DESIGN OF A FINGER EXOSKELETON FOR HAND REHABILITATION

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FACULTY OF ENGINEERING
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[DESIGN OF A FINGER EXOSKELETON FOR HAND REHABILITATION]

ABSTRACT

A large number of people who suffer from the impairment of hand due to the consequences of stroke, aging, and trauma. They lost the ability to grasp and the basic function of hands movements. It caused so much problems and inconvenience for patients because hands are extremely important in both work and life. Thus, a device to aid, assist and rehabilitate the fingers' movement is necessary and called upon. Many researches have investigated into the possibilities of various approaches to tackle the issue. Therefore I designed and manufactured a novel exoskeleton device in order to reach a rehabilitation goal for hand and fingers. Servo motor and Arduino uno were adopted to build the device. The methodology was used in this project is quantitative approach to determine the degree of the PIP joint of each finger, and use two different measurement which are conventional way and Kinovea way. The design process and the manufacture process were conducted in the lab at Kuala Lumpur, the data were collected in China, all the participants are Chinese. Their age is between 13 to 34. 19 subjects were participated in the experiments. They were asked to performed a set of movements for right hand fingers. They need to flex their fingers into the maximum angles and extend into minimum angles, therefore reaching extremes of motion. Only the right hand was needed and only the data at PIP joints were recorded. The differences for degree of ROM among subjects were discussed, and differences of the degree of ROM of each joint were discussed. By comparing with the data, we can conclude that the device can mimic real hands and finger movements for rehabilitation goal.

Keywords: Rehabilitation, fingers, prosthetic

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LIST OF SYMBOLS AND ABBREVIATIONS

CMC	:	Carpometacarpal
COR	:	Centre of Rotation
DIP	:	Distal Interphalangeal
EMG	:	Electromyography
CMC	:	Carpometacarpal
IP	:	Interphalangeal
MCP	:	Metacarpophalangeal
PIP	:	Proximal Interphalangeal
ROM	:	Range of Motion

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INTRODUCTION

1.1 Background of hands prosthetic

The background of the hands prosthetic and the reason why hand rehabilitation devices are discussed in this part, the objective of this study and the problem we observed will be discussed later. It is shown that hands play a significant role in fulfilling our daily tasks. And it is also important to learn the how to heal the injured fingers. In the process of finger rehabilitation, some crucial factors must be noticed, such as DOF of each finger and the angle of ROM (range of motion). In addition, the types of hand prosthetic and the common mechanisms will be presented in chapter2. The methodology of the study will be briefly mentioned at the end of background.

Hand movements play a vital role in fulfilling daily tasks, part of the reason is that we need use our fingers to perform sophisticated tasks and movements. Also, sign language uses the change of hands' gesture to achieve, with the interaction of thumb, index finger, middle finger, ring finger, and small finger, human can manipulate objects as they want. When the function of finger movements is damaged, the quality of life and happiness will directly be affected in a negative way.

Meanwhile, current researches only concentrate on improving the quality and effectivity of rehabilitation process. Studies indicate by doing repetitive finger movements can improve the speed of recovery process. There are many devices that people can turn to as a supplementary tool. For example, using exoskeleton devices can create a external force to make the fingers move which help patients to recover faster.

Generally speaking, it is not very common to apply exoskeleton on the finger for rehabilitation comparing to lower extremity and arm rehabilitation, the choices for hand and fingers are limited in many ways including quality and quantity. However, this field is attracting more attentions and researchers are exploit the potential in this field. The reported devices for the hand vary widely when it comes to Range Of Motion (ROM), DOFs, design strategy and finger kinetics and kinematics. There are 2 types in the field of therapy, one is passive another is active procedure. The devices with passive function only support a few DOFs and it is not widely used as active ones. Furthermore, they have no feedback functions for doctors and therapists to choose. (S. Ueki et al, 2010).

There are many devices with different design philosophies which showed promising results. For example, robotic methods have been applied to provide stable source of quantitative data and reflect physical properties precisely within a wide range of variation. With the aid of computer system, the improvement and advancement can be achieved by the feedback of analysis. It not only helps the patients, but the therapists enjoy the continuous support to operate and monitor the condition of the hands.

Another method is hand exoskeleton structure which has been widely applied in hands rehabilitation fields. It was widely considered that an exoskeleton can be put on a appointed part of human body and then by using mechanical guidance or actuation, it can achieve normal motions. Recent studies showed the hand exoskeleton can be used for adjusting flexion/extension of hands movement, allowing patients gaining the movements of their fingers.

Exoskeletons are the most common type of hand rehabilitation robots and usually consist of an outer structure placed on the back of the hand or finger joints(depend on the injured part)and transmitting motion to the fingers, typically to support finger flexion and/or extension. A wide variety of hand exoskeleton systems designed for stroke rehabilitation can be found in the literature, ranging from under-actuated single degree of- freedom (DOF) devices actuating all fingers together.

1.2 OBJECTIVE

The purposes of this project are:

1. To design a finger rehabilitation device that able to restore the flexion and extension ability for upper limb rehabilitation

2. To analyses the adduction and abduction ability of the finger device with the normal human degree movements.

1.3 Problem statement

A large number of people who suffer from the impairment of hand due to the consequences of stroke, aging, and trauma. They lost the ability to grasp and the basic function of hands movements. It caused so much problems and inconvenience for patients because hands are extremely important in both work and life. Thus, a device to aid, assist and rehabilitate the fingers' movement is necessary and called upon. Many researches have investigated into the possibilities of various approaches to tackle the issue.

There are many devices with different design philosophies which showed promising results. For example, robotic methods have been applied to provide stable source of quantitative data and reflect physical properties precisely within a wide range of variation. With the aid of computer system, the improvement and advancement can be achieved by the feedback of analysis. It not only helps the patients, but the therapists enjoy the continuous support to operate and monitor the condition of the impaired parts.

Although those devices are proved effective and showed promising results, most devices are large and difficult to be carried around. These are major defects and disadvantages could result in the extension of recovering session and increase the workload of therapists.

Hands have a rather complex structures and lots of degrees-of-freedom. My proposal is by using simple circuits and suitable sensors to determine the basic structure of finger rehabilitation. So, in this study I will only focus on one DOF to create a simple and clear design for hands.

1.4 Design mechanism

The hands have 3 positions, which are flexion, extension, and relaxed hand position. The main mechanism herein discussed.

The whole designing and producing stage will be divided into 3 sessions.

1. Draw a draft of prototype model
2. Build the prototype and find and select the most suitable sensor for the model
3. Test the prototype

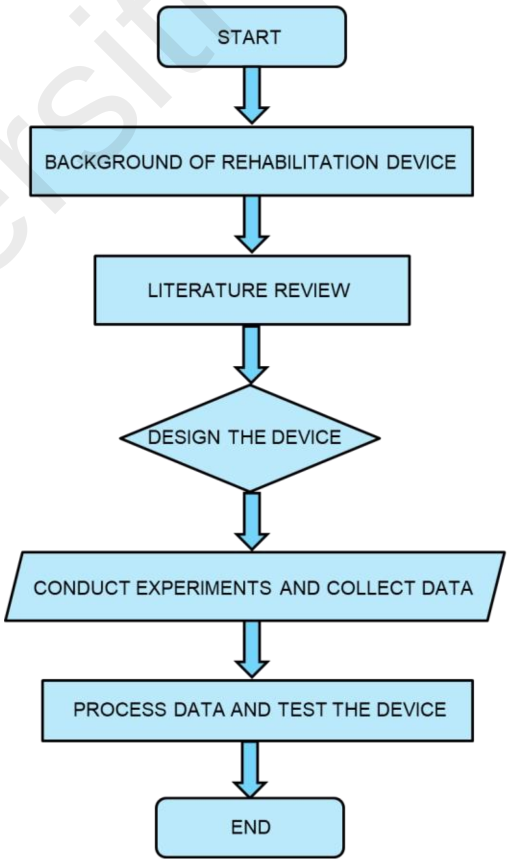
In session one, the preliminary and basic design will be drafted, it's a reference for other sessions to proceed. 3 main factors should be considered in the designing session: comfort, aesthetic, and safety. This session is also a time for preparations, to purchase the accessories and materials required.

In session two, proper sensors for the prototype will be selected and tested. The sensor used is tension sensor. It gives the feedback and determine the tension between the cables. Also, the actuators will be used to adjust the variations depending on the design preference. The actuators can offer precise control over the force and joint. In addition, the grasping experiments are needed to figure out the comfort scale and the angles of joints of the fingers. Because different people have different hands shape and finger length, to avoid the variations of individuals, subjects will go through same procedures.

In session three, the adjustments for the prototype will be made to tackle the possible problems encountered. In the meanwhile, simulation and test will be conducted to determine the function and effectiveness of the device. By comparing the test results, measurements will be taken to further modify the prototype.

My purpose of conducting this project is compile the types of exoskeleton devices for hand rehabilitation, and help patients suffered from impaired hand functions or strokes to recover. This exoskeleton device which I designed has the characters of simplicity and comfortability, it also has wearable structure to aid finger motions in 1 degree of freedom (DOF). A hand flexion and abduction experiment by healthy people with no hand or finger problems were performed, this is to explore the general hand degree and to compare with the movement of the suggested robotic hand.

1.5 Flowchart of the research process



LITERATURE REVIEW

There are many mechanisms for applying hand exoskeleton methods, such as link driven mechanism, wire driven mechanism, and pneumatically driven mechanism. These mechanisms have their advantages and disadvantages. Normally researchers can choose based on their preference and avoid the shortage in designing the hand exoskeleton devices.

2.1 Mechanism

As we all know it's generally difficult to precisely design a hand exoskeleton that perfectly fit the human hand's structure and joints movements. But there is also new mechanism developed to better the user experience and coordinate the relationship with power and structure. A study recently proposed a new mechanism called multi-layered compliant mechanism which support the robotic exoskeleton devices. (Jumpei Arata,2013) By using this mechanism, the device itself can be light weighted and assist large body positioning.

2.1.1 multi-layered compliant mechanism

One DOF was applied on three finger joints, which are DIP, PIP and MCP. Plenty actuators were used to achieve the basic function of flexion and extension motions for injured fingers. It also can give an assist robotic support to rehabilitation therapist during the treatment procedure. And it allows patients to carry it home for further daily activities support because its light weigh, no noise and elastic structure.

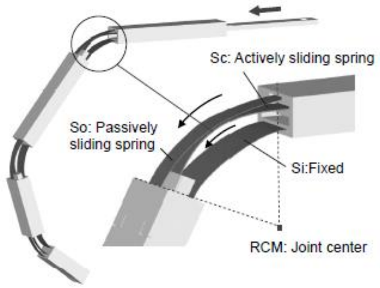


Figure 2.1 multi-layered compliant mechanism

To realize the three-layered spring mechanism, the motion was fixed based on finger flexion and extension. So, every finger has three DOF position to realize hand grasping. Another advantage of this device is highly adaptivity which give a safe environment. More than that, this device does not have many controls and actuators to limit the mass and reduce the size keeping a comfortable wearing experience. By controlling a single actuator, the device can actuate four fingers simultaneously. The goal of rehabilitation device is to fulfill the task of daily living activities.

2.1.2 Link mechanism

Another popular mechanism that is widely taken into consideration is Link Mechanism. An intension-driven device for fulfilling daily hands movements was presented. The device uses the principle of link mechanism, which can assist finger functions in both abduction and adduction ways. More than that, continuous passive motion (CPM) must be provided when applying this mechanism to reduce stiffness and improve range of motion (ROM).

These studies with clinical tests also show that the link mechanism exhibits great superiority in power transmission. Researchers can turn to many supplementary devices, such as virtual reality gloves and finger exoskeleton devices; it is not hard to find the finding on their mechanism, generally speaking, virtual center of rotation (VCR) is a better choice for developers. The marvelous thing is that almost every transmission system and mechanical joint are found on the ground of the back or top side of each finger, and in this way, they can assist fingers to achieve a natural rotation goal for finger movement. (Satoshi Ito, 2011)

In recent years, many devices and prototypes of hand rehabilitation have been proposed, and they are developed for the capacity of 18 DoFs of motion, 3 DoFs for assisting each finger, 4 DoFs for the thumb, and 2 DoFs for the wrist.

The study focused on the assistance of the motion of the opposable thumb; this paper presents the structure of the hand rehabilitation equipment and the control system for operating it. When it comes to upper limb rehabilitation, a novel technology on automated supplementary support method was adopted. It can create a symmetrical motion to help patients recover. However, it has not been widely used in the hand and finger rehabilitation area. To achieve the goal of fast recovery, researchers need to explore new mechanisms and new strategies for hand rehabilitation.

Generally, 4 DoFs determined the function of human finger movements, such as the abduction and adduction movements on finger joints, extension/ flexion for the metacarpophalangeal (MP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints, as well as the MP joint.

It is reported that the PIP and DIP joint can collaborate and reach the goal of flexion and extension movements. The joints are working in unity, and they are not independent parts. Furthermore, the DIP joint is considered as a support for other joints movements. We can see from Fig2 that the 2 motors on MP joints are very table; this design is to maintain the 2 DoFs of motion. Abduction and adduction functions are achieved by the first motor assists, while the extension and flexion functions are achieved by the second motor. In this way, the 2 DoFs are guaranteed. It is also beneficial for researchers to calculate the kinematics of the link mechanism simply. (K.Y. Tong, 2010) 803059362

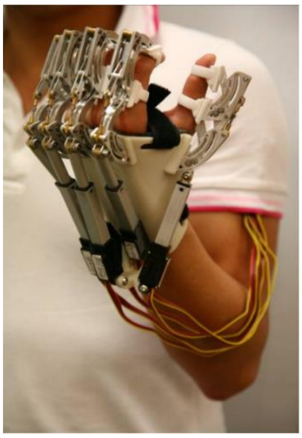


Figure 2.2 Link mechanism

2.1.3 Wire-driven mechanism

Wire-driven mechanism-based rehabilitation is not quite popular as other approaches and mechanisms. However, the devices have the same purpose as other devices. However, it is necessary that in the rehabilitation field, each device need to consider patients based on their conditions and choose the best treatment.

The most famous device using a wire-driven mechanism is the myoelectric signals (EMG)-controlled exoskeleton system. The original proposal is for this device is to help the patients who could only gain partial control of the hand or lost some function of hands and fingers. The fundamental philosophy of this system is using the EMG signal to anticipate the patients' intention when they want to perform an intended gesture or movement. They adopted the glove shape and plastic material to build the device. Pullies and servo motors were connected by 2 wires, ensuring the exoskeleton had a firm structure (Shahrol Mohamaddan, 2010). Thumb uses 1 wire to coordinate, and another wire controls the rest 4 fingers. The function of these 2 wires is simultaneous.

The finger movement and the range of motion were controlled by the mechanical pulling force generated by the wire mechanism. 2 different cables are adopted in the design, one is extensor cable, another is flexor cable. The former is in charge of abducting the finger, and the latter is adducting the finger.

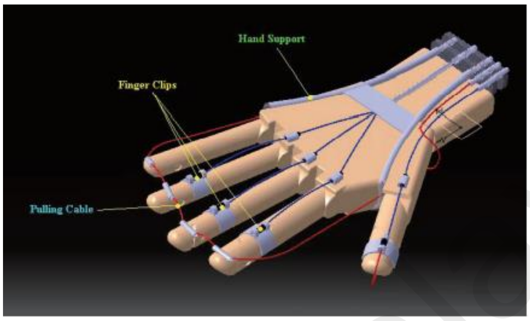


Figure 2.3 wire mechanism

2.1.4 pneumatically driven mechanisms

The PneuGlove is a new type of glove which was designed to support extension function to human segments. The glove can be seen as a connection which links a wireless system called the Shadow Monitor. The primary function is to use different kinds of sensors to get the joint kinematics data. The PneuGlove can be used either in fundamental life interactions or performed on a VR environment platform.

The mechanism of the PneuGlove is to help segments extension and flexion by unitizing air pressure so that the purpose of stretching hand and finger movements. In this way, it makes daily activities like grasp-and-release movements possible. (Lauri Connelly, 2010) fingers and hands must extend and flex so that the function of grasping, carrying, and relaxation can help the healing and rehabilitation. One side of the PneuGlove is a well-designed air bladder, and the other side is a lycra backing on the dorsal side. There is a zipper to support the donning and doffing function of the glove, in the scenario of hands with flexor hypertonia, the glove can perform well comparing other mechanism. Additionally, on the dorsal side of the PneuGlove, there are10 polyester sleeve pockets to link the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints of the fingers and the MCP and interphalangeal (IP) joints of the thumb, in that case, the sensors can be shored up from the Shadow Monitor.

The process of manufacturing air bladder is rather complicated. Firstly, 5 independent channels were made from polyurethane. The function of extension can be achieved by the air pressure within the channel which holds a force of extension. Open-cell foam within each channel helps to reduce the restriction of airflow within the channel during hand flexion. To make sure every digit part can function automatically, each bladder channel must physically isolated with others supplementary parts.

In terms of potential problems, it should be noted that the extension assistance can affect the joint subluxation and hyperextension, which means the joint can flex without any limitation. This could lead to the failure of the unsuccessful grabbing natural objects with this glove. Thus, it is necessary that to connect every channel through air valves and flexible tubing, to an electro-pneumatic servo valve. In figure4, the servo valve can supply air pressure between 0–10 psi, and then linearly proportional transmitted to a command voltage.

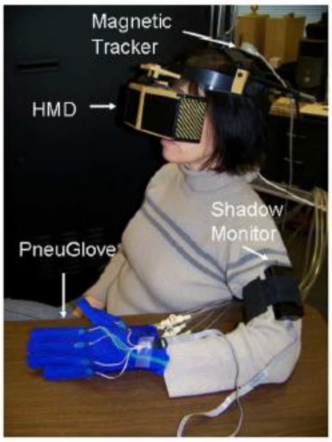


Figure 2.4 pneumatically driven mechanisms

2.2 Control system

The previous studies on control systems gave many choices, many pieces of literature have presented the basic control methodology; in this article, a theory was proposed and led to an assumption, in the process of rehabilitation of tendon therapy, it is crucial to avoid the risk of gap formation and suture break. As for that, subjects can have the opportunity to make their injured finger recover at a desirable speed; in this way, they can regain the ability to feel the pain or other sensation. Based on that theory, they designed a bilateral control mode in which only the patients can adjust the rehabilitation device, not the doctors or therapists so that the patients can have a comfortable user experience. The implementation of this control method requires an MCS operation system to realize bilateral control. On the other hand, in order to make the control system more intellectual and repeatable, this strategy needs extra tests and more accurate human control so that the possibilities of getting second damage will be significantly reduced, the patients would have a better and safer user environment. Moreover, it is necessary to consider the position and force control. Thus, the speed of transmitting the information will be vastly improved compared to other control strategies in the process of finger recovery.In addition, the need for a free force sensor is called upon for a better user experience as well as realizing the function of locating the position and other kinematic information. Motion control is different from patient to patient, it indicates that the use of the robust motion control is found on the ground of different using feelings. (Simon Lemerle, 2018) The patients would also provide feedback during the rehabilitation therapy, so the researcher can adjust the function and evaluate the system's accessibility during the process.

In this case, the researcher used a control system based on the Arduino platform for different control strategies such as EMG(Electromyography), BCI (Brain-computer interface), and SR(speech recognition). (Tzu-Heng Hsu, 2017)

Generally, a BCI system requires a usual attention level and extra reliability level in terms of muscle control, it is a difficult and complex function to achieve, so the researcher decided to use Speech Recognition to realize the command function. The control over fingers. SR systems normally transmit the voice order to a system then transform them into the text message. We can see that it is necessary to restore the voice information in advance as a reference, then the SR system will automatically compare the voice message with the reference, and if it fits the programmed scenario, the motor will accept the voice message as a motor will start to work.

Hypothetically speaking, if we need to observe or capture EMG signals, the electrodes are needed for sensing electron waves of the skin surface. Then the process of analyzing and relocating the digital signal, the EMG will appear on the featured space. It is expected that the EMG have different feature thus can be divided into different clusters.

Through a BCI system, commands and orders will be directly transmitted to devices without the fuss of passing the passage of brain nerves or muscles. For instance, to evaluate the durability and the functionality, the BCI will provide 2 different approaches for detecting the EEG signals. There are 2 types of EEG, dependent class, and independent class. The former will generate brain signals through a specific channel; however, this channel will not be used as a corridor for another brain signal to pass. To be more exact, a dependent BCI can produce many letters which only one pops up at a certain time, the user needs to pick the letter out when the visual information appeared. At this time, the signal that BCI detected in EEG signal. However, the production of the EEG signal is based on the looking direction, so that the peripheral nerves and extraocular muscles could initiate the signal.   (M. Zardoshti-Kermani,1995)

Meanwhile, a dependent BCI does not support the monitoring of the eye location, and it also has no extra communication passage for the brain. However, it still has its advantages on some level.

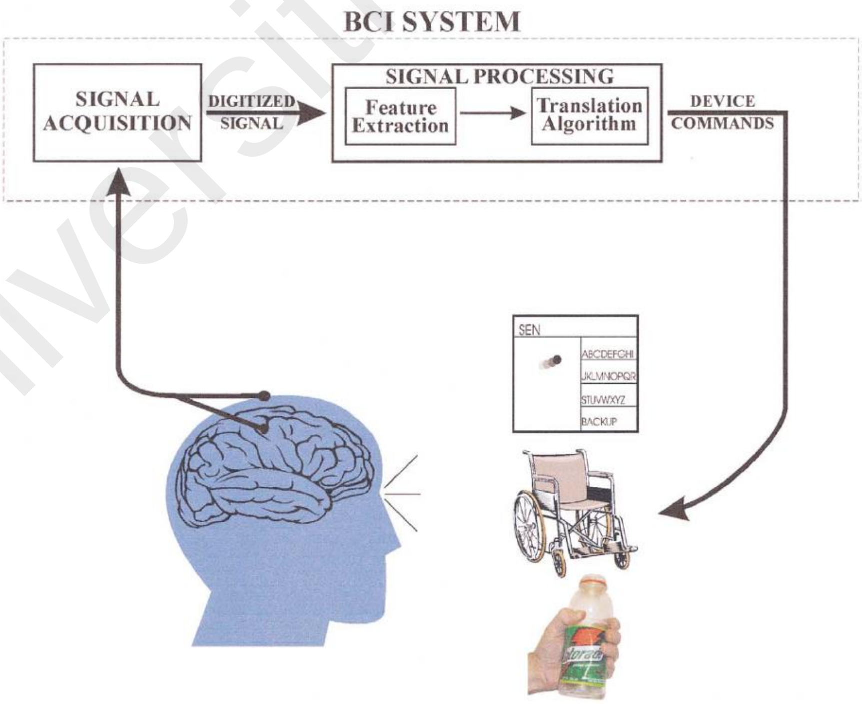


Figure 2.5 BCI system

Another approach that was commonly adopted is ASR (automatic speech recognition). Like SR(speech recognition), it also has the function of transform the speech information into text. And to reverse this protocol, normally the text is transformed into speech or voice message. This process is called speech synthesis. However, speech synthesis is different from voice control in terms of its mechanism. The voice control process consists of initializing and digitalizing voice information, they are normally natural sounds when it comes to the end of the process. In addition, it also has the limitation in durability, flexibility, and digital storage compared to SS.

There are lots of platforms in which can perform the ASR process, such as personal computers, Microsoft speech engines. Through these operation systems, the ASR can achieve cell control and cell supervision, as well as integrating the system.

Moreover, the are other platforms to operate, their platform can also collaborate to reach a certain goal or function, such as the Microsoft Speech Application Programming Interface (SAPI) and Microsoft's Speech SDK, they can produce the speech context to voice processing software. This API can integrate data clusters and divide them into different data groups, and they also support platform backups, so that the data are retrievable, and transfer them into different PCs, which allows researchers and developers to select desirable technology and platform.

2.3 The structure of hand

In most of the references, finger joints can be seen as an ideal rigid structure, in this way, the researchers can easily calculate the data. Consider the index finger's situation, it can be divided into three phalanges: middle phalange, proximal phalange, and distal phalange. Generally, the DIP joint is the one that is in between of distal phalange and the middle phalange. It is not what we are focusing on now.

The PIP joint is the one in-between the middle phalange and the proximal phalange. My project is mainly focused on this joint, most experiments are conducted on the ground of the PIP joint. MCP joint is in between the proximal phalange and the metacarpal skeleton is. Similarly, it is also not the area that we are looking for. Only one DOF is available of DIP and PIP joints which is capable of extending and flexing the fingers. However, there are 2 DOF in the MCP joint to reach the goal of extending and flexing the fingers. The abduction and adduction process is the most important process that needs extra research. It needs 6 muscles and 4 tendons and ligaments to coordinate the abduction and adduction process.

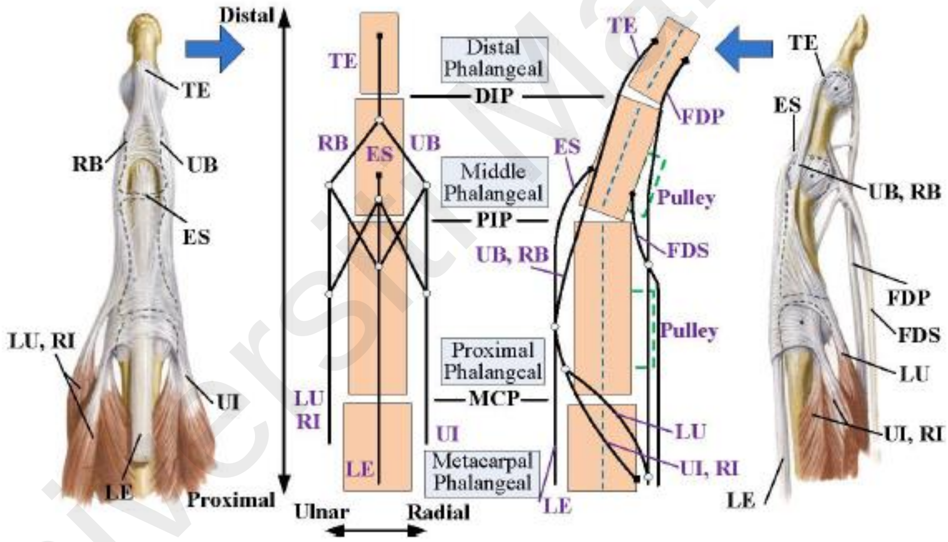


Figure 2.6 Muscles and joints of fingers

Different finger joints have different DOFs, each of them supports a big movement motion range. This project focuses on the PIP joint's movement, we measure the degree of PIP joint in both conventional way and Kino vea way. The MCP joints can flex around 45 degrees, the PIP joints can flex 30 to 45 degrees, the same as the DIP joints. The standard error is around 10 degrees to 20 degrees. The data are similar from different people, however, the data on extension varies from person to person. In terms of DIP joints, the extension degree is beyond 0 degrees and depends on the subject's situation. The movements of fingers are also requiring the participation of muscles, the muscles are not only from the hands but also from the arms and forearm (Ismail Ben Abdallah, 2007).

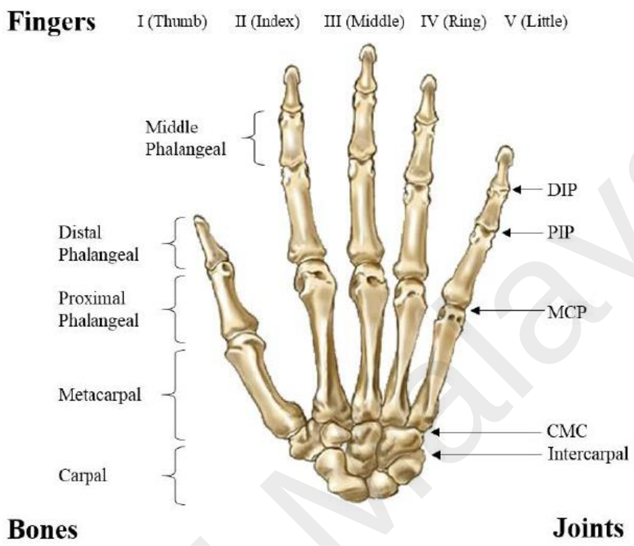


Figure 2.7 Bones and joints of fingers

2.4 Kinovea

It is an application which can be downloaded on computer. The majority group of are athletes, doctors in rehabilitation fields, sports analysists who need collect data from videos. The 4 main characterizes of kinovea are capture, observation, annotation, and measurement, by using these characters we can learn from the body motion to get kinetic and kinematic data.

Generally, this application does not have the direct access of managing your video clips, however it can provide the function of browsing hard drives and video documents. The function of playing video is on the ground of FFMpeg libraries. The advantages of it is to read any types of video format. A very special method for Static images is that it can be converted into 10-second videos therefor allowing manipulate many annotations pages on just one picture. Additionally, it can provide 26 languages for world users in UI surface. (Irene Cabrera-Martos 2019)

2.4.1 Measurement

In terms of measurement, I use a protractor to measure the flexion and extension angle of each PIP joint and use a ruler to measure the distance of each finger. To decrease the standard error and increase the precision, in Kinovea, the function of zooming in is adopted. In addition, to achieve the precision goal, the flat, 2D, axis-aligned calibration, a robust grid-based calibration for rotation is adopted, it can collaborate with perspective-aware coordinate systems. This function allowed measuring the data even if the plane of motion is not aligned with the camera. The coordinate system typically needs to adjust because it will cause lens distortion. However, the distortion can be repaired and compensated. This operation generally needs the assistance of an extra lens calibration. Meanwhile, the intrinsic parameters of the camera are also required for shooting and adjusting the video.

The effectiveness of finger expansion can be quantitatively measured using Kinovea software. The video was taken when the experiment was conducted; then the video was uploaded to the system. The difference between the initial and final angle. To use the Kinovea software, firstly, the video was uploaded into the Kinovea software. Then choose the angle option then place the angle mark on the PIP joint; the actual angle will appear on the screen. Moreover, the value of the angle will be recorded in the software for users to check. Screen to calculate the expansion time for each state. (R. Sulaiman,2015)

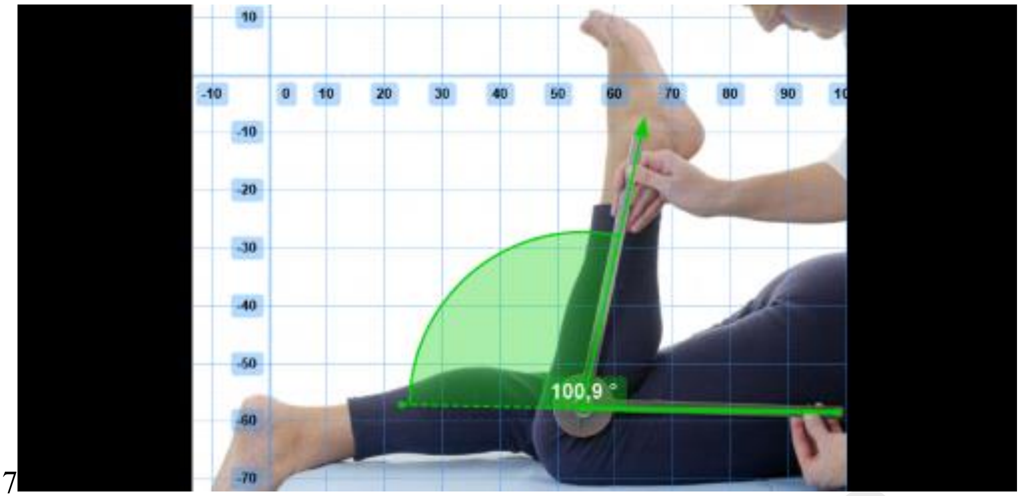
7 

Figure 2.8 Measurements of kinovea

2.4.2 Annotation

Key images and abundant text comments are available for all users in Kinovea. Basic annotations like labels and numbers, lines and arrows, curves, multi-line paths, rectangles, markers, drawings can be added to the project when users need to give a rich interpretation on the platform. Annotation drawings names and styling properties can be copied and pasted and add to frames and videos. External images can be added as a supplementary tool whenever the user wants to add them.

Kinovea also provides many advanced tools, such as the bike-fit, archery, or human model tools. The software also has a preprogrammed library of settings and procedures if the users do not have a clear thought of how to set up the software.

Users can also customize the tools based on their needs to achieve better performance on their subjects, such as kinematic and kinetic tools, diagrams tool, angle tool (John I. Calle-Sigüencia, 2018)

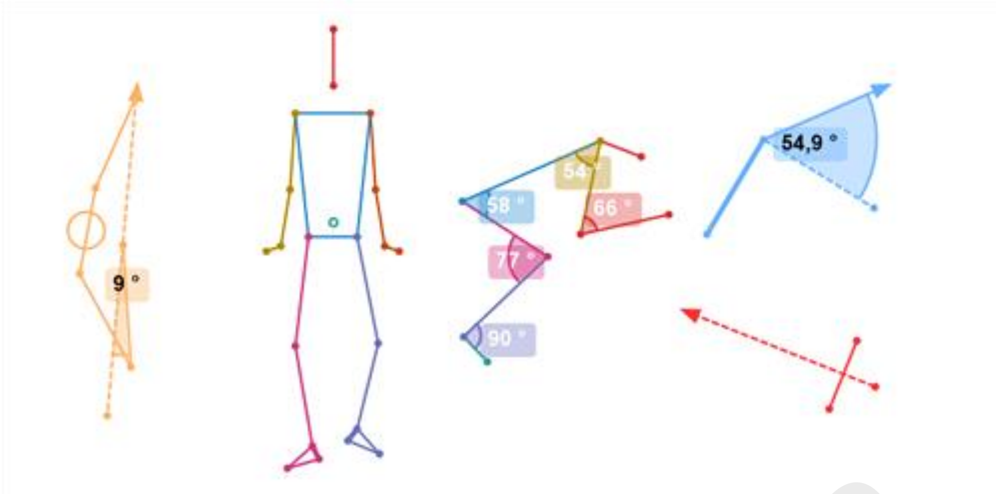


Figure 2.9 Annotation of kinovea

These findings have their advantages and disadvantages. In order to design and manufacture the desirable hands rehabilitation device, it is very crucial to understand all possible rehabilitation methods for hand recovery as well as the construction of hand and fingers. To determine the most suitable method and device is based on the patients experience which consists of material, comfort, and the performance of the device.

METHODOLOGY

The validity and reliability using the measurement approach of kinovea is tested, it recorded finger motion and angles, and then compared to the traditional measurements of finger motion using protractor and ruler.

I will present the research type and methodology in this part. In this experiment, I recruited 19 subjects to flex and extend all five fingers and take the data on their PIP joint. When it comes to the data collection, the fingers' length and the range of motion are recorded then compared with kinds of literature data. Servo motors and wires were connected through Arduino Uno, and code was preprogrammed on the Arduino. The analysis of the angles is collected by using Kinovea software. Last, the mean and SE(standard error) of PIP joints' flexion and extension angle were calculated. The conventional way and Kinovea way were presented, respectively.

3.1 Participants

In recent studies, many researchers have focused on improving the rehabilitation of hands function and receiving promising results. Nineteen participants were recruited by me, consisting of 8 females and 11 males. They are all health subjects with no finger or hand injured and other hand or finger related illness.

3.2 Data Analysis Software and Process

The data analysis primarily utilized kinovea and Excel. The raw data was collected in kinovea and exported as an Excel file, which was then recoded. To cluster data, the t-test was introduced to see the comparison of conventional measurements and kinovea measurements. T-tsest is a test approach that quantifies the correlations related a set of data were as a cluster and was a standardized measure of scale reliability. Additionally, tables, graphics were plotted through excel and statistics description were provided for comparison of the data for further discussion.

3.3 Platform

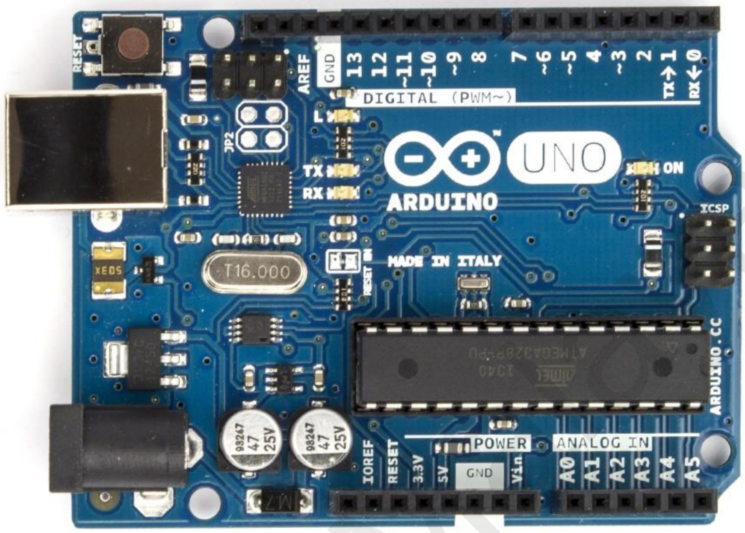


Figure 3.1 Arduino Board display

Normally, Arduino Uno is used as a microcontroller, this board is founded on the ground of the ATmega328P. It generally utilized as an electronic piece for basic projects and widely adopted in biomedical engineering field, electronic engineering field, and mechanic engineering field. In my project, I only used the Arduino Uno board, it has 14 digital input/output pins for multiple manipulation and control. More than that, 6 analog input pins is also attached on the board which gave researchers more freedom to choose. The Arduino board has to be charged by USB port or DC electro supply, there are 2 plugs in board. It is very beginner-friendly, even without programming background, users still can access to the Arduino library for function code.

3.4 coding

```
#include <Servo.h>

Servo myservo;

int pos = 0;

void setup() {
  myservo.attach(9);  // attaches the servo on pin 9 to the servo object
}

void loop() {
  for (pos = 0; pos <= 180; pos += 1) {
    // in steps of 1 degree
    myservo.write(pos);
    delay(15);
  }
  for (pos = 180; pos >= 0; pos -= 1)
    myservo.write(pos);
    delay(15);
  }
}
```

Figure 3.2 Coding of the device

This code was a preprogrammed code which was restored in Arduino library, users only need to input the spin degree and selected the desirable position. Then wires were needed to connect the Arduino board and the servo motors. Figure 11 shows that the servo motor was connected with the 9^{th} pin on the board and the spin degree is 180 degree.

3.5 prototype

Figure 3.3 prototype for the hands rehabilitation

RESULT AND DISSCUSSION

19 subjects were participated in the experiments. They were asked to performed a set of movement for right hand fingers. They need to flex their fingers into the maximum angles and extend into minimum angles, therefore reaching extremes of motion. Only the right hand was needed and only the data at PIP joints were recorded. Protractor and ruler were adopted as a conventional way for finger motion measurements. Then the videos were asked to shoot by each participant which contained the finger motion movements same as the conventional way. Then kinovea were performed to process the data and make sure it did not exclude any abnormalities, however they are not expected to be reported in the results section.

4.1 Gender

Gender Of those 19 participants, 8 were women and 11 men, representing a gender balance of 42.1% in women and 57.9% in men.

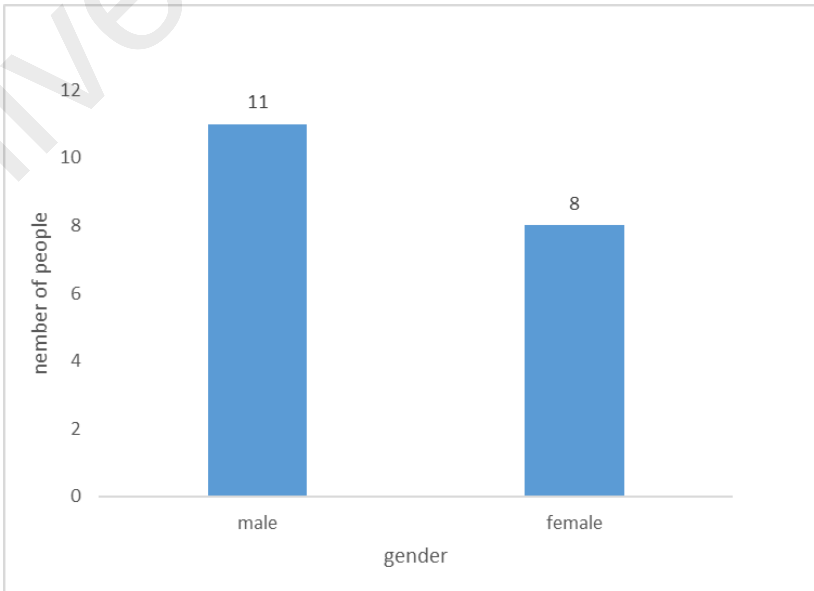


Figure Gender distribution

4.2 Age

The overall age range of participants was from 14 to 34, which has no noticeably younger or older bias. There is a strong bias toward a younger subject in our sample, with 68.4% of the total subjects coming from millennials aged 24. I particularly choose these subjects because during the prevail of covid-19, it is the safest choice to select subject from close friends or family members rather than real hospital subjects. So, the subjects have a dramatic character toward younger in my research. This study does not prove that all younger audiences are suitable for the rehabilitation design or older people are not fit for the finger rehabilitation design; it only indicates that the research still have potential for other audience. For further tests, the age groups were combined into: high school students, fourteen; college-aged students, twenty-four; young adults, twenty-nine to thirty-six. And in future, the middle-aged people and elder people will be taking into consideration for the improvement of the finger rehabilitation design.

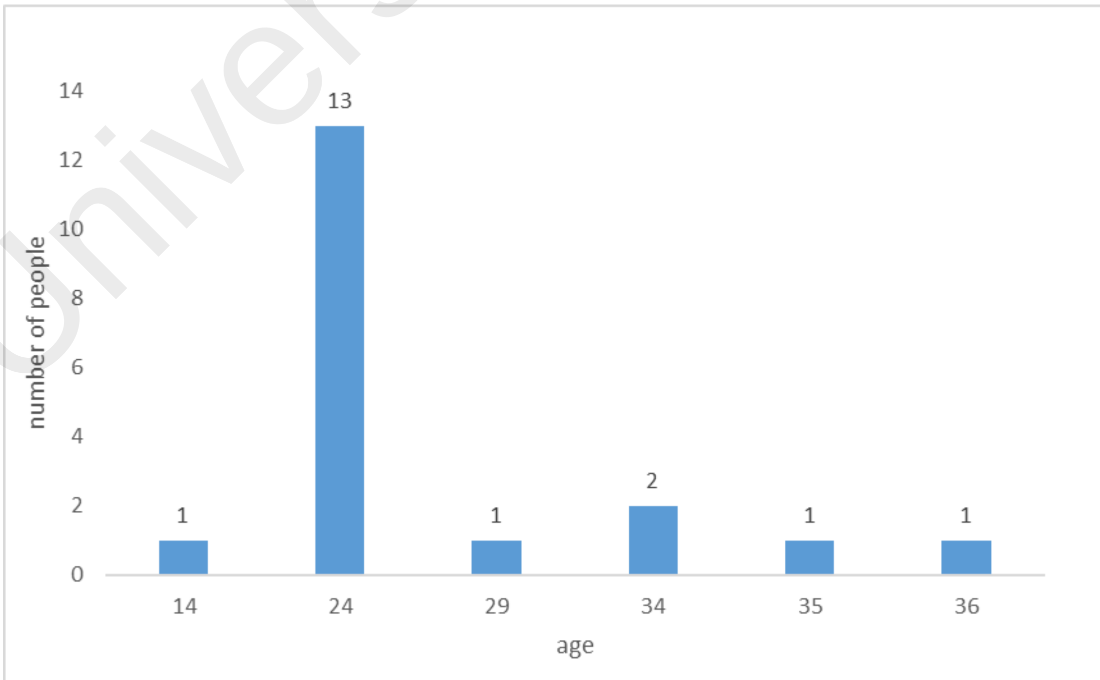


Figure 4.2 Age distribution

4.3 Results and discussion

Table 4.1: Finger length

	Thumb	index	middle	ring	little
mean	6.2cm	8.5cm	9.3cm	8. 8cm	7.0cm
SD	0.51	0.88	1.05	1.05	0.91

Table 4.2: Conventional measurements

	Thumb	Index	Middle	Ring	Little
Flextion	180±0	180±0	180.±0	180±0	180±0
Rest	241.84±14.44	255.21±7.86	251.68±12.42	256.32 ± 15.63	258.47 ± 12.31
Extension	275.53±9.85	309.63±7.37	302.4±13.98	305.8±6.12	305.2 ± 9.24

The subjects' mean finger length from thumb to little finger are 6.2cm, 8.5cm, 9.3cm, 8.8cm, 7.0cmrespectively, it is within the healthy people's finger length range. But due to all subjects recruited are Chinese, so there are the possibilities that the device may not suitable for people from other ethics or region`s other than Asian.

Using the 2 methods to measure the degree of ROM of PIP joint of each subjects' finger, the results came out very similar. We adopted 3 positions, which are flexion state, rest state and extension state. In conventional measurement, and in flexion state, the mean degree of ROM for PIP joints of each finger are all 180°, it was because the ruler and protractor has accuracy limits, the tools cannot measure the degree perfectly, thus causing bigger deviation and error. And in rest state, the degree of ROM for PIP joints of each finger (from thumb to little finger) are 241°, 255°, 251°, 256°, 258° (for standard deviation please refer to table 4.4). And the degree of ROM in extension state, they are 275°, 309°, 302°, 305°, 305°, respectively.

Table 4.3: Kinovea measurements for human fingers

	Thumb	Index	Middle	Ring	Little
Flexion	174.16±8.37	177.00±5.97	179.21 ± 10.88	184.47 ± 11.57	179.11 ± 10.86
Rest	246.21 ± 12.32	261.89 ± 16.06	258.95 ± 12.05	257.05 ± 19.68	258.84 ± 16.96
Extension	273.00 ± 12.15	312.63±6.41	311.53 ± 11.49	309.42 ± 9.05	306.63 ± 12.94

On the other hand, for Kinovea measurement, the degree of ROM is more accurate, for example, in the flexion state, the degree of ROM for each finger is 174°, 177°, 179°, 184°, 179°. And in rest state, the degree of ROM for each finger is 246°, 261°, 258°, 257°, 258°. In the extension state, the degree of ROM for each finger is 273°, 312°, 311°, 309°, 306° (for standard deviation please refer to table 4.3)

Table 4.4: Kinovea data for rehabilitation fingers

	Thumb	Index	Middle	Ring	Little
Flexion	181	205	214	220	211
Rest	208	223	232	231	245
Extension	224	251	252	241	256

As for the data of the designed device, in Kinovea measurement, and in flexion state, the degree of ROM for each finger is 180°, 205°, 214°, 220°, 211°. Comparing to the human fingers, it has the error of 0~11° (Moroz, 2017), however it is within a reasonable range. In rest state, the degree of ROM for each finger is 208°, 223°, 232°, 231°, 245°, and it also fi the categories of human finger with error of 13°~45°.

The results show that statistically significant test result ($P \leqslant 0.05$), the t value is 0.004. which means the test hypothesis is right (Jamshed,2014). When the P-value is more significant than 0.05, it indicates that the conventional way and the Kinovea way are close, which can be seen as the proposed prosthetic hand can mimic the function of the natural hand.

However, to prove that this device and functions the same as the natural person's hand, its range of motion should be closed to usual healthy fingers. But in some cases, because the patients' hands or fingers cannot perform well, the angle could be smaller than healthy people. The device can adjust the patient's movement by attaching it to the back of the patient's hand to realize the rehabilitation goal. Furthermore, because of the covid-19 situation, the experiment on comfortability could not be finished, so the device could cause pain and discomfort, which require further adjustment.

Meanwhile, I also compared the data under influence of the factor of gender. From table 4.5 and table 4.6, we can see that the female data and the male data are the same in flexion state, both in conventional way and Kinovea way. And it is very similar in the case of rest state for both females and males.

In Kinovea way, the female thumb has a tendency of larger degree of ROM than male's, 281° for female and 267° for male. It is possible that in this cluster of subjscts, the Chinese female has more wide range of ROM for thumb, in this case, when encountered female patients, certain arrangements or adjustments for this rehabilitation device on thumb degree need to be made based on patients' needs (E. B. Brokaw,2011).

Table 4.5: Female data for conventional way and kinovea way

Female	State	Thumb	index	middle	Ring	Little
Conventional way	Flexion	180	180	180	180	180
	At rest	243±15	253±6	252±12	251±21	258 ± 10
	Extension	280±9	310 ± 7.5	303±14	306±6	303±7
Kinovea way	Flexion	178±6	177±6	180±12	181±8	180 ± 12
	At rest	246±13	263 ± 14	254±12	251±26	259±2
	Extension	281±14	312±7	306±16	309±7	304 ± 17

Table 4.6: Male data for conventional way and kinovea way

Male	State	Thumb	index	middle	Ring	Little
Conventional measurement	Flexion	180	180	180	180	180
	At rest	240±15	256±9	250±13	260±10	258±14
	Extension	272±9	309±8	301±15	305±7	306±10
Kinovea measurement	Flexion	171±9	176±6	178±10	186±13	178±6
	At rest	246±12	260±14	262±11	261±13	258±16
	Extension	267±6	312±6	315±6	309±10	308±10

CONCULUSION

5.1 Conclusion

In this study, the process of the design and manufacturing the device is to begin with the background research and then the graphic design, followed with data collection of healthy subjects. In this way the range of motion is determined. It is also beneficial for the test of the device.

However, even though the angles for joints are varies to different patients, it is proven that during flexion, the PIP joint shows the largest flexion and extension angle. The result of this study can prove that this device is designed to avoid COVID-19 situation and offer the simulation to mimic the real hand. Real hand can Attached to prosthetic hand. And using circuits and coding the prosthetic hand make the real fingers move to reach a rehabilitation goal.

5.2 limitation

Because of the prevail of covid-19, I was not able to use the device to test on real patients with hands' problems. Only the healthy people's data were collected to conduct a comparison. This was to prove that the device can mimic the real human finger movements and be used as a method for hands rehabilitation.

The potential of this kind prosthetic was also unclear. Because most of the exoskeleton devices were in the metal or plastic shell and hold upon the joints. The study on the device of human hands shape is not widely discussed in most of the findings.

5.3 Future work

The future work on this project will focus on the durability test of the proposed prosthetic hand, and the user satisfaction. Due to the covid-19 situation, this finger rehabilitation device is not tested on patients with hands injuries. So next step is to recruit patients in a hospital or clinic and adjust the device based on their needs. It is necessary to take questionnaires on the patients' user experience, Furthermore, the durability of the device will be tested. The materials of the device are manifold, so optimization of various materials can be tested. In this project the 3D printing technology was adopted, it was not clear that whether using other materials such as plastic, carbon fabric, etc. will improve the user experience. Thus it requires further experiment.

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