A Multi Finger Haptic Hand with Force Feedback

Mina R. Ramzy[1], Emam F. Mohamed[2], H. E. A. Ibrahim[2] and Yehia H. Hossamel-deen[3]
[1]*Mechatronics Department, Higher Technological Institute, Tenth of Ramadan, Egypt*
[2]*Electrical and Control Engineering Dept., Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt*
[3]*Mechatronics Department, Future University in Egypt, Cairo, Egypt*

Keywords: Robotic Hand, Glove Control, Haptic, Force Feedback.

Abstract: This paper presents a proposal for a twelve degrees of freedom robotic hand system controlled via haptic technology with force control and force feedback. This robotic hand can be used in hazardous environment, deserted places, or aerospace. To achieve this goal, an experimental set up in addition to a computer simulation of this robotic hand system have been carefully designed and built. The experimental set up consists of three main modules which are: the control Glove, the robotic hand, and a microcontroller. An integral controller algorithm is applied to make the robotic hand track and follow the position and movement of the haptic glove with force feedback. Three modes for force limitation are considered according to the application, which are suitable for grasping of: brittle, elastic, and hard components. For computer simulation of the system, a mathematical model has been derived considering a 3 DOF for each finger. To be compatible with robot hand used in the experimental work, only four fingers are considered i.e. total 12 DOF. The experimental work shows good gripping abilities following the glove movement and acceptable force feedback to the user hand, while the simulation results give a qualitative agreement with the experimental ones.

1 INTRODUCTION

The word haptics is derived from the Greek word *haptikos* that means "to be able to come into contact with". The study of haptics came from advances in virtual reality. It is a form of human and computer interaction that provides an environment that one can explore through direct interaction with their senses. For this project we are using a user at one end (master) and a robot on the other (slave).

There must be feedback to interact with the environment. That feedback is called haptic feedback and also known as force feedback. As regards some robotic tasks, a higher degree of precision is required, which cannot be obtained from visual feedback only. This adds a new dimension of control to help make tasks more realistic. For example, the user should be capable to feel the response from an object that she/he touches at one end. Only the user at the control side who can feel the response.

Haptics includes both kinesthetic and force information that make the users to be able to feel the texture of surfaces, temperature and vibration, etc. and cutaneous (tactile) information that the skin feels and do not necessarily need movement but rely mainly on the skin receptors like the feel of forces pushing on their skin and respond to them. The feedback must be both accurate and fast enough to meet the system requirements specified according to the type of tasks that will be performed. (Adrian et al., 2004).

A haptic system consists of two main parts: the human part and the machine part. Both parts will be provided with the necessary sensors, processors and actuators. In the case of the human system, nerve receptors implement sensing, brain implement processing and muscles implement actuation of the motion performed by the hand while in the case of the machine part, the functions mentioned are performed by the sensors, computer and motors; respectively. (Rangoonwala et al., 2011).

The main objectives of this paper is to design and implement a four finger robotic hand for grasping objects of different shapes, sizes and material. This hand is to be controlled by a glove. It follows the movement of the user hand wearing the glove and at the same time it gives the user a feel of how hard the robotic hand is gripping the object by the force feedback mechanism fixed to the glove. This project has a variety of applications in the places where the

Ramzy, M., Mohamed, E., Ibrahim, H. and Hossamel-deen, Y.
A Multi Finger Haptic Hand with Force Feedback.
DOI: 10.5220/0005959401780184
In *Proceedings of the 13th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2016) - Volume 2*, pages 178-184
ISBN: 978-989-758-198-4

user need to use his hands and at the same time to be away of that place like hazardous environment, deserted places, and aerospace.

2 MODELING AND SIMULATION

The under actuation approach is use. In this approach the number of actuators are less than the number of DOF. The mechanical design determines the movement and behavior of the passive finger joints. One of the advantage of this approach is that the finger adapt passively to the shape of the object being grasped.

2.1 Dynamic Model of Finger Mechanism

A phalanx is the section of the finger between each joint so each finger, other than the thumb, has three phalanges. Phalanx 1 is the one closest to the palm. Figure 1 shows the forces, mass, and angles involved in the movement of the phalanges of one finger only.

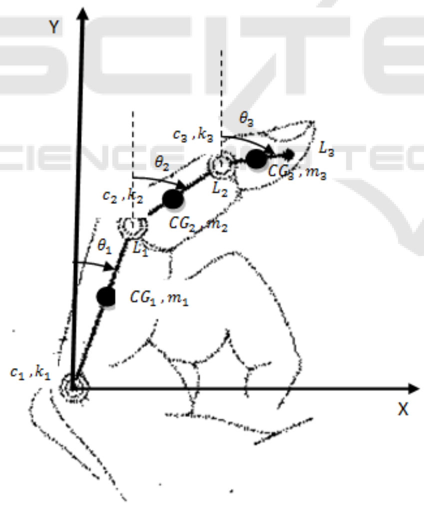

Figure 1: The spring loaded finger mechanism.

An idealized mechanical model is used in which each phalange is assumed to be infinitely rigid with its mass concentrated at the midpoint. All joints are assumed frictionless. The first phalanx is assumed to only move in a circular motion since the first joint is assumed to be stationary and the phalanx is assumed to be rigid. The motion of the masses m2 and m3 is more complicated involving circular motion about the joint and the movement of the joint. The Lagrangian method is used to get the equations of motion. For each finger, the three differential equations are (Ramzy e.all, 2014):

$$\ddot{\theta}_1 = \frac{A_4}{2A_1}\dot{\theta}_2^2 \sin(\theta_2-\theta_1) - \frac{A_4}{2A_1}\ddot{\theta}_2 \cos(\theta_2-\theta_1) + \frac{A_5}{2A_1}\dot{\theta}_3^2 \sin(\theta_3-\theta_1) - \frac{A_5}{2A_1}\ddot{\theta}_3 \cos(\theta_3-\theta_1) + \frac{B_1}{2A_1}\sin\theta_1 - \frac{B_4}{2A_1}\theta_1 + \frac{B_7}{2A_1}\theta_2 - \frac{c_1-c_2}{2A_1}\dot{\theta}_1 + \frac{c_2}{2A_1}\dot{\theta}_2 \quad (1)$$

$$\ddot{\theta}_2 = -\frac{A_4}{2A_2}\dot{\theta}_1^2 \sin(\theta_2-\theta_1) - \frac{A_4}{2A_2}\ddot{\theta}_1 \cos(\theta_2-\theta_1) + \frac{A_6}{2A_2}\dot{\theta}_3^2 \sin(\theta_3-\theta_2) - \frac{A_6}{2A_2}\ddot{\theta}_3 \cos(\theta_3-\theta_2) + \frac{B_2}{2A_2}\sin\theta_2 - \frac{B_5}{A_2}\theta_2 + \frac{B_7}{2A_2}\theta_1 + \frac{B_8}{2A_2}\theta_3 - \frac{c_2+c_3}{2A_2}\dot{\theta}_2 + \frac{c_2}{2A_2}\dot{\theta}_1 + \frac{c_3}{2A_2}\dot{\theta}_3 \quad (2)$$

$$\ddot{\theta}_3 = -\frac{A_5}{2A_3}\dot{\theta}_1^2 \sin(\theta_3-\theta_1) - \frac{A_5}{2A_3}\ddot{\theta}_1 \cos(\theta_3-\theta_1) - \frac{A_6}{2A_3}\dot{\theta}_2^2 \sin(\theta_3-\theta_2) - \frac{A_6}{2A_3}\ddot{\theta}_2 \cos(\theta_3-\theta_2) + \frac{B_3}{2A_3}\sin\theta_3 - \frac{B_6}{A_3}\theta_3 + \frac{B_8}{2A_3}\theta_2 - \frac{c_3}{2A_3}(\dot{\theta}_3-\dot{\theta}_2) + \frac{1}{2A_3}F \quad (3)$$

Where

$$A_1 = \left[\tfrac{1}{2}J_1 + \tfrac{1}{2}m_2L_1^2 + \tfrac{1}{2}m_3L_1^2\right] \quad (4)$$

$$A_2 = \left[\tfrac{1}{2}J_2 + \tfrac{1}{8}m_2L_2^2 + \tfrac{1}{2}m_3L_2^2\right] \quad (5)$$

$$A_3 = \left[\tfrac{1}{2}J_3 + \tfrac{1}{8}m_3L_3^2\right] \quad (6)$$

$$A_4 = \left[\tfrac{1}{2}m_2L_1L_2 + m_3L_1L_2\right] \quad (7)$$

$$A_5 = \left[\tfrac{1}{2}m_3L_1L_3\right] \quad (8)$$

$$A_6 = \left[\tfrac{1}{2}m_3L_2L_3\right] \quad (9)$$

$$B_1 = \left[\tfrac{1}{2}m_1 + m_2 + m_3\right]gL_1 \quad (10)$$

$$B_2 = \left[\tfrac{1}{2}m_2 + m_3\right]gL_2 \quad (11)$$

$$B_3 = \left[\tfrac{1}{2}m_3\right]gL_3 \quad (12)$$

$$B_4 = \tfrac{1}{2}[k_1 + k_2] \quad (13)$$

$$B_5 = \tfrac{1}{2}[k_2 + k_3] \quad (14)$$

$$B_6 = \left[\tfrac{1}{2}k_3\right] \quad (15)$$

$$B_7 = k_2 \quad (16)$$

$$B_8 = k_3 \quad (17)$$

θi is the angle between the vertical and the *i*th phalanx ,
Li is the length of the phalanx,
mi is the mass at the center of the *i*th phalanx,
ki is the spring stiffness coefficient of the spring of *i*th joint, ci is the damping coefficient of *i*th joint and
Ji is the moment of inertia of the ith phalanx.

2.2 Simulation

A step input is applied to the SIMULINK model and the finger response is plotted as shown in Figure 2. Two step inputs are applied successively to record the response in both direction of the finger movement. The overall finger bend angle is plotted against time.

Figure 2: Simulated finger response (theta in radian).

3 EXPERIMENTAL WORK

The experimental process layout is shown in Figure1. It is divided into three parts. The first part is the glove that is divided into two parts: the flex sensor and the feedback mechanism. The second part is the signal processing and controller. The third part is the robotic hand which contains the potentiometers for angle feedback and the force sensor for the force feedback. Several designs are made for both the robotic hand and the feedback mechanism with the help of 3D printer until we found the best performance of grasping and following the commands of the human hand. In the following subsections, each part will briefly highlighted.

3.1 Glove

The glove contains two parts: The first part is the flex sensor that converts the fingers movement to signals Proportional to the angular movement of the fingers for the controller. This represents the reference signal. The second part is the force feedback mechanism.

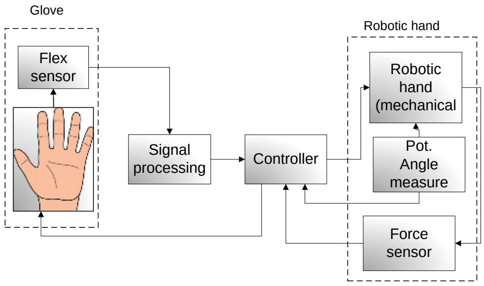

Figure 3: The process layout of the experimental setup.

3.1.1 Flex Sensor

The Flex Sensor is a resistive carbon elements technology. As it is a variable printed resistor, The Flex Sensor fulfills great form-factor on a thin flexible substrate. Whilst it is bent see (Figure 4), the sensor changes the resistance output value according to the bend radius, the more it bends, the higher the resistance value. Figure5 presents the characteristic of flex sensor. This characteristic is obtained by the datasheet of the used flex sensor. (spectrasymbol manual).

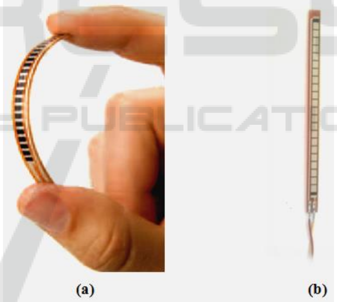

Figure 4: Flex sensor (a) Flex sensor under bending (b) Flex sensor in normal position.

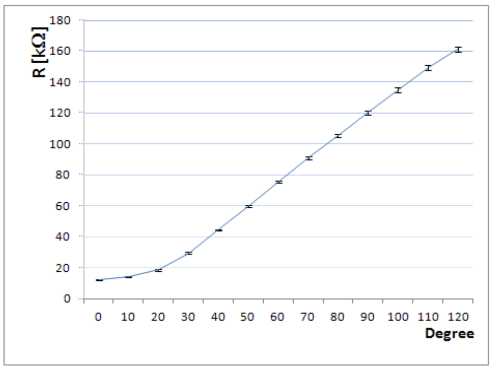

Figure 5: The characteristic of flex sensor.

The main function of the flex sensor in the experiment is to convert the human finger joints (knuckles) angle movements to a proportional analogue signal. Figure 6 demonstrates the flex sensor setup on the hand. The glove is used to fix the flex inside the fingers and the force feedback mechanism.

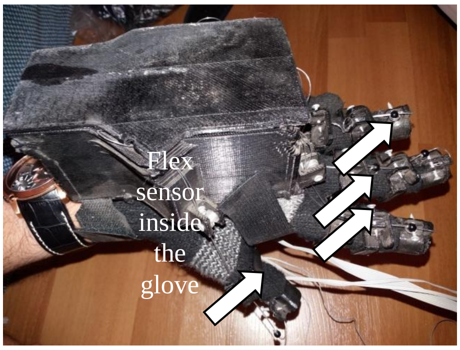

Figure 6: The actual flex sensor setup on the hand and the force feedback mechanism.

3.1.2 Force Feedback Mechanism

The force feedback mechanism is actuated by a servo motor connected to the fingertip by a wire fixed to the plastic rings fixed on the glove fingers. The wire runs along the finger length across the rings. The servo rotate according to the amount of the force applied to the force sensor fixed to the tip of the robotic hand. That gives the user the sense of how hard the robotic hand is gripping the object. Figure 7 shows the glove feedback mechanism diagram. Figure 8 shows the actual glove feedback mechanism.

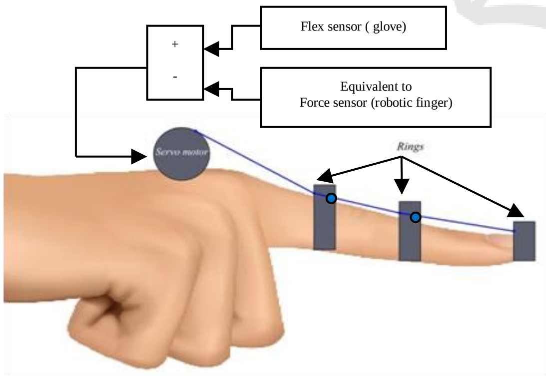

Figure 7: The glove feedback mechanism diagram.

3.2 Robotic Hand

The robot hand which is used in the experimental work has twelve degrees of freedom.

Each finger has three degrees of freedom. It is under actuated since one actuator moves the three phalanges of each finger. This robotic hand will mimic human hand. It adapts passively to the object profile. Each finger is controlled by geared servo motor to bend and elastic element to straighten. Figure 9 shows robotic hand.

Figure 8: The actual glove feedback mechanism.

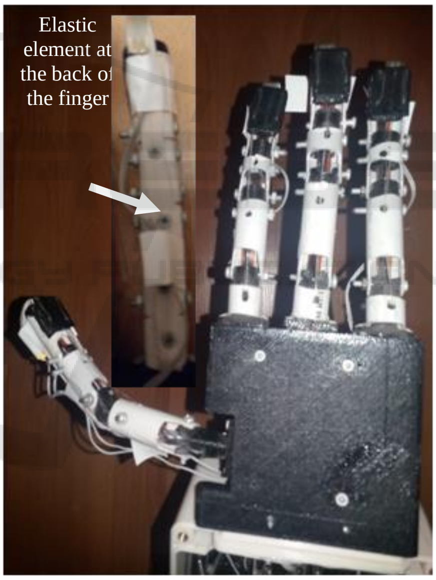

Figure 9: The robotic hand.

3.1.3 Force Sensing Resistor

Force Sensing Resistors (FSR) is a very thin, robust, polymer device that when pressure is increased on the surface of the sensor the resistance decreases. It is used for the sensation of pressure, weight, contacts and as a touch sensor. This FSR resistance will vary depending on how much force (100g to 10kg /0.981N to 98.1N) is being applied to the sensing area. Figure10 shows Force sensing resistor (FSR) while Figure11 presents its characteristics. This characteristic is obtained by the datasheet of the used FSR (Interlink electronics catalog).

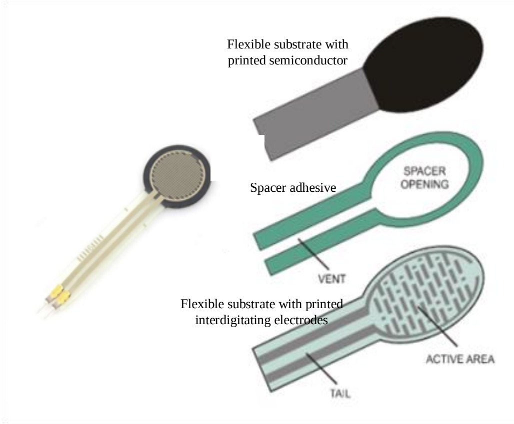

Figure 10: Force sensing resistor (FSR).

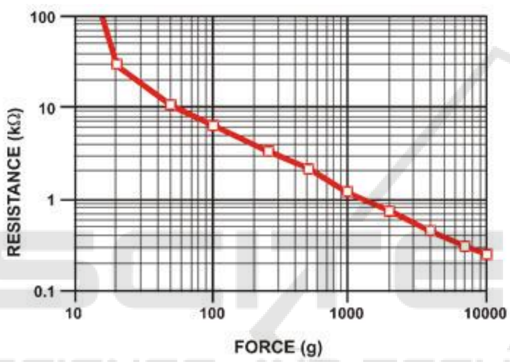

Figure 11: Characteristics of force sensor.

The main function of force sensor in the experiment is to convert the force on the tip of the robotic finger to an analogue signal. Figure 12 demonstrates the force sensor setup on the robotic finger.

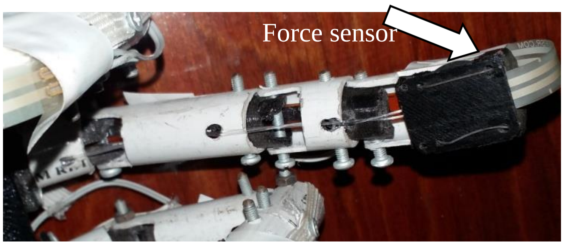

Figure 12: The actual force sensor setup on the robotic finger.

In this work, three modes of force limitation are to be considered according to the robotic hand application. The first mode is for brittle objects like a lamp (30N). The second mode is for elastic objects like rubber ball (70N). The third mode is for hard objects (98N). The 3 modes values are assumed for demonstration and proof of the applicability of the concept. Actual limiting value needs more search.

3.3 The Controller

The Arduino Mega is a microcontroller board uses the ATmega1280. It is the Microcontroller which is used in the experimental work. It is used to convert the analogue signal from the flex sensors signal and force sensor to a digital signal.(Arduino manual) According to the integral control algorithm , it will send commands to the servos to control the robotic hand and the feedback mechanism. In our experimental work, kp and kd unexpectedly leaded to instability. Only the ki had normal effect on the system response. The increase of Ki decreases the rise time but increases the overshoot and vice versa. So we used the fine tuned integral controller. Figure13 demonstrates the effect of ki on a simple system with different ki values.

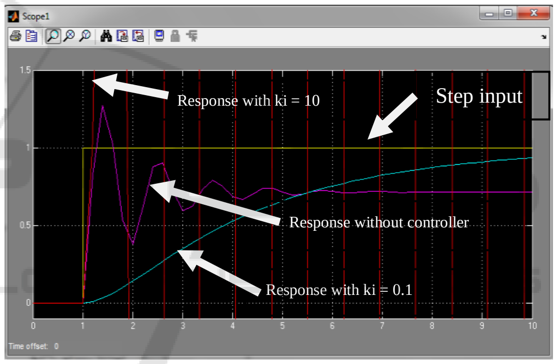

Figure 13: The effect of different ki on a simple system.

By applying the fine tuned integral controller, the overshoot is minimized and at the same time the rise time is kept small. In this fine tuned integral algorithm, a higher Ki is used at first then a smaller Ki near the required value. Ki was found experimentally. The known tuning methods (e.g. Ziegler-Nichols tuning method) were not applicable to our system due to instability with any values for ki and kd. Figure 14 shows the closed loop block diagram of the finger.

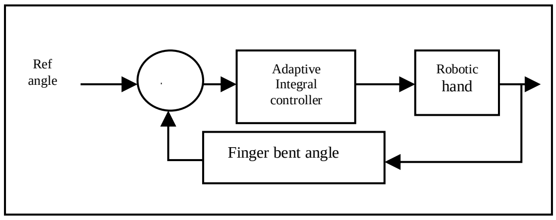

Figure 14: The closed loop block diagram of the finger.

3.4 Experimental Results

A prototype version of this robotic hand has been constructed and tested. The controlling algorithm software has been written in C and uploaded to the Arduino microcontroller.

To test the grasping ability of the hand, it was made to grasp different objects, each having different shape, size, surface conditions and hardness, and the force feedback by the user sense. The object was held so that the center of mass was within the workspace volume of the thumb and fingers and oriented to grasp so that the major axis of the object was parallel to the palm and aligned with the fingers. Once the objects were positioned in the work space of robotic hand, the user moves his hand that is wearing the glove in grasping movement. The grasp was determined to be successful if the robotic hand correctly held the object and the user feels the hardness of the grasp by the force feedback mechanism. Figure15 shows the robot hand grasping different objects of different geometry. The response of the robotic hand was monitored and adjusted by the Integral controller algorithm. The overall robotic finger bend angle is plotted against time In Figure 16 (A)&(B) for the cases without and with control; respectively. To be noted it is plotted by MegunoLink plotting tool.

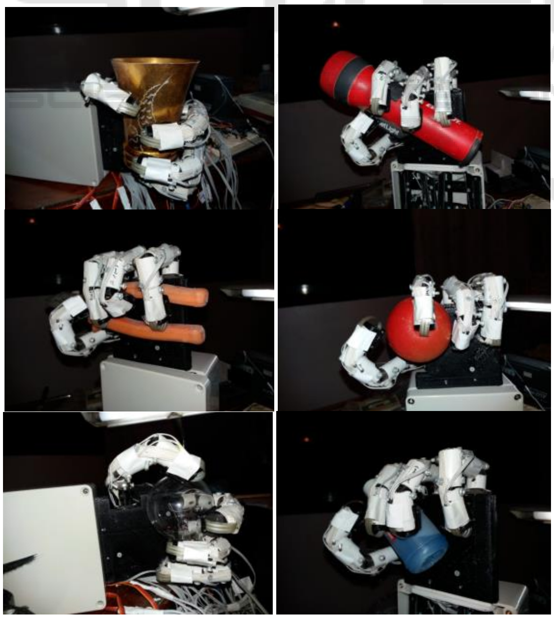

Figure 15: The robotic hand grasping a variety of objects (Cup, torch, pliers, Ball, light Bulb, and bottle).

From figure 16, it can be seen that the improvement in the response after applying the fine tuned integral control. Table 1 shows the characteristics of the system response with and without the controller.

Table 1: The characteristics of the system response with and without the controller.

	Without controller	With controller
Overshoot	5.5%	Negligible
Rise time	0.2667 s	0.24 s
Steady state error	Negligible	Negligible

4 CONCLUSIONS & RECOMMENDATIONS

A proposal for a robotic hand system controlled via haptic technology with force control and force feedback is introduced. This robotic hand mimics the movement of glove worn on a human hand. This robotic hand can grasp a variety ofobjects with different surface characteristics and shapes. It adapts passively to the objects profile & material. Three modes for force control can be selected by user which makes the proposed system suitable to be used with different objects with different brittleness or softness. The force feedback mechanism gives the user sense of the how hard the robotic hand gripping the object Both the experimental and simulation results show a qualitative agreement in response to a step reference input. A fine tuned integral control system has been utilized to enhance the performance of this system. The application of this control algorithm improves the overshoot from 5.5% to negligible and the rise time from 0.2667s to 0.24S. The instability for all values of Kp and Kd in the PID controller need more investigation to be able to apply better control. This proposed system can be used in hazardous environment, deserted places, or aerospace. However, this robotic hand has some limitations as it cannot be used to perform fine manipulations like writing. More future work can be done in this area. Also, the control of which mode to be applied (Brittle, elastic, or hard) is done through switches adjusted manually. Future work is needed to be implemented autonomously.

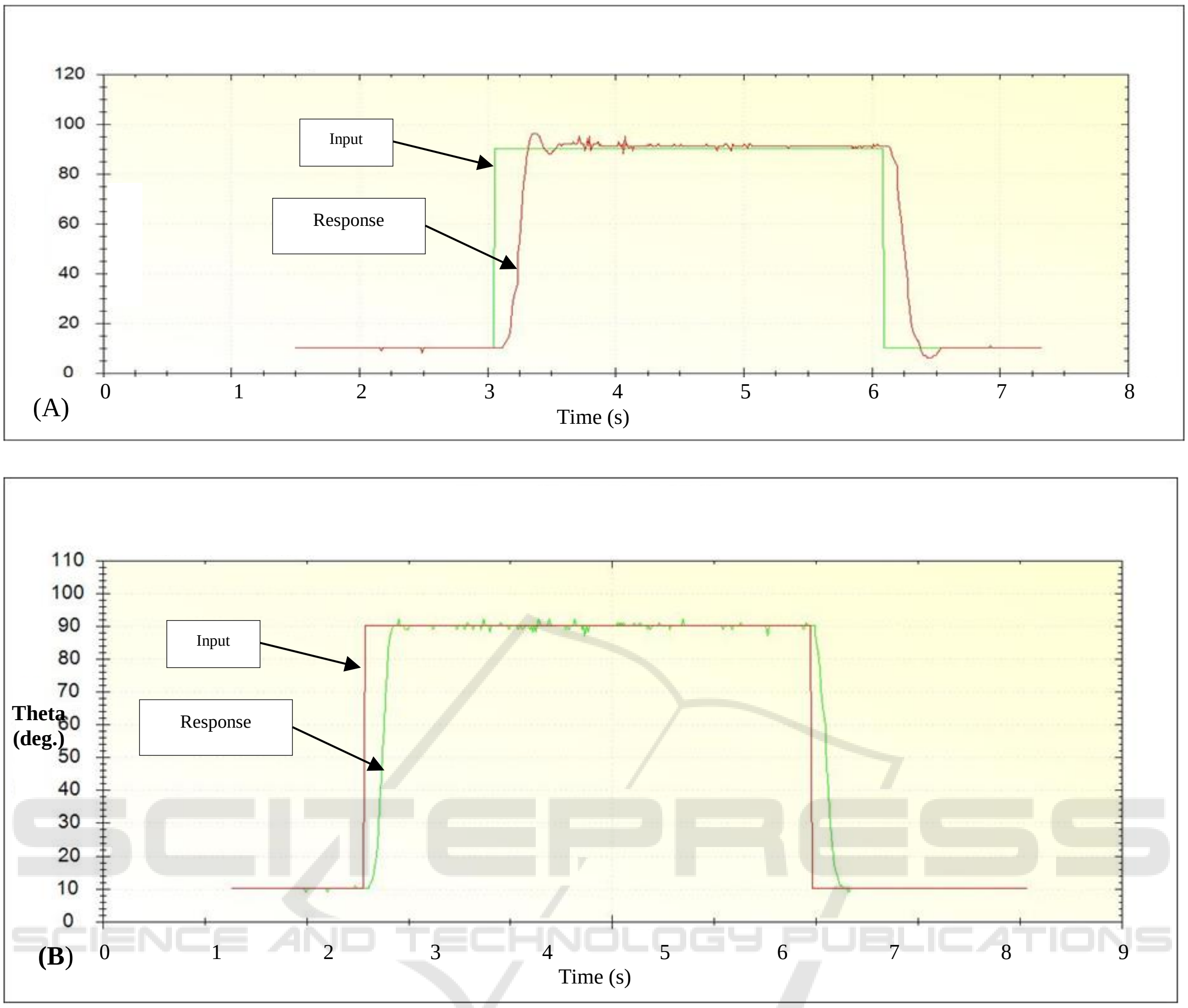

Figure 16: The experimental response of the robotic hand (A) Without control (B) With control.

REFERENCES

Adrian Cuadra, Colson Griffith, Scott Gunther, Krista Hirasuna, Matt Kalkbrenner, Carol Reiley, C. (June 9, 2004). "*Haptic Integration of an IBM Robotic Manipulator*." Santa Clara University, Department of Computer Engineering, Electrical Engineering, and Mechanical Engineering.

Rangoonwala Denish, Mr.Nikunj Patel *"A seminar report on haptic technology"* 2011, C. K. Pithawal college of engineering & technology, Surat.

Fahad W. and Muhammad A., "Dynamic Finger Movement Tracking and Voice Commands Based Smart Wheelchair", *International Journal of Computer and Electrical Engineering*, Vol. 3, No. 4, 2011, pp. 497–502.

"FSR® Integration Guide & Evaluation Parts Catalog with Suggested Electrical Interfaces", Interlink electronics, California.

Flex sensor special edition length, spectrasymbol, USA.7.

Klaus Schmidt, MSc. Johan Tegin, MSc. Pieter Grebner, "*Robot hand design -palm improvement and a robotic hand-arm interface*", Royal institute of technology (KTH).

Ramzy Mina, Haggag Salem, Hossamel-din Yehia , "Modeling and verification of spring loaded robotic finger mechanism", presented and published on: "*2014 15th International Workshop on Research and Education in Mechatronics (REM)*, El Gouna, Red Sea, Egypt, 9-11 september 2014- published on IEEE explorer; http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6920235&isnumber=6920214, doi:101109/REM.2014.6920235.

https://www.arduino.cc/en/Main/ArduinoBoardMega.