UTHM HAND: Kinematics behind the Dexterous Anthropomorphic Robotic Hand

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Abstract. This paper describes a novel wireless robotic hand system. The system is operated under master-slave configuration. A human operator tele-operates the slave robotic hand by wearing a master glove embedded with BendSensors. Bluetooth has been chosen as the communication medium between master and slave. The master glove is designed to acquire the joint angles of the operator's hand and send to slave robotic hand. The slave robotic hand imitates the movement of human operator. The UTHM robotic hand comprises of five fingers (four fingers and one thumb), each having four degrees of freedom (DOF), which can perform flexion, extension, abduction, adduction and also circumduction. For the actuation purpose, pneumatic muscles and springs are used. The paper exemplifies the design for the robotic hand and provides the kinematic analysis of all the joints of the robotic hand. It also discusses different robotic hands that have been developed before date.

Keywords: Robotic hand, Tele-operation, Multi-fingered hand, pneumatic muscles, solenoid valves, kinematics.

1 Introduction

Robots have become an integral part of modern human life. With every passing year the population of robots is being increased. The industry has replaced a large number of human workers with lesser number of robots on the grounds of economy and efficiency. A robot is a modern version of slave, which perform any task in its capacity satisfying the old human instinct to rule. A robot follows the command as ordered by the human master. Therefore the humans can still enjoy mastering a dumb but efficient slave under their supremacy.

The intelligence of humans has been linked to the hands. Aristotle and Anaxagoras had been discussing this association hundreds of years ago [1]. Humans are the only specie that has been gifted with this kind of dexterous hands, where the universe of full of various species. These hands are capable of doing so many tasks in our routine like dexterously handling different things and even sensing. Therefore this has been discussed from long to be one of the reasons that humans are so intelligent.

The human hand consists of fifty four bones whereas the complete body of an adult human contains two hundred and six bones [2], which is around 26% of the total

S.G. Ponnambalam et al. (Eds.): IRAM 2012, CCIS 330, pp. 119–127, 2012.

human bones. When discussing the robotic hands, the segments or parts that join together to build the robotic hand are mostly less than this number. Even after reaching this number, it cannot compete with the human hand in a broad range of tasks. The reason is the structure of human hand and the material used in human hand that cannot be compared by the material available for robotic hands. The toolset and materials of Mother Nature is far advance than any of the latest technology.

A robotic hand system has been developed that is perfectly compliant to the needs of industry and the hand alone can also be used in prosthetics and rehabilitation. The shape, size and weight of the hand is comparable to actual human hand, therefore it is an anthropomorphic hand. The robotic hand is very flexible so that it can attain dexterous manipulation and can pick and place different things of different shapes and sizes like a normal human hand. The complete system should be able to fix the reprogramming issue and reduce the human injuries in extreme environments.

2 Literature Review

The research on robotic hands is being done for a long period of time. Looking back to the history of robotic hands, in 1961 Heinrich Ernst developed for the first time, the MH-1 a computer operated mechanical hand at MIT [4]. Theoretically the least number of DOF to achieve dexterity in a robotic hand with rigid, hard-finger, non-rolling and non-sliding contacts, is nine [5]. The proof for this theory was the development of Stanford/JPL hand.

The development of MIT/UTAH hand [6] was the beginning of more complex robotic hand structures. It was the first robotic hand capable of dexterously manipulating objects. A detailed study on the robotic hands performing dexterous manipulation can be seen in [3].

In order to actuate the finger joints in the robotic hand artificialitists has been using electric motors quite frequently [7], [8]. Electric motors have been proved to be very accurate in position and velocity control and also provide much force for the grasping function required by the robotic hand.

The MIT/UTAH hand had three fingers and one thumb [6]. They removed the little finger to avoid complexity in their dexterous robotic hand NASA's Robonaut Hand had twelve DOF and five fingers like human hand [9]. Brushless DC motors and gear head were used for the finger actuation. The anthropomorphic NTU hand had seventeen DOF with five fingers and was comparable to the size of human hand [10]. Similarly the DIST-Hand was developed with sixteen DOF and high level of dexterity [11]. It had four fingers actuated by tendon drive and DC motors. The DLR-Hand also used dc motors with transmission tooth belt and harmonic drive gears [12]. Compact fluidic hand had been developed and reported with fourteen DOF [13]. The hand is powered by fluidic actuators and a miniaturized hydraulic system was developed to be embedded inside the robot hand. The Keio hand had been developed having twenty DOF almost the same as human hand [14]. This hand has been actuated uniquely using ultra-sonic motors along with elastic elements. Another unique design using spring as actuating element has been reported [15]. The said robot had three fingers and was reported achieve very high acceleration. This robotic hand was reported for capturing purposes.

3 Master Glove

The control of the under discussion robotic hand is done by using tele-operation. For the actuation of anthropomorphic and dexterous robotic hand, all the angles of finger joints of the human operator must be tracked. Tracking of angles is done by a special glove, which is embedded by BendSensors and it is also capable of tracking the sideways movement of the joint that connects the finger to the palm as well i.e. abduction and adduction. The details of calculations, the sensors location in the glove and the modeling for torque produced at all joints can be seen in [16]. The operator wearing the specially designed master glove, by the authors, is shown in Figure 1.

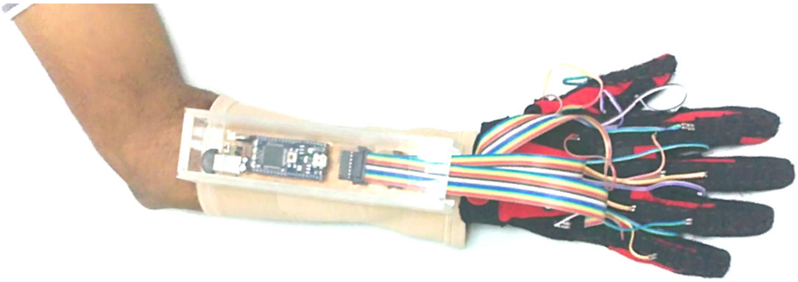

Fig. 1. UTHM hand operator wearing master glove embedded with sensors

In this project, BendSensors are embedded in the glove to track the joint angles. This is a kind of potentiometer strip that changes the value of resistance when it is bent. The change of resistance value is proportional to the angle that the sensor is bent. This sensor has been used in voltage divider configuration. To sense the voltage levels, high speed Analog to Digital Converter (ADC) has been used which is capable of giving throughput of 50 kilo samples per second with each sample of 12 bits. The maximum angle of 120^o can be observed between the joint joining the proximal and middle segment of the finger. The microcontroller acquires the digital values of the BendSensors. These sensor values are sent to the robot hand so that the robot hand can mimic the movement of the human operator. The robot hand has been setup in the listening mode so that the glove module can send connection request. After the establishment of connection the master glove transmits the angle while the slave robotic hand receives it. This is a one way data transfer, therefore the master acts as a transmitter and slave acts as a receiver. The transfer rate has been set to 10 packets per second, where each packet contains the angle information of complete hand.

4 Robotic Hand

The theme of UTHM hand is to develop a dexterous and anthropomorphic robotic hand; therefore the inspiration for the look and feel has been taken from human hand. The look and feel as well as the size of all the fingers and palm is very much comparable to human hand. The hand comprises of five fingers including the thumb. The structure for all the fingers including the thumb is same while the difference is size, as the sizes varies among the fingers in normal human hand. The designed hand is capable of twenty DOF which does not include the wrist and arms. Twenty DOF is from the summation of all the fingers as each finger exhibits four DOF. All the joints are pin joints using the dowel pins for connecting the different segments of hand.The details of mechanical design and motion mechanism can be seen in [17].

Jacques Denavit and Richard Hartenberg introduced a convention in order to standardize the coordinate frames for spatial linkages [18], [19]. The Denavit-Hartenberg parameters (also referred as DH parameters) are the four parameters associated with this convention for attaching reference frames to the links of a spatial kinematic chain, or robot manipulator. This convention will be used in this robotic hand as every finger of the robotic hand represents one serial chain. There have been many conventions being developed in the past but the reason to choose this approach is because this approach remains standard for the serial linkages in robot manipulators.

In this convention, coordinate frames are attached to the joints, as shown in Figure 2, between two links such that one transformation is associated with the joint, [Z], and the second is associated with the link [X]. The coordinate transformations along a serial robot consisting of n links form the kinematics equations of the robot;

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

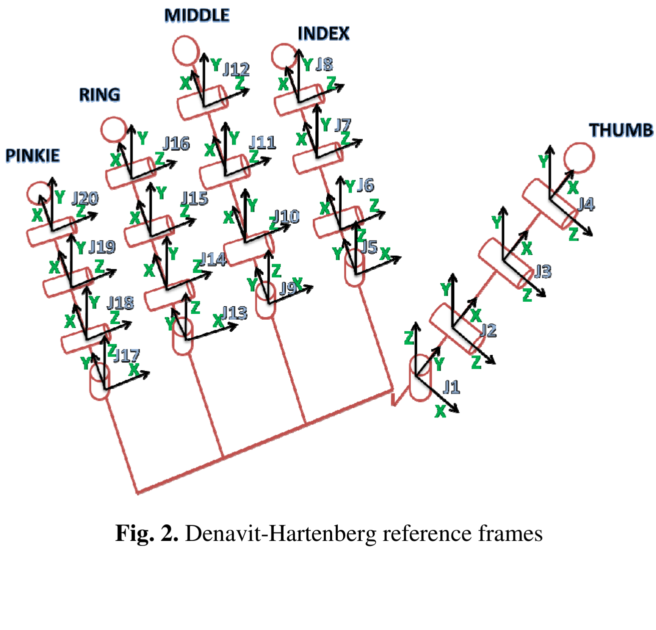

Fig. 2. Denavit-Hartenberg reference frames

This convention allows the definition of the movement of links around a common joint axis S_i by the screw displacement,

$$[Z_i] = \begin{bmatrix} cos\theta_i & -sin\theta_i & 0 & 0 \\ sin\theta_i & cos\theta_i & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where θ_i is the rotation around and d_i is the slide along the Z axis, either of the parameters can be constants depending on the structure of the robot. Under this convention the dimensions of each link in the serial chain are defined by the screw displacement around the common normal $A_{i,i+1}$ from the joint S_i to S_{i+1}, which is given by

$$[X_i] = \begin{bmatrix} 1 & 1 & 0 & r_{i,i+1} \\ 0 & cos\alpha_{i,i+1} & -sin\alpha_{i,i+1} & 0 \\ 0 & sin\alpha_{i,i+1} & cos\alpha_{i,i+1} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where $\alpha_{i,i+1}$ and $a_{i,i+1}$ define the physical dimensions of the link in terms of the angle measured around and distance measured along the X axis.

It is common to separate a screw displacement into the product of a pure translation along a line and a pure rotation about the line, such that

$$[Z_i] = Trans_{(Z_i)}(d_i)Rot_{(Z_i)}(\theta_i) \text{ and}$$

$$[X_i] = \mathrm{Trans}_{X_i}(r_{i,i+1})\mathrm{Rot}_{X_i}(\alpha_{i,i+1})$$

Using this notation, each link can be described by a coordinate transformation from the previous coordinate system to the next coordinate system.

$$^{n-1}T_n = \mathrm{Trans}_{Z_{n-1}}(d_n).\mathrm{Rot}_{Z_{n-1}}(\theta_n).\mathrm{Trans}_{X_n}(r_n).\mathrm{Rot}_{X_n}(\alpha_n)$$

Note that this is the product of two screw displacements. The matrices associated with these operations are:

$$\mathrm{Trans}_{Z_{n-1}}(d_n) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathrm{Rot}_{Z_{n-1}}(\theta_n) = \begin{bmatrix} \cos\theta_n & -\sin\theta_n & 0 & 0 \\ \sin\theta_n & \cos\theta_n & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathrm{Trans}_{X_n}(r_n) = \begin{bmatrix} 1 & 0 & 0 & r_n \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathrm{Rot}_{X_n}(\alpha_n) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha_n & -\sin\alpha_n & 0 \\ 0 & \sin\alpha_n & \cos\alpha_n & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Solving for ${}^{n-1}T_n$

$${}^{n-1}T_n = \begin{bmatrix} \cos\theta_n & -\sin\theta_n\cos\alpha_n & \sin\theta_n\sin\alpha_n & r_n\cos\theta_n \\ \sin\theta_n & \cos\theta_n\cos\alpha_n & -\cos\theta_n\sin\alpha_n & r_n\sin\theta_n \\ 0 & \sin\alpha_n & \cos\alpha_n & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

From the above matrix, rotation (R) and translation (T) can be visualized as;

$$R = \begin{bmatrix} \cos\theta_n & -\sin\theta_n\cos\alpha_n & \sin\theta_n\sin\alpha_n \\ \sin\theta_n & \cos\theta_n\cos\alpha_n & -\cos\theta_n\sin\alpha_n \\ 0 & \sin\alpha_n & \cos\alpha_n \end{bmatrix}, T = \begin{bmatrix} r_n\cos\theta_n \\ r_n\sin\theta_n \\ d_n \end{bmatrix}$$

Then the position and orientation of the end-effector attached to serial chain of n joints with reference to initial frame are given by

$${}^{0}T_n = {}^{0}T_1 {}^{1}T_2 \ldots {}^{n-2}T_{n-1} {}^{n}T_n$$

Using the DH transformation matrix from one frame to the other frames, the position of one segment relative to the other segment can be calculated in this robotic hand. The calculated values of DH parameters are as follows;

Table 1. DH parameters for the robotic UTHM Hand

Joint	d(mm)	θ	r(mm)	α
J1- J2	0	90°	6.7	90°
J2- J3	0	0°	33	0°
J3-J4	0	0°	33	0°
J5-J6	0	90°	6.7	90°
J6-J7	0	0°	26.4	0°
J7-J8	0	0°	26.4	0°
J9-J10	0	90°	6.7	90°
J10-J11	0	0°	26.4	0°
J11-J12	0	0°	33	0°
J13-J14	0	90°	6.7	90°
J14-J15	0	0°	26.4	0°
J15-J16	0	0°	26.4	0°
J17-J18	0	90°	6.7	90°
J18-J19	0	0°	26.1	0°
J19-J20	0	0°	19.8	0°

The transformation matrices from base joint to the distal segment of each finger using the values of DH parameters of the UTHM Hand are computed individually. The resultant matrices after solving for the values of DH parameters of each finger are as follows;

$$^{J1}T_{J4} = {}^{J1}T_{J2}\,{}^{J2}T_{J3}\,{}^{J3}T_{J4} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 72.7 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{J5}T_{J8} = {}^{J5}T_{J6}\,{}^{J6}T_{J7}\,{}^{J7}T_{J8} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 59.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{J9}T_{J12} = {}^{J9}T_{J10}\,{}^{J10}T_{J11}\,{}^{J11}T_{J12} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 66.1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{J13}T_{J16} = {}^{J13}T_{J14}\,{}^{J14}T_{J15}\,{}^{J15}T_{J16} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 69.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{J17}T_{J20} = {}^{J17}T_{J18}\,{}^{J18}T_{J19}\,{}^{J19}T_{J20} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 52.9 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

This kinematics analysis can be further used for the dynamics of the robotic hand by calculating the force, velocity, contact locations etc. These transformation matrices help in transforming the base axes to the distal segment of the corresponding finger, which is mostly utilized in grasping. Therefore we can know the location of distal segments with respect to the base of the finger. It is pertinent to mention here that, the circular or rotational motion of the finger can be traced as the combination of extension, flexion, adduction and abduction movements of the fingers. The final transformation matrices of the fingers are already shown to be encapsulating the translational and rotational components.

5 Conclusion

The overview of the dexterous anthropomorphic robotic hand system has been elaborated in this paper. The robotic hand system is based on Tele-operation using

Bluetooth as the communication channel between them. The design has been made simpler and its demand for space has been reduced from previous designs of robotic hands by using combination of pneumatic actuator and springs. The state of the art microcontroller has been used as the control and processing unit for both the master glove and robotic hand. This robotic system has many applications for the developments of safe industrial environments, whereas the robotic hand alone can also be used for different applications in industry as well as for rehabilitation. The paper has focused on the kinematic analysis by using the standard DH parameters convention by calculating the reference frames and the parameter values of all the joint of the UTHM Hand.

Acknowledgments. This research work is fully funded by Fundamental Research Grant Scheme (FRGS) (VOT 0715), Ministry of Higher education, Malaysia and Graduate Researcher Incentive Grant (VOT 0868), University Tun Hussein Onn Malaysia (UTHM). We would like to thank the staff of Electrical Instrumentation and Measurement Laboratory of UTHM for the technical support.

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