20 DOF Robotic Hand for Tele-operation: - Design, Simulation, Control and Accuracy test with Leap Motion

Lamyanba Heisnam, Bhivraj Suthar

Abstract— **Robot hands with lower degree of freedom are used to reproduce the gesture of our hand, there are many gestures of our hand which cannot be reproduced in these hands. In this paper, we propose a design of anthropomorphic robot hand using twenty servo motor for twenty degree of freedoms which we can reproduce the exact and every gesture of our hand so that it is suitable for dexterous task like surgery. The accuracy of the proposed design to reproduce gestures and motion of our hand by simulating in Leap Motion Diagnostic Visualizer using Leap Motion Controller as a sensor are measured in this paper. The angle measurement method between fingers and bones of the same finger in Leap Motion Controller is also presented. Accuracy test and control system is also described.**

Key words- *Robot hand, dexterous, gestures, Leap Motion Controller.*

I. Introduction

Many robot hands have been developed so far. Robot hands like Gifu [1], Robonaut hand [2], and Anthrobot hand [3] are having five fingers and sixteen, twelve, sixteen, degree of freedom respectively. And hands like Robomec Robot Hand [4] and WENDY hand [5] are having fingers less than five so it cannot be used to reproduce the exact gestures and motion of our hand. Stanford-JPL hand[6], Shadow hand[7], NAIST hand 2[8], DEXMART Hand[9], robot hand developed in [10], Utah/MIT hand[11] are string driven which are bulky and the strings are cumbersome and the design is not compact. So, there is lack of combination of compact, five-fingered and high degree of freedom. For teleoperation and to produce the exact gesture and motion of our hand, we need a five-fingered and high degree of freedom robot hand. In the string-driven system, the elasticity of the string causes inaccurate joint angle control and the long wiring of string may obstruct the robot motion when the hand is attached to the tip of a robot arm. So, we need a compact and self-contained hand. We propose a design of anthropomorphic hand with twenty servo motors which is compact and light-weight. While teleoperating if the gripper has the same shape and motion of the hand then, the operator can operate effectively with less training.

There are many teleoperating techniques like using mechanical devices like joystick [12-14] and data gloves [15-19]. Teleoperating using joystick make the operator feel uncomfortable and unnatural. Data gloves may make the operator feel more comfortable and natural but it may restrict the motion of our fingers. So, contactless technique provides more natural and do not restrict the motion. In our teleoperating system, we propose the use of Leap Motion Controller as a contactless sensor.

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In this paper, we present the design of anthropomorphic hand having twenty servo motors for twenty degree of freedom which can be teleoperated by Leap Motion sensor. The angle between each fingers and the angle between the bones of the same finger are measured from the data from Leap Motion. Firstly, we describe the mechanical design considerations and details of degree of freedom. In section 3, details of Leap Motion sensor, angle measurement between the fingers and bones of the same finger is described. In section 4, simulation and accuracy test is described and latency of the system in section 5. In section 6, Control system of the proposed tele-operating system is described. Conclusion and future work is presented in section 7.

II. Mechanical Design Details

A robot hand for teleoperation has to meet the requirements as a service robot hand [21] do.

- *Structural Requirements*: For dexterous motion, it needs a lot of active joints. And to minimize the disturbance caused by the hand, all components should be integrated to the hand.
- *Functional Requirements*: Grasping motions similar to human is needed. To produce these motions, the hand should have five fingers and high degree of freedom.

String driven robot hand [7-11] and hands having lower degree of freedom [1-3] do not satisfy the structural requirements. And hands having fingers less than five [4-5] do not satisfy functional requirements. Human fingers consists of three joints – metacarpophalangeal(MCP) joint, proximal intephalangeal(PIP) joint and distal interphalangeal (DIP) joint.PIP and DIP joints have almost one degree of freedom and MCP joints has two DOF. In our design, we place one servo motor at each DOF as shown in Fig. 1. For every fingers, a servo motor is fixed in the coronal plane to provide one degree of freedom of the MCP joints. A series of three servo motors is attached to each output shaft of the servo motor hence providing one degree of freedom of the MCP joint and another two degree of freedoms of PIP joint and DIP joint. Each finger is having four degree of freedoms. As the servo motors are placed on the fingers and palm, the hand is compact and self-contained. So, the number of active joints and compactness increase satisfying the structural

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requirements. As there is one servo in each DOF, it can produce any gesture of our hand so grasping motions similar to human can be obtained satisfying the functional requirements.

A servo motor [22] is a closed-loop servo mechanism that uses the position feedback to control its motion and final position. The measured position is compared to the command position. If the output position differs from that required, an error signal is generated to bring the output shaft The measured position is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stop.

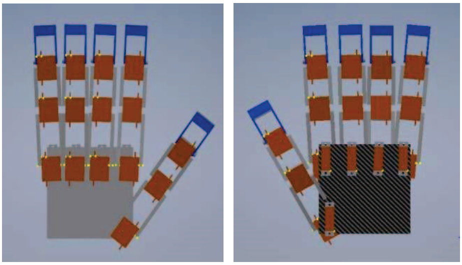


Figure 1. Front and Back veiw of CAD model of proposed robot hand (brown coloured part representing servo motors)

III. Measuring Angles Between Fingers and Bones

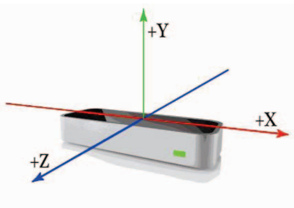


Figure 2. Leap Motion Controller

A Leap Motion Controller consists of two stereo cameras and three infrared LEDs. It tracks infrared light with a wavelength of 850 nanometers, which is Outside the visible light spectrum. The device operates in an intimate proximity with high precision and tracking frame rate and reports discrete positions and motion. The device has an interaction space of eight cubic feet, which takes the shape of an inverted pyramid. It tracks hands at up to 200 frames per second. It gives a 150 degrees field of view.

A. Measuring angle between the fingers

The angle between the thumb and index finger in the coronal plane is measured by taking the dot product of vector along metacarpal of thumb and metacarpal of index finger as done in [24].

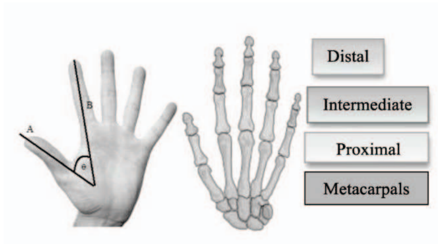


Figure 3. The finger bones structure[23]

The angle between other fingers are calculated by taking the dot product of vectors along proximal of the the finger.

$$\theta = \cos^{-1}\frac{\mathbf{A}.\mathbf{B}}{|\mathbf{A}| \times |\mathbf{B}|}$$

Where

A = vector along metacarpal of thumb
B = vector along metacarpal of index finger

B. Measuring angle between bones of same finger

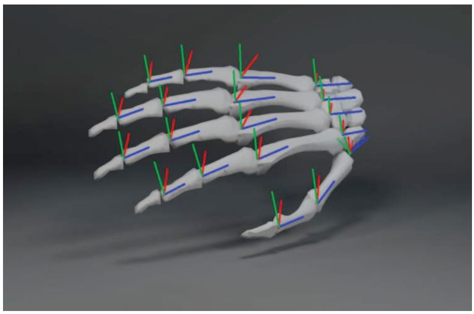


Figure 4. Skeleton of hand with UCS

We assigned the user co-ordinate system (UCS) at every joints of the fingers. We take x-axis perpendicular to the length of the bone which is denoted by red line. We take z-axis along the length of the bone which is denoted by blue line. The position of UCSs in a hand is shown in Fig. 4. When the fingers move, the relative orientation of the UCSs changes. The angle between the two z-axis of the two adjacent bones gives the angle between the two adjacent bones. The gestures of the hand above the sensor and the corresponding positions and orientations of the UCSs are shown in Fig. 5.

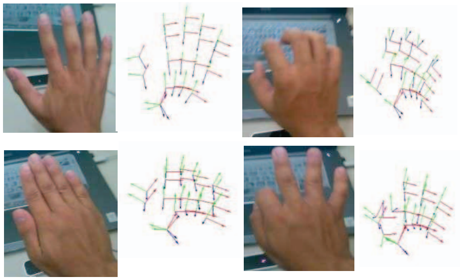


Figure 5. Hand gestures and corresponding UCSs

IV. Simulation & Accuracy Test

As we get the values of the angles between fingers and the angles between bones of same finger, it can be fed to the servo motors through a microcontroller. For simulation, we use Leap Motion Diagnostic Visualizer. When our hand moves above the Leap Motion Controller within the interaction space, the simulated hand in Leap Motion Diagnostic Visualizer also moves correspondingly. The angles calculated by the above method are used to position the joints of the simulated hand. The simulated robot hand in the Leap Motion Diagnostic Visualizer is as shown in Fig. 6.

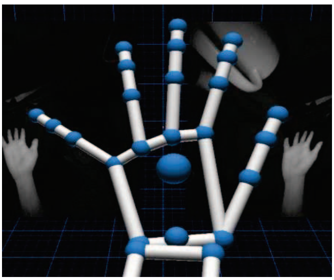


Figure 6. Leap Motion Diagnostic Visualizer

In Static Position Error experiment performed in [25], the wooden hand was held at a point in the middle of the sensors' range, and the sensor data was collected for ten seconds. The standard deviations of the Leap's static data ranges from 0.01mm to 0.04mm. This could potentially allow for very fine tool position control. However, when movements are considered far away from the center of the sensor's range, errors increase significantly.

A. Accuracy test in Static Condition

In this test, we measure the ability of the system to reproduce the gesture produced by hand in static condition. The gesture of our hand above the sensor is maintained so that the simulated hand takes the corresponding gesture. The gesture of the actual hand and the simulated hand is shown in Fig. 7.

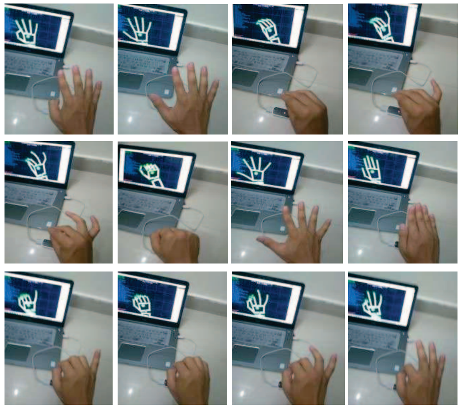
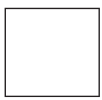


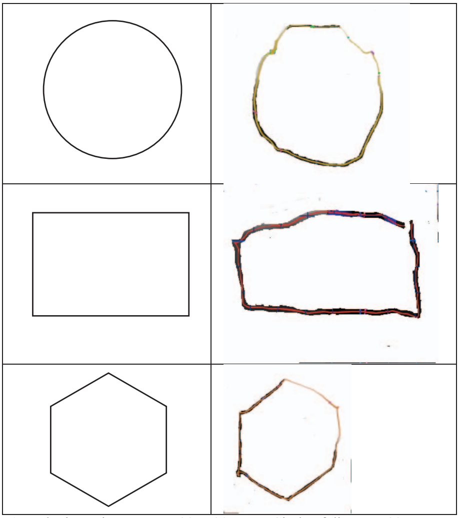
Figure 7. Gestures produced by actual and simulated hand

B. Accuracy test in Dynamic Condition

In the experiment performed in [25] to test the positional consistency and accuracy of the sensor systems, an artificial hand was used. A wooden hand was attached to the robot arm and programmed to move linearly between points in the cubical workspace. Use of artificial hand and robot arm to test positional consistency and accuracy of the sensor give results different from using actual hand. In teleoperation for surgical tasks, the master is the actual hand and the slave has to reproduce the motion of the actual hand.

Table 1. Shapes produced by simulated hand

Shapes over which index finger moves	**Shapes produced by simulated hand**
	



Actual Dimensions: square 90 X 90 mm2 , Circle of diameter 90 mm, Rectangle 90 X 45 mm2 , Regular hexagon of 45 mm.

In this test, the ability to reproduce the motion of the actual hand by simulated hand is measured. For the same, the index finger is moved along the drawings of various shapes. The drawing produced by the simulated hand is shown in Table 1.

V. LATENCY

In surgical robots, the surgeon needs to respond quickly from the visual feedback. Even if the master (surgeon console) and the slave (surgical robot) are located in the same room, physically separating the two sub-systems introduces time delays that affect the surgeon's performance and ultimately the outcome of the surgical performance. So, lower latency is required for surgical tasks. Leap Motion is having average frame rate of 110.7 fps. And the average latency measured during the accuracy tests are found to be 11.21 ms. The frame rate of kinect sensor is 30 fps. The average latency of kinect given in [25] is 74.9 ms. So, Leap motion is having lower latency compared to kinect. So, it can be used in teleoperation for surgical tasks.

VI. CONTROL SCHEME FOR TELEOPERATION

The data from Leap Motion is shown in the table below. Here, the value in the direction row gives the unit vector along the direction of the bone. The cross -product of these vectors give the angle between them. When a hand is placed within the working range of Leap Motion. It gives data about the position of the hand. The data are published in the pc to obtain the angle between the bones of the finger.

Table-2. Leap motion data.

Type: Middle finger Metacarpal bone Direction: (0.0, 0.2, -1.0) Proximal phalanx bone Direction: (0.2, 0.5, -0.9) Intermediate phalanx bone Direction: (0.0, 0.2, -1.0) Distal phalanx bone Direction: (-0.1, -0.1, -1.0)	***Type: Ring finger*** Metacarpal bone Direction: (0.2, 0.1, -1.0) Proximal phalanx bone Direction: (0.4, 0.3, -0.9) Intermediate phalanx bone Direction: (0.2, -0.0, -1.0) Distal phalanx bone Direction: (-0.1, -0.3, -1.0)
Type: Index finger Metacarpal bone Direction: (-0.1, 0.2, -1.0) Proximal phalanx bone Direction: (0.0, 0.7, -0.7) Intermediate phalanx bone Direction: (-0.1, 0.5, -0.9) Distal phalanx bone Direction: (-0.2, 0.3, -0.9)	***Type: Thumb*** Metacarpal bone Direction: (-0.3, 0.4, -0.8) Proximal phalanx bone Direction: (-0.7, 0.3, -0.7) Intermediate phalanx bone Direction: (-0.6, 0.2, -0.8) Distal phalanx bone Direction: (-0.7, 0.3, -0.6)
Type: Pinky finger Metacarpal bone ; Direction: (0.3, 0.1, -1.0) Proximal phalanx bone ; Direction: (0.7, -0.0, -0.7) Intermediate phalanx bone ;Direction: (0.5, -0.3, -0.9) Distal phalanx bone ; Direction: (0.2, -0.5, -0.9)	

These angle values can be serial communicated to the Arduino and it send signal to the servo motor to rotate by that much angle. As all the servo motors rotate to the corresponding angles, the robot hand reproduced the motion and gesture of Our hand as shown in fig. 8.

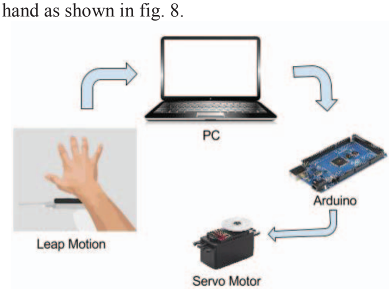


Figure 8. Control system

VII.CONCLUSION AND FUTURE WORK

From the simulation and accuracy test, we can conclude that the proposed design and the control scheme can be used to reproduce the gesture of our hand and there is need for improvement in the sensor and filters to reproduce the motion more accurately. Robot hand having higher degree of freedom is suitable for reproducing the gesture of our hand. The robot hand will be compact. As the robot hand is dexterous, it can be used to grip various tools used in surgery and other teleoperation tasks.

In the future, we will fabricate this hand to verify the simulation and haptic system will be implemented. We will improve the filters to reproduce the motion accurately so that it can be used in surgical tasks.

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