Design and Fabrication of Mechatro Hand

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ABSTRACT
The main objective of this work is to design and fabricate an artificial robot hand to mimic the human hand. Each finger in the hand had fifteen degrees of freedom and capable of applying independent forces to grasp an object. Forward and Reverse kinematics has then been done on the designed hand using D-H method in order to find joint angles for the different configurations.

Keywords—Mechatro Hand, Kinematic Analysis, Denavit-Hartenberg (D-H), Flex sensors.

I. INTRODUCTION

1.1 Human Hand
The human hand has 27 bones excluding the sesamoid bone. Fourteen of which are the phalanges consists of proximal, intermediate and distal of the fingers. The metacarpals are the bones that connects the fingers and the wrist. Each human hand has 5 metacarpals and 8 carpal bones.

[Diagram of human hand]

Fig: 1.1 Bone skeleton of Human hand

Anatomy of the human hand shown in Figure 1.1. From the anatomy it can be seen that the index, middle, ring and little finger have three phalanges, while the thumb only has two phalanges. Furthermore, it is evident from the anatomy of the human hand that it consists of segments that are held together by joints. A kinematical model of the hand is therefore required to model the articulation of fingers.

1.1.1 Different Movements in Human Hand

Flexion: This movement refers to rotating the fingers in the direction of the palm
Extension: This movement refers to rotating the fingers away from the palm. Furthermore, flexion/extension motion occurs at each of the four joints of the finger.
Abduction: This motion refers to spreading the fingers apart from each other.
Adduction: This motion refers to bringing the fingers close to each other.

Moreover, abduction and adduction motion occurs at the metacarpophalangeal joint of the fingers. In addition, the abduction/adduction of the thumb occurs at the metacarpophalangeal and trapeziometacarpal joints.

[Diagram of hand movements]

Fig-1.2 Hand Movements

1.2 Control Glove
The purpose of the control glove is to give the input to the Mechatro-arm through the flex sensors attached to it. The flex sensors which sense the flexion of the fingers of the operator give input to the processor accordingly and then produce the appropriate output.
1.2.1 Mechatronics

Mechatronics is a design process that includes a combination of Mechanical Engineering, Electrical Engineering, Telecommunications Engineering and Computer Science Engineering. Mechatronics is a multidisciplinary field of Engineering.

1.3 Kinematic Analysis

Kinematic analysis is one of the first steps in the design of most industrial robots. Kinematic analysis allows the designer to obtain information on the position of each component within the mechanical system. This information is necessary for subsequent dynamic analysis along with control paths.

II. LITERATURE REVIEW

Pramod Kumar Parida et al [1] designed a robot a hand with 25 degrees of freedom by following the anatomy of human hand. The kinematic analysis of the hand offers confirmative results for effective grasping and manipulating objects.

Georg Stillfried et al [2] developed the robot system close to human hand. Studied the kinematic and dynamic behavior of human hand. Large number of MRI report are studied using image processing and modeling methods and results are explained in his paper.

G. Hirzinger et al [3] developed ultra light weight robots with articulated hands. The design consists of sensorized joints with complete state feedback and the underlying mechanisms. Integrated four fingered hand consists of 13 actuators.

Ian M. Bullock et al [4] Explained about incredible complexity of the human hand and its difficulties in modeling. When implementing a kinematic hand model, many simplifications are made, either to provide simpler analytical solutions, to ease implementation, or to speed up computation for real time applications. This paper provides a brief overview of the biomechanics of the human hand, followed by an in-depth review of kinematic models presented in the literature.

Elango Natarajan and Litu Dhar et al [5] designed Multi-fingered robot hand is the one which can be employed in power grasping as well as precision grasping. Mechanical hands find use in remote manipulations in space, nuclear and undersea exploration and prosthetics. Development of such dexterous hand is a challenging one. On the attempt of developing a three fingered robot hand, firstly, the mechanical structure of the hand is done. Forward kinematics has then been done on the designed hand using D-H method.

Dr. Shantanu K. Dixit, Mr. Nitin S. Shingi et al [6] explained about robots that are programmed to perform specific tasks this limits the use of these robots. To increase the use of robots where conditions are not certain such as fire fighting or rescue operation we can make robots which follows the instruction of human operator and perform the task, in this way decisions are taken according to the working conditions by the operator and task is performed by the robots thus we can use these robots to perform those tasks that may be harmful for humans. Also this system is not complex as sensors used are common i.e. Flex sensors, Ultrasonic sensor, Electronic compass and accelerometer.

III. KINEMATIC ANALYSIS

3.1 Kinematic Chain

Kinematic chain refers to an assembly of rigid bodies connected by joints that is the mathematical model for a mechanical system. As in the familiar use of the word: chain, the rigid bodies, or links, are constrained by their connections to other links. A kinematic chain may be an open kinematic chain or a closed kinematic chain. Four bar mechanism is an example of closed kinematic chain and our fingers are examples of open kinematic chain.

3.2 Kinematics equations

The kinematics equations for the series chain of a robot are obtained using a rigid transformation $[Z]$ to characterize the relative movement allowed at each joint and separate rigid transformation $[X]$ to define the dimensions of each link. The result is a sequence of rigid transformations alternating joint and link transformations from the base of the chain to its end link, which is equated to the specified position for the end link.

$$[T] = [Z_1][X_1][Z_2][X_2] \ldots [X_{n-1}][Z_n],$$

Where $[T]$ is the transformation locating the end-link. These equations are called the kinematics equations of the serial chain.

3.2.1 Forward kinematics

It refers to the use of the kinematic equations of a robot to compute the position of the end-effector from specified values for the joint parameters. The kinematics equations of the robot are used in robotics, computer games, and animation.

3.2.2 Inverse Kinematics

It refers to the use of the kinematics equations of a robot to determine the joint parameters that provide a
desired position of the end-effector. Specification of the movement of a robot so that its end-effector achieves a desired task is known as motion planning. Inverse kinematics transforms the motion plan into joint actuator trajectories for the robot.

3.3 Denavit-Hartenberg (DH) matrix

The matrices associated with these operations are:

\[
\text{Trans}_i(d_i) = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & d_i \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
\text{Rot}_i(\alpha_i) = \begin{bmatrix}
\cos \alpha_i & -\sin \alpha_i & 0 & 0 \\
\sin \alpha_i & \cos \alpha_i & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
\text{Trans}_i(a_{i,i+1}) = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \alpha_{i,i+1} & -\sin \alpha_{i,i+1} & 0 \\
0 & \sin \alpha_{i,i+1} & \cos \alpha_{i,i+1} & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

Similarly,

The use of the Denavit-Hartenberg convention yields the link transformation matrix, \[ i-1T_i \] and is known as the Denavit-Hartenberg matrix

\[
i^{-1}T_i = \begin{bmatrix}
\cos q_i & -\sin q_i \cos \alpha_i & \sin q_i \sin \alpha_i & L_i \cos q_i \\
\sin q_i & \cos q_i \cos \alpha_i & -\cos q_i \sin \alpha_i & L_i \sin q_i \\
0 & \sin \alpha_i & \cos \alpha_i & d_i \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

3.4 Kinematic model of Hand

The multi-fingered robot hand acts as a multipurpose gripping device for various tasks. Since it is designed to mimic the human hands, most anthropomorphic robot hands duplicate the shape and functions of human hands. The structure of the designed anthropomorphic hands is almost the same as that of a human hand as shown in Figure. The finger segments in human hand give us the inspiration to design an independently driven finger segment to construct a whole hand. The segmental lengths of the thumb and fingers are taken proportionately to hand length and hand breadth with a fixed wrist. Typically the hand motion is approximated to have 27 DOF, which includes 2 DOF at wrist. In the present study we consider the wrist as a fixed origin and hence the two DOF at this point are not considered and other 15 DOF are considered. Each finger is modeled with 3 DOFs.

3.5 Position Analysis of Hand

For convenience, let \( q_i = \Theta_i \)

DH matrix for the first link:

\[
^{0}T_1 = \begin{bmatrix}
\cos \Theta_1 & -\sin \Theta_1 & 0 & L_1 \cos \Theta_1 \\
\sin \Theta_1 & \cos \Theta_1 & 0 & L_1 \sin \Theta_1 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^{1}T_2 = \begin{bmatrix}
\cos \Theta_2 & -\sin \Theta_2 & 0 & L_2 \cos \Theta_2 \\
\sin \Theta_2 & \cos \Theta_2 & 0 & L_2 \sin \Theta_2 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
^{2}T_3 = \begin{bmatrix}
\cos \Theta_3 & -\sin \Theta_3 & 0 & L_3 \cos \Theta_3 \\
\sin \Theta_3 & \cos \Theta_3 & 0 & L_3 \sin \Theta_3 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

The overall transformation matrix which determines the position of the end-effector is given by:

\[
^{0}T_3 = ^{0}T_1^{*1} T_2^{*2} T_3
\]
The above matrix gives the overall transformation of the end-effector with respect to the fixed origin. The coordinates of the end-effector are given by:

\[
\begin{pmatrix}
 x \\
 y \\
 z \\
\end{pmatrix} =
\begin{pmatrix}
 \cos(\theta_1 + \theta_2 + \theta_3) & -\sin(\theta_1 + \theta_2 + \theta_3) & 0 & L_1 \cos(\theta_1 + \theta_2 + \theta_3) + L_2 \cos(\theta_2 + \theta_3) + L_3 \cos(\theta_3) \\
 \sin(\theta_1 + \theta_2 + \theta_3) & \cos(\theta_1 + \theta_2 + \theta_3) & 0 & L_3 \sin(\theta_1 + \theta_2 + \theta_3) + L_2 \sin(\theta_2 + \theta_3) + L_1 \sin(\theta_3) \\
 0 & 0 & 1 & 0 \\
 0 & 0 & 0 & 1 \\
\end{pmatrix}
\]

Let us consider local origins for each and every finger at its fixed link. This implies

\[
\begin{pmatrix}
 x_0 \\
 y_0 \\
 z_0 \\
1 \\
\end{pmatrix} =
\begin{pmatrix}
 0 \\
 0 \\
 0 \\
1 \\
\end{pmatrix}
\]

Hence

\[
\begin{pmatrix}
 x \\
 y \\
 z \\
\end{pmatrix} =
\begin{pmatrix}
 L_1 \cos(\theta_1 + \theta_2 + \theta_3) + L_2 \cos(\theta_2 + \theta_3) + L_3 \cos(\theta_3) \\
 L_3 \sin(\theta_1 + \theta_2 + \theta_3) + L_2 \sin(\theta_2 + \theta_3) + L_1 \sin(\theta_3) \\
 0 \\
 1 \\
\end{pmatrix}
\]

These are the transformation equations for the end effector using the DH matrices.

**IV. FABRICATION OF HAND**

**4.1 Links**

The links are cut from Aluminium rod as shown in the Fig-4.1. Each of the links is cut suitably at an angle of 45 degrees.

**4.2 Specifications**

- **Material**: Aluminium
- **External diameter**: 12.7mm
- **Thickness**: 2mm
- **Density**: 2700kg/m³
- **Tensile strength**: 68.3 N/mm²

**4.3 Wing**

Wings are generally used in toggle bolts for supporting purpose. They are used here for extension of fingers. These are made of 0.1mm G.I sheet as shown in Fig-4.2.

**4.3.1 Spring**

- **Type of spring used**: Torsion Spring
- **Material**: Spring steel
- **Number of turns**: 7
- **Diameter of wire**: 0.5mm

**4.4 Preparation of Fingers**

- The links are initially cut from Aluminium pipe with the help of Hack-saw frame at an angle of 45 degrees (wherever required)
- After preparing the links holes of diameter 2.5mm are drilled on the links
- Then the wings and the links are assembled with help of 2.5mm dia and 12.7mm height bolts as shown in the Fig-4.4.

**Fig-4.1 Link representing length of the Finger**

**Fig-4.2 Development for making wings**

**Fig-4.3 Torsion Spring**

**Fig-4.4 Assembly of Fingers**
4.5 Preparation of Hand
- Palm is prepared by cutting GI sheet suitably
- All the fingers are prepared as mentioned above
- The fingers are then assembled to the palm with the help of nut and bolts of dia 2.5mm and height 25.4mm

V. ELECTRONICS

5.1 Sensor
A sensor is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.

5.1.1 Flex Sensor
The Flex Sensor patented technology is based on resistive carbon elements. As a variable printed resistor, the Flex Sensor achieves great form-factor on a thin flexible substrate. When the substrate is bent, the sensor produces a resistance output correlated to the bend radius—the smaller the radius, the higher the resistance value. Spectra Symbol has used this technology in supplying Flex Sensors for the Nintendo Power Glove, the P5 gaming glove. They are usually from 1” to 5” long.

5.1.2 Servo-Motor
A servomotor is a rotary actuator that allows for precise control of angular position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.

5.1.3 Processor
A microprocessor incorporates the functions of a computer’s central processing unit (CPU) on a single integrated circuit (IC), or at most a few integrated circuits. All modern CPUs are microprocessors making the micro- prefix redundant.

The microprocessor is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Microprocessors operate on numbers and symbols represented in the binary numeral system.

The processor used here is Atmega328 and is Arduino compatible. Fig-5.4 Shows the total circuit diagram.
VI. RESULTS

6.1 Kinematic analysis of Mechatro-hand

The kinematic analysis of the Mechatro-hand has been done and the following equations 3.1 and 3.2 are obtained from the DH matrices for each link.

\[ X = L_1 \cos(\theta_1 + \theta_3) + L_2 \cos(\theta_1 + \theta_2) + L_4 \cos(\theta_4) \]

\[ Y = L_2 \sin(\theta_1 + \theta_2) + L_3 \sin(\theta_1 + \theta_3) + L_4 \sin(\theta_4) \]

Using Matlab, the above equations are solved with their respective joint limits and link lengths. Because of the range given in the values of angles, the path that the fingertip traces is plotted with their respective fixed links as their local origins.

The graphs for all the 5 fingers are obtained as follows:
In all the plots,
x is taken along X-axis
y is taken along Y-axis
VII. CONCLUSION

A systematic process for developing the kinematic model and confirming its effectiveness through virtual testing is presented. The model considers five fingers similar to human hand for manipulating objects securely. The joints, links and other kinematic parameters are chosen in such a way that they replicate a human hand.

In this paper we have tried to simplify the design procedure and the kinematic analysis as simple as possible. Forward and Inverse both the procedures of kinematic analysis has been explained in detail. All the design considerations and the assumptions have been clearly stated. Mechatro Hand is fabricated operated with flex sensors.

REFERENCES

[2] Georg Stillfried and Patrick van der Smagt, Movement model of a human hand based on magnetic resonance imaging (MRI), ICABB-2010, Venice, Italy, October 14-16, 2010