Development of Robotic Hand

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A Dissertation Submitted to
Indian Institute of Technology Hyderabad
In Partial Fulfillment of the Requirements for
The Degree of Master of Technology

भारतीय प्रौद्योगिकी संस्थान हैदराबाद
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July, 2015

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Acknowledgements

I have a dream of becoming an IITian and now it's came true. I express my sincere gratitude to my advisor Dr. R. Prasanth Kumar for making my dream to happen and for encouraging me during my Master's thesis work. I am always inspired with his work throughout my stay at IIT Hyderabad. He taught me how to be dedicative to our work and his patience towards my mistakes encouraged me to learn a lot. I am thankful to him for having believe on my ability to do work.

I would like to thank Prof. U.B Desai, Director, IIT Hyderabad and Prof. Vinayak Eswaran, HoD, Department of Mechanical and Aerospace Engineering, IIT Hyderabad for their direct and indirect support to my thesis.

I would like to thank my examiners Dr. Chandrika Prakash Vyasarayani, Dr. Viswanath Chinthapenta, Dr. B Venkatesham and my external examiner Dr. S Sireesh for their valuable suggestions and appreciations for all the reviews.

I would like to thank the IIT Hyderabad Central Workshop and Manufacturing Lab staff for helping me in all fabrication works. And my sincere thanks to Satyanarana sir and M A Somashekar for helping me at any time, when I request them for fabrication works.

I would like to thank my parents Dhana Laxmi and Haribabu, sister Neelima for their support and encouragement throughout my life. Thanks to my grandmother Anasuya for always caring and wants me to be the best.

I would like to thank my lab mates Lokesh, Janardhan, Santhosh kumar and Vikram for their contribution to my work.

Finally, special thanks to my best friends S.Shiva Kumar, Giridhar, Deepak, Ratikant, Sivanand, Lingeshwar, Srinivas, Jyothi, K.Naresh Reddy and my roomie Pratap Rao Patel for making me emotionally strong with their constant support. I thanks to my friends Ranjith kumar, Venkatesh, U. Sai Kumar, Prasuna, Pavan Kumar, Jaya Naidu, Srikanth, Uday kumar whom, I always remember throughout my life for helping me to be a best person through their friendship.

Dedicated to

My Parents and All my Teachers

Abstract

Humanoid robots have become more important in the military applications, space exploration missions and hazardous environments like mining. The purpose of a humanoid robot is to walk, jump, run, grasp the objects, manipulate the objects etc., Robotic hand plays an important role for a humanoid robot. This thesis focuses on the development of robotic hand for the humanoid robot. It includes (a) Development of robotic hand (only four fingers) with tendons and servo motors, (b) Development of robotic hand only with the servo motors for practicing the human grasps and the heavy wrap has been demonstrated, (c) Design of robotic Arm and the experimental setup to conduct experiments for improvising the robot efficiency.

Robotic hand is analyzed by considering each finger as each module. These fingers has 3 degrees of freedom, which is actuated by 3 servo motors and complete hand has 4 fingers with 12 degrees of freedom. Kinematic analysis is done by calculating Denavit-Hartenberg (DH) parameters.

Fingers have been fabricated by the Fused Deposition Technique with the plastic material. These fingers have in-built pulley and the provisions for the tendons. It has 12 degrees of freedom which is done by 12 servo motors. These servo motors are controlled by Arduino Nano board. Fish wires have been used as tendons which act like a human muscles to drive the finger joints. This can also be used a Rehabilitation purpose.

Another version of robotic hand has been developed by using only the servo motors, which are commercially available low cost motors so as to reduce the cost of the robot. This robotic hand is used to perform the human grasps. Heavy wrap, which is a type of human grasp has been demonstrated with this robot.

Robotic arms has been designed to mount on a work table, which helps in conducting the experiments with the robotic hand. This even helps to improve the efficiency of the robot. Each robotic arm has 5 degrees of freedom and a total of 10 degrees of freedom for two arms.

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Chapter 1

Introduction and Literature Review

1.1 Introduction

In order to build a humanoid robot, building a robotic hand plays an important role. Its role is to grasp and manipulate the objects without damaging from one place to another in any intrinsic environments. This also acts as an end effecter to any manipulator. Robotic hand is an imitation of human hand and it should consists same DOF as of human hand. Difficulty in the problem is to perform all the grasps like human, manipulate the things with a light weight, compact size robotic hand. It should detect, sense and determine the objects to manipulate and act intelligently. We designed the robotic hand which is driven by cables actuated by servo motors. These cables are similar to the tendons in the human hand which are actuated by elongation and contraction of muscles.

During the past few years, the pace of research on artificial multi-fingered hands for robot manipulators has significantly increased [10-23]. Each finger of multi-fingered robot hands can be considered as an independent manipulator; thus, operation of a hand requires coordinated motion of several separate small manipulators. When holding an object with a multi-fingered hand, the grasp must satisfy a number of conditions, such as static equilibrium, no slippage, and the ability of resisting disturbance in all directions.

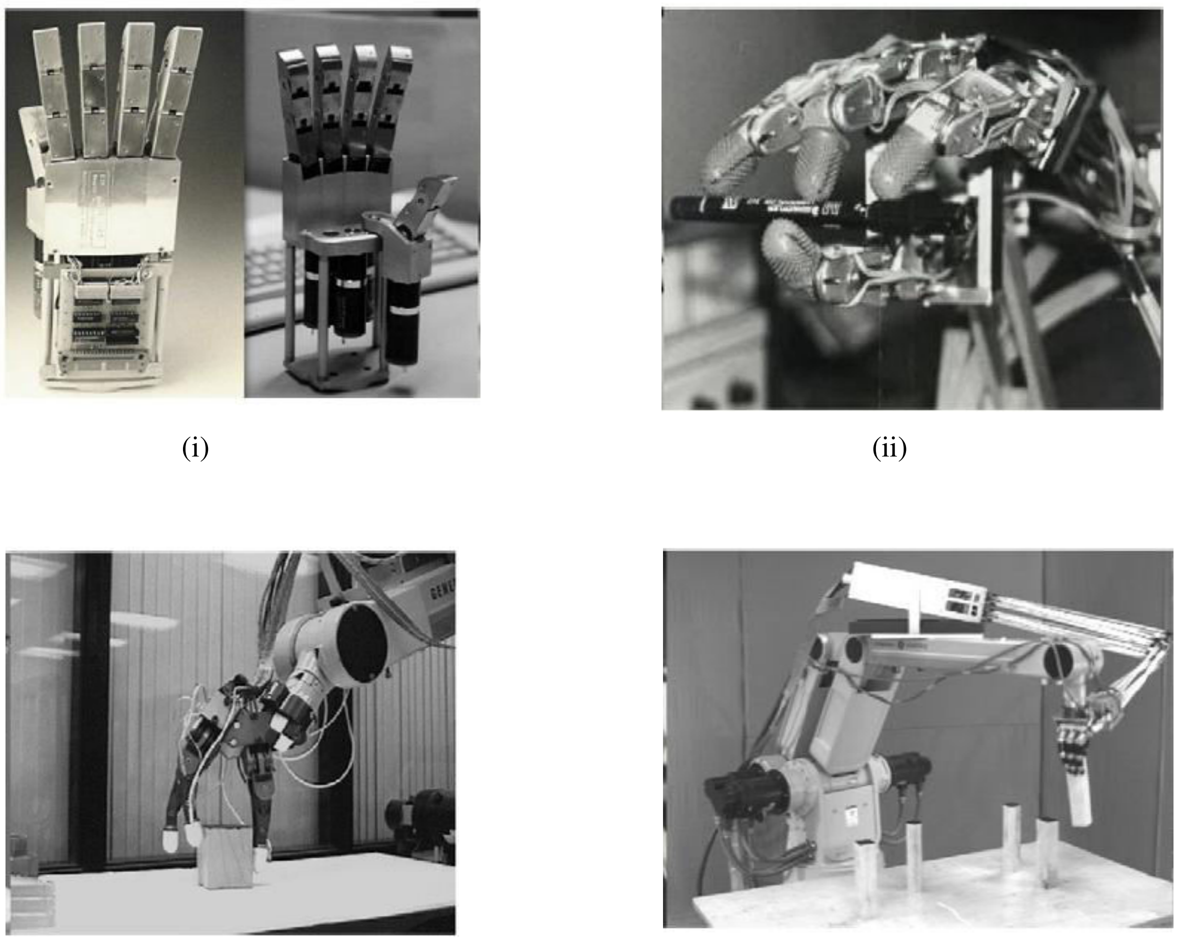
Now a days, robotic hand is also using as rehabilitation medicine.

1.2 Motivation

It is necessary to reduce the human damage during the wars or working in any hazardous environments like Mining, Nuclear plants or in Space applications. So, to replace the human interaction, researchers have started working on the development of human like machine called humanoid robot. The purpose of this humanoid robot is to walk, jump, run, process and grasp the objects, friendly interaction with the people etc., like human. One of the important task in developing the humanoid is the robotic hand. It has to process the things and grasp the objects without damaging the objects. Difficulty in the development of robotic hand is to perform all the grasps like human, manipulate the things with a light weight, compact size robotic hand. So, it is necessary to study the kinematics and dynamics of human hand, control systems, actuators and sensors in order to achieve a compact size robotic hand.

1.3 Literature Review

Early 1990's 1) Belgrade/USC [1], 2) UTAH [3], 3) JPL [4], 4) Reading University – CybHand [2] are considered as early attempts to emulate human grasps [5].



(i) (ii)

(iii) (iv)

Fig 1. (i) Belgrade/USC [1], (ii) Reading University – CybHand [2] ,(iii) JPL Hand [4] , (iv) UTAH Hand [3]

Since 1997 DLR has developed two generation of multisensory dexterous robot hands: DLR hand I and II [6], [7]. Highly integrated multisensory mechatronic hands. DLR hand II is more powerful and reliable than DLR hand I. Cables between the hand and main microprocessor has been greatly reduced from more than 400 to only 12. DLR hand II is recognized as one of the best robotic hand in the world [8]. The extra degree of freedom of thumb enables the hand not only for power grasping but also for fine manipulation. But it is not easy to manufacture, since all motors are specially designed and the analog hall sensors must be glued and calibrated carefully. Since 2001, Based on the experience of DLR hand II, HIT (Harbin Institute of Technology) and DLR jointly developed a modular four-finger dexterous robot hand: the **DLR HIT-Hand** [9]

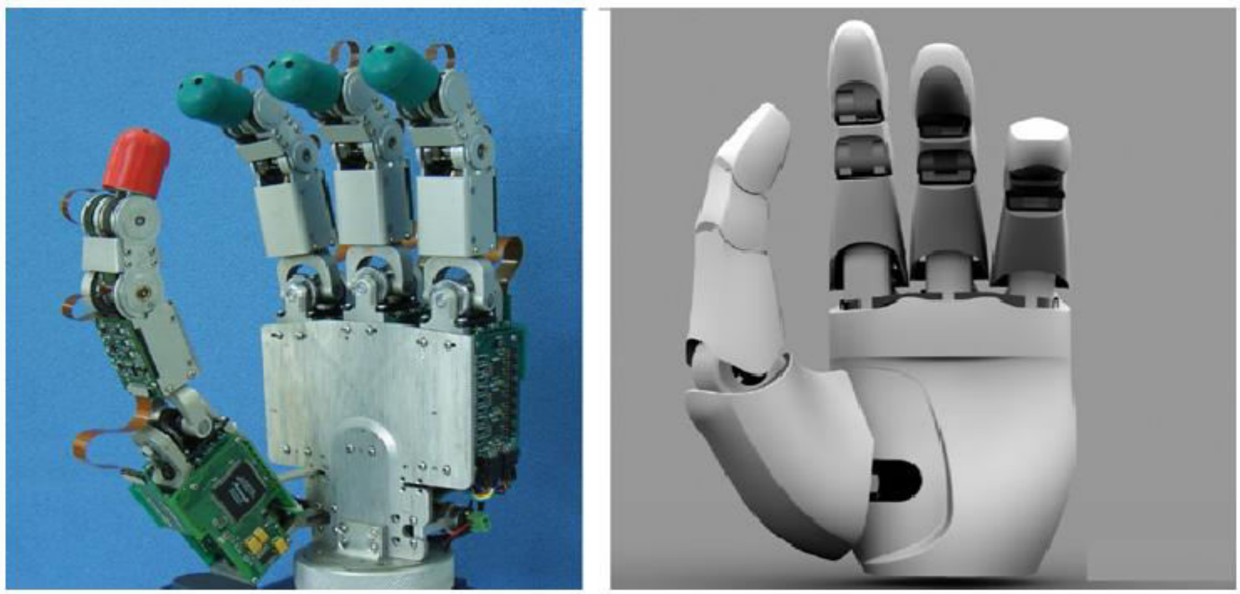


Fig 2. DLR-HIT Hand [9]

The goal of DLR-HIT project is, to build a smaller robot hand than DLR hand II, cost should be low. The amount of cables is reduced from 12 in DLR-hand II to 5. Actuators are all commercially available brushless DC motors. Joint angles are measured by non-contact Hall sensors instead of potentiometers.

1.4 Objective and Scope

The main objective is to develop a robotic hand which can grasp and manipulate the objects. Replicate all the functionalities of the human hand, instead of replicating the mechanism. The total price should be as low as possible and the performance must be as high as possible. It should replace the human damage in hazardous environments, wars etc.

1.5 Problem Statement

Is to develop the robotic hand for a humanoid at a low cost and high performance. The required finger parts are to be fabricated by FDM and the actuation is done by the cheaply available servo motors. These servo motors are controlled by Arduino Nano board. Each finger has 3 Dof's and the hand has 4 fingers.

Developed robot should perform all the grasps as of human.

Chapter 2

Modeling

2.1 Kinematic analysis of robotic hand

In order to analyze the kinematic and dynamic behavior of a human finger, we assign the coordinate system to every joint according to the DH parameter rules. As shown in the fig. 3, three coordinate systems are assigned to each joint and one at the finger tip. The DH parameters of the finger under consideration are defined in the following table,

θ	α	d	a (mm)
θ_1	0	0	25
θ_2	0	0	25
θ_3	0	0	15

Table 1: DH parameters

Where,

θ is angle of rotation about the joint axis

α is angle about common normal, from old z axis to new z-axis

d is offset along previous z to the common normal

a is length of the common normal (link length)

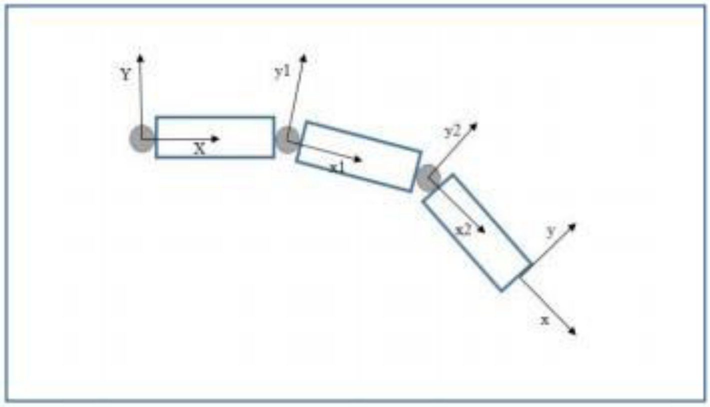


Fig 3. Links and the coordinate system according to DH parameter rule

2.2. Fabrication

Finger parts are fabricated using the FDM (Fused deposition modelling) process. This is a rapid prototyping process in which the given shape of a CAD model is laid layer by layer. The finger CAD models are represented in the fig. 4. These models are designed such that they should accommodate the tendons over the pulleys at the joint. The pulley is in-built into the model. By using a proper technique the tendons are lined into the finger parts which goes from the pulleys to the motor. The material used in the FDM process is ABS plus plastic and whose properties are given in the table 2 [24]. ABS means Acrylonitrile butadiene styrene.

Property	ABSPlus
Tensile strength	44 MPa
Elongation at break	24.3%
Flexural strength	68.9 MPa
Flexural modulus	2,198 MPa
Specific gravity	1.04

Table 2: Properties of ABS plus plastic

The finger parts are assembled with the pins, which acts as the revolute joints. Fish lines or wires are used as tendons. These tendons are driven by servo motors (Fig: 5) to actuate each joint of the finger. Servos are controlled by the Arduino Nano board. The chassis is designed to accommodate the 12 servos with occupying less space. It is fabricated by using aluminum plate of thickness 2 mm.

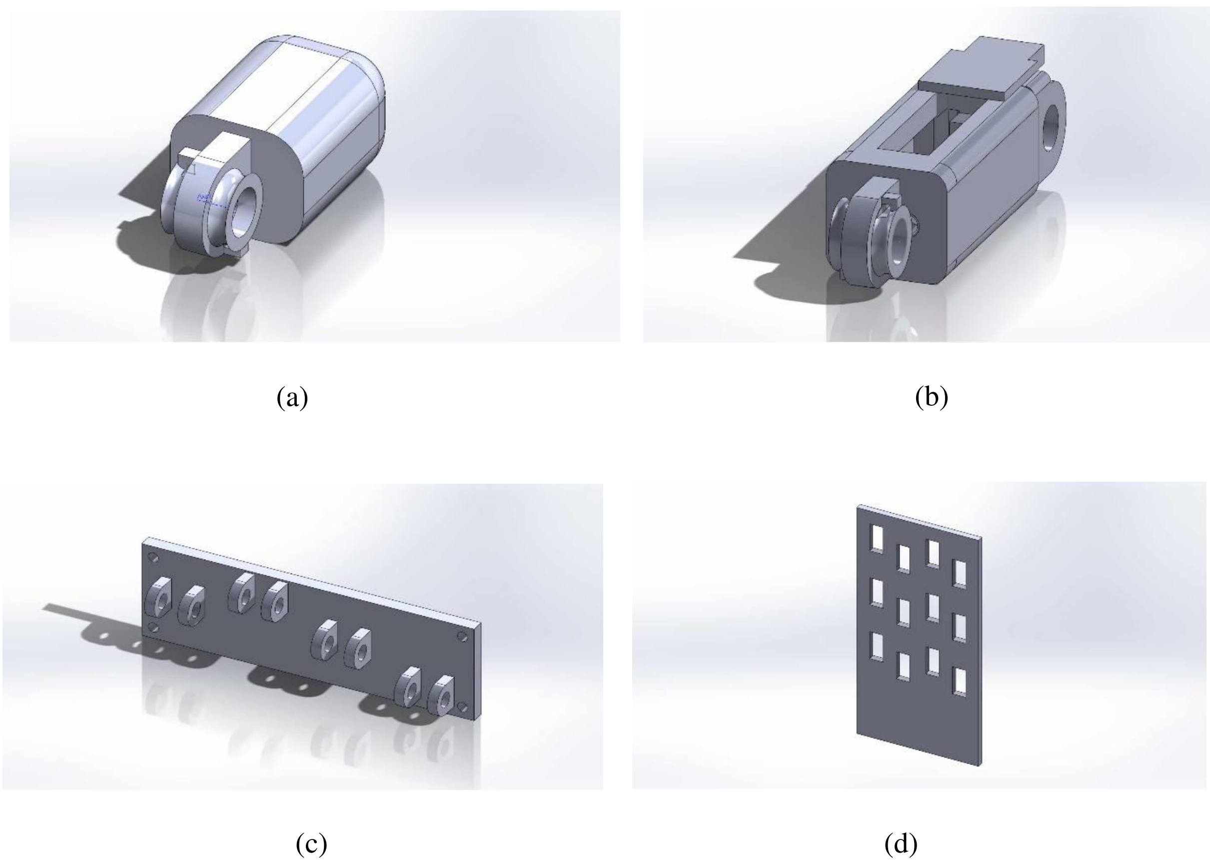


Fig 4. CAD models of the finger and palm. (a) Distal end, (b) proximal end and middle part, (c) Base for fingers (palm) and (d) motor casing

Fig 5. Micro Servo

Specifications of the motor [25]:

Dimensions	Length: 23.1 mm Width: 12.2 mm Height: 29.0 mm
Weight	9 gms
Torque	at 4.8 V :1.80 kg-cm
Speed	at 4.8 V : 0.12sec /60 deg (no load)

Table 3: Specifications of Servo motor

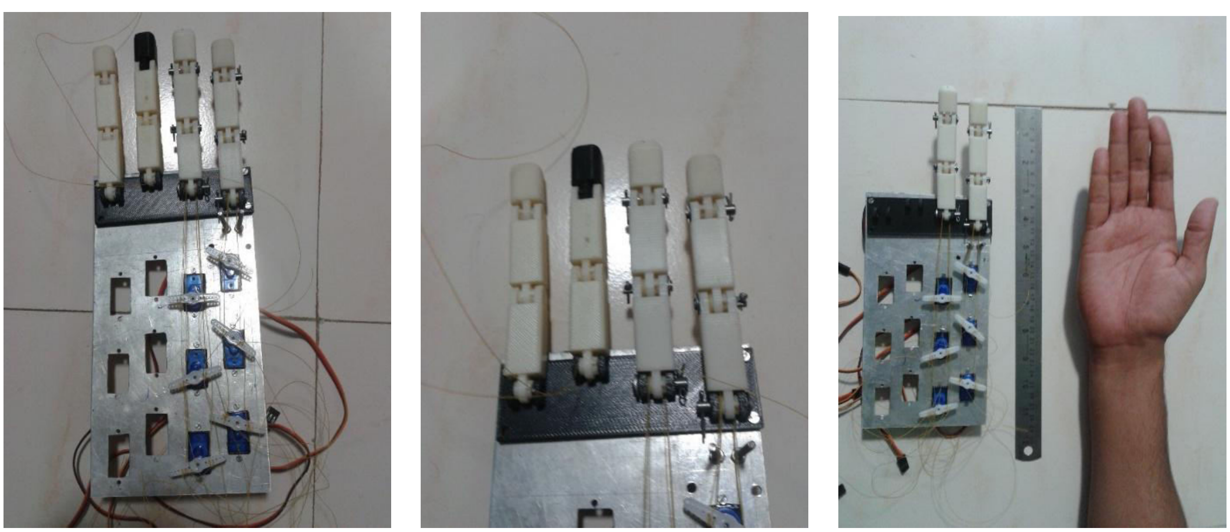


Fig 6. Images of the robotic hand

Specifications of robotic hand:

Total weight	**320 gms** including controller (arduino nano)
Dimensions	It can fit in a rectangular box of **28 cm * 10 cm**
Number of fingers	**4**
Total Dof	**12**
Number of actuators	**12**
Controller	**Arduino Nano**

Table 4: Specifications of robotic hand

Chapter 3

Calculations

While analyzing the kinematics and dynamics of the finger module using multi body dynamics, all the calculations are with respect to the joint coordinate system. So it is necessary to know the relation between the joint torque and the torque applied by the motor, similarly in case of joint displacement and the motor rotation. Let τ_1 be the torque at the finger joint and τ_2 be the torque at the motor, then due to design considerations,

$$\frac{\tau 1}{\tau 2} = \frac{r2}{r1}$$

Where,

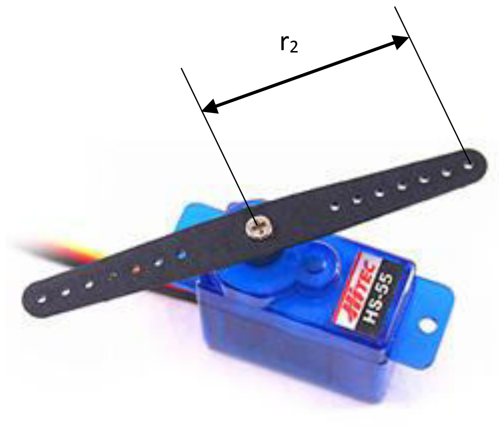
r_1 = radius of the pulley at the finger joint and

r_2 = half of the horn length of the motor as shown in the figure,

Similarly,

Let, θ_1 be the joint displacement of the finger and θ_2 be the rotation made by the motor, then

$$\frac{\theta 1}{\theta 2} = \frac{r2}{r1}$$



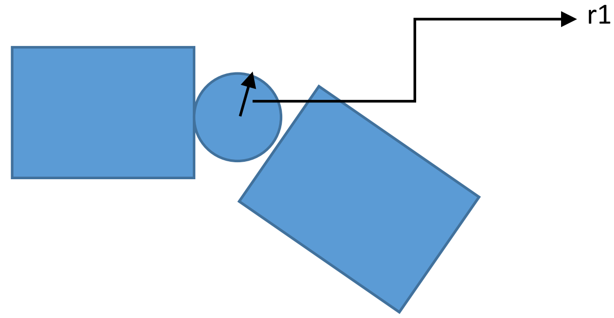


Fig 7. (a) Representation of r_2, (b) Representation of finger joint with the radius of the pulley

Difficulties in actuation

With this designed model, the proximal joints cannot be actuated individually with single motor. As shown in the fig. the tendon which is connected to the distal link will pass over the proximal link's pulley. While the proximal link is actuated the tendon connected to distal link will also pass over the proximal pulley. This results in the indirect actuation of the distal link. In order to avoid this, the amount of tendon which has undergone the winding has to be compensated by providing the same amount of tendon (wire) to keep the distal link constant. This can be achieved by actuating the motor which is connected to distal link which is undesirable, as it is using two motors in order to actuate a single (proximal) joint.

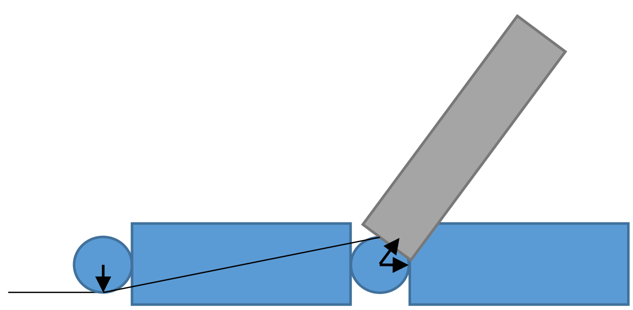


Fig 8. Actuation of Distal link

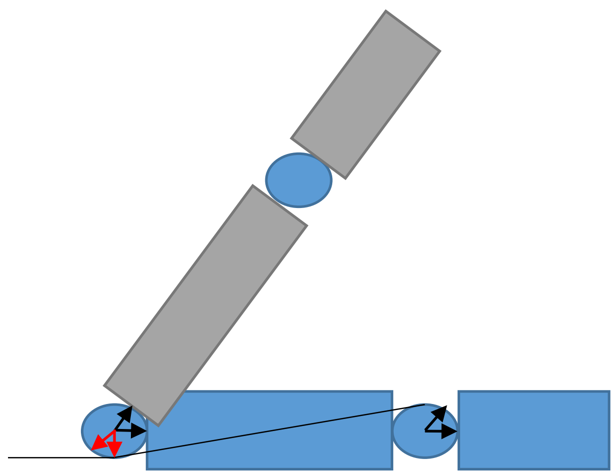


Fig 9. Actuation of Proximal link

Chapter 4

Classification of Human Grasp

Human grasp can be classified as follows [26]:

- Power Grasp
  - Non-Prehensile
  - Prehensile
- Precision Grasp
  - Circular
  - Prismatic

Heavy wrap is a type of Power Grasp, which is used to grasp the cylindrical objects. It can be used for both larger and smaller diameter objects and all the fingers will wrap over circumference of the object.

4.1 Kinematic Analysis of Heavy wrap

Heavy wrap is to hold both large and small cylindrical objects. Fingers of the hand get in contact with the object at the point of contact or point of tangency to the object. In order to calculate the point of contact of the fingers, robot should have a prior knowledge of the object (diameter and length).

Point of contact is calculated by considering a line passing through the external point and is a tangent to the circle. As shown in the fig. 10, there exists two tangents passing through a single external point. So there exists two different wraps for a given cylindrical object and it is necessary to decide which wrap can be feasible for given object and position of the object.

In order to calculate the point of contact, first we fix the coordinate system at the joint between palm and the finger. So, to calculate the first point of contact we consider the origin P (fig. 11), as the first external point and the point of tangency to the object is the first point of contact. Similarly for the second point of contact, the external point will be the tip of the first link and the point of tangency through the tip of the link is the second point of contact. Same procedure is repeated in order calculate the other point of contacts as shown in the fig 11.

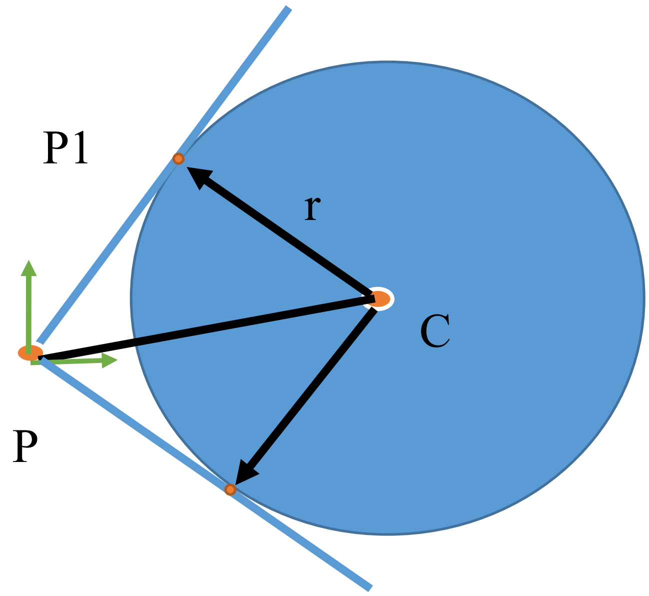


Fig 10. Tangents passing through the external point

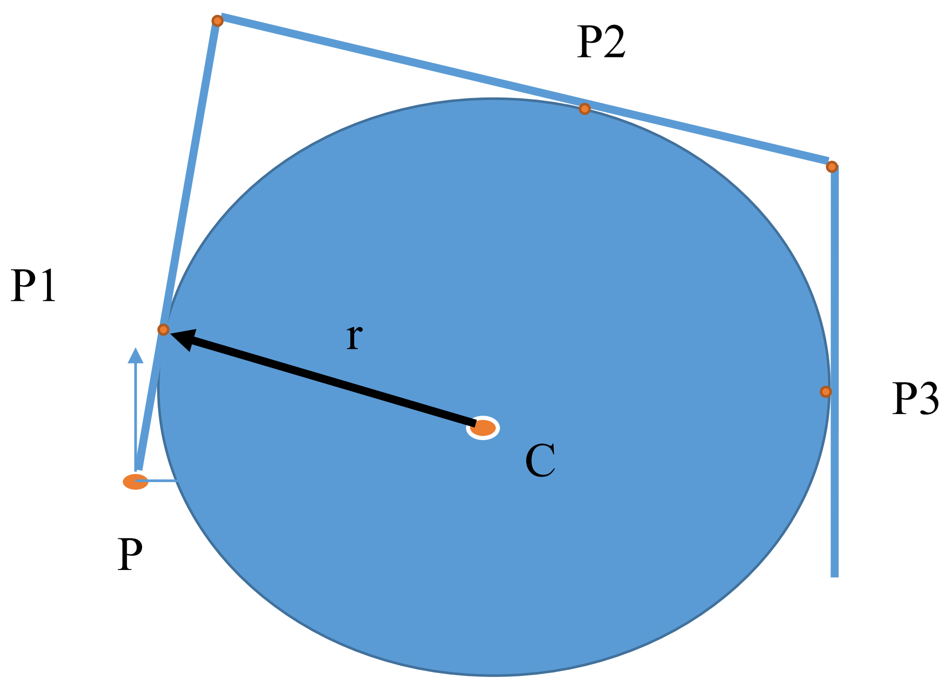


Fig 11. Point of Contacts of the Finger

4.2 Demonstration of Heavy Wrap

Robotic hand with only servo motors have been developed to perform the human grasps. It doesn't require any tendons and each joint is actuated by each servo motor. The motor is aligned in such a way that the motor axis and the joint axis will coincide.

Servo motors are connected with plastic casings which are fabricated by FDM process. Using this robotic hand, heavy wrap is demonstrated. As shown in the fig 12, robotic hand is grasping a 500gms water bottle and holds it firmly. In order to have a proper grip, a rubber tube is mounted over the bottle.

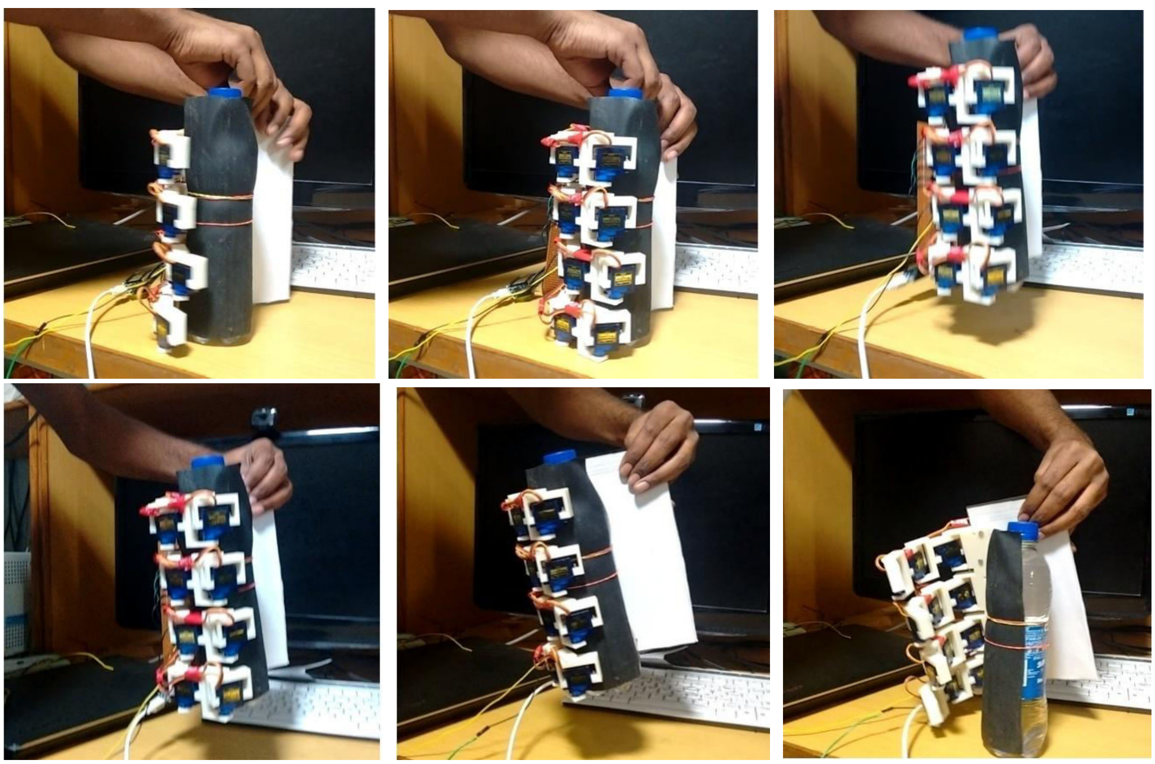


Fig 12. Demonstration of Heavy wrap

5. Design of Robotic Arm

Robotic arm helps in transferring the objects from one place to another and increases the stability of humanoid robot while walking and running. Robotic arm is designed by considering 5 degrees of freedom to each arm and it should be mounted on a work table to perform experiments with the robotic hand. In order to practice different grasps and to increase the performance of the robotic hand this experimental setup has been developed. Fig. 13, represents the 3-D model of the robotic arm with the stand. Stand helps in mounting the robotic arms over the work table and provides stability to the setup.

Each arm has 5 Degrees of freedom with a total of 10 Dof's for two arms. These are actuated by 10 Dynamixel Pro H54-200 servo motors as shown in the fig. 14 and even acts as the links to the arm. All the motor casings have been fabricated using Aluminum in order to have light weight and low cost with high strength. Dynamixel Pro is an integrated actuator composed of a gear reduction system, controller, driver and network for constructing modular robots. It has a maximum resolution of 5, 02,000 steps per one full rotation.

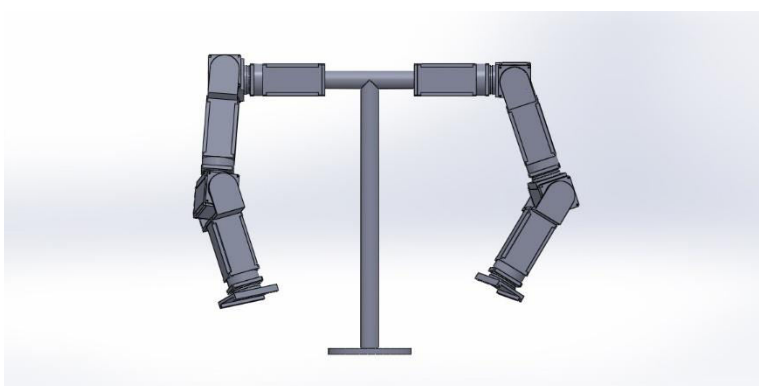


Fig 13. 3-D Model of robotic hand

Specifications of actuators [27]:

Model	Dynamixel Pro H54-200
Dimensions (in mm)	54*54*126
Torque	44.2 Nm
Weight	855gms
Rated voltage	24V

Table 5: Specifications of actuators

Fig. 14 Dynamixel Pro H54-200 actuator

5.1 Kinematic analysis of Robotic Arm

5.1(a) Forward kinematic analysis

Forward kinematic analysis of robotic arm is done by considering the coordinate systems to each link in such a way that it should satisfy DH parameter rules. As shown in the fig. 15, the coordinate system is attached and the corresponding DH parameters are tabulated in the table 6. The transformation matrix is as follows,

$$
T = \begin{bmatrix} Cos(\theta_i) & -sin(\alpha_i)cos(\theta_i) & sin(\theta_i)sin(\alpha_i) & a_i cos(\theta_i) \\ sin(\theta_i) & cos(\theta_i)sin(\alpha_i) & -cos(\theta_i)sin(\alpha_i) & a_i sin(\theta_i) \\ 0 & sin(\alpha_i) & cos(\alpha_i) & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

θ	**α**	**d**	**a (mm)**
θ_1	-90	0	145
θ_2	90	0	0
θ_3	-90	0	145
θ_4	90	0	0
θ_5	-90	0	145

Table 6: DH parameters of robotic arm

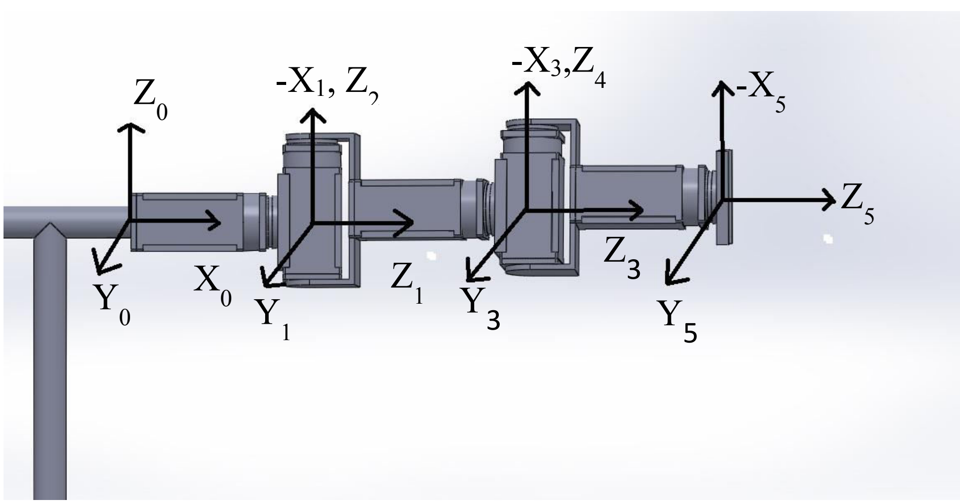


Fig. 15 Coordinate system for robotic arm according to DH Parameter rule

5.1(b) Inverse kinematics of Robotic Arm

Human arm has 7 degrees of freedom and is analyzed by considering 3 degrees of freedom at the shoulder, 3 degrees of freedom at the wrist and 1 degree of freedom at the elbow. In order to analyze the inverse kinematics of the human arm, shoulder is fixed at the origin as shown in fig 16.

Inverse kinematics is the process where we know the position of the end effector or wrist and we need to find all the joint angles in order to reach the required wrist position. So at the required wrist position the elbow joint has redundant positions on the circle as shown in the fig. 16. It is necessary to provide the position of the elbow on the circle, this is given by providing the swivel angle.

Swivel angle (ϕ) is defined as the angle between any reference plane passing through the shoulder and the wrist and the plane passing through all the three points shoulder, wrist and the elbow. Following equations are the joint angles θ_1, θ_2 according to the required wrist and elbow position. Similarly we can calculate θ_3, θ_4 can be calculated which is dependent on position of the wrist.

$$\theta_1 = atan\left(\frac{ex}{ey}\right),$$

$$\theta 2 = \mathrm{atan}\left(-\frac{\sqrt{lu^2 - ez^2}}{\mathrm{ez}}\right)$$

Here,

(ex,ey,ez) is position of elbow,

lu = length of the upper link

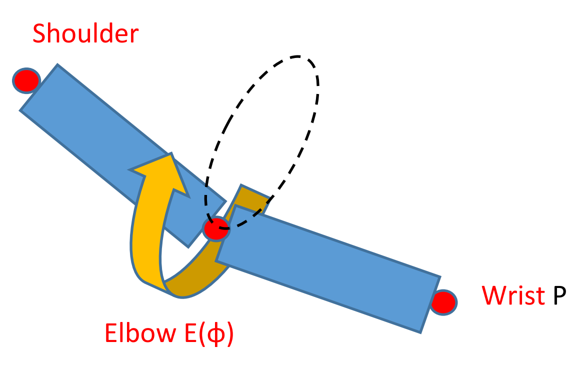


Fig. 16 Representation of locus of the elbow joint

5.2 Experimental Setup

All the motor holders have been fabricated in the IITH central workshop and Manufacturing Lab (fig. 17). Experimental setup has been mounted on a working table, where the experiments are to be carried out (fig. 18). This helps in improvising the performance of the robotic hand and arm.

Fig. 17 Image Courtesy: IITH workshop, Fabrication of experimental setup

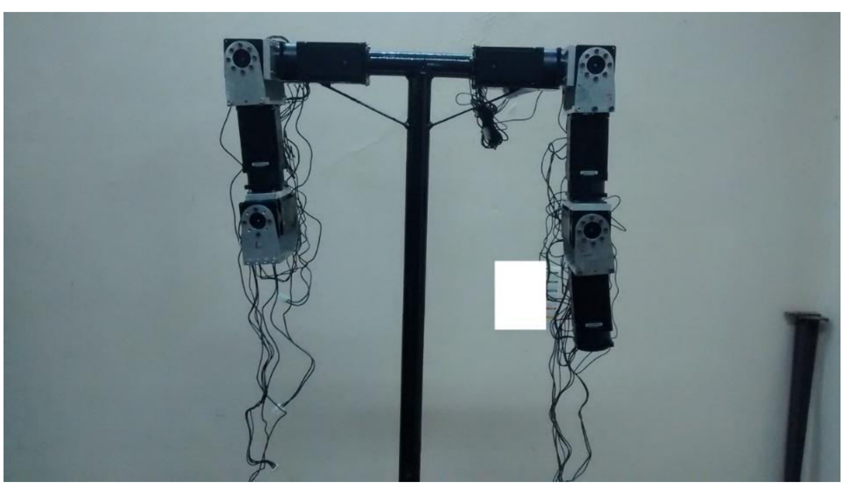


Fig. 18 Experimental setup of robotic arm

6. Conclusion and Recommendation for Future work

6.1 Conclusions

- Robotic hand with four fingers, which uses Servo motors and Tendon mechanism to actuate has been developed.
- Robotic hand with only servo motors has been developed and demonstrated the Heavy wrap by using the same.
- Robotic arm with 5 Dof of each arm has been mounted on a working table which is used as an experimental setup for enhancing the performance of the robotic hand and the grasp ability.

6.2 Recommendation for Future work

- The complete hand is to be fabricated using FDM, which can be controlled by the servo motors and Arduino nano board.
- Orientation for the thumb is to be optimized and implemented onto the robotic hand.
- Force, torque, position sensors have to be included into the finger and should be automated.
- It should perform all the grasps similar to the human hand.
- Wrist should be included in the robotic arm.

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