make a rigid exoskeleton for fingers [27]. Ganesan et al. also follow the same way of designing [28]. They also aim to make the prototype low cost as this research. This provides a basic idea for the project.

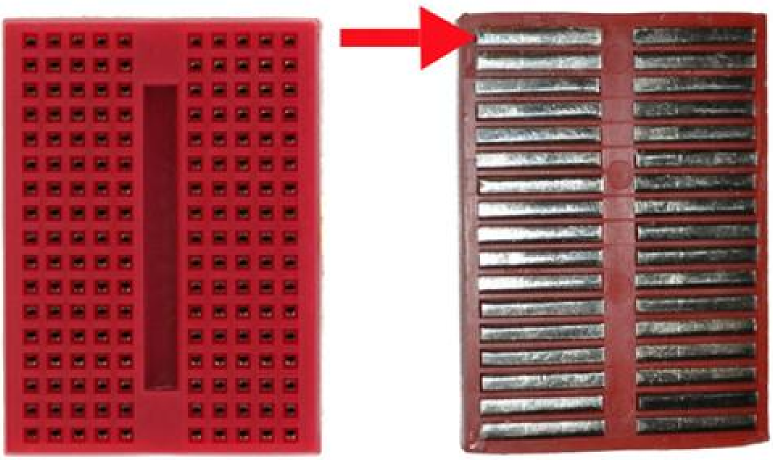
(picture 4, sourced by Arduino.cc)

To control this device, Matlab is an excellent choice to choose as well. Nair and Ezhilarasi found that Matlab can easily collect the data feedback from the users and make a table to show how they have changed over time[24]. They apply this advantage to the adjustment of the output automatically. Gasser has also chosen Matlab for its multifunction. The LabVIEW of Simulink can build a simulating circuit for the Design to simulate data from the expected device in different conditions(variables). The research said that another big advantage of Matlab is combining the data of location by the points from the links to use the matrix calculation to simulate kinematics. It is widely used in exoskeletons to use forward kinematics in the link analysis to use the rotating angles from the motors to determine the location of the end effects in the coordinate system[29]. This helps the user and designer know how the linked part is moving and the input of the external elements. Some researchers also think a feed-forward control is an excellent choice for an automatic device because it can control the equipment without the software interface[30]. He wants to let the robotic arm make a smooth output by itself following the arm's movement.

If the cables of the robotic exoskeleton are the nerves of the body, the breadboard is similar to the nerve plexus. A breadboard is a board of wood expected for cutting bread [31]. In the early history of electronics, electronic components were much more significant than today's size, especially with the integrated circuit. People even have not invented the transistors and the breadboard at that time. Electronic engineers use the cutting board as the base platform to contain the tubes, transformers, capacitors and other electrical components. Cutting boards are cheap, sturdy, easy to get and convenient to fix on or take off the opponent's onside. So most of the electrical engineers choose them as the basement.

(picture 5, old breadboard, sourced by Young)

Breadboards nowadays are much smaller and work as a circuit boards. The way to use that also becomes more accessible. All the user needs to do is plug the wire or the components inside the board's holes connected by copper strips underneath. This is why the breadboard is also called a plugboard.



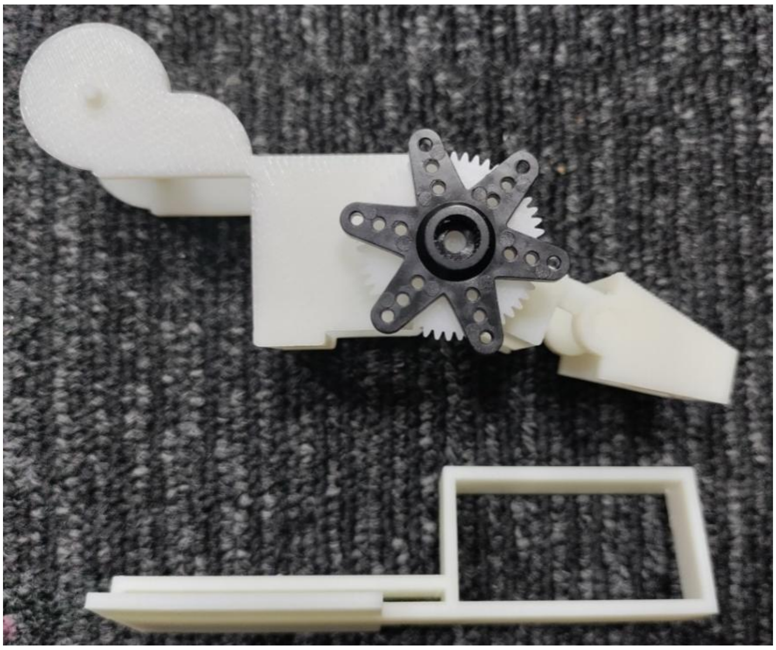
(picture 6, sourced by guokr.com)

The muscle of the robot is its actuator----which is in the form of the motors in the exoskeleton. A servo motor is a rotary or linear actuator that allows for precise control of angular or linear position, velocity and acceleration[32]. It consists of a motor and a sensor for position feedback. They are suitable for a closed-loop system widely used in projects such as robotics, automated manufacturing, etc. This kind of motor has a disadvantage: it usually forgives its function of keeping rotating for the stable and controllable. But the robot's joint link usually has no necessary 360 degrees to keep spinning, so a servo motor is the best choice for most drives and joints in the exoskeleton[33]. For most of the Design, a servo motor can include the function of a rotary encoder and a standard actuator. This will save the cost of the prototypes a lot.

3. Project realization

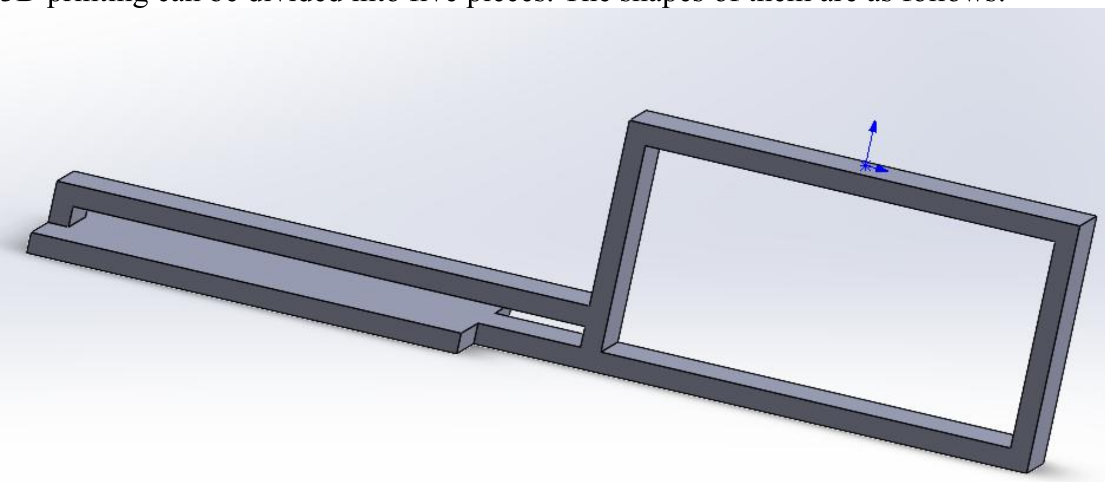
3.1 solid part designing

The prototype design is based on the assistance structure of the finger, as shown in the picture below.



(picture 7, sourced by the author)

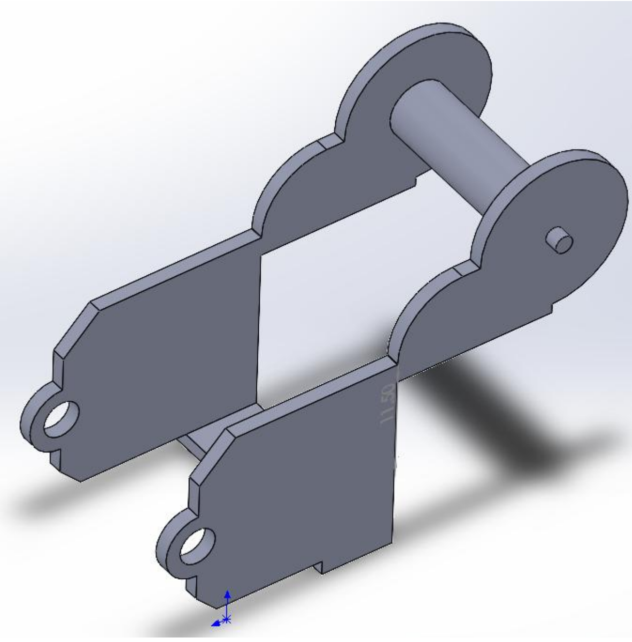
This is working as the bending assistance equipment by the rotating and gear drive. The finger is designed to be contained inside and use the sensor on the device to control the rotating of the motor to let the finger move to its exciting place. The whole solid structure for 3D printing can be divided into five pieces. The shapes of them are as follows:



(picture 8, basement, sourced by the author)

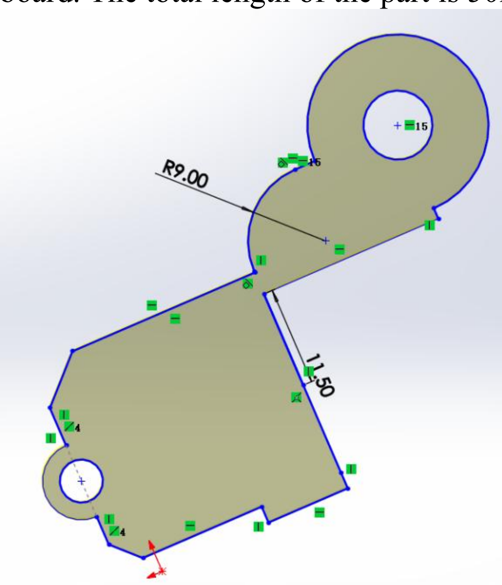
The picture above is the base of the whole exoskeleton. The very narrow slot is for the bondage to attach the structure to the palm. The wrist bandage is easy to get from the shop. Due to this reason, the slot is left for only 2mm. The framework has a width of 10mm, and the bottom board is three times wider than the other part. The big hole in the middle is for the servo motor. The length of the rectangle in the middle is 40mm, and the width is 20mm. This is similar to the size of the servo motor used in this project. The engine is not flat and has 39mm and 19mm at both ends. This Design leave space for the motor to plug in without too much friction. The typical thickness of the base is 2mm, so it will not be heavy.

The part below is for the first link of the finger. This is also the thickest link of the finger.



(picture 9, first link, sourced by the author)

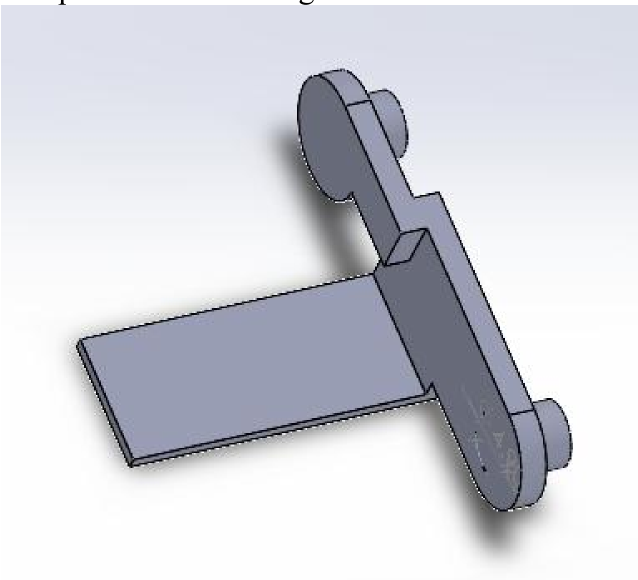
Because of the thickness of the first link, the prototype is designed to be larger than other links. The distance between the left and right sides is 25mm, and both sides' thickness is still 2mm. There is only 22mm for the broadest part of the finger, so there is enough space for moving. The height of the main features is 11.5mm, and 1 mm for the thickness of the bottom board. The total length of the part is 50mm.



(picture 10, flat figure for the first link, sourced by the author)

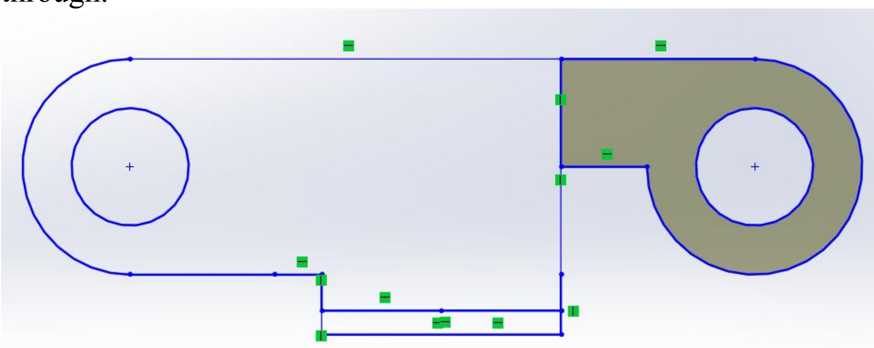
The first link of the finger is 11.4mm to the author, and the distance between the first two knuckles is 50mm as well. The base board is the place for the fsr sensor, so it is necessary to leave 0.1mm for the finger so that the pressure will not be too much when the finger doesn't want to bend down. The height of the shaft axis compared with the top of the finger is 11.8mm, which equals the sum of the base thickness and the distance between the motor's centre and the other motor's short side. There is also a tiny bulge on both sides of the shaft axis to fix the position of the gear because it is easy to assemble between these two parts(glue them up).

The part below is the right half of the middle link.



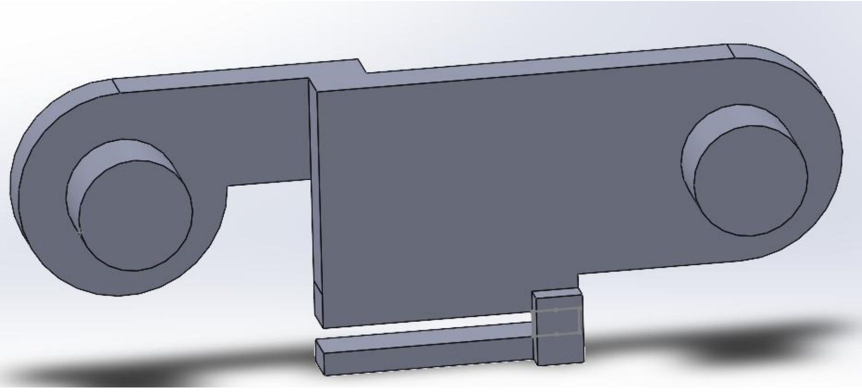
(picture 11, middle link left, sourced by the author)

Not the same as the designing of the body, the middle link is the narrowest part of the hole structure. As before, the baseboard at the bottom is only 1mm thick, and both bulges are 0.1mm lower in diameter. This gives space for the mistake of the 3D printer so that to make sure the two parts can assemble together. They are also 3mm in height which is 1mm longer than the thickness of the first link. The extra length makes another bulge and allows the gear to fix onside to let the motor drive the exoskeleton by gear drive transmission. Same as the part before, the middle links are 2mm thick on both sides. The middle link should link the other two parts of the finger as a link in the middle. This is the reason why it has two bulge connections. They are not in the same line because of the different diameters of the finger. The surface for the two links to stick to each other is 4.5mm×2.5mm, ensuring they can stick to each other. The middle link is designed to be 21mm wide, and the big knuckle of the middle link of the author is 20.5mm. The small knuckle is only 15mm, but the forward part has 21-2-2=17mm in width. This means that the middle part can still sandwich the finger. The rotating of a roller is from the midpoint of its cross-section. The middle of the bulges is 6mm away from the bottom, and the final knuckle is 12mm tall. This still allows the finger to pass through.



(picture 12, flat figure of both middle links, sourced by the author)

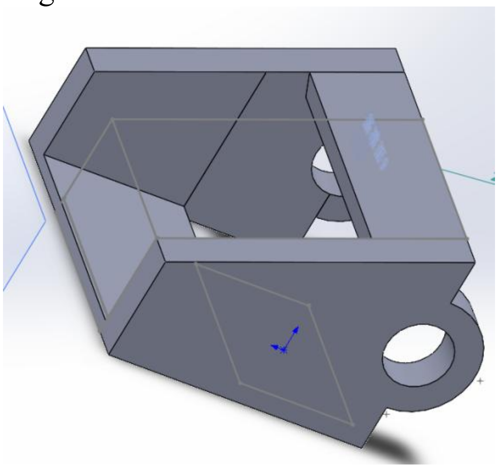
The left part of the middle link is similar to the right one, but there is a notch instead of the baseboard.



(picture 13, left middle link, sourced by the author)

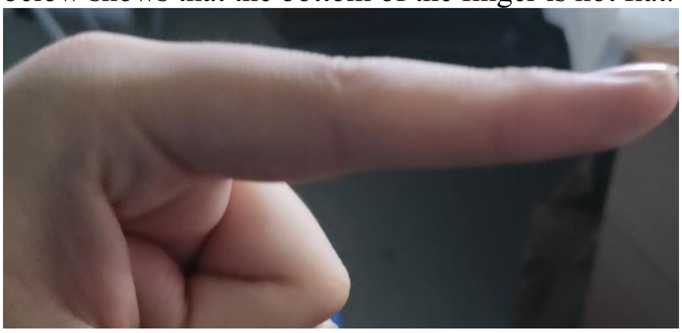
In the picture above, it is clear that there is a block stick between the significant part and the base. The distance between two middle points of bulges is 26.1mm, equal to the length of the authors' central link. This block stops the baseboard of another half to prevent the two parts from getting close. It can stick two parts of the link to one as well.

The final part of 3D printing is the forward link of the finger. This is the end effector of the device. The diameter of the hole is 5mm, which is still 0.1mm more than the bulge in the middle, but the thickness of left and right sides are 3mm this time and there will be no bulge after plugging the bulges inside from the centre. This part has 20mm long and hollows out in different regions. The end of the slop is 11.68mm tall, but the forward link of the authors' finger is less than 10mm thick.



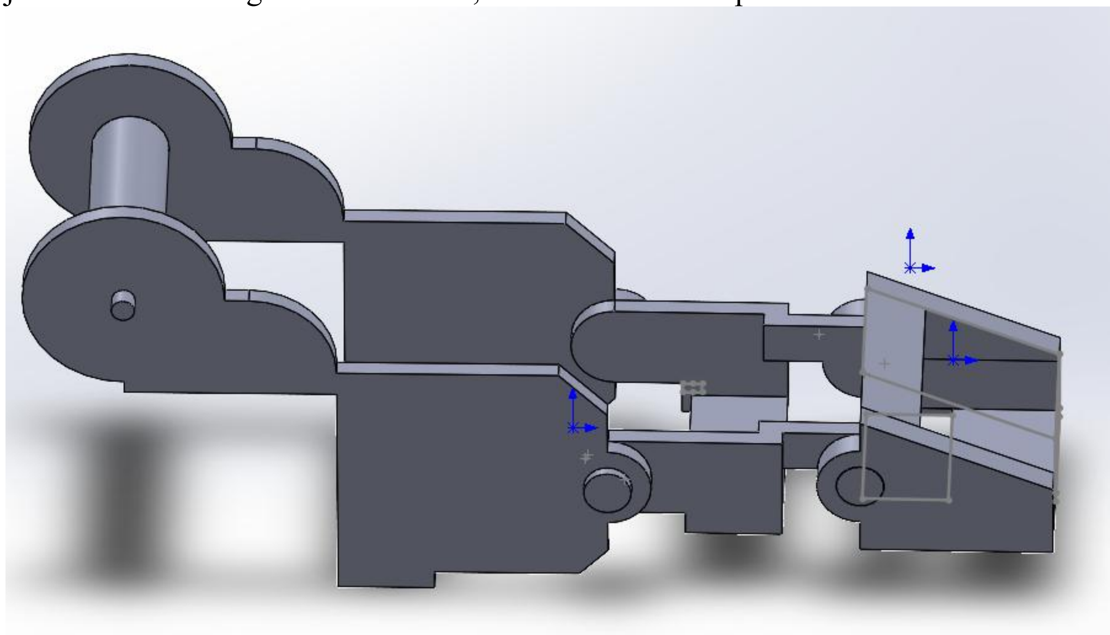
(picture 14, forward link of the finger, sourced by the author)

It can easily be found that the exoskeleton's base board are not the same height. The picture below shows that the bottom of the finger is not flat.



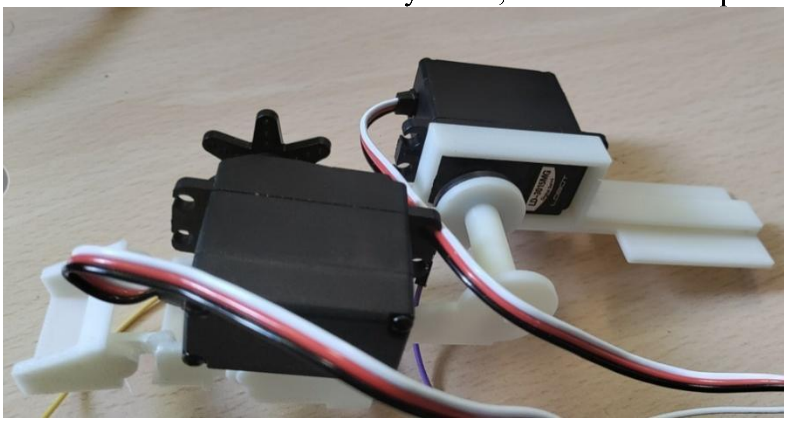
(picture 15, finger, sourced by the author)

This is also why the baseboard is not at the same height when all the parts are assembled. The picture below shows the figure of the assembly. The picture showed that the finger's path is in the middle and all the joints correspond to the joints. The shaft axis is above the root knuckle joint. When the finger buckles down, the shaft axis will spin with the knuckles.

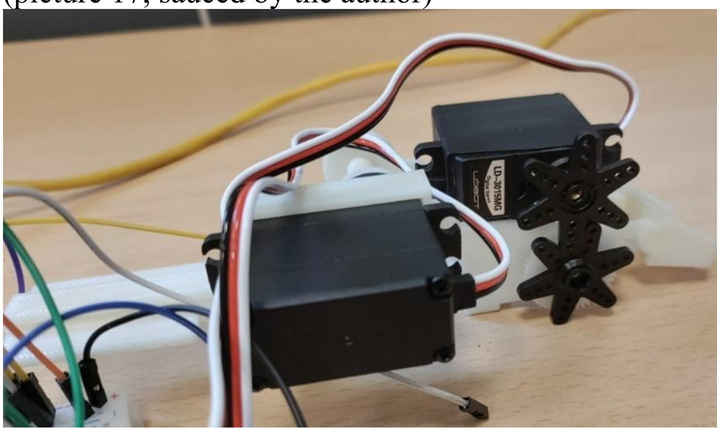


(picture 16, assembling, sourced by the author)

Combined with all the necessary items, it looks like the picture below.



(picture 17, sauced by the author)



(picture 18, sauced by the author)

The motor here is Hiwonder LD-3015MG Full Metal Gear Digital Servo with 17kg High Torque[34]. The datasheet below shows the performance of this kind of motor.

LewanSoul LD-3015MG Standard Full Metal Gear Digital Servo with 17kg High Torque for RC Car Robot(Control Angle 270)

EUR 15,99

- 17kg large torque. 15 kg·cm (208 oz·in) 6.6V; 17 kg·cm (236 oz·in) 7.4V
- Full metal gear. it's better for accuracy, service life has been greatly increased
- 270 degree rotation. Controllable angle range from 0 to 270 degrees, Excellent linearity, precision control. Can be rotated within 360 degrees when power off
- Using high-precision potentiometer with new design. Accuracy and linearity have been greatly improved! Accurate movement can satisfy the needs of making robots
- Dimension: 40*20*40.5mm(1.57*0.78*1.59inch)

Produktbeschreibungen

Specifications:
Weight: 60g(2.1OZ)
Dimension: 40*20*40.5mm(1.57*0.78*1.59inch)
Speed: 0.16sec/60°(7.4V)
Accuracy: 0.3°
Torque : 15 kg·cm (208 oz·in) 6.6V;17 kg·cm (236 oz·in) 7.4V
Working Voltage: 6-7.4V
Min Working Current: 1A
No-Load Current: 100mA
Spline: 25T(6mm diameter)
The servo wire: 30cm(11.8inch) in length
Control Specifications:
Control Method: PWM
Pulse Width: 500~2500
Duty Ratio: 0.5ms~2.5ms
Pulse Period: 20ms

(picture 19, datasheet, sauced by modellbau-haeger.de)

Hiwonder.co, a technology company with mechanical components for their primary business, provides this kind of motor.

$\tau = r \times F$ (1)

In this datasheet, it said that it has 17kg.cm ample torque in 7.4V and 15kg.cm torque in 6.6V. in the equation above, $\tau$is the torque of the joint in the point, r is the radium which means the distance from the middle of the link to the knuckle, and F is the force effect on the point. This is the force provided by hand and the device to drive the link to move. All the links are around 1cm to 2cm. So the device's assistance can help with the output of the finger at least 8kg in on link. This is extensive support to the fingers on output, especially for the patients. Four fingers on the palm will provide more than 32 kg of grip power, which is very near to a healthy adult.

3.2 programming design

The programme is the leading way to set the rule for the device to enable the device to understand what to do next. In the project plan, the way to control the robot exoskeleton is to press on the fsr sensor. This simulates the grasp or gives force to drive the finger. Usually, the sensor can have an output of about 0-5V by different force effects on the sensor. Still, unfortunately, the sensor broke down in an accident and can only have very little output. This is also why the range of the voltage is so small in the programme. The accident gives the idea to the author to prepare both hands to use the device when some weak part breaks down, such as the fsr sensor being out of work.

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'Servo, SPI, I2C');%claim the device and function want to use
v1=readVoltage(a, 'A0');
v2=readVoltage(a, 'A1');%claim fsr sensor
p1 = servo(a, 'D3', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
p2 = servo(a, 'D4', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);%servo motor
writePosition(p1, 0);
writePosition(p2, 0);%motor back to 0 before using
X=0;
Y=0;
l1=40;
l2=30;
theta1=0;
theta2=0;
t=input('wana control by yourself?1/0')%different functions to choose
```

(picture 20, code, sourced by the author)

First of all, claim the type of the microcontroller and its port of it. Here in this project, the board type is Arduino Uno, and the port number of the microcontroller is 5. The programme needs to call out servo motor and fsr sensor function, so claim them in Arduino command here as well. Next, give the variables a name. The fsr sensor should link to the analogue pin, so here define the read value from two analogue pins with V1 and V2. The Servo motor can only plug in the digital pin, so they start with D. Here, name the variable with P1 and P2 for the servo's position. Before starting with the primary function, reset the motor to 0 degrees. Then define the original value of some variable which will change after. The theta is the angle at which the motor rotates from 0 degrees.

```
if t==1%control by fsr sensor
    while X<90&&Y<90%up right cornor to close
        hold off;%clean the table
        mouse_position=get(gca,'CurrentPoint');%get the location by clicking
        X=mouse_position(1,1);%X-axis
        Y=mouse_position(1,2);%Y-axis
        plot(X,Y,'gs','linewidth',20);%draw the dot on the coordinate with green
    if theta2<63&&v2>0.4
        theta2=theta2+3;%press on the sensor and still can bend down, go down
    else if theta2==63&&v2>0.4
        theta2=theta2;%finger want to keep gridding
    else if theta2==0&&v2<=0.4
            theta2=theta2;%don't get upper when the finger is straight
    else
        theta2=theta2-3;%release
    end
    end
    end
```

(picture 21, code, sourced by the author)

The first function is the original function prepared before the broke down of the sensor. The main function combines a "game" with the exoskeleton. Define a point on the screen, and use the exoskeleton to control the screen's character to reach the same point as the snake game. Here the author prefers to ise the while loop as the main loop because before the demand of the while loop is satisfied, the loop will go on continually. The while loop starts with a hold-off because cleaning all the plot drawing from the last loop is necessary. The screen table will be full of the previous output result if not wiped off the previous slot. The best way to find a point on the table is to click on the table. So here to, use the mouse position command. It can put the current position of the mouse into memory. Next, place the x-axis and the y-axis of the position into two memories called X and Y as the coordinate location. Then, draw that point on the table. Here choose the light green colour to make the point easy to find.

The sensors control the motors. So it is necessary to divide different feedback of the sensor into several parts and add extra events to them. The rotating range defines as 63 degrees for both joints. The first condition is when voltage feedback is higher than 0.4, and the rotating angle is smaller than the limitation, let the rotating angle increase. Usually, the output of the fsr sensor should be over 4 when there is pressure on the sensor. 0.4 is the new roughly dividing line between press and not press after the breakdown. When the rotation reaches the limitation, but the finger still gives pressure to the sensor, let the links keep in that position. When people hold a fist with their hand, their fingers should have pressure on each other, and the finger's position remains. So as this condition. When the angle is 0 degree and the finger no longer press on the sensor, the link should not let the finger bend over a horizontal flat. It is like the finger is released, and the palm is open to keep that position. Other than the three conditions above, the finger will recover from bending, opening the hand bit by bit. It is similar to a person releasing his hand.

```
    writePosition(p2, theta2/270);%realize by actuator
    pause(0.01);%then check with another group of sensor and actuator
    if  theta1<63&&v1>0.4
         theta1=theta1+3;
    else if theta1==63&&v1>0.4
            theta1=theta1;
    else if theta1==0&&v1<=0.4
            theta1=theta1;
    else
        theta1=theta1-3;
    end
    end
    end
    writePosition(p1, theta1/270);%servo work from 0-270 degree,cut the full range to 270 to simulate
    pause(0.01);
```

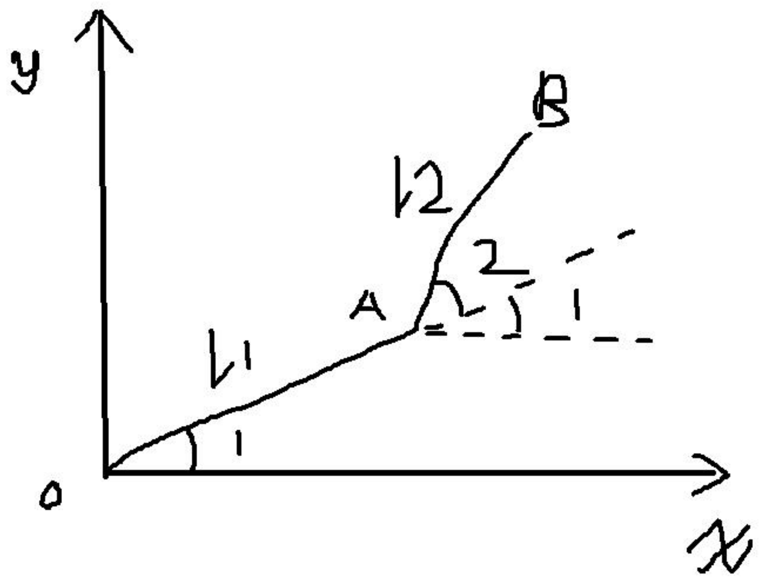
(picture 22, code, sauced by the author)

After that, write down the position by the motor and check with the other joint. The value inside the read position can only read from 0 to 1, meaning the percentage of the full rotating range. The maximum working area for the servo motor is from 0 to 270 degrees. So, divide the theta value by 270 for the corresponding r value. It is translated from the value of the degree.

```
    x1=l1*cos(0.5*pi-theta2*pi/180);
    y1=30+l1*sin(0.5*pi-theta2*pi/180);
    x2=l1*cos(0.5*pi-theta2*pi/180)+l2*cos(0.5*pi-(theta1+theta2)*pi/180);
    y2=30+l1*sin(0.5*pi-(theta2*pi)/180)+l2*sin(0.5*pi-(theta1+theta2)*pi/180);
    plot([0,x1],[30,y1],[x1,x2],[y1,y2],'LineWidth',2);
    hold on;
    plot(X,Y,'gs','linewidth',20);
    grid on;
    axis([0 100 0 100]);
    pause(0.2);
    end
```

(picture 23, code, sauced by the author)

After deciding the value of the rotating angles, it is time to draw the whole links of the finger out. When the angle of the joint and the link length are ready, and it needs to deal with the location of the end effect, it is a question of forward kinematics [35]. For example, to find out the location of the end effect below:



(picture 24, forward kinematic, sauced by the author)

This picture shows that the x-axis can get from the cos, and the y-axis can get from sin.

$$X_a = l_1 \cos\angle 1 \qquad (2)$$

$$Y_a = l_1 \sin\angle 1 \qquad (3)$$

So based on the location of point A and treating it like the original start, the site of point B can be defined in the same way.

$$X_b = X_a + l_2 \cos(\angle 1 + \angle 2) = l_1 \cos\angle 1 + l_2 \cos(\angle 1 + \angle 2) \qquad (4)$$

$$Y_b = Y_a + l_2 \sin(\angle 1 + \angle 2) = l_1 \sin\angle 1 + l_2 \sin(\angle 1 + \angle 2) \qquad (5)$$

Back to the code, the finger here is designed to bend vertically. So the $\angle 1$ here is 90 degrees minus the rotating angle. The kinematic link does not start from the O point to put the simulation link in the middle of the table. Once the exoskeleton is designed in a more rigid material, and the structure is thin, the finger can bend more like the bare hand without the device. It will leave enough space for another link to bend down so that when the end effect is lower than the original point, the links will not go out of the table. That is to say. This programme can also be used in the further Design of this project. The l_2 = 30. This is the reason why the manipulator starts from (0,30). Draw the manipulator down on the table and hold on the figure. There will be another plot after that. Command "plot" will cover the figure on the table before without the hold on command.
Last but not least. Define the range of the showing table on the screen. It is essential to leave a pause after every command execution because Matlab will report an error without delay.

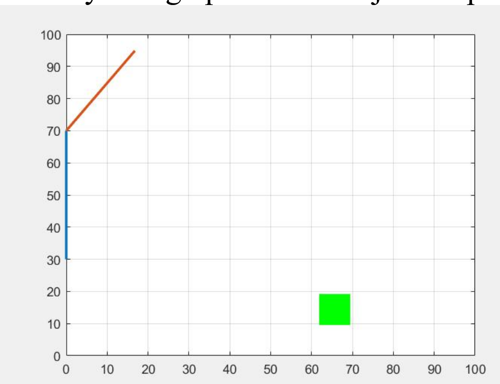
```
else%control with the control panel
    while X<90&&Y<90
        hold off;
        mouse_position=get(gca,'CurrentPoint');
        X=mouse_position(1,1);
        Y=mouse_position(1,2);
        if X>80&&X<90&&Y<10&&Y>0&&theta2<63%buttom for bend down the secon knuckle
            theta2=theta2+1;
            writePosition(p2, theta2/270);
        else if X>80&&Y>10&&Y<20&&X<90&&theta2>0%buttom to bend back the second knuckle
                theta2=theta2-1;
                writePosition(p2, theta2/270);
        else if X>70&&X<80&&Y<10&&Y>0&&theta1<63%bend down the first knuckle
                theta1=theta1+1;
                writePosition(p1, theta1/270);
        else if X>70&&X<80&&Y>10&&Y<20&&theta1>0%bend back the first knuckle
                theta1=theta1-1;
                writePosition(p1, theta1/270);
        else if X>60&&X<70&&Y>0&&Y<10&&theta1<63&&theta2<63%bend down bottom for both joints
                theta1=theta1+1;
                theta2=theta2+1;
                writePosition(p1, theta1/270);
                writePosition(p2, theta2/270);
        else if X>60&&X<70&&Y>10&&Y<20&&theta1>0&&theta2>0%bend back both joints
                theta1=theta1-1;
                theta2=theta2-1;
                writePosition(p1, theta1/270);
                writePosition(p2, theta2/270);
        else
            theta1=theta1;
            theta2=theta2;%don't move if one of the joints on control reach its limitation
```
(picture 25, code, sauced by the author)

When the sensor breaks down, the self-control function can no longer be used. So here to add another part to control the manipulator without the sensors. The control panel can still control the exoskeleton when the sensor is not working. It is necessary because the solid structure is rigid, and the user cannot move the part with the exoskeleton because of the fault. It is not safe for the user to use the device to hold something that can split out or something fragile.

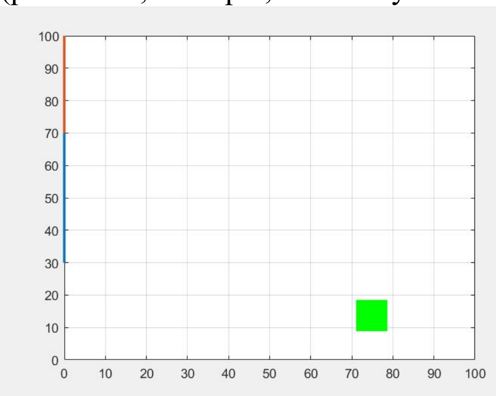
Here choose to control the manipulator by the control panel. It is still based on the table made of axis and clicking to make this function a panel with buttons. Still use the if loop here to check which button the user just clicked on—then compare it with the function. Here to define six buttons with different commands. Link 1 bends down and bends up, link two bends down and bends up, and both bend down and bend up. Things that need to be considered are when the link bends up too much up to another side will report an error, so here also define that the rotating angel should focus in a specific range from 0 degrees to 63 degrees. Firstly, use the capacity of the axis to confirm a square space on the table to make the button. The x-axis is between 80 and 90, while the y-axis is from 0 to 10. if the rotating angle hasn't reached the limitation, the finger can still bend down.

The if statement fits the demand of the checking and choosing. Compared to the continuous while loop, the if statement will only be read once in each loop. This describes that the function will run again before the user wants to close it. When the condition of the if statement is satisfied, the command inside the if statement will be executed. Otherwise, run the command in else if. Once every requirement has been checked, and no one fits the current situation, it will go to another. This characteristic enables the if loop to make a choice function. Then the whole structure becomes to if statement in the side while loop, which means that the programme will react to any operating from the user before the user wants to stop the programme. Back to the code, the square range from 80 to 90 in x and 10 to 20 in y is for bending back link 2, the square range from 70 to 80 in x and 0 to10 in y is for bending down link 1, and square range from 70 to 80 in x and 10 to 20 in y is for bending back link 1. The other group on the 60-70 x-axis is the down and up for both links. When there is a bend down, check if it reaches 0 degrees. When there is a bend back, check if it is at 63 degrees. Otherwise, keep its position.

In the second function, once clicking on the button, the manipulator will keep moving until the different commands are given. If one of the rotating angels back to 0 or one of them reach the maximum limitation, both links will stop moving. In the example below, it is clear that the first rotating angel equals 0, and the other one is still on its way back. The manipulator will not move anymore to protect the structure from breaking. By this condition, it can be reset by rising up the second joint separately.



(picture 26, example, sauced by the author)



(picture27, example, sauced by the author)

The rest of the code is easy to understand. After drawing down the plot on the figure chart and ending up all the loops, reset the actuators to 0 degrees and close all the charts.

```
                x1=l1*cos(0.5*pi-theta2*pi/180);
                y1=30+l1*sin(0.5*pi-theta2*pi/180);%forward kinematic, start from (0,30) simulate palm
                x2=l1*cos(0.5*pi-theta2*pi/180)+l2*cos(0.5*pi-(theta1+theta2)*pi/180);
                y2=30+l1*sin(0.5*pi-(theta2*pi)/180)+l2*sin(0.5*pi-(theta1+theta2)*pi/180);
                plot([0,x1],[30,y1],[x1,x2],[y1,y2],'LineWidth',2);%draw the links
                hold on;% not disappear until th next clicking
                plot(X,Y,'gs','linewidth',20);%cover the old spot
                grid on;% use web table to find the buttom
                axis([0 100 0 100]);%define the range of showing table
                pause(0.1);
        end

end
writePosition(p1, 0);
writePosition(p2, 0);%motor back to 0 after using
close all;
```

(picture 28, code, sauced by the author)

There are two extra tool programmes to check if the sensors and the motor work well. The first one is for testing the fsr sensor. Press on the sensor and run this code. It will tell you the read value from the sensor.

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'SPI, I2C');
v=readVoltage(a, 'A0');
r=readVoltage(a, 'A1');
disp(v)
disp(r)
```

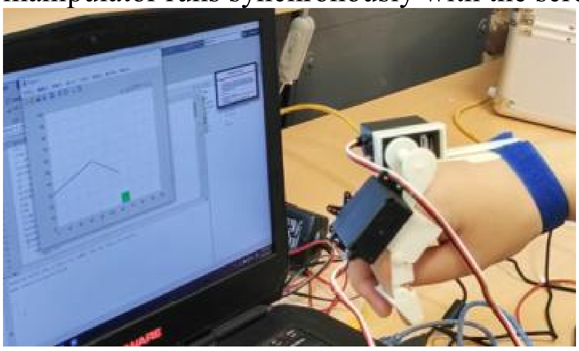
(picture 29, extra code, sauced by the author)

The other one is for the servo motor. Run this code and input the number of degrees. Check if the motor has rotated a right degree or not.

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'Servo');
r = servo(a, 'D3', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
s = servo(a, 'D4', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
in=0;
writePosition(r, 0);
writePosition(s, 0);
while in<1
    angle1=input('an angle between 0 and 149');
    x1=angle1/270;
    writePosition(s, x1);%%write the position by motor. "s" means which motor to do.
    angle2=input('an angle between 0 and 149');
    x2=angle2/270;
    writePosition(r, x2);
    in=input('good(1)/not good(0)');
end
writePosition(r, 0);
writePosition(s, 0);
```

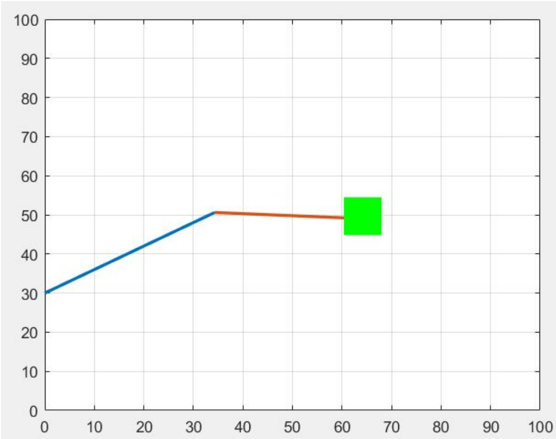
(picture 30, extra code, sauced by the author)

The code is already tested by the author and runs well. The picture below shows that the manipulator runs synchronously with the screen figure.



(picture 31, real photo, sauced by the author)

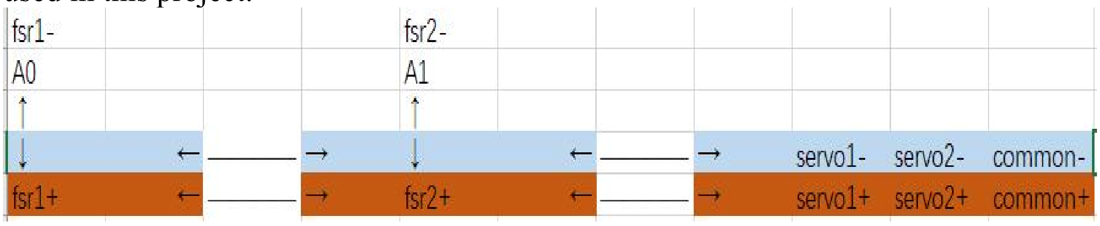
Because of the breakdown of the sensors, there is no photo to prove it, but a screenshot was taken instead. Use the mouse to click on a random place in the table and use a little push and release on the finger to control the manipulator to let the links reach the green point.



(picture 32, screenshot, sauced by the author)

3.3 Wiring

As the nerves of the robot wires integrate different part of the robot into an exoskeleton. As we all know, taking a picture of the breadboard and the microcontroller will be confusing because they are so dense. Here is a straightforward way to link these wires on a breadboard. The picture below is drawn in excel. The orange represents a positive line, and the blue represents a negative. There are 4×2 pins in a group, and three groups of bottom lines are used in this project.



(picture 33, breadboard, sauced by the author)

4. Difficulties and Improvement

The project is not smooth sailing all the time. First of all, is to choose a robust sensor. Though prepared the issue checking tool and the computer-controlled function to cope with this situation, there still needs a sensor which will not be easy to get a broke down because controlling the sensor means controlling the body directly. This is one of the essential targets for the exoskeleton. Then is the strength of the linked part of the hardware. The part of the skeleton usually only got 2mm in thickness. The 3D printing is printing in plastic, and the thin connection is not strong enough to bear the bending when assembling. One of the parts is broken by the author during the assembling, and that part is repaired by super glue for plastic. Another design problem is that the finger is soft. One of the bear boards of the sensor is too tight for the forefinger, and the other is too loose. Muscles can change their shape by extrusion, so it is necessary to have a better skeleton CAD design on the size the next time. The bulge block in the middle blocks the rotating of the second joint, limiting the rotating angles. It can change a direction to fix the bear board of the sensor and no longer block the way. The second motor on the finger's middle is fixed by super glue. It is stable but not easy to disassemble. So as the other motor. The motor's wire hasn't been considered when designing, so it cannot put the motor fully inside the hole prepared for it. These two points should be considered if there is another chance to make the prototype in the future. Then, better space management is helpful.

Too many wires link between the breadboard, Arduino Uno and the manipulators. It is so inconvenient to wear the device because of the limitation of the cables. Some of the wires link between the breadboard groups, and can use the iron wire instead. The breadboard and the microcontroller can store on the back of the hand to enable the hand to move anywhere by adding some framework design. It is also necessary to arrange the wires and fix or weld the framework. Next, a user-friendly control interface is essential. It may help the user know how to use this quickly. After that, if there is a wireless blue tooth connector, such as the wireless mouse link between the computer and the device, it will be more convenient for daily life. Patients can use this device in the house anywhere to do their rehabilitation or help their hands in everyday life, such as picking things or using tools.

Last but not least, a better power supply is also necessary to improve the mobilization of the device. The output from the computer by the Arduino board only got up to 5V in the power supply. The author tried to link all of the components by the output from the computer, but it was not enough for two servo motors. So here, use the DC power supply with a fixed voltage to have enough current on all the components. A rechargeable lithium battery will be an excellent choice to solve the mobilization problem of power supply.

5. Budget

One of the targets of this project is low cost. All the materials except for 3D printing can get from amazon. Each thin film Force-Sensitive Resistor pressure sensor costs £5.71, and one ELEGOO UNO R3 Board for Arduino with USB Cable cost £11.99. Each LewanSoul Hiwonder LD-3015MG Digital Servo costs £18.99. One breadboard cost £3.99. Breadboard jumper wire costs £17.99, and the gear uses the star size control horn instead. All of these items only cost £83.37. Usually, it costs over £400 on the internet to buy a rehabilitation exoskeleton.

6. Conclusion

Due to the performance of the prototype and its budget, it is a successful project. Though the sensor breaks out in an accident, the designer still makes some extra functions and some checking tools as compensation. For a prototype, it just costs £88.37. After some reform and further study, the cost can be even lower than the cheapest rehabilitation exoskeleton people can find by mass production. Not only for rehabilitation, but this kind of device may also be helpful in the assistance area with some simple changes. Not only the low cost, but this project also has some other advantages. It has a light burden for the user as a piece of medical equipment and can control finger knuckles separately. One step further, it is easy to check the fault of the device and no very complex design exists in the prototype.

On the other hand, there is still some disadvantage waiting for solved. The motors are still too big for the fingers. It is not comfortable to wear a big device on the finger. Sensors are weak, so it needs to re-design a slot for it. Being a grid exoskeleton, the touching feeling of the finger is not good. It can leave more space for the skin so the user can touch the items he wants to catch or use. If there is more time to go further in this study, this exoskeleton will get one step closer to perfect.

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8. Appendix

1. main

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'Servo, SPI, I2C');%claim the device and
function want to use
v1=readVoltage(a, 'A0');
v2=readVoltage(a, 'A1');%claim fsr sensor
p1 = servo(a, 'D3', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
p2 = servo(a, 'D4', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-
6);%servo motor
writePosition(p1, 0);
writePosition(p2, 0);%motor back to 0 before using
X=0;
Y=0;
l1=40;
l2=30;
theta1=0;
theta2=0;
t=input('wana control by yourself?1/0')%different functions to choose
if t==1%control by fsr sensor
    while X<90&&Y<90%up right cornor to close
        hold off;%clean the table
        mouse_position=get(gca,'CurrentPoint');%get the location by clicking
        X=mouse_position(1,1);%X-axis
        Y=mouse_position(1,2);%Y-axis
        plot(X,Y,'gs','linewidth',20);%draw the dot on the coordinate with green
    if theta2<63&&v2>0.4
        theta2=theta2+3;%press on the sensor and still can bend down, go down
    else if theta2==63&&v2>0.4
        theta2=theta2;%finger want to keep gridding
    else if theta2==0&&v2<=0.4
            theta2=theta2;%don't get upper when the finger is straight
    else
```

```
        theta2=theta2-3;%release
    end
    end
    end
    writePosition(p2, theta2/270);%realize by actuator
    pause(0.01);%then check with another group of sensor and actuator
    if  theta1<63&&v1>0.4
         theta1=theta1+3;
    else if theta1==63&&v1>0.4
            theta1=theta1;
    else if theta1==0&&v1<=0.4
            theta1=theta1;
    else
        theta1=theta1-3;
    end
    end
    end
    writePosition(p1, theta1/270);%servo work from 0-270 degree,cut the full range
to 270 to simulate
    pause(0.01);
    x1=l1*cos(0.5*pi-theta2*pi/180);
    y1=30+l1*sin(0.5*pi-theta2*pi/180);
    x2=l1*cos(0.5*pi-theta2*pi/180)+l2*cos(0.5*pi-(theta1+theta2)*pi/180);
    y2=30+l1*sin(0.5*pi-(theta2*pi)/180)+l2*sin(0.5*pi-(theta1+theta2)*pi/180);
    plot([0,x1],[30,y1],[x1,x2],[y1,y2],'LineWidth',2);
    hold on;
    plot(X,Y,'gs','linewidth',20);
    grid on;
    axis([0 100 0 100]);
    pause(0.2);
    end
else%control with the control panel
    while X<90&&Y<90
        hold off;
        mouse_position=get(gca,'CurrentPoint');
        X=mouse_position(1,1);
        Y=mouse_position(1,2);
        if X>80&&X<90&&Y<10&&Y>0&&theta2<63%buttom for bend down the secon knuckle
            theta2=theta2+1;
            writePosition(p2, theta2/270);
        else if X>80&&Y>10&&Y<20&&X<90&&theta2>0%buttom to bend back the second
knuckle
                theta2=theta2-1;
                writePosition(p2, theta2/270);
        else if X>70&&X<80&&Y<10&&Y>0&&theta1<63%bend down the first knuckle
                theta1=theta1+1;
                writePosition(p1, theta1/270);
        else if X>70&&X<80&&Y>10&&Y<20&&theta1>0%bend back the first knuckle
                theta1=theta1-1;
                writePosition(p1, theta1/270);
        else if X>60&&X<70&&Y>0&&Y<10&&theta1<63&&theta2<63%bend down bottom for
both joints
                theta1=theta1+1;
                theta2=theta2+1;
                writePosition(p1, theta1/270);
                writePosition(p2, theta2/270);
        else if X>60&&X<70&&Y>10&&Y<20&&theta1>0&&theta2>0%bend back both joints
                theta1=theta1-1;
                theta2=theta2-1;
```

```
                writePosition(p1, theta1/270);
                writePosition(p2, theta2/270);
        else
            theta1=theta1;
            theta2=theta2;%don't move if one of the joints on control reach its limitation
        end
        end
        end
        end
        end
        end
            x1=l1*cos(0.5*pi-theta2*pi/180);
            y1=30+l1*sin(0.5*pi-theta2*pi/180);%forward kinematic, start from (0,30) simulate palm
            x2=l1*cos(0.5*pi-theta2*pi/180)+l2*cos(0.5*pi-(theta1+theta2)*pi/180);
            y2=30+l1*sin(0.5*pi-(theta2*pi)/180)+l2*sin(0.5*pi-(theta1+theta2)*pi/180);
            plot([0,x1],[30,y1],[x1,x2],[y1,y2],'LineWidth',2);%draw the links
            hold on;% not disappear until th next clicking
            plot(X,Y,'gs','linewidth',20);%cover the old spot
            grid on;% use web table to find the buttom
            axis([0 100 0 100]);%define the range of showing table
            pause(0.1);
    end

end
writePosition(p1, 0);
writePosition(p2, 0);%motor back to 0 after using
```

2. fsr

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'SPI, I2C');
v=readVoltage(a, 'A0');
r=readVoltage(a, 'A1');
disp(v)
disp(r)
```

3. servo_drive

```
clc;
clear all;
a = arduino('COM5', 'Uno', 'Libraries', 'Servo');
r = servo(a, 'D3', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
s = servo(a, 'D4', 'MinPulseDuration', 700*10^-6, 'MaxPulseDuration', 2300*10^-6);
in=0;
writePosition(r, 0);
writePosition(s, 0);
while in<1
    angle1=input('an angle between 0 and 149');
    x1=angle1/270;
    writePosition(s, x1);%%write the position by motor. "s" means which motor to do. x1 should between 0-1, x1 is the persentage you want to rotate
    angle2=input('an angle between 0 and 149');
    x2=angle2/270;
    writePosition(r, x2);
    in=input('good(1)/not good(0)');
end
```

```
writePosition(r, 0);
writePosition(s, 0);
```