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Novel Approach to Control of Robotic Hand Using Flex Sensors

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ABSTRACT

This paper discuss about novel design approach to control of a robotic hand using flex sensors which indicates a biomechatronic multi fingered robotic hand. This robotic hand consists of base unit, upper arm, lower arm, palm and five fingers. The aim is to develop an anthropomorphic five fingered robotic hand. The proposed design illustrates the use of 5 micro DC motors with 9 Degrees of Freedom (DOF).Each finger is controlled independently. Further three extra motors were used for the control of wrist elbow and base movement. The study of the DC motor is being carried out using the transfer function model for constant excitation. The micro DC motor performance was analyzed using MATLAB simulation environment. The whole system is implemented using flex sensors. The flex sensors placed on the human hand gloves appear as if they look like real human hand. 89v51 microcontroller was used for all the controlling actions along with RF transmitter/receiver. The performance of the system has been conducted experimentally and studied.

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1. INTRODUCTION

Human hand consists of bone muscles, ligaments, tendons, veins, arteries and nerves. The entire human hand is composed of 26 bones and 19 muscles [1]. The human hand helps us to grab select, sense and perform all other control actions required in day to day life. Researchers have tried to control the robotic hand using flex sensors[2] with end effectors as grippers but with a wired communication. However researchers have tried to replicate the natural biomechatronic human hand system [2, 3]. Several attempts have been made to design human like robotic hand with end effectors as simple grippers to complex structure [4, 5, 6, 7]. L. Zollo et.al [8, 9] has designed a 3 digit robotic hand with necessary control system and analysis with 10 DOF which is light weighted. Ohnishi K et al [9] have designed a four fingered hand with 8 DOF but the structure remains complex with seventy eight tactile sensors. Ohnishi.K et al [10] have also designed Harris Arm with intelligent hand with 8 DOF but the overall length and weight of structure remains high and it is difficult to use in practical applications. Asma S. Ali et.al [11] have designed assistive robotic arm for quadriplegic, Athetoid cerebral palsy. The entire hand was constructed with PVC tubing and end effectors were grippers. G. Guo et.al [12] have designed 3 fingered 9 DOF based on Stanford/PJL, Utah/MIT hand, where the weight of entire hand and volume were reduced based on design minimization. In this paper we have designed a robotic hand which is ease in design, flexibility, cost, battery operated with charger unit.

2. DESIGN APPROACH AND MATERIALS USED

2.1 Design Approach

In designing the robotic hand, the functional characteristics and study of human hand are studied. The requirements and dimensions of human hand of various subjects are listed out like kinematics, dynamic performance, and anatomy gesture grasping capabilities along with functional capabilities. The manipulator design was based on articulated configuration and wrist was designed based on spherical configuration [12]. The robotic hand consists of five fingers which are controlled by five DC motors placed in the palm reproducing the principle of extrinsic muscles. The principle of abduction/adduction is achieved by placing the DC motor inside the palm through a wheel gear mechanism, the movement from palm to lateral position and vice versa is as shown in Figure 1, so that the thumb can fix its position when the power is off. The same principle is extended for other fingers too.

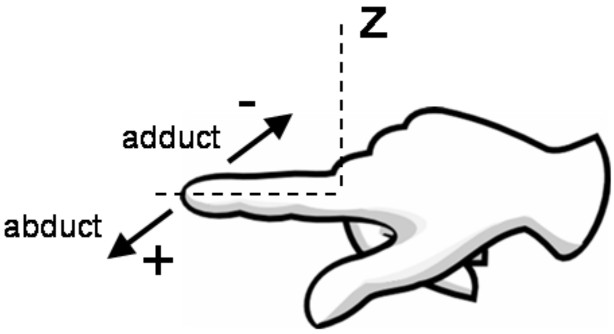

Figure 1.ab/adduction of human hand (courtesy Department of Bioengineering, NUS, Singapore).

2.2 Finger Movement Design

The main focus for designing the finger movement is to reduce the number of actuators which is used to control the movement of the finger and make things easier for the action of the finger. Figure 2 shows in which the finger is designed with accommodating procedure to keep the finger in straighten position at rest. When the actuator is activated, the finger will bend and fold up and stay in the same position. The same method is valid with other fingers also, with each finger is independently controlled. When the actuator becomes inactive, the compliant mechanism would return the fingers to rest. That is one actuator performs two operations viz closure of finger and retaining state of rest. Hence number of actuator is reduced to 5 or in other words 5 actuators are necessary to control all the fingers. The anatomy behind the human fingers is shown in Figure 3. A simple iron metal chain is used to control movement of finger. This movement is similar to as that of human hand.

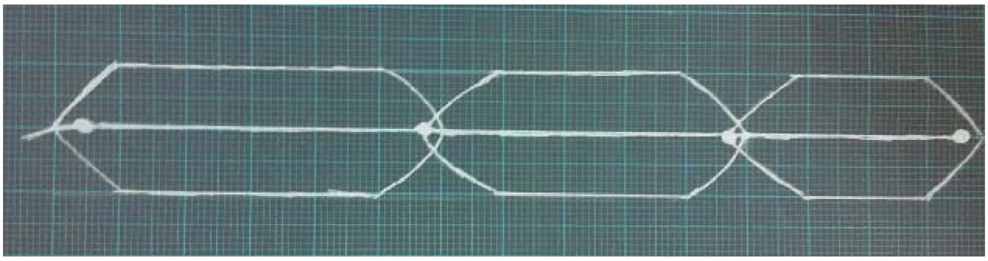

Figure 2 Single Tension Cable Design Proposal

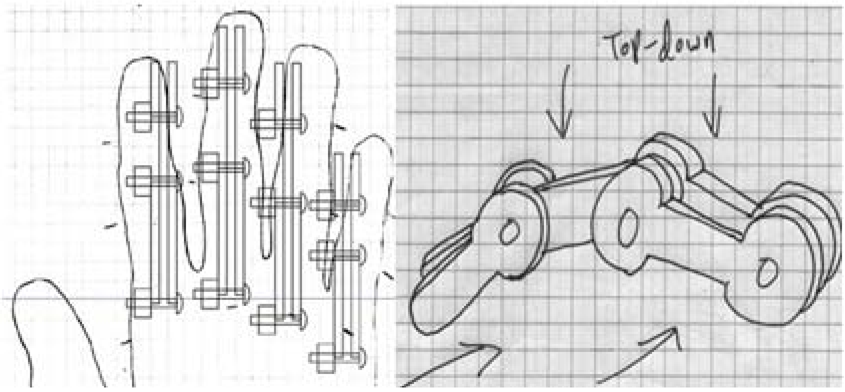

Figure 3 Anatomy inside Robot finger

2.3 Hand Sizing

In designing the robotic hand, human hand dimensions are required. We have compiled the dimensions from both males and females of ethnic background. In order to provide stable grasp and pick, further dimensions were increased on finger geometry and also elbow section. The overall dimension of hand along with base unit is tabulated as shown in Table 1, which is used in designing the hand for our study. Some of the dimensions are less and compact compared to existing anthropomorphic robotic hand [10].

2.4. Materials Used

Research has been conducted regarding materials and parts. The entire robotic hand is constructed with the help of PVC tubing. The base portion holds two 6V batteries. It is also enclosed with AC-2 pin socket to charge the battery. The entire material is placed on Al- rubber-Al which is free from environmental constraints. Figure 4 shows the above mentioned base units with necessary electronic instrumentation which is used for experimental study.

Table 1. Hand Dimensions

Sl.No	Quantity	Values
1.	Length of ARM	580mm
2.	Palm width	140mm
	Wrist width	80mm
	Fore arm	101mm
	Mid arm	105mm
	Elbow	114mm
3.	Weight of Arm	0.825kg
	Weight of Base	3.43kg
4.	Palm Length	127mm
5.	Thumb length	80mm
6.	Index finger Length	100mm
7.	middle finger length	110mm
8.	Ring Finger length	92mm
10.	little finger length	68mm
11.	Base radius	145mm
12.	Supply Voltage	
	Base Movement	12Volts
	Finger Movement	6 Volts
13.	Maximum closing time	
	Of each finger	4.7 seconds

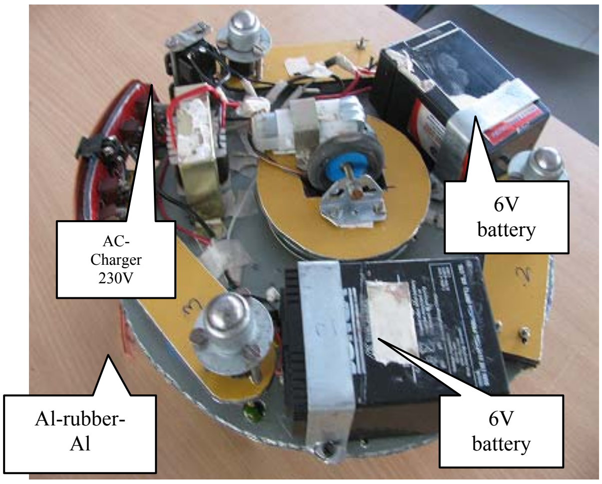

Figure 4. Base unit with necessary electronics

3. ANALYSIS OF DC MOTOR WITH SYSTEM EQUATIONS

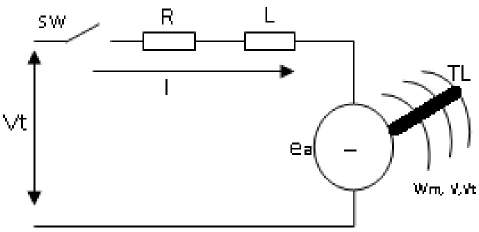

Figure 5. Schematic Diagram of DC motor

Figure 5 shows the Schematic Diagram of DC motor. These motor are basically armature voltage controlled motors at constant excitation or may be micro permanent motor. These motor control the actions of joints of fingers. The performance of these motors is to be evaluated by the control system analysis. For that the following method is used to find the transfer function of the model.

3.1 System Equations

The Motor Torque T is related to armature current **i** with motor torque constant K

$$T = ki \tag{1}$$

Generated voltage, e_a is related to angular velocity

$$e_{a =} \ \mathrm{k}\omega_n = \frac{kd\theta}{dt} \tag{2}$$

Based on Newton’s law and Kirchhoff’s law we can write the equations from Fig 5 as

$$J\frac{d^2\theta}{dt^2} + \mathrm{b}\frac{d\theta}{dt} = K_i \tag{3}$$

$$\mathrm{L}\frac{di}{dt} + R_i = \mathrm{V} - \frac{Kd\theta}{dt} \tag{4}$$

3.2 Transfer Function

Applying Laplace transform equation 3 and 4 can be written as

$$\mathrm{JS^2\theta(s) + bS\theta(s) = KI(s)} \tag{5}$$

$$LsI(s) + RI(s) = V(s) - K\,\theta(s) \quad (6)$$

Where s denotes the Laplace operator. Finding an expression for I(s)

$$I(s) = \frac{[V(s) - Ks\theta(s)]}{Ls+R} \quad (7)$$

Replacing equation (7) in (5) to obtain:

$$JS^2\theta(s) + bS\theta(s) = K\frac{[V(s) - Ks\theta(s)]}{Ls+R} \quad (8)$$

This equation for the DC motor is shown in the block diagram in Figure 6. From equation (8), the transfer function from the input voltage, V (s), to the output angle, θ

$$G_a(s) = \frac{\theta(s)}{V(s)} = \frac{K}{\{s[(R+Ls)(Js+b)+K^2]\}} \quad (9)$$

From the block diagram in Figure 6, the input voltage V (s) and to the angular velocity, **ω**, are related to:

$$G_a(s) = \frac{\omega(s)}{V(s)} = \frac{K}{\{s[(R+Ls)(Js+b)+K^2]\}} \quad (10)$$

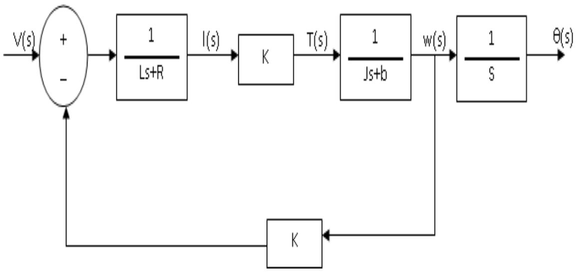

Figure 6. Closed Loop system of DC Motor

For the Motor used at elbow, the Power is equal to 3.6 watts, the rotor inertia J be assumed as 0.02, Speed is equal to 38 RPM (max), and supply voltage is given as 6 V, then the torque constant K can be calculated from equation,

$$\omega_m = \frac{V}{K} = \frac{2\pi N}{60}$$

Similarly for the motor used to control the movement of finger uses a supply voltage of 6V, Power pf 3.198Watts, Speed pf 71 RPM (max) with same rotor inertia J of 0.02. It is found that, $K_1 = 1.5077$, $\omega_{m1} = 4\ radsec^{-1}$, with load torque T1 of 0.9 Nm motor with 38 RPM and, $K_2 = 0.807$, $\omega_{m2} = 7.43radsec^{-1}$ motor with 71RPM with load torque T2 of 0.430 Nm.

The Modeling and analysis is done for both the motors with two constraints viz, Operation of motor with load and operation of motor without load. The M- file and Simulink model are related by SIM function [13, 14]. The right angle shaft Gear 3 motor is used to control the robotic arm. It can rotate 360° with 1.6 sec. It operates in 6 V. In order to control the movement of fingers, miniature metal gear motorwith 71-RPM, operating a voltage of 6 V. These motors are used one for each finger.

4. BLOCK DIAGRAM OF PROSTHETIC ROBOTIC HAND

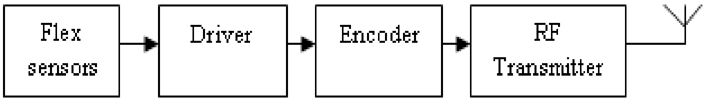

Figure 7. Transmitter section

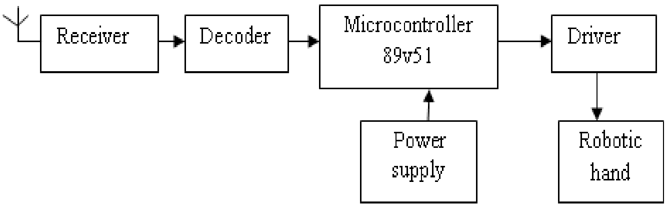

Figure 8. Receiver section

The Flex sensor is placed in the human hand along with sensors which has a nominal resistance of 10K ohms during un flexed and increases gradually when flexed. This change in resistance is passed to LM324. The output of LM324 is passed to controller which it will continuously monitor the bend of the flex sensor according to that it will control the robotic hand. The Flex sensor is placed in the human hand, used to control the Prosthetic Robotic hand. As the fingers bend, there will be a change in resistance, thus voltage drop is fed to the driver circuit. This data is encoded (HT640) and transmitted with the help of RF Transmitter operating with a frequency range 434MHz as shown in Figure 7. On the other end in the receiver side as shown in Figure 8, this data is decoded with the help decoder (HT648) and passed to 89v51 microcontroller for the movement of hand. The robotic hand operates in a 12V battery. It also consists of charger for the battery to get charged. This 12V battery is sufficient enough to control all the 9 micro DC motors. Unlike the normal human hand, the robotic hand is capable of movement of palm, finger and elbow. The entire hand is mounted on a base unit where it can move forward/reverse and a full degree of rotation. Figure 9 shows the hardware circuitry for transmitter section in which FS1 to FS5 denotes the flex sensors along with LM324, encoder and transmitter connections. Figure 10 shows the hardware connections for receiver sections. The various values of Flex sensor bent along with the LM324 voltage for different angles are tabulated in Table 2.

Table 2. Flex sensor readings

Resistance In KΩ	Voltage in Volts	Angle in degree	LM324 circuits output in volts
26.18	0.82	90	3.74
40.26	0.67	75	3.19
48.74	0.45	60	2.7
52.92	0.40	45	2.2
57.10	0.37	30	1.7
60.40	0.32	15	0.5
63.5	0.30	00	0.0

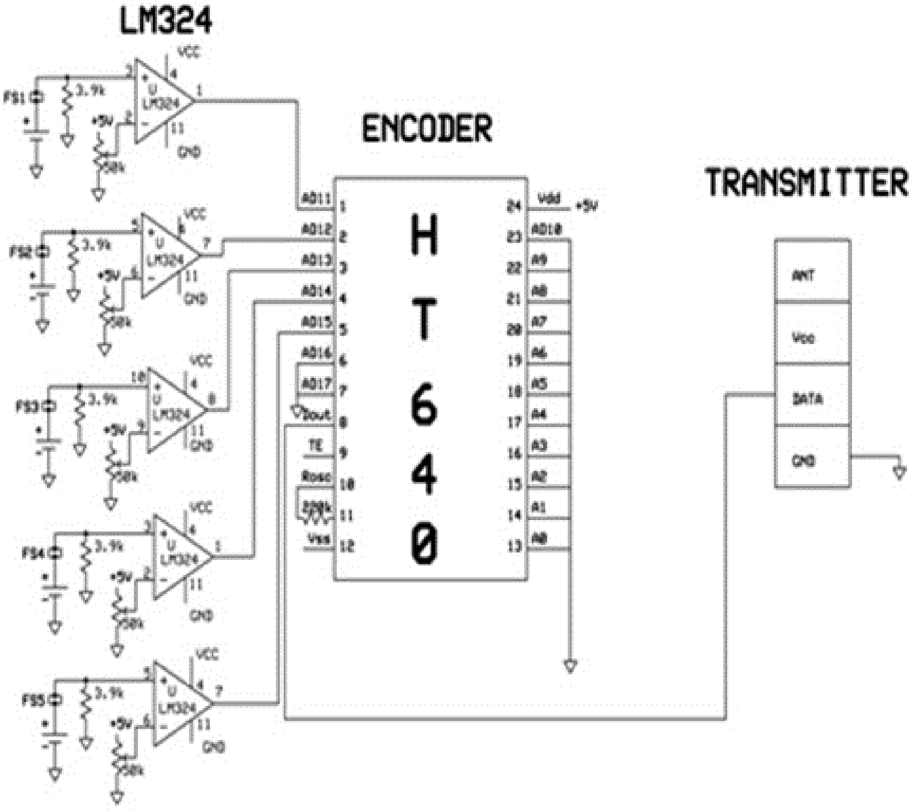

Figure 9. Hardware Circuit for Transmitter Section

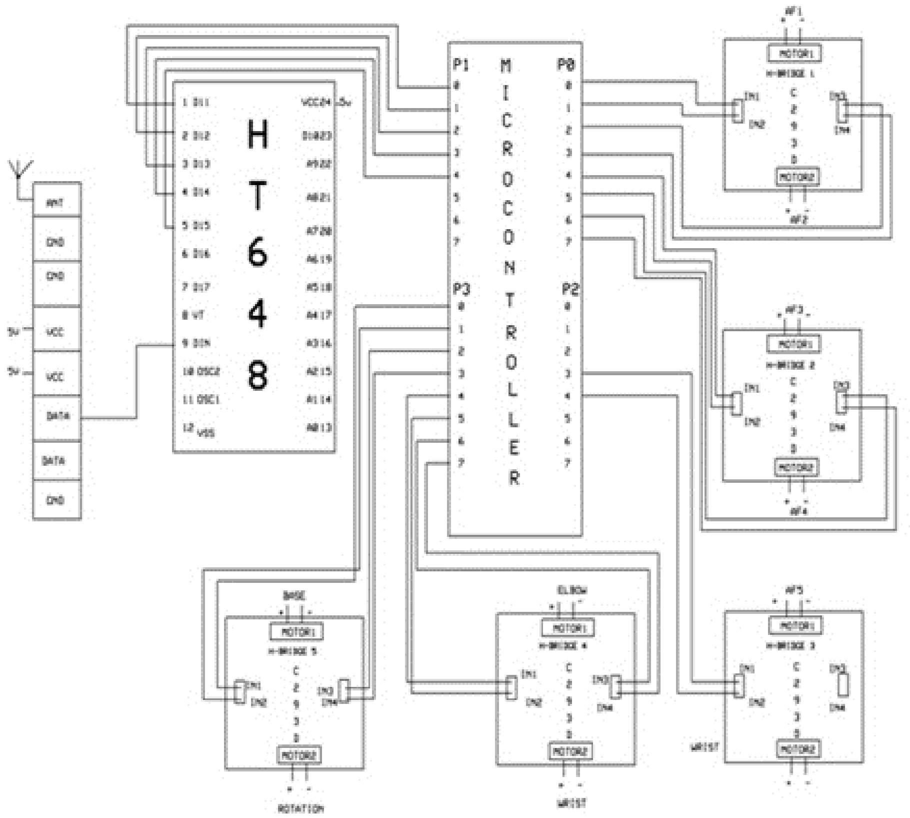

Figure 10. Hardware Circuit for Receiver

Consider the example where if the bits received by decoder “10000” then the hexadecimal value of 0X1f is sent to the finger through controller for contraction. However this data is required for the complete contraction of fingers. Figure 11(a & b) shows the initial experimentation that was made to glow the LED by the movement of flex sensors placed in the glove. Likewise the above process was experimentally carried out for other movement of hand. Which are listed below in Table 3.

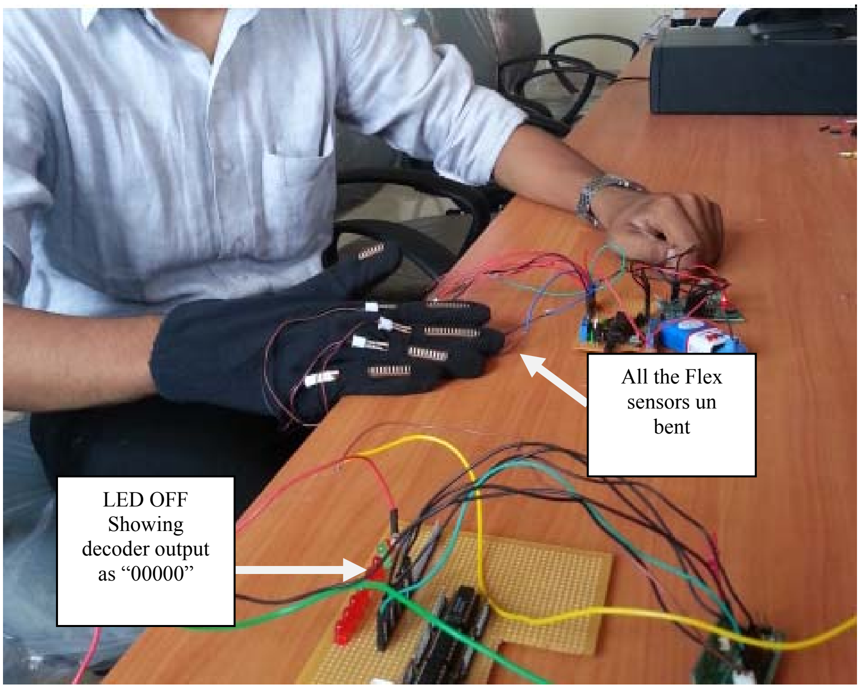

Figure 11(a). Shows Flex Sensors without bending

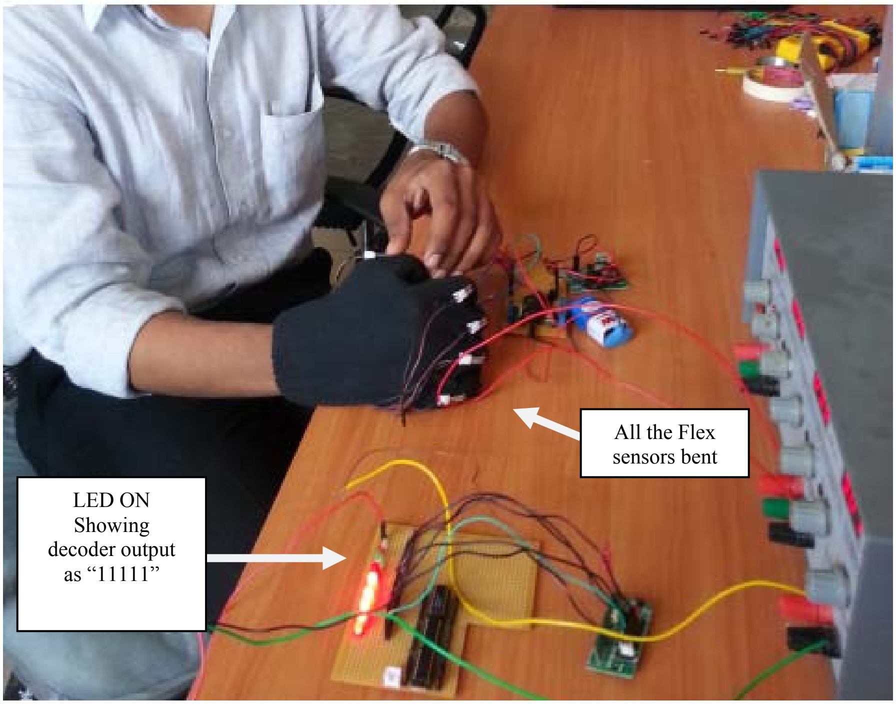

Figure 11(b). Flex senors Bent indicating all the LED’s On

Table 3. Input from Flex sensors

Sl.No	Direction of Port 1	Hex data
1	Finger movement	
	• contraction	0x1f
	• Relaxation	0x1e
2	Wrist	
	• Forward	0x01
	• Backward	0x00
3	Elbow	
	• Forward	0x02
	• Backward	0x03
4	Elbow rotation	
	• Clockwise	0x04
	• Anti clockwise	0x06
5	Base movement	
	• Forward	0x05
	• Backward	0x06
6	Base rotation	
	• Clockwise	0x09
	• Anti clcokwise	0x0a

5. RESULT ANALYSIS

The movement of robotic hand is controlled by a DC motor. Figure 12 highlights the performance of the system by means of following dynamic characteristics Viz,

(a) Variation of Torque in N/m with respect to rotor speed in rad/sec
(b) Variation of Rotor speed in rad/sec with angular displacement
(c) Variation of displacement with respect to time in seconds
(d) Variation of current with respect to time in seconds

Initially torque is high which actuates the robotic hand for movements, and then torque decays with respect to increase of rotor speed as indicate Figure 12(a). The rotor speed exponentially increase with respect to angular displacement as shown in Figure 12(b). Figure 12(c) illustrates the variation of angular displacement with respect to variation of current and Figure 12(d) shows the exponential decaying of current with respect to time this is similar to variation of Torque shown in Figure 12 (a) since torque is proportional to current. The same analysis is also carried out for two different motors with and without load in Figure 12 (Miniature metal gear motor). From the analysis, it is clear that motor is working as per our requirements [10]. The initial experimental setup which is shown in was carried out with bread board and later all the electronics with necessary instrumentation was mounted on PCB Figure 13.

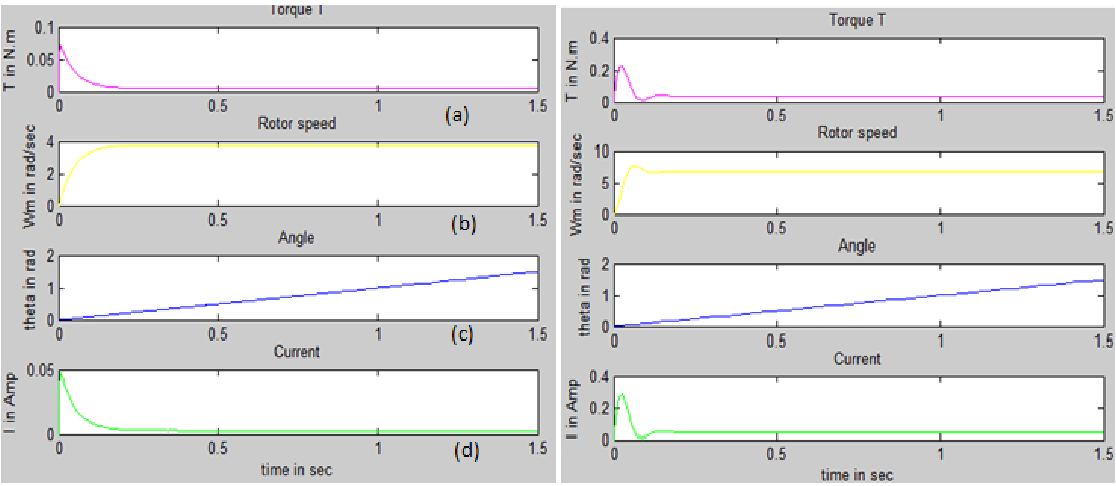

Figure 12. Simulink analysis Right angle Shaft Dc Motor (Left) and Miniature metal gear motor (Right)

Testing was also carried out to pick up a hand ball made up of woolen weighing 20 grams approximately. However we have made 5 attempts to pick the ball from the floor of which 3 out of 5 times was successful in completing the task. The success rate was about 60 percent. The various positions of picking and holding the ball is shown in Figure 14.

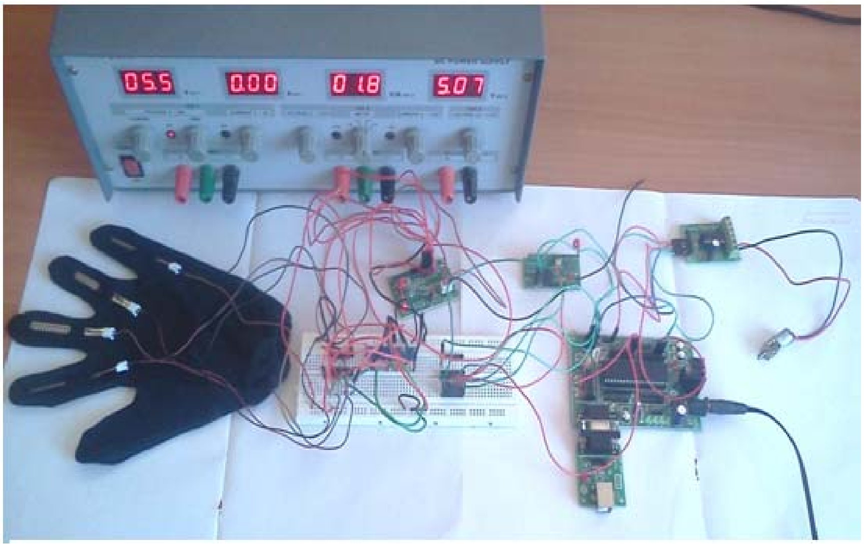

Figure 13. Experimental setup indicates Flex sensors mounted on Woolen Hand Glove controlling One DC motor.

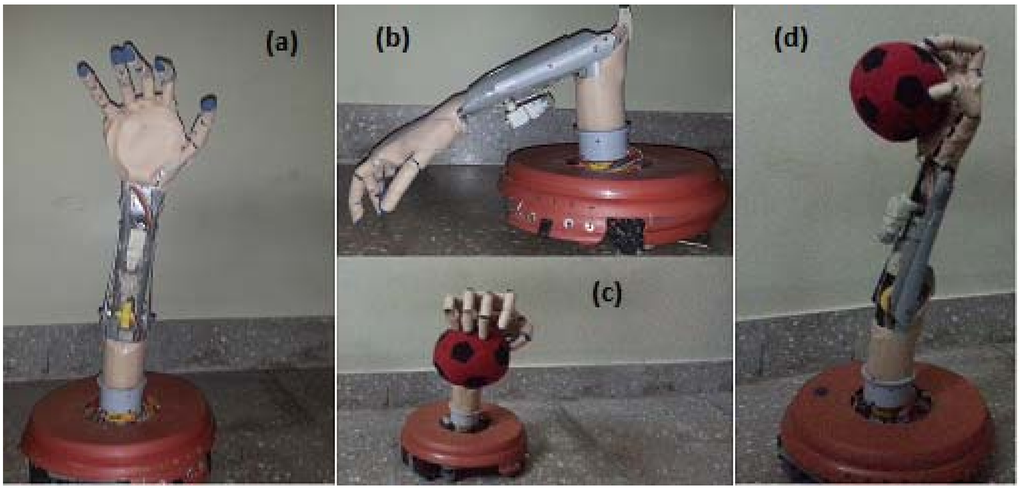

Figure 14. Various positions of Robotic hand to pick up a woolen ball

6. CONCLUSION

The method proposed in this paper is simple and easy way to control the robotic hand using flex sensors. Further the CAD design model for the same is excluded due to increase in cost. Care was taken in designing the robotic hand and it remains the challenging task. The physical dimensions were designed taking into the account the hand should be able to pick, grasp, and hold the object tightly. Due to RF transmitter/receiver the range of movement of hand was limited to short distance. In the course of experimentation the authors have also studied the analysis of DC motors using MATLAB/SIMULINK. Furthermore miniaturization of device can be done by using MEMS technology, increasing range of transceiver and high speed processors.

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