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DEVELOPMENT OF BIOMECHATRONICS DESIGN OF AN ARTIFICIAL ARM.

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A thesis submitted in
Fulfillment of the requirement for the award of the
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ABSTRACT

Arm rehabilitation activities need to be continuously monitored in order to provide information of rehabilitation results to be analyzed by physical therapist. The purpose of monitoring is to help them to improve rehabilitation process. Moreover, a portable and simple home-based rehabilitation device can help patients to improve daily rehabilitation activity. Some previous studies regarding home-based rehabilitation process have shown improvement in promoting human movement recovery. But existing rehabilitation services are expensive and need to be supervised by physical therapist, which are complicated to be used at home. This project focuses on the development of a measurement hand gripper, to help handicap patient because of some complications such as accident and disease. This project concourses on the designing of mechanical equipment, sensors equipped Smart Glove and a measurement gripper device. The devices will move based on a human operator's finger movement using the Smart Glove. The system development involves a Microprocessor Arduino and HyperTerminal as a core processing for the instrumentation, communication and controlling applications. A series of flex force sensors are fitted in a glove to get reading from the movement of human fingers. The evaluation in first real hardware experiment showed a good and promising performance of the position mapping as a variety of different grasp types ranging from precision to power grasps can be performed. The quality of the force feedback is strongly affected by the maximum torque measurable by the Hand gripper and the performance of the force controller. Finally, the intelligence, learning and experience aspects of the human can be combined with the strength, endurance and speed of the artificial hand gripper in order to generate proper output of this thesis.

ABSTRAK

Aktiviti pemulihan lengan perlu dipantau secara berterusan dalam usaha untuk menyediakan maklumat keputusan pemulihan untuk dianalisis oleh ahli fisioterapi. Tujuan pemantauan adalah untuk membantu mereka untuk meningkatkan proses pemulihan. Selain itu, alat mudah alih ini dapat membantu pesakit untuk meningkatkan aktiviti pemulihan setiap hari. Beberapa kajian sebelum ini menunjukkan ia dapat meningkatkan dalam membantu proses pergerakan pemulihan manusia. Perkhidmatan pemulihan yang sedia ada adalah mahal dan perlu diselia oleh ahli fisioterapi, selain ia amat rumit untuk dipraktikkan di rumah. Projek ini memberi tumpuan kepada pembangunan penggenggam tangan pengukuran untuk membantu pesakit yang cacat kerana beberapa keadaan seperti kemalangan dan penyakit. Projek ini mengandungi rekabentuk peralatan mekanikal yang dilengkapi oleh Sarung Tangan Pintar dan Sensor Pengukuran Penggenggam Tangan. Alat ini akan bergerak berdasarkan pergerakan jari pengendali manusia menggunakan Sarung Tangan Pintar . Pembangunan sistem ini melibatkan ”Microprosessor Arduino dan HyperTerminal” sebagai sistem pemprosesan teras untuk instrumentasi, komunikasi dan aplikasi mengawal pergerakan sistem. Satu unit sensor lenturan dipasangkan di dalam sarung tangan untuk membaca dari pergerakan jari manusia. Penilaian dalam eksperimen perkakasan sebenar yang pertama menunjukkan prestasi yang baik dan menjanjikan pemetaan kedudukan sebagai pelbagai jenis genggaman yang berbeza dari ketepatan untuk mengukur nilai kekuatan genggaman yang boleh dilakukan. Kualiti maklum balas daya yang amat bergantung oleh kilasan maksimum boleh diukur oleh genggaman tangan dan prestasi pengawal kekuatan. Akhir sekali aspek kecerdasan, pembelajaran dan pengalaman manusia yang boleh digabungkan dengan kekuatan, ketahanan dan kelajuan genggaman tangan palsu ini boleh menghasilkan keputusan yang tepat didalam kajian ini.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADC	-	Analog to Digital Converter
AHG	-	Artificial Hand Gripper
MCP	-	Metacarpo Phalangeal
PIP	-	Proximal Phalangeal
DIP	-	Distal interPhalangeal
ADL	-	Activity of Daily Living
AROM	-	Active Range Of Motion
AAROM	-	Active Assisted Range Of Motion
AC	-	Alternate Current
COM	-	Communication
CTRL	-	Control
DC	-	Direct Current
DOF	-	Degrees Of Freedom
EE	-	Energy Expenditure
HT	-	HyperTerminal
EMG	-	Electromyography
FSR	-	Force Sensitive Resistor
GB	-	Gigabytes
GND	-	Ground
Hz	-	Hertz
IDE	-	Integrated Development Environment
IMU	-	Inertial Measurement Unit
LCD	-	Liquid Crystal Display
mm	-	milimeters
MMC	-	Multimedia Card
MTC	-	Minimum Toe Clearance
PC	-	Personal Computer
PWM	-	Pulse Width Modulation
RM	-	Measurement resistor

RROM	-	Resistive Range Of Motion
UTHM	-	Universiti Tun Hussein Onn Malaysia
Vref	-	Reference Voltage
WSNs	-	Wireless Sensor Neworks
A	-	Ampere
g	-	Gravity force
K	-	Kilo
M	-	Mega
V	-	Voltage
W	-	Watt
˚C	-	Degree celcius
°	-	Degree
µF	-	Microfarads
µ	-	Micro
Ω	-	Ohm
%	-	Percent
3D	-	Three Dimensions

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The purpose of designing an artificial hand or robotic hand is to replicate or imitate sensory-motor capabilities of human hand (R. Vinet and N. Beaundry, 1987). Robotic technology is actively being introduced in the development of new methods and devices which contributes in assisting human limbs rehabilitation processes(A.T.Miller And P.K. Allen,1999). At present, due to the advancement of robotic technologies, it have changed the method from utilizing grippers with only two rigid fingers, and no phalanges, to the development of human-like hands with at least three to five functional fingers, each with two to three phalanges (Rajiv and Yeh Clement, 1990) .

A master-slave robotic system is a popular tool in application related to rehabilitation and remote handling operation (Ludovic Dovat and Olivier Lambercy, 1992). This system enables the personnel to maintain safe working distance from hazardous work environment (Jayarajan K. and Manjit Singh, 2006). Moreover, in the field of health-care such as tele-surgery and rehabilitation, remote handling tools involving the usage of robotic hands are also employed to improve human limbs function (Atkins Dj, Heard Dcy, Donovan Wh,1996.). There are many types of five fingers robotic hand which here been developed and most of them involve innovative mechanism or myo-electric control systems. As an example, a five finger adult sized anthropomorphic hand that is known as the Montreal hand with passive adaptive capabilities by means of a clutch, a cable system, and a spring-loaded pulley mechanism was developed (R. Vinet and Y. N. Beaundry, 1987).

Rajiv and Doshi (1992) had developed a multiple motors and sensory feedback robotic hand which can grasp object. From both cases, the robotic hand gave a more human-like finger function. But there are many setbacks mainly due to oversize, overweight and it is costly. It is proven that the imitation is an element which is important in proper improvement of social and communicative skills (Sari Avikainen and Andreas Wohlschlager, 2003).

Mirror Visual Feedback (MVF) therapy or mirror therapy is an imitation method introduced back in early 1990s, which is based on mirror illusion to help patient's limb practice due to cerebral vascular accident injuries, post-stroke or amputated (Ramachandran V.S. And Eric L.Altschuler, 2009). When human limbs such as leg or arm is amputated, the patients may still feel the presence of the limb and in some cases the patients still feel the pain such as burning, cramping or crushing (Ramachandran V.S and Mitchell S.W, 2000). As shown in Figure 1.1, a "1meter X 2meter" was utilized foot mirror in a mirror visual feedback therapy that requires patient to place his paralyzed left hand on the back of the mirror with a normal hand on its right (Ramachandran V.S., Hirstein .W 1998). This will assist patients to imagine that through the normal hand reflection and from the phantom hand movement it recovers the psychological effects after the hand amputation (Ramachandran V.S,1995).

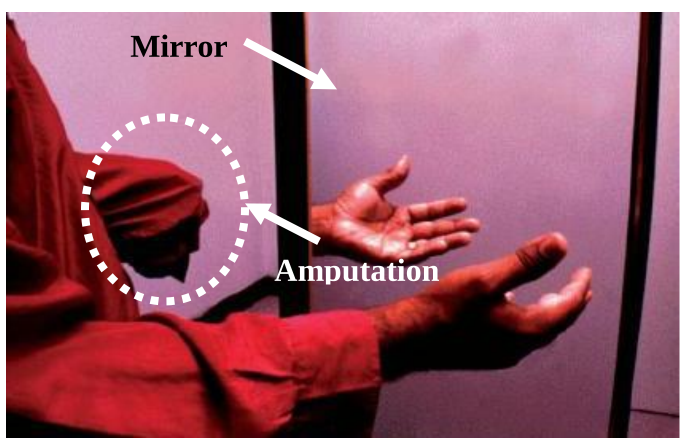


Figure 1.1: Mirror Visual Feedback (MVF) therapy.
(Ramachandran V.S and Mitchell S.W, 2000)

Several research were conducted that based on these findings and continued with the use of virtual reality technology. The outcome was encouraging and proven partially effective for reducing pain due to the phantom hand (Ramachandran V.S and Mitchell S.W, 2000).Other researchers also had applied different approach by incorporating robotic hand technology in mirror therapy. A master-slave robotic hand rehabilitation device was developed which incorporates five fingers functions that are supported with a cable system via a computer controlled servo motors (Stein R.B., Cody F.W., Capaday C. 1988). The light-weight servo motors mechanism was controlled with a user glove that worn by the normal hand. Once the glove is worn, the robotic hand will be substitute the phantom hand through mirror visual feedback therapy process (Sok, jin-hwan, an, tae-hee, kim,.2010) . In this thesis, the concepts of the robotic hand development that cater to the hardware and software design are presented.

1.2 Problem Statement

Rehabilitation processes are based on clinical assessment tools which can be executed by self-report (home base) and observer-rated (done at rehabilitation centre) (Roy et al., 2009). Observer-rated by caregivers can be time consuming and patients need to have repeated observations at rehabilitation centre which can be a burden to the health care cost. While the reason of post-stroke rehabilitation is to facilitate community integration, early discharge and home-base rehabilitation (with the support of caregiver) is the logical choice because the patients integration with community can be commenced sooner (Nancy et al., 2000). Moreover, early home-base rehabilitation proved to promote a better physical health because it appeared to permit motor and functional gains that occurred with natural recovery and satisfaction with community integration (Nancy et al., 2000). Early discharge and home-based rehabilitation can reduce the usage of hospital beds without compromising clinical patient outcomes. However, for home-based rehabilitation with the support of caregivers, on behalf of the caregivers, they are exposed to the potential risk of poorer mental health (Anderson et al., 2000). Moreover, on behalf of patients, if they have financial restriction or no insurance coverage, then they need to face higher medical costs in order to have caregivers support at home.

Thus, how to effectively motivate patients to do the regular physical activity is an important research topic (Eriksson Et Al., 2005). Therefore, in this work, we propose the use of an assistive device as a substitution of caregivers supported rehabilitation. A robot hand is defined as that can mimic the movements of a human hand in operation. Stable grasping and fine manipulation with the multi fingered robot hand are playing an increasingly important role in manufacturing and other applications that require precision and dexterity (Spires Mc, Miner.2000). Nowadays, most of robotics hand with multi-fingered used as service robot, human friendly robot and personal robotics. Tele-operation is the controlling of a robot or system over a distance where a human and a robot collaborate to perform tasks and to achieve common goal (Stein R.B., Cody F.W., Capaday C. 1988). The operator is the human controlling entity, whereas the tele-operator refers to the system or robot being controlled.

Traditional literature divides tele-operation into two fields: direct tele-operation, with the operator closing all control loops and supervisory control, if the tele-operator (a robot) exhibits some degree of control itself (Ramachandran V.S and Mitchell S.W, 2000). Tele-presence means that the operator receives sufficient information about the tele-operator and the task environment, displayed in a sufficiently natural way, that the operator feels physically present at a remote site (Christine K.Cassel, 2003). The feeling of presence plays a crucial role in teleoperation, the better he can accomplish a task.

Advanced research had been conducted to produce advantages to the robot industries by considering combination of telecommunication systems with another robot increasing group work robots in order to speed up the performance of the tasks and works (Sok, Jin-Hwan, An, Tae-Hee, Kim,2010) . One method type of communication system that can embed into the robots peripheral is via using Bluetooth technology.The challenging thing is to develop anthropomorphic dexterous multi-finger robot, in order to get the precise and accurate grasp of the robotic hand (S.Lee Saridis, G.N.Graham,1997). It is approximate the versatility and sensitivity of the human hand. Nowadays these are various types of robotics hand and its application. The most important aspects to be considered are their stability, reliability and economically (Tetsuya Mouri, Haruhisa Kawasaki, & Katsuya Umebayashi, 2005). Main parts are a characteristic of robot hand is not the same as human. All of robot hand mechanism totally related to the cost. Simplifying the robot mechanism with low cost which is similar to human is most challenging task (Taylor C.L, Craig L, Ten, 1997). Therefore, design and fabrication of human hand will be done in this research especially for master-slave with data logging communication network (Takahashi C. D., Der-Yeghiaian L., Le V. H., & Cramer S. C, 2005). This promote flexibility to the artificial hand gripper with each of the fingers can be either controlled individually or remove quickly by simply removing one screw. As a result the artificial hand gripper that requires servicing will be easily for swapping out fingers (T .Murphy, D. Lyons And A Hendriks 1993). The artificial hand gripper is also equipped with data logging system which provides medical experts with patient’s data for further analysis of rehabilitation process and education purposes.

1.3 Aim and objectives.

The aim of this research is to assist handicap individual for providing amputee with an enhanced version of economical and affordable artificial hand gripper. The construction of the artificial hand gripper involves the design and the development of a hand gripper with five fingers, arm and bicep. In order to achieve this aims, the objectives are formulated as follows:

a. To design and develop a fully functional 5 fingered robotic hand (slave) controlled by a Smart Glove (master) via cable connection.
b. To evaluate the performance of the flexible bend sensors and flexi-force sensors attached on the master (Smart Glove).
c. To develop data logging system for monitoring the amputee performance during rehabilitation.
d. To enable patients with arm disability caused by stroke disease or other illnesses to practise the rehabilitation process at home without the supervision of therapist.

1.4 Project Scope

This project is primarily concerned with the artificial robots hands applied with sensors mimic to the human hands. The scope of this project involves two parts which are hardware and software implementation. The scopes of this project are:

a) Hardware:
   - Smart glove development that incorporates flex sensor for collecting data from amputee normal hand.
   - Using Arduino microprocessor for data acquisition purpose such as digital conversion and servos control.
   - Gear system development for bicep and shoulder of artificial hand gripper.

b) Software:
   - Data logging via hyper terminal with Microsoft Excel.
   - Program development for mapping Analog Digital Converter data to servo motion.

1.5 Thesis Layout

The thesis is organized as follows:

Chapter 1: Introduction

This chapter discusses all the background aspect of the project, the problem statement aims and objective, project scope, thesis layout and achievement.

Chapter 2: Literature review

This chapter includes the previous studies on the research subject, carried out by some researchers in the design of pumps and accessories, and some important theory deeply related to the project.

Chapter 3: Development of Artificial Hand Gripper Design (AHG) by using 3-D design

This chapter presents the detail design of the construction of the artificial hand gripper by using 3D design utilizing Google Sketch-Up software.

Chapter 4: Development of Flex Sensitivity Resistant

This section discusses the results of the design and development of the hardware, software and Smart Glove using Flexi sensor

Chapter 5: Development of the Artificial Hand Gripper

This section discusses the results of the design and the development of the hardware, software and control system of the artificial arms movement.

Chapter 6: Conclusion

This section discusses the conclusion of the project and provides suggestion for further work.

1.6 List of Achievement.

1.6.1 List of Publication.

The research described in this thesis has led to the following presentations and publication.

1. A. M. MOHD ALI, R. AMBAR AND M. M. ABDUL JAMIL, “Development of master –slave robotics hand for mirror visual Feedback Therapy (MVF) ”. UniKL-BMI Journal of Electronics Technology 2011.Volume.1,pp5-13.

2. A.M. MOHD. ALI, R. AMBAR, M.S. AHMAD & M.M. ABDUL JAMIL.“Arduino Based Arm Rehabiliataion Assistive Device”. UniKL BMI Journal of Engineering Technology (JET) 2011.Volume .1,pp11-44.

3. A. MALIK .MOHD ALI , A.JALALUDIN M.WAHI , RADZI BIN AMBAR ,M. MAHADI .ABDUL JAMIL , Development of Artificial Hand Gripper by using Microcontroller. Journal International Journal of Integrated Engineering (IJIE) 2011.Volume 3, pp7-13.

1. A. MALIK MOHD ALI, M. YUSOF ISMAIL, M. MAHADI ABDUL JAMIL, J. SHARIF .proceeding paper: “Development of Artificial Hand Gripper for Rehabilitation Process”. The 5th Asian Pacific Conference on Biomedical Engineering Biomed, Kuala Lumpur, Malaysia,Volume 35, pp. 785-788, 5th - 2011.

2. A. M. MOHD ALI, M. Y. ISMAIL, AND M. M. ABDUL JAMIL, “Development of Artificial Hand Gripper for Rehabilitation Process”, IFMBE proceedings: Kuala Lumpur International Conference on Biomedical Engineering Biomed, Kuala Lumpur, Malaysia, 20-23 June, Springer-Verlag Berlin Heidelberg Volume 35, pp. 785-788, 5th-2011.

3. A. M. MOHD ALI , R. AMBAR AND M. M., ABDUL JAMIL. “Artificial Hand Gripper Controller via Smart Glove for Rehabilitation Process”. International Conference on Biomedical Engineering ICoBE 27-28 Feb. 2012 Volume 35, pp. 785-788, 5th-2012.

4. A. M. MOHD ALI, R. AMBAR AND M. M. ABDUL JAMIL. “Development of Master Slave Robotics Hand for Mirror Visual Feedback Therapy”. Conference on Biomedical Engineering ICoBE 27-28 Feb. 2012 Volume 35, pp. 785-788, 5th-2012.

5. A.MALIK MOHD ALI, M. MAHADI , J. SHARIF. “ Development of Artificial Hand Gripper” ASQED 2011 Number 51) .The 4th Asia Symposium on Quality Electronic Design ASQED Kuala Lumpur, Malaysia. 2012-(Submit).

6. A.MALIK MOHD ALI, M. MAHADI. " Biomechatronics Design of Novel Artificial Arm with hand gripper. " Conference on Biomedical Engineering & Sciences (IECBES 2012) 17th- 19th langkawi, Malaysia. 2012(Accepted).

7. A. MALIK MOHD ALI, M. MAHADI, " Biomechatronics Design of Novel Artificial Arm . " Biomedical engineering international Conference BMEICON 23th- 25th October 2013/ Krabi,Thailand -2013.

8. A. MALIK MOHD ALI, M. MAHADI, "An Empirical Framework for Controlling Artificial Hand Gripper System using Smart Glove. Conference International Symposium on Medical and Rehabilitation Robotics and Instrumentation 2th- 4th Disember 2013/ MRR1 Uitm Shah Alam Selangor.

1.6.2 Patent

1. **Title: A system for Rehabilitation exercise of an Extremity Mammalian and Method There of - (Smart Glove)**

   Status patent: Complete
   Reference: IPR/UTHM/PA/7/2013
   Date Filling: 07 February 2013
   Application Patent no: PI-201-3000-408
   Under: University Tun Hussein Onn Malaysia.

1.6.3 Research Grant

1. **Title: Design and Development of Motion Analysis System for Medical Sport Technology**

   Status patent: RM 30,000
   Reference: UTHM/PPI/600-5/1/14 Jld3(75)
   Date Filling: 17 April 2013
   Duration Grant: 12 month.
   Under: University Tun Hussein Onn Malaysia.

1.6.4 List of Awards

1. Competition : International Technology Exihibition Convention
   Center .Kuala Lumpur 2013.
   Title Project: Biomechatronics Design of Novel Artificial Arm.
   Gold Medal.

2 Competition : UTEM Research and Innovation Expo (UTEMEX-2013)
   Universiti Teknikal Malaysia Melaka.
   Title Project : Biomechatronic Design of A Novel Artificial Arm.
   Gold Medal.
   Special Awards IPTA/IPTS.

3. Competition : Malaysian Technology Exhibition 2013
   Title Project: Biomechatronics Design of A Novel Artificial Arm
   Silver Medal

4. Competition : Quality and Innovation Awards KKLW 2012
   Title Project: Development of Artificial Hand Gripper And Smart
   Glove For Rehabilitation.
   Civil Service Technical Innovation Category
   First.

5. Competition : Majlis Amanah Rakyat.Malaysia 2012
   Title Project: Development of Artificial Hand Gripper and Smart Glove
   For Rehabilitation.
   First Technical Innovation category.

6. Competition : International Technology Exihibition Convention Center .Kuala Lumpur 2012.
   Title Project: Development of Smart Glove As An Assistive Device.
   Gold Medal.

7. Competition: Inventions and Innovation Nuclear Malaysia 2011
   Title Project: Development of Artificial Hand Gripper By Using Microcontroller.
   Gold Medal.

8. Competition: Inventions and Innovation Nuclear Malaysia 2011
   Title Project: Development of Artificial Hand Gripper By Using Microcontroller.
   Overall Winner Inventions.

9. Competition: Inventions and Innovation Nuclear Malaysia 2011
   Title Project: Design And Development of Arm Rehabilitation Monitoring Device.
   Silver Medal.

10. Competition: Industrial Art and Technology Exhibition(Inatex2011) Universiti Teknologi Malaysia.
    Title Project: Development of Artificial Hand Gripper By Using Microcontroller.
    Silver Medal.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The objective of this chapter is to describe the robotics system, human hand and the basis for designing hand model. The content is explained about human hand, shoulder movement and categories of amputation. The range of motion for the wrist and the joints of hand also explain in this chapter

2.1 Robotic Hand Technology Developments

Robotics technology nowadays moves forward until now **(**A.T.Miller And P.K. Allen. 1999). The technology developments since 70's era until now are rapidly changing the robotic hand engineering history. Existing hand now can divided into four types where are; Robot hands of 80's, commercial hands, research hands and prosthetics (Zeeshan Omer Khokhar, Zhen Gang Xiao, 2009). Development of robot hands early 80's start with, soft gripper in Figure 2.1 Hirose Soft Gripper by Shigeo Hirose from Tokyo Institute Technology (Alison L. Hall. 2005). This development began late 70's with one degree of freedom when it graduated pulleys at joints and create evenly distributed forces (Fischer T. Rapela and D.Woern h, 1999).

Figure 2.1: Hirose soft gripper
(Fischer T. Rapela and D.Woern h, 1999)

Then, in 80's, Rajko Tomovic and George Bekey pioneering effort in development of first prototypes Belgrade, USC hand in Figure 2.2 after world war II, four degree of freedom (1 for each pair of fingers and two for thumb).It's also have some adaptability such as one finger in a pair if other stalls can flex (Fischer T. Rapela and D.Woern h, 1999).

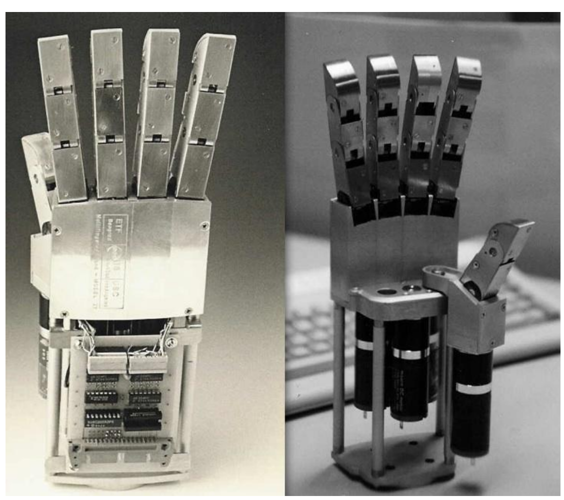


Figure 2.2: Belgrade - USC hand.
(Fischer T. Rapela and D.Woern h, 1999)

In the same era, more development and research done for this field to upgrade the prototypes and technologies (Atkins Dj, Heard Dcy, Donovan Wh 1996.) For example Stanford-JPL hand in Figure 2.3 prototype with nine degree of freedom designed. Others feature such as four tendons or finger also designed for fingertip manipulation is combined with strain gauge fingertip sensors (Fischer T. Rapela and D.Woern h, 1999)

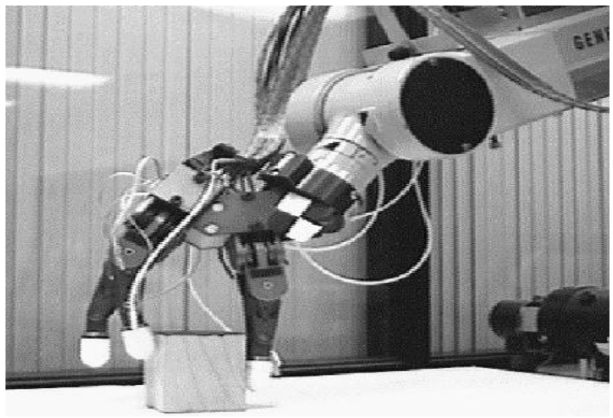


Figure 2.3: Stanford-JPL hand
(Fischer T. Rapela and D.Woern h, 1999)

Then Utah-MIT hand in Figure 2.4 developed in 80's upgrade with 16 degree of freedom with 32 tendons (Banerjee, P.Bagchi, 2003). Sensor used for position and tendon tension sensing by Hall Effect. This hand strength durability about 7lb. fingertip force same as human level with complex tendon mounting scheme (Huu and Cong-Nguyen, 2009).

Figure 2.4: Utah-MIT hand
(Huu and Cong-Nguyen, 2009)

Hence the research and development in this disciplined increased and move towards, more of prototypes being commercialize being robotic hand products due to highly demand in industries or another platform also commercialize **(**Plettenburg, D.H 1998) . Barrett hand from Barrett Technology in Figure 2.5, Incorporated used four motors, one motor per finger for three finger and plus another spread motor for palm. The breakaway technology allows fingers to adapt to object geometry (Pons Jl, Ceres R, Rocon E, Reynaerts D, Saro B, Levin S, Van, 2005) . It's also including the optical encoder for position sensing. This hand capability to maintain up to 3.3lb. fingertip force and the weight of this hands about 1.18 kg. Finally, this commercial hand sells about 30K United State Dollar (Huu and Cong-Nguyen, 2009).

Figure 2.5: Barrett hand
(Huu and Cong-Nguyen, 2009).

After that, Gifu Hand in Figure 2.6 developed by Kawasaki and Mouri, Gifu University which is sold by Dainichi Company (Pylatiuk C, Mounier S, Kargov A, Schulz S, Bretthauer G, 2004): . It is about 50K United State Dollar with 0.6 lb. fingertip force and this hand weight is 1.4 kg. Gifu Hand have 16 controlled degree of freedom (last two joints coupled except thumb) combined with pressure sensing, but no accurate position sensing (Nicolas Gorges, Andreas J. Schmid, Dirk Gager And HeinzWarn, 2008). One of this disadvantage is its size is larger than human size and its sensor not too sensitive (Huu and Cong-Nguyen, 2009).

Figure 2.6: Gifu hand
(Huu and Cong-Nguyen, 2009).

Another commercial hand is DLR - HIT hand in Figure 2.7 developed by Gerhard Hirzinger, This hand sold by Schunk Company about United State Dollar 60K. This hand larger than human size which is capability to maintain up to 1.5 lb (Peter S.Lum, Charles G. Burgar , Peggy C. Shor, Matra Majmundar, Machiel Van Der Loos.2002). fingertip force with Hall Effect sensors and the weight of this hand about 2.2kg. It has 13 controlled degree of freedom last two joints of each finger are coupled (Furie B. and Furie B.C,2008).

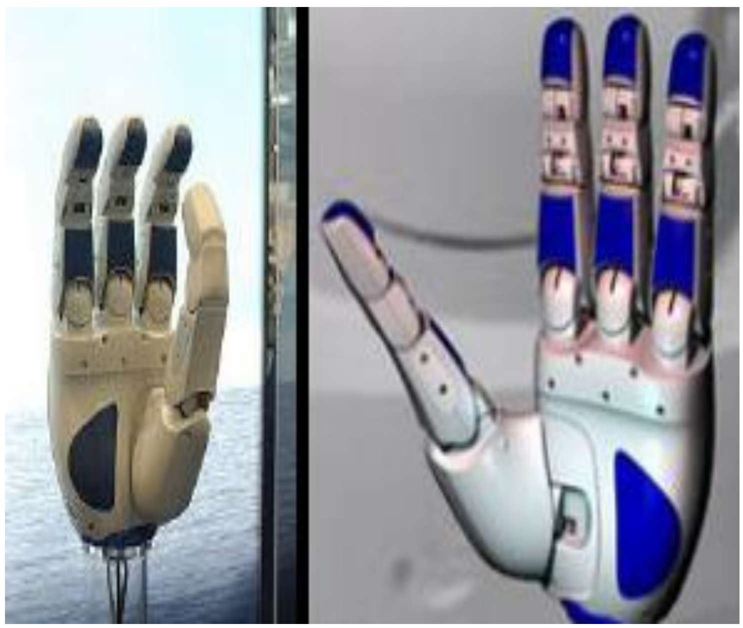


Figure 2. 7: DLR-HIT hand
(Furie B. and Furie B.C,2008)

Finally, the latest product from Shadow Robot Company is Shadow Hand shown in Figure 2.8. It was have 20 controlled degree of freedom (last two joints coupled except thumb) with Hall Effect position sensing, air pressure sensing and tactile array (Plautz, E.J.; Milliken, G. W. & Nudo, R J 2000). It was about United State Dollar 100K for normal type and latest with motorized about United State Dollar 200K. This hand being able brings about 1lb. fingertip force mounted and its weight is 3.9kg (P.Lum Et Al.2002) . Best features in this hand is added with pneumatic actuators add compliance, wear and control issues. It system actuator drive by artificial muscle, it can work on highly back drivable embedded with low inertia electric motors. That's why; it used by British for research into bomb disposal for example cutting wires (Furie B. and Furie B.C,2008)

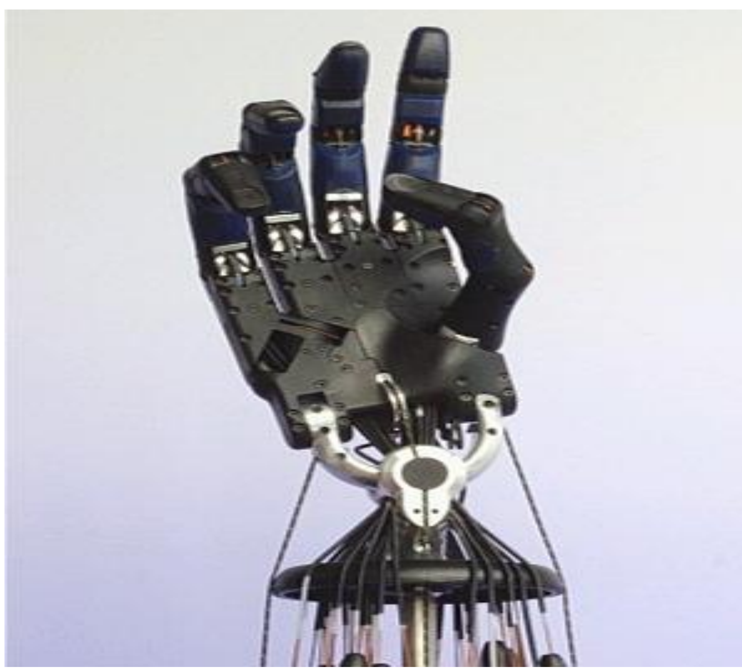


Figure 2.8: Shadow hand
(Furie B. and Furie B.C,2008).

2.2 Human Hand and Shoulder movement.

The wrist contains several joints, including radiocarpal joint, several intercarpal joints, and five carpometacarpal joints (V. M. Zatsiorsky, 1998). The generic term “wrist joint” is usually referred to radiocarpal joint which is formed between the distal end of the radius and the proximal row of the carpal bones (except the pisiform bone). Rotation of the human forearm occurs by the rotation of the radius bone about the ulna bone (Smith et al., 1996). In a position with the arms by the side of the body and the palms of the hand facing forward, the forearm is supinated. If then the palm is rotated to face backwards the forearm is pronated. Figure 2.9 shows the supine position the radius and ulna run parallel to one another, whilst in the pronated position the radius crosses the ulna (Kapandji, 1970).

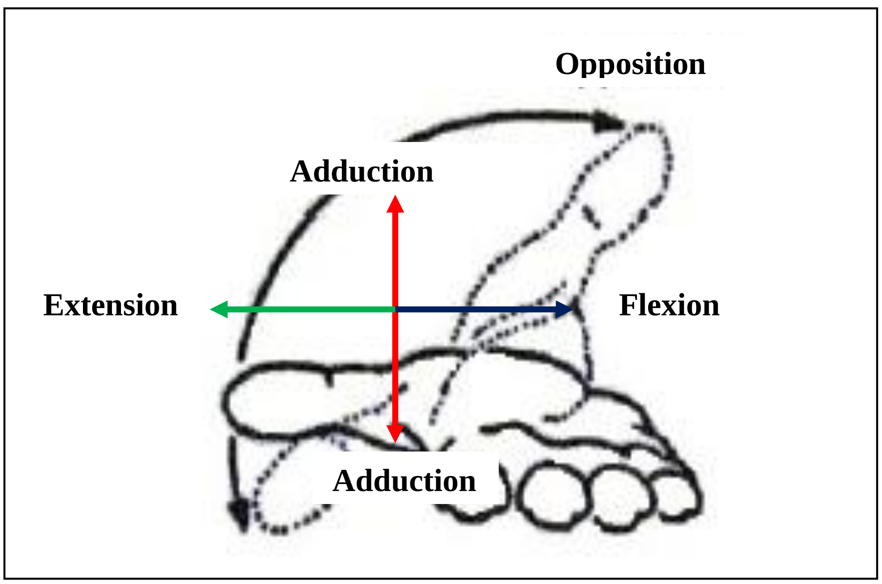


Figure 2.9: The movements for the thumb during Abduction/adduction, and flexion/extension for the thumb.
(Kapandji, 1970).

Tables 2.1 and 2.2 show the range of motion for each finger, where "H" means hyper-extension. Not all the fingers have these movements, and these tables do not cover all the populations. Figure 2.9 shows the movements for the thumb; for our model, the movement of opposition and Retro-Position are simulated by the sum of the movements of the Carpometacarpal (MC) and Metacarpophalangeal joint(MCP) joints.

Table 2.1: Range of movements for the joints of the thumb(in degrees). (Kapandji, 1970).

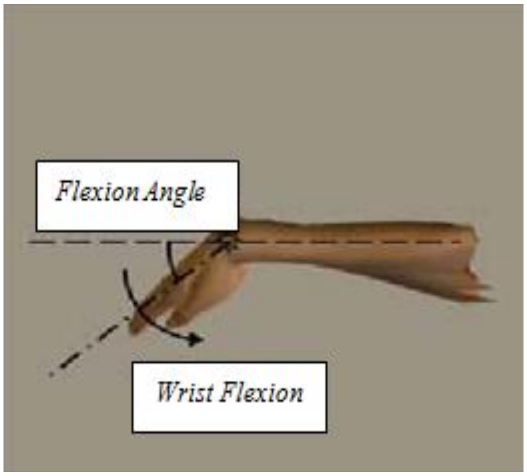
Thumb	*Action*	*Normal (in degree)*
Carpometacarpal (CMC)	Adduction/Abduction	0°(contact)-60°
Carpometacarpal (CMC)	Extension/Flexion	25°-35°
Metacarpophalangeal (MCP)	Extension/Flexion	10º hyper-extension - 55 °
Metacarpophalangeal (MCP)	Adduction/Abduction	0° - 60°
Interphalangeal (IP)	Extension/Flexion	15º Hyper-extension -80°

Table 2.2: Range of movements for the joints of the fingers; "H" is Hyper-extension in degrees. (Kapandji, 1970).

FINGER	MCP(Extension/ Flexion)	MCP(Extension/ Flexion)	MCP(Extension/ Flexion)	MCP(Extension/ Flexion)
Index	0º to 80º	0º/100º	10° hyper-extension /90°	13° /42°
Middle	0ºto 80º	0º/100º	10° hyper-extension /90°	8°/35°
Ring	0ºto 80º	0º/100º	20° hyper-extension /90°	14°/20°
Pinky/ small	0ºto 80º	0º/100º	20° hyper-extension /90°	19°/33°

When taken as an entity, the wrist joints are considered one joint, called the wrist joint and permits two degree of freedom, wrist flexion-extension motion and radial-ulnar deviation motion N.Dechev, W.L.Cleghorn,S.Naumann (2001).”. Wrist radial-ulnar deviation motion is also named as wrist abduction-adduction motion. During wrist flexion, the palm approaches to the anterior surface of the forearm and the reverse movement is the extension (O. Kerpa, D. Osswald, S. Yigit, C. Burghart, And H. Woem,2003). Wrist radial deviation is bending the wrist toward the thumb side and the opposite movement is the ulnar deviation.

Human wrist flexion-extension and radial-ulnar deviation motions are shown in Figure 2.10 (a), (b) and (c) respectively. In the human wrist, two degree of freedom motions are generated with an instantaneous center of rotation, although the path of centrode is small (C. L. Taylor, and R. J. Schwarz, 1999). However, customarily, the path of the center of rotation is ignored and the rotation axes for flexion-extension and radial-ulnar deviation are considered as a fixed one (V. M. Zatsiorsky, 1998). Usually, the movable range of wrist motion is 65° to 85° of flexion, 50° to70° of extension, 15° to 25° of radial deviation, and 25° to 45° of ulnar deviation (G.Thompson and D.Lubic, 2000).



(a)

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