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Kinematic Analysis of Anthropomorphic Servomotor Actuated Robotic Hand

Amir Khan, Nirmaan Manocha, Harsh Agnihotri, Eram Neha

Galgotias College of Engineering and Technology, Greater Noida, U.P., India

Corresponding Author: eramneha@gmail.com

Abstract

This paper shows the kinematic analysis of various phalanges of an anthropomorphic robotic hand i.e., Index finger, Ring finger and Thumb to find the coordinates of their finger-tip and operating zone of the hand. Anthropomorphic comes from the Latin word which means replica of human being. Kinematics is applied in astronomy to portray the movement of bodies of different shape, size and structures; and in mechanical planning, better mechanics and biomechanics than depict the movement of different phalanges and joints. In this paper, the forward kinematics of the planned hand is completed utilizing the Denavit Hartenberg - (D-H) parameters, to compute the position and direction of every one of the fingertips. With the help of (D-H) parameters the transformation matrix of index finger, ring finger and thumb has been formed to find finger-tip coordinates at maximum joint angles. Coordinates of the finger-tip is been shown and plotted for all possible fingertip and their trajectories to shows finger and thumb movement in space with the help of Robo-Analyser. These analysis indicates that this hand is able to effectively play out the ideal challenge effectively.

1. Introduction

A robot is a mechanical gadget frequently looking like a human or parts of a human working under some supervision and giving higher efficiency than its human counter-part. Current robots are normally electro-mechanical machines directed by a PC programme or electronic hardware. Robots can be independent or semi-independent what's more, range from humanoids to modern robots, altogether modified swarm robots, and, surprisingly, infinitesimal and nano robots. Mechanical hand is the end effector, or automated hand, can be intended to play out any ideal desired task like welding, grasping, turning and so forth, depending upon the application. Automated hands are sub divided into two fingered automated hand and multi-fingered automated hand or multi-finger robotic hand. Grippers and grasper which are currently in market are inefficient and complex due to the geometry of the object which the hand is holding. Thus, the need of multi-fingered robot arms arises which might be capable of appearing task on various geometrical object. Robotic hands can be utilized in modern applications, for example, grasping objects from transport lines or it tends to be utilized in a further developed job, for example, bomb defusal, where it would be hazardous for a human to communicate.

Kinematic analysis is the most common way of approximating the kinematic expanses used to portray motion. The research of kinematics can be automated and performed virtually with the availability of various efficient software's. In order to carry out such evaluation, the knowledge of the phalanges length as well as the placement, offsets, twist angle, twist angle offset is required. Mathematical equation forming is significant in laying out the analysis of an Anthropomorphic robotic hand. In this paper, by utilizing the Denavit-Hartenberg (DH) calculation that gives a framework technique and matrix method to determine the coordinates for hand which will be graphically plotted. With use of these equations, we can

*Author for correspondence

finally find the co-ordinates point of each fingertip. These fingertips will be further used to analyse the workspace and operating range of the hand. The forward kinematic arrangement of a hand can be utilized to decide the position and direction of the robot hand comparative with the robot base coordinate framework. It will give a brief idea of grasping of different geometrical objects.

A number of researchers classify the kinds of equilibrium grasps and set up a trendy framework for the willpower of the steadiness of the draw close [1]. In different paper, researchers have also proposed an analytical formulation for simulation and design of a one degree of freedom articulated finger mechanism with three phalanges. The components is based totally on a look at of the format and operation of an index human finger [2]. This paper develops the kinematic touch model of a multi-finger robot hand which will attain a entire description of the machine which is required for manipulation and grasping of objects [3]. This paper offers experimental outcomes on the 5-finger dexterous robotic hand with its fingertip Cartesian coordinate to decide its operating and running range [4]. The paper offers a control method for centered deformable devices, concentrated on elastic foams, primarily based on tactile information. A model at distinctive elastic properties of the item is executed, due to the fact the deformability degree is estimated during the grasping process. Several experiments are proven with a view to reveal the reliability of the tactile-primarily based method [5]. However, grasping hand technique manage via tactile sensing with robotic arms is still extraordinarily unexplored. In this paper, we employ tactile sensing for multi-fingered robotic arms to regulate the grasping force to stabilize unknown items without earlier expertise of their form or bodily dimensions [6]. Manipulation is one of the maximum important fields in robotics. in spite of the truth that, even given the lengthy statistics of manipulation research, technology for multi-fingered robot hands are nonetheless in development. This paper investigates past studies research on manage systems of multi-fingered robot arms for grasping and manipulation [7]. Three utilizations of the presentation lists are thought of: (1) the plausibility investigation for a given assignment, (2) the direction planning giving an ideal errand way, and (3) design advancement with various undertaking necessities [8]. This paper develops the kinematic, dynamic and phone anthropomorphic robotic hand (Barrett Hand) to be able to achieve a whole description of the machine this is required for manipulation duties. those models do no longer great do not forget the mechanical coupling and the breakaway mechanism of the underneath-actuated robot hand however additionally they collect the pressure transmission from the hand to items, which is probably represented as triangle meshes [9]. Grasp It is a really perfect surroundings for hold close evaluation and making plans, and it may serve as a take look at mattress for brand new grasp evaluation, hold close synthesis, and manipulation making plans algorithms. it's miles viable to test these algorithms tonnes greater quick and for extra hand designs than could be possible inside the lab the usage of an actual robot [10]. The proposed shape provides advantages which include more desirable kinematic performance and simplicity of the mechanical layout. through the kinematic analysis, its miles show that the ANTHRPOMORPHIC-Hand indicates remarkably high dexterity, nicely surpassing that of present robotic hands with traditional MCP joints [11]. A bioinspired optimization changed into accomplished to clear up a mechanism that generates the critical trajectories for emulating a human finger's movement and showed the advancement of prototype that might be grasped the gadgets with specific geometries with energy and precision grip, immoderate lights the robotic hand's dexterity and flexibility [12]. This paper have presented the improvement of a new soft humanoid hand able to greedy one-of-a-kind styles of objects robustly. showed that this hand is compliant, lightweight, and occasional cost. Its pneumatic actuation permits the smooth hand to have excessive compliance even as grasping, allowing it to keep away from negative grasped gadgets [13].

Robotic hand help in execution of a certain tasks rapidly, effectively, and incredibly precisely. Robotic hand incorporates a progression of joints, end effector and controllers that cooperate to intently perform the movement and usefulness of a human hand. With faced pace advancement in technology, industries have great needs for automation and robotics. Robotic arm can perform on various size of applications. Robotic hands fill a few astonishing roles like the human hands, in this way offering high adaptability as far as the roles performed.

2. The Proposed Model

This robotic hand is made up of five fingers and a palm, all of which are made using 3D production. The work phases begin with the design stage, which is completed using SolidWorks software, followed by 3D printing to ultimately assembly, and connection of the actuation system. Excluding the thumb, each finger is made up of three phalanges, which act as links that are connected by pins. The pin is fastened to hold the hinge. The 5-fingered anthropomorphic hand replicate with the human hand body structure as shown in Fig 1. The palm is a one part built in a totally erudite layout which is the centre that connects the hands and the thumb. These sections guarantee that the ligaments for each finger won't hinder with others and oblige development in a particular region makes the control of development simple to certain places.

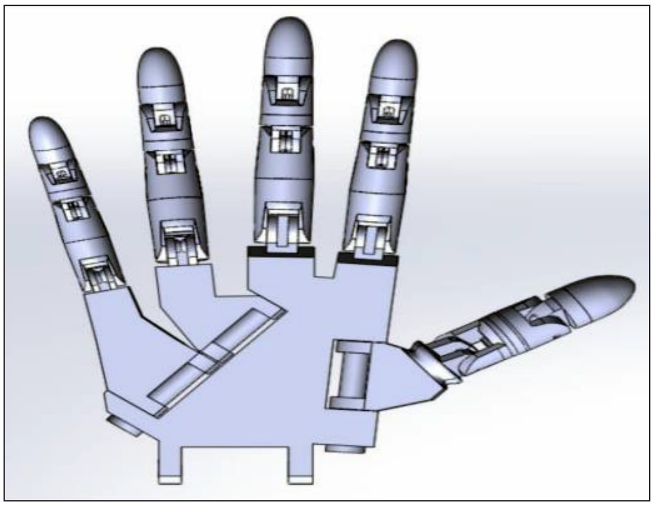

Fig. 1: SolidWorks Version of the Hand

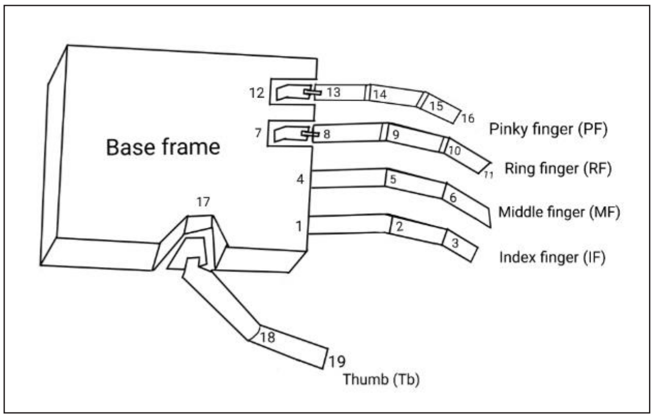

Fig. 2: Kinematic Version of the Hand

Proposed automated hand comprises of 4 fingers, thumb and a palm, all planned utilizing SOLIDWORKS. The Index, Middle finger and Thumb will have 3 Degree of Freedom (DOF) while Ring and Pinky finger will have 4 DOF. The Palm is the base beginning of mechanical hand which is in focus and interface all fingers and thumb. Fishing wire will be associated with each finger at each joint to give the direct movement i.e., expansion and contraction of the fingers and the thumb. The fishing mesh 200LB is utilized on the grounds that it is long as it can pull and is sufficiently slight to allow the finger to twist. Each finger will have a different set of wires, associated further to the servomotors giving the engine driven movement to the fingers. An outer power supply is added on the grounds that regardless of whether these servos are little, they draw an excessive amount of current could reboot your board. By associating these servomotors at the foundation of the palm the hand will be saved from vibrations caused due to servomotors. Servomotors is utilized to drive the finger of the hand and will give greater dependability to the framework when contrasted with the pulley driven framework. This mechanism is less complex and more advanced than actual tendon driven methodology.

3. Kinematic Model of Anthropomorphic Robotic Hand

Kinematic model helps in the analyses of the motion of the robot. The hand is made up of various phalanges, link and pin joints for its stable movement and grasping. This hand has high DOF to raise the grasping capability of five finger robotic hand, taking the number to 17 DOF. The kinematic model of the hand is easy to plan and portrays the hand's possible movements in general. It is easy to understand and delivers the most dependable results.

The proposed hand has 5-fingers: the Index finger (F_1), the middle finger (F_2), the ring finger (F_3), the Pinky Finger (F_4) and one thumb (T_1) (Fig. 2). As proven in Fig. 2, the F_1, F_2, F_3, F_4 and T_1 are in collection. There are 3 phalanges, i.e., proximal, middle and the distal phalanges, in every finger. Finger F_1 & F_2 has three DOFs while the finger F_3 & F_4 has four DOF's and the thumb has 3 DOF's. for this reason, the hand has a complete of 17 DOFs. In addition, the palm is likewise delivered for strong grasping. The finger version has 5 frames attached to every joint as shown in parent 3. A base frame is secured to the fixed joint, having the coordinates as X_0, Y_0 and Z_0. similarly, X_1, Y_1, Z_1, X_2, Y_2, Z_2; and X_3, Y_3, Z_3 constitute the coordinate frames at joint 1, joint 2, and joint 3, respectively. The kinematic version for all of the 3 fingers is the same as they have the equal hyperlink length. The finger includes 3 phalange, specifically the proximal, middle and distal, with the joint angles described as Ψ1, Ψ2, and Ψ3.

However, Fig. 4 shows the kinematic version of the thumb, within the thumb, the proximal phalange is uniform, and it has 3 DOF and for this reason, the joint perspective $t_1 = 90$ The angles t_2 and t_3 range within their angular limits, and therefore, it possesses best three DOFs and for the Fig. 6, it shows the kinematic version of the ring finger.

4. Forward Kinematics of the Hand

Forward kinematics is used to find the position and direction of the finger-tip regarding the palm or base casing. A course system is named for all joints of the fingers and thumb of the five-fingered mechanical hand according to the standard D-H documentation as displayed in Figures 3-5 individually. After this, a table of

D-H parameters is characterized for every finger including thumb as shown in Table1 for DH parameters for index finger, DH parameters for thumb shown in Table 2 and DH parameters for Ring (F_3) Finger as shown in Table 3 (Tables 1, 2 and 3). The following transformation matrix will be used for the intended cause.

N = rot. (x, j-1) Trans. (x, Lj-1) rot. (z, j). (z, Sj) (1)

where,

j = Number of phalanges

N = Alteration matrix at some joint.

Ψ= Joints angle

β = Phalange twist angle

L= Phalange length

S = Offset provided to joint

In this example, the 4 transformation matrix can be received for the index finger and thumb. 5 transformation matrix may be received for ring and pinky finger. The very last function and orientation can be determined through multiplying the corresponding transformation matrices for exceptional phalanges of the finger as follows:

Using Equation 1, the forward kinematic equation for the index (F_1) and Middle (F_2) fingers of the anthropomorphic robotic hand is obtained as

Where,

N_{f1} = Index finger transformation matrix

N_T = Thumb transformation matrix

N_{f3} = Ring finger transformation matrix

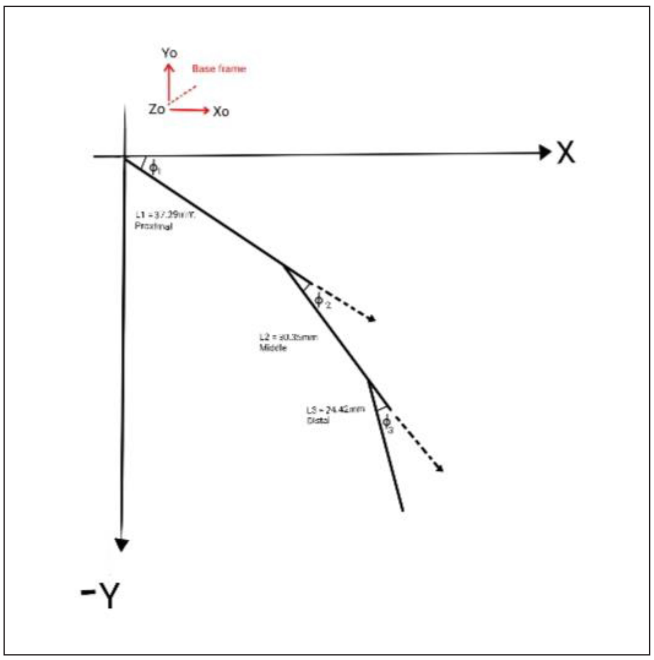

Fig.3: Kinematic Model of Index Finger

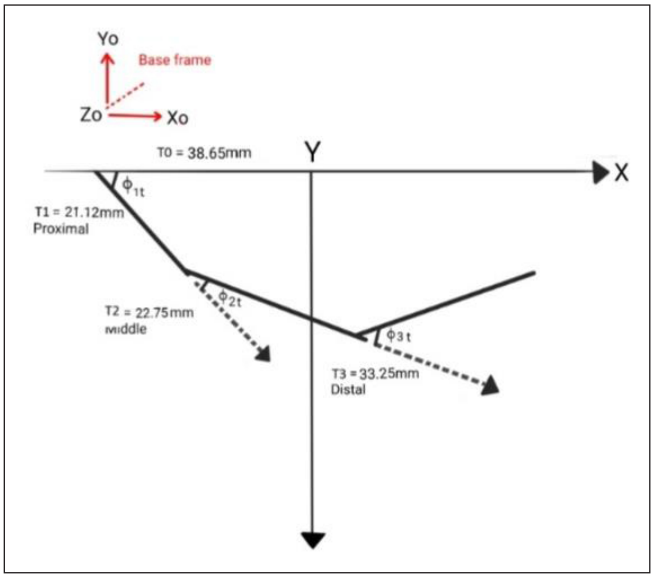

Fig.4: Kinematic Model of Thumb

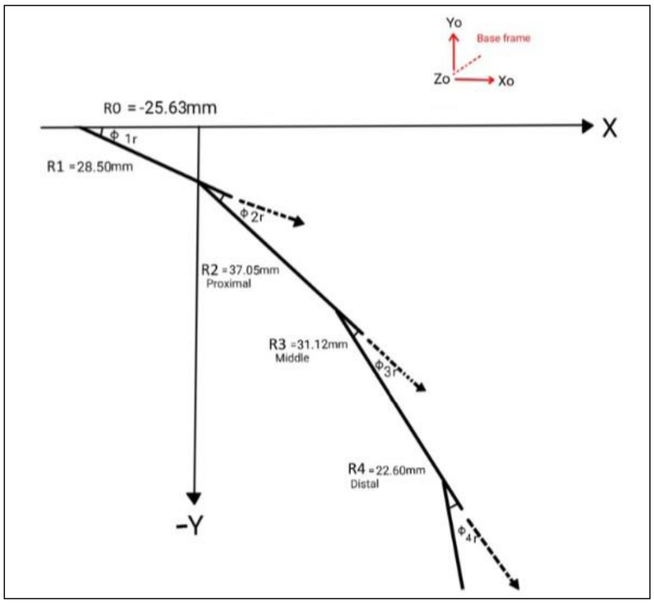

Fig.5 : Kinematic Model of Ring Finger

Table 1: Index (F_1) Finger DH Parameters Table

Link Length (mm) (L_{1-2})	Link Twist Angle (0) β_{1-2}	Joint offset (mm) S_j	Joint Angle (0) Ψ_i
L_0=0	β_0=0	S_0=0	Ψ_0=900
L_1=37.29	β_1=0	S_1=0	Ψ_1=0-500
L_2=30.35	β_2=0	S_2=0	Ψ_2=0-650
L_3=24.42	β_3=0	S_3=0	Ψ_3=0-950

Table 2: Thumb (T_2) DH Parameters Table

Link Length (mm) ($L_{1\text{-}2}$)	Link Twist Angle (0) $\beta_{1\text{-}2}$	Joint offset (mm) S_j	Joint Angle (0) Ψ_i
T_0=38.65	β_0=0	S_0=0	Ψ_0=0°
T_1=21.12	β_1=0	S_1=0	Ψ_1=90°
T_2=22.75	β_2=0	S_2=0	Ψ_2=0-80°
T_3=33.25	β_3=0	S_3=0	Ψ_3=0-100°

Table 3: Ring (F_4)Finger DH Parameters Table

Link Length (mm) ($L_{1\text{-}2}$)	Link Twist Angle (°) $\beta_{1\text{-}2}$	Joint offset (mm) S_j	Joint Angle (°) Ψ_i
R_0=-25.63	β_0=0	S_0=0	Ψ_0=0°
R_1=28.50	β_1=0	S_1=0	Ψ_1=0-10°
R_2=37.05	β_2=0	S_2=0	Ψ_2=0-50°
R_3=31.12	β_3=0	S_3=0	Ψ_3=0-65°
R_4=22.60	β_4=0	S_4=0	Ψ_4=0-95°

$$\begin{vmatrix} \cos(\Psi_1+\Psi_2+\Psi_3) & -\sin(\Psi_1+\Psi_2+\Psi_3) & 0 & L_1\cos\Psi_1+L_2\cos(\Psi_1+\Psi_2)+L_3\cos(\Psi_1+\Psi_2+\Psi_3) \\ \sin(\Psi_1+\Psi_2+\Psi_3) & \cos(\Psi_1+\Psi_2+\Psi_3) & 0 & L_1\sin\Psi_1+L_2\sin(\Psi_1+\Psi_2)+L_3\sin(\Psi_1+\Psi_2+\Psi_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$\begin{vmatrix} \cos(\Psi_1+\Psi_2+\Psi_3) & -\sin(\Psi_1+\Psi_2+\Psi_3) & 0 & L_1\cos\Psi_1+L_2\cos(\Psi_1+\Psi_2)+L_3\cos(\Psi_1+\Psi_2+\Psi_3) \\ \sin(\Psi_1+\Psi_2+\Psi_3) & \cos(\Psi_1+\Psi_2+\Psi_3) & 0 & L_1\sin\Psi_1+L_2\sin(\Psi_1+\Psi_2)-L_3\sin(\Psi_1+\Psi_2+\Psi_3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

$$\begin{vmatrix} \cos(\Psi_1+\Psi_2+\Psi_3+\Psi_4) & \sin(\Psi_1+\Psi_2+\Psi_3+\Psi_4) & 0 & L_1\cos\alpha_1+L_2\cos(\Psi_1+\Psi_2)+L_3\cos(\Psi_1+\Psi_2+\Psi_3)+L_4\cos(\Psi_1+\Psi_2+\Psi_3+\Psi_4) \\ \sin(\Psi_1+\Psi_2+\Psi_3+\Psi_4) & \cos(\Psi_1+\Psi_2+\Psi_3+\Psi_4) & 0 & L_1\sin\alpha_1+L_2\sin(\Psi_1+\Psi_2)+L_3\sin(\Psi_1+\Psi_2+\Psi_3)+L_4\sin(\Psi_1+\Psi_2+\Psi_3+\Psi_4) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

5. Fingertip Trajectories

This work examines the trajectory of index finger and thumb during the movement of hand particularly for grasping various shapes and sizes of object. Kinematic version of the hand is display in Fig. 6, With help of Robo analyser and using DH parameters, we are able to find the path of all the fingers-tip and tips. Fig. 7 displays trajectory formed by the fingertip of index finger on maximum angles at different joints.

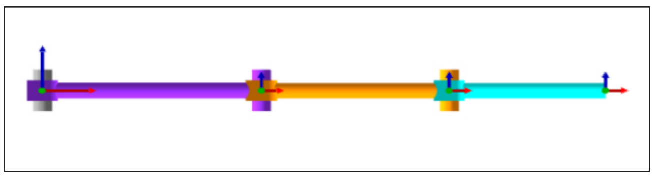

Fig. 6: Depiction of finger

With the help of Robo-Analyser different graphs are been plotted by fixing the angles at maximum value as shown in Figs. 8 and 9. These graphs give the co-ordinates point of every phalange at their maximum possible angle of rotation. In Fig 8 proximal trajectory shows the different coordinate at different angle of considering the motion

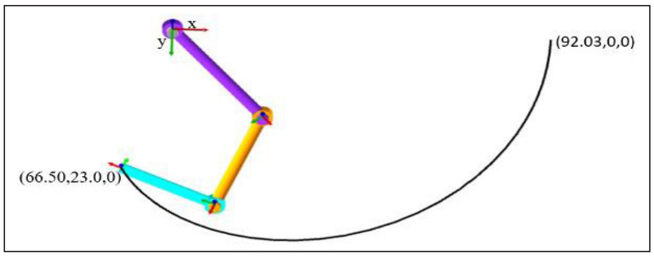

Fig. 7: Trajectory formed by finger

time to be 4 second. Middle phalange trajectory shows coordinates while distal phalange trajectory shows the coordinates of Index finger. The maximum possible rotation angle of phalanges has been taken to find the x,y coordinates of the fingertip position at maximum angle i.e. ϕ_1=50, ϕ_2=60 and ϕ_3=95. Origin of the graph will be y=0 at min joint angle, thus the movement of the finger will be in 4th coordinate of the graph in the decreasing direction of y, when the joint angle is expanded in angular range. Similarly, the value of x coordinate will decrease significantly from the origin point when the joint angle will increase. This shows us the working range and gives the brief view of various objects with different dimensions the hand can grasp firmly.

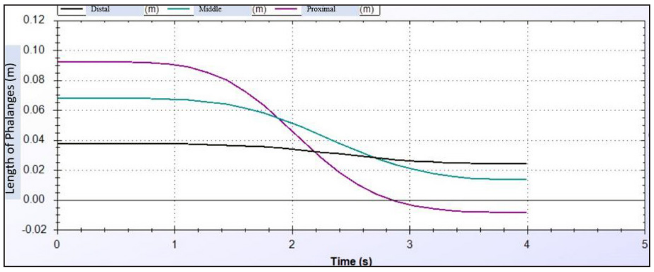

Fig.8: Index Finger X-Axis Co-ordinates at Maximum Joint Angle

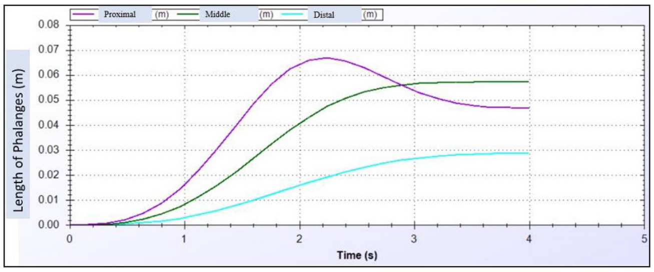

Fig.9: Index Finger Y-Axis Co-ordinates at Maximum Joint Angle

Similarly, Figs. 10 and 11 show the coordinates point of different phalanges of thumb which can be plotted on graph to indicate the workspace and its operating range. With these actual coordinates we can plot a graph in X-Y plane which can define operating range of the thumb. In Figs. 10 and 11 the distal trajectory shows the distal coordinates while proximal and middle show the coordinates of proximal and middle phalange. Maximum rotation angle of every phalange is been taken in the case of thumb i.e., ϕ_1=90, ϕ_2=80 and ϕ_3=100. The direction of the thumb will be in increasing y direction at starting motion and the motion will be in decreasing y direction for the remaining movement of the thumb. At the same time the finger will be in negative Y direction.

On comparing the motion of thumb and finger, it's far observed that the movement of the palms and thumb are in perpendicular course to every different. With lower in the value of x-coordinate, price of y-coordinate is developing in case of the arms, and with decrease in the

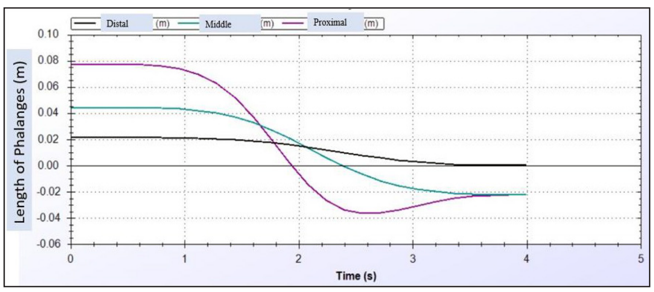

Fig.10: Thumb X-Axis Co-ordinates at Maximum Joint Angle

value of x-coordinate, the cost of y-coordinate is likewise growing for the thumb. by way of plotting a number of trajectories of all the arms and thumb blended, running range and of the robot hand can easily be defined.

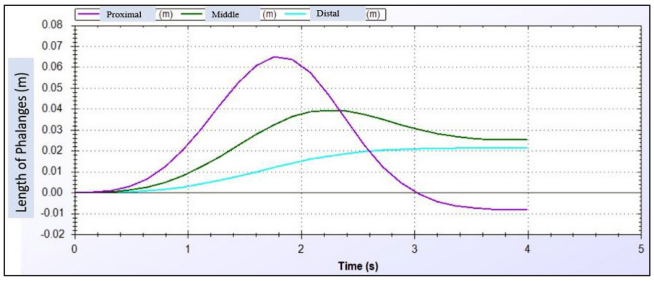

Fig.11: Thumb Y-Axis Co-ordinates at Maximum Joint Angle

Similarly, Figs. 12 and 13 shows the coordinates point of different phalanges of Ring finger which can be plotted on graph to find the actual coordinates which are further plotted in Table 6. With these actual coordinates we can plot a graph in X-Y plane which can define operating range of the thumb. In Figs. 12 and 13 the distal trajectory shows the distal coordinates while proximal and middle show the coordinates of proximal and middle phalange. Maximum rotation angle of every phalange is taken in the case of ring finger i.e., ϕ_1=10, ϕ_2=50, ϕ_3=90 and ϕ_4=95. In ring finger there are four phalanges instead of three which gives it a four DOF to a ring finger.

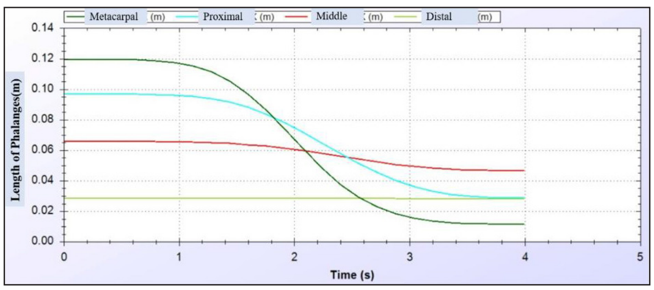

Fig.12: Ring Finger X-Axis Co-ordinates at Maximum Joint Angle

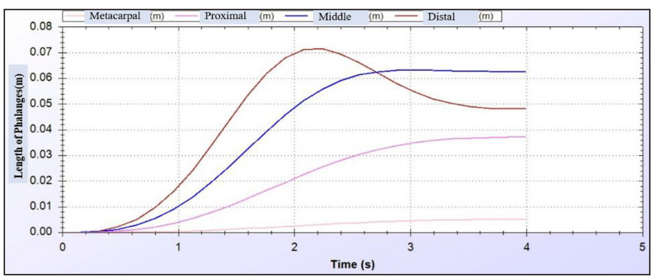

Fig.13: Ring Finger Y-Axis Co-ordinates at Maximum Joint Angle

With the help of these graphs shown in Fig. 5 to Fig. 13 we have found the fingertip coordinates of Index finger, thumb and ring finger consecutively at different angle ranging from minimum angle to the maximum angle of rotation. To decrease the complexity of the graphs, distal and middle joint angles are fixed and proximal angle is been increased by the period of 10 degree. This gives us the increasing or decreasing value of coordinates in X-Y plane by which the operating range of the fingers and thumb can be found. By doing this analysis on every finger and thumb 3D space of hand can be easily defined. The coordinates of the Index fingertip, thumb-tip and ring finger-tip is shown in Tables 4, 5 and 6.

Table 4: Index Finger Tip Co-ordinates at different angles

	Angles (degree)	Index Finger Tip Co-ordinates (mm) (x, y, z)
1	0°	92.03, 0, 0
2	10°	91.60, -4.0, 0
3	20°	90.80, -8.0, 0
4	30°	89.0, -12.0, 0
5	40°	76.50, -16.0, 0
6	50°	63.50, -18.1, 0
7	60°	50.10, -23.0, 0
8	70°	46.50, -25.0, 0
9	80°	33.20, -24.0, 0
10	90°	17.50, -23.0, 0
11	95°	-1.50, -22.0, 0

Table 5: Thumb Tip Co-ordinates at different angles

	Angles (degree)	Thumb Tip Co-ordinates (mm) (x,y,z)
1	0°	-38.35,0,22.65
2	10°	-33.95, -5.8,22.65
3	20°	-26.55, -11.0, 22.65
4	30°	-14.15, -17.0, 22.65
5	40°	-6.85, -22.0, 22.65
6	50°	9.85, -26.0, 22.65
7	60°	13.35, -28.0, 22.65
8	70°	22.95, -32.0, 22.65
9	80°	27, -33.0, 22.65
10	90°	32.15, -34.0, 22.65

Table 6: Ring Finger Tip Co-ordinates at different angles

	Angles (degree)	Ring-Finger Tip Co-ordinates (mm) (x,y,z)
1	0°	120.0,56.72
2	10°	115.0, -5.8,56.72
3	20°	109.8, -11.0,56.72
4	30°	91.65, -17.0,56.72
5	40°	79.50, -22.0,56.72
6	50°	64.50, -26.0,56.72
7	60°	51.60, -28.0,56.72
8	70°	38.60, -32.0,56.72
9	80°	21.50, -33.0,56.72
10	90°	11.80, -34.0,56.72
11	95°	-3.76, -34.0,56.72

6. Conclusion

In this chapter we have done forward kinematic analysis on anthropomorphic robotic hand which consist of 17 DOF and 18 different phalanges. The index, middle finger and thumb have 3 phalanges while ring and pinky finger have 4 links (phalanges). Forward kinematic analysis is done by both mathematically as well as with the help of software i.e., Robo analyser. Complexity of forward kinematic increases with increase in DOF so to analyse the forward kinematics we have use DH parameters to form transformation matrix. Transformation matrix is formed with the help of DH parameter and after multiplying these transformation matrices the equations are formed which gives the co-ordinate point of link at different angles. These equation also gives us the brief view of operating range and workspace of robotic hand. The same analysis is been done with the help of software i.e., Robo-analyser which shows the feasibility as well as workspace of the hand. the help of rob analyser we have formed the different graphs between the link length and time taken which shows the path of fingertip co-ordinates by maximizing and minimizing the joint angles between the various phalanges.

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