

# Development of a Multi-Fingered Robotic Hand

Abhon Adus, Taiwo Amosun

Department of Mechanical and Mechatronics Engineering, Federal University Otuoke, Bayelsa State, Nigeria  
adusaa@otuoke.edu.ng

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## Abstract:

The development of a robot came into existence due to the search for a way to reduce or eliminate human labour. In practice, a robot is an electro-mechanical machine that is guided by computer and electronic programming and can be autonomous, semi-autonomous or remote-controlled. This work developed a prototype model of the multi-fingered robotic hand. It consists of two parts which are the hardware and the software parts. The hardware part involves the design of mechanical and electrical structures. For the software part, the PIC 18F4520 microcontroller was chosen, programmed and interfaced with all hardware and electronic devices. Each circuit design was carried out separately and simulated to ensure it was working perfectly before making the PCB board. Hardware structures were designed, fabricated and assembled accordingly. Tests were carried out to analyse the mechanical structure of the link using solid works 12. The result of the structural analysis shows that Maximum von-misses stress is only 7.4 N/mm<sup>2</sup> which is way below the yield strength 27.6 N/mm<sup>2</sup> of the material. The maximum displacement is 0.0189634 mm which is considerably small. Meanwhile, the equivalent strain is 6.84391e-05. Finally, the multi-finger robot hand was tested by inserting different objects into the palm of the robot hand.

*Keywords* — Robot, Multi-finger, Hardware, Software, Programming

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## I. INTRODUCTION

Over the years, several researches in the robotics field have been based on the development of the multi-fingered robotic hands. The robotic hand is a mechanism that can mimic the movements of a human hand in operation. Stable grasping and fine manipulation with the multi-fingered robot hand are playing an increasingly important role in manufacturing and other applications that require precision and dexterity (Arslan and Hacıoghi, 2009, Guo et al, 1995).

The motion exhibited by multi-fingered robot hands is configured right from design in a wide range of varieties to satisfy the functions of stable grasping and fine manipulation of a variety of objects effectively (Montana, 1995; Curkosky and Kao, 1989). The capability of a robot is assessed by the performance of its end-effector. Several types of end effectors exist, however; to suit the tasks the type of

robot arm is meant to execute (Crage, 2005; Gosselin and Laliberte, 1998). Some of these types are:

- Single end effectors
- Two arm grippers
- Three-fingered robot hand and many more.

Under-actuated robot hand generates triggering properties meaning they cannot always ensure full whole-hand grasping. Under-actuation is a technique in robotics that has been widely applied to the design of multi-fingered robots (Folgheraite and Gini, 2000). Basically, it makes the property of the system have a lesser-input vector of smaller dimension than the output vector. Practically, in robotics, it means having fewer actuators than degrees of freedom (DOF). Applying this concept to robotic grasping arises from a simple fact: it is desirable to be able to grasp objects using a simple control rather than having to command and coordinate several actions. Some of the previous research on multi-fingered robotic hands includes kinetostatic analyses of under-actuated fingers by Birglen and Gosselin

(2004). Butterfass et al (2001) presented the next generation of a Dextrous robot hand. Cabus et al (2006) designed and optimized under-actuated robotic hands. Ceccarelli also presented the design considerations for under actuated grasp with a one-degree-of-freedom (D.O.F) anthropomorphic finger mechanism. Folgheraite and Gini, 2001 also presented human-like hierarchical reflex control for an artificial hand.

## II. METHODOLOGY

This work developed a multi-finger robot hand which consists of three major stages mechanical design structure, electrical design and programming. The multi-fingered robot hand is a 10 DOF articulated hand. The hand is made of three fingers with 4 linkages, 3 moveable links and 1 fixed link which is known as the base link. The robot hand is capable of individual finger movement; however, each of the joint segments cannot be independently operated. The hand consists of three servomotors; each servo motor is attached to the base link providing flexion for each joint. Since there is no independent movement of each joint this creates a need for the development of a transmission mechanism. A linkage-based mechanism is designed with the sole purpose of transmitting the torque produced by the servo motor from the base to the fourth link (distal phalanges). Each of the finger segments is coupled through the linkage connection providing the hand with a realistic imitation of the grasp motions of the human hand.

### 1. THE MECHANICAL STRUCTURE DESIGN

The design of the Three-finger Robot Hand is mainly inspired by the design of the LARM and Barrett's hand. There was a lot of innovation that has been done from the sketching. The main objective is to converse the robot design, material and approach to construct mechanical structure. Figure 1 depicts the three-finger robot hand built which consists of base plate (Palm), base link, first link (Proximal Phalanx), second link (Middle Phalanx), third link

(Distal Phalanx) and manipulator mechanism. Most of these parts are built from raw material and some are modified to fit with this project. The links are made up of aluminium alloy, the screws, washers and nuts are steel. Aluminium alloy is used to obtain a light robot and also to achieve the target of the servo-motor being able to drive the links to move. Figure 1 is the mechanical structure of the three-finger robotic hand.

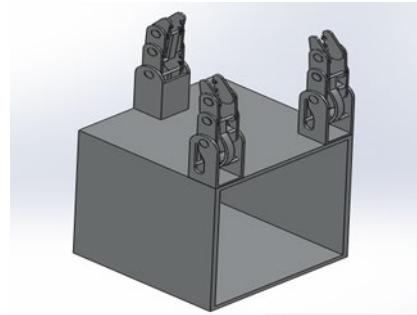


Figure 1: Mechanical Structure for the Three-finger Robotic Hand

### 2. STATIC STRUCTURAL ANALYSIS OF THE LINKAGE.

This analysis covers two kinds of analyses (Static structural and rigid body analysis) on the linkage to determine some very important parameters to be considered during production. The purpose of performing the static structural analysis is to determine the displacements, stresses, and strains that occur when a load is placed on the palm of the robot finger.

#### ASSUMPTIONS:

- Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly concerning time.
- The Static structural analysis of the linkage was performed in SolidWorks 2010.
- Selected material for the linkage and joints = Aluminium alloy (1060 alloy)
- Yield strength =  $27.6\text{N/mm}^2$
- Maximum weight of object = 1kg
- The Applied force on the top of each link = 10N

Figure 2 shows the 3D model of a single finger.



Figure 2: A 3D FEA model of a single finger

### 3. ELECTRONIC CIRCUIT DESIGN

The electronic part is divided into four parts which consist of power distribution circuit, a control or main (servo motors and LCD interface) circuit, a sensor circuit and a switch circuit. Figure 3 depicts the schematic diagram of the electronic circuit of the robotic hand.

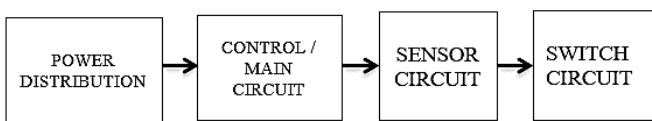


Figure 3: Flow diagram of the electronic circuit

The control/main circuit consists microcontroller circuit (PIC18F452), display, potentiometer, crystal (Oscillator), slide switch, resistor and capacitors and the sensor circuit includes IC LM324, LED, potentiometer and an extension circuit such as sensors (LDR) and actuators (servo motor). Meanwhile, switch circuits were constructed using a toggle switch, slide switch and 547 transistors.

All the electronic circuits' parts were done with a printed circuit board (PCB) and were connected by rainbow wire called jumpers to make the connection neat. Several switches were put on the circuit as function as On/Off power respectively to the servo motor.

### A. THE POWER SUPPLY CIRCUIT

The power distribution circuit includes two different types of 5vdc supply. 5V, 1A supply via the LM7805 regulator and 5V, 3A supply via the TIP2955 power transistor as shown in the circuit diagram below. The reason for this power supply division is that the servo motors require more current to get them running and the LM7805 voltage regulator cannot provide sufficient current for this purpose also the other components in the circuit cannot be operated at a higher current above 1A. This prompted the design of a separate power supply for the servo motors to ensure the stability of the circuit. The mains power supply comes from an AC-DC adaptor that supplies 12V at 3.2A, to the power supply circuit which then distributes the power accordingly. Other components such as the 3A fuse ensure that the current that will be supplied to the servo motor does not exceed 3A. Figures 4 and 5 show the schematic of the power distribution circuit and power distribution circuit connection board.

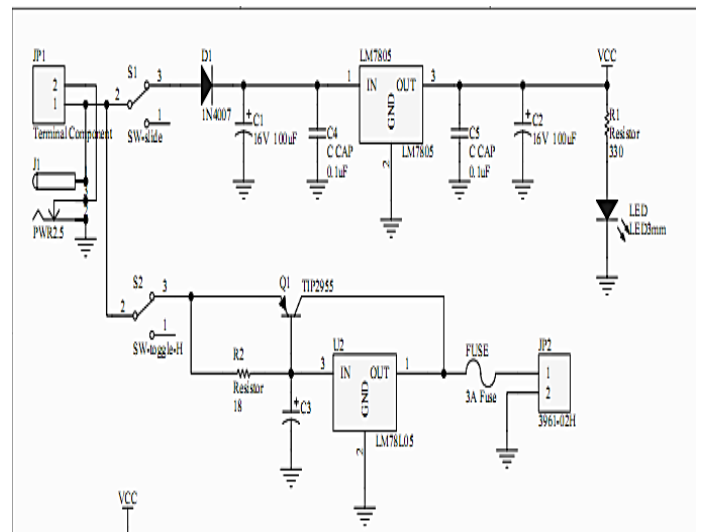


Figure 4: Schematic of Power distribution circuit

The switches were used to start the power supply to individual circuits operating at different levels of current. Heat sinks were also used to absorb the heat produced by the voltage regulators.



Figure 5: Power distribution circuit connection

### B. MAIN OR CONTROL CIRCUIT

The main component of the control circuit is the microcontroller PIC 18F4520, this controller reads signals from the input switches and sensors to control the fingers. The control circuit also includes terminals for the three servo motor pins and another terminal for the 5V, 3A input power supply for the servo motors and another 5V, 1A input terminal for the microcontroller to operate. Another component of the control circuit is the 16x2 Liquid crystal display (LCD). The LCD simply indicates and displays the status of the robot during operation. The microcontroller's ability to store and run unique programs makes it extremely versatile. To construct a robot, microcontrollers are usually used to act as the brains of the robot. The microcontroller controls and monitors various input and output devices, such as light sensors, servo motors etc. The PIC18F4520 microcontroller is used as the brain and controls the actions of the robot, so that the robot can act accordingly after processing the input signals received. This microcontroller is chosen because it is small, provides enough input and output ports and supports more functions. Furthermore, a comprehensive set of development tools, application notes and datasheets are also available for download. Figure 6 below shows the pinouts for the microcontroller

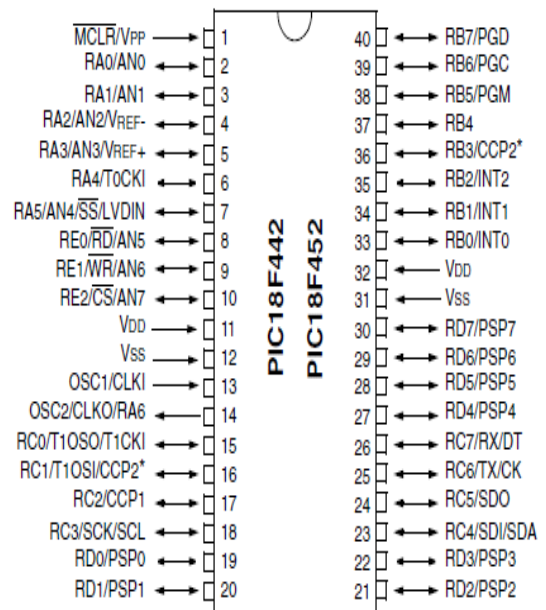


Figure 6: Pin outs for the microcontroller PIC 18F4520

### C. PWM CONTROL

The servo motors use PWM to control the angle at which they turn. PWMs are normally used to control the speed of a motor in most applications but in this work, the PWM is not used to control the speed but the angle of rotation of the servo motors. The servo motors used are capable of turning from 0° to 180°. The frequency of this PWM is required to be 50Hz since this is the frequency the servo motor can be operated, having a period of 20ms. The servo motors have a response width of 0.56ms to 2.5ms; this will make the servo motor turn from 0° to 180°. The servo motors consist of three wire colours with yellow, red and brown. The red and brown are the power supply and ground cables respectively, while the yellow cable supplies the signal to the servo motor from the PIC18F4520 I/O port.

Figure 7, below explains how the PWM was programmed; the period of the waveform is always kept at 20ms, but the duration of time at which the amplitude stays high determines the angle at which the servo motor turns.

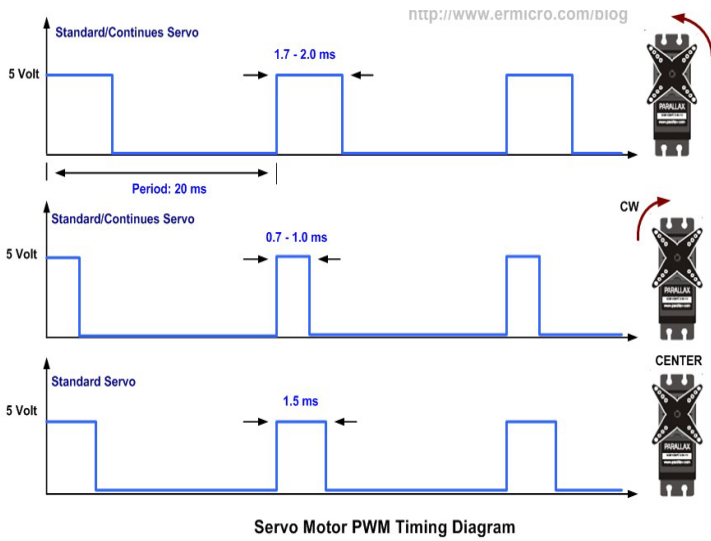


Figure 7: PWM (Pulse width 0.5ms – 2.5ms)

This concept was used to program the servo motors for the required angle we want it to turn. At 0.5ms, the servo motor is at 00 while at 2.5ms the servo motor is at 1800. Port C pins were programmed as the PWM pins in the microcontroller.

#### D. SENSOR CIRCUIT

The sensor circuit provides the interface between the object to be grasped and the control circuit, the circuit is constructed using LDR as the primary sensors and LM324 comparator IC, the sensors are placed on the open surface of the finger robot, and when an object is placed on top of it thereby obstructing the light that reaches it, the resistance of the LDR increases thereby sending a voltage signal to the Microcontroller which then closes the respective fingers. When the object is placed on the object, the LDR sends a voltage to the LM324 which compares the voltage with a reference voltage and sends a digital output to the transistor switch that in turn sends a 5V signal to the microcontroller. Figures 8 and 9 depict the sensor circuit and pin-out of the comparator.



Figure 8: Sensor circuit board

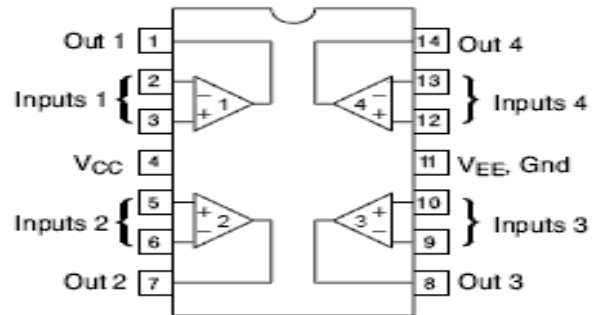


Figure 9: Pin-out of the comparator LM324

#### E. SWITCH CIRCUIT

The switch circuit serves as a platform for the signals from the control or main circuit. It consists of the manual and the automatic mode. Its main components include the Toggle switch, slide switch, transistors 547 and 9 in 1 pin connector. The Toggle switch is the link between the manual mode and the automatic mode. When the manual mode is activated the slide switches are used to control the finger, each slide switch represents each finger. In the automatic mode, the LDR sensors are used to control the finger and the sensor circuit is activated in the case. Figure 10 shows the switch circuit board.



Figure 10: Switch circuit board

#### 4. THE HAND ACTUATOR MODEL

Controlling the robotic finger is an integral part of the joint control device. These joint controllers receive the desired joint displacements and output control signals in digital form that after processing through a D/A converter are interpreted by the actuators. Each joint has a separate joint controller, actuator and speed-reducing gear. The mechanism of each of the robotic fingers is meant to feature a spring to reduce forced torques on the actuator, as well as strain the fingers from freely falling into positions that may prevent the actuator from being able to retrieve; and also aid in grasping when responding to control from the PID controller.

#### 5. TESTING OF THE MULTI-FINGER ROBOT HAND

The multi-finger robot hand was tested by inserting different objects into the palm of the robot hand. The following objects were used in testing the functionality of the Three-finger robot hand developed.

- Cylindrical pipe
- Cylindrical cup
- Rectangular foam

Figures 11, 12, 13, 14, 15 and 16 depict different views of the prototype multi-finger robot hand during testing.

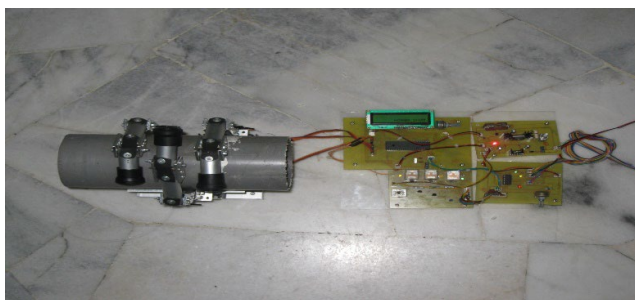


Figure 11: Grabbing a cylindrical pipe with the Three-finger Robot Hand (Top view)

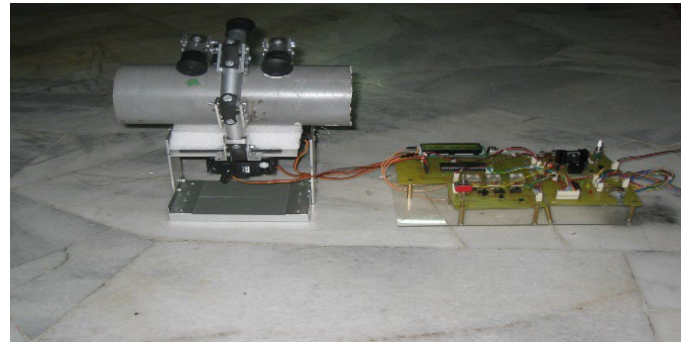


Figure 12: Grabbing a cylindrical pipe with the Three-fingered Robot Hand (Front view)

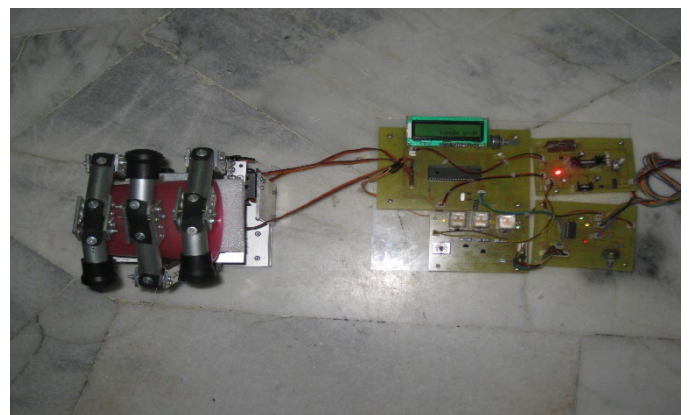


Figure 13: Grabbing a cylindrical cup with the Three-fingered Robot Hand (Top view)

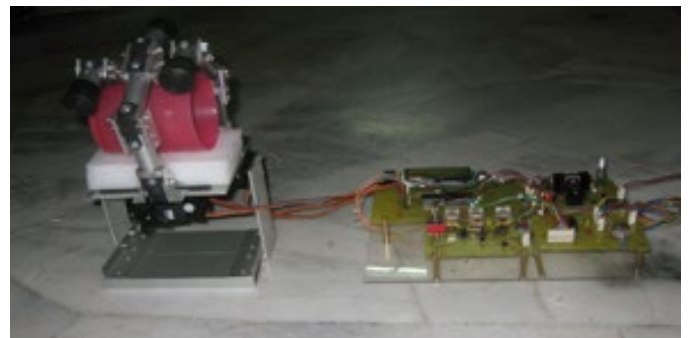


Figure 14: Grabbing a cylindrical cup with the Three-fingered Robot Hand (Front view)

Meanwhile, the equivalent strain is  $6.84391e-05$ . Therefore, the material can withstand the applied load /force and even more without getting deformed.

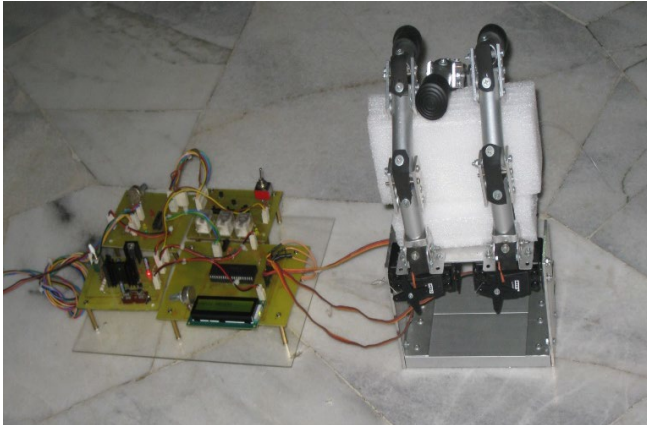


Figure 15: Grabbing Rectangular foam with the Three-fingered Robot Hand (Front view)

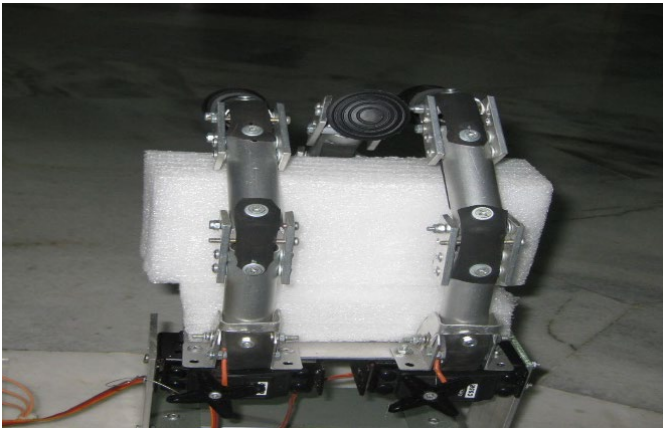


Figure 16: Grabbing Rectangular foam with the Three-fingered Robot Hand (Side views)

### III. RESULTS AND DISCUSSION

The structural analysis carried out on the link during the mechanical design of this multi-finger robotic arm shows that the force to be applied on the link is 10N. The result of the structural analysis done in Solid Works 2012 is shown in Figures 17, 18 and 19 below.

The Maximum von-mises stress is only 7.4 N/mm<sup>2</sup> which is way below the yield strength 27.6 N/mm<sup>2</sup> of the material. The maximum displacement is 0.0189634 mm which is considerably small.

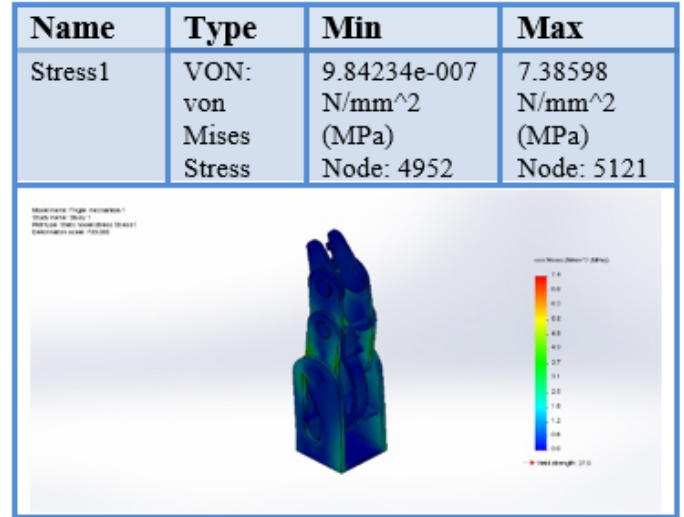


Figure 17: Von-mises stress plot

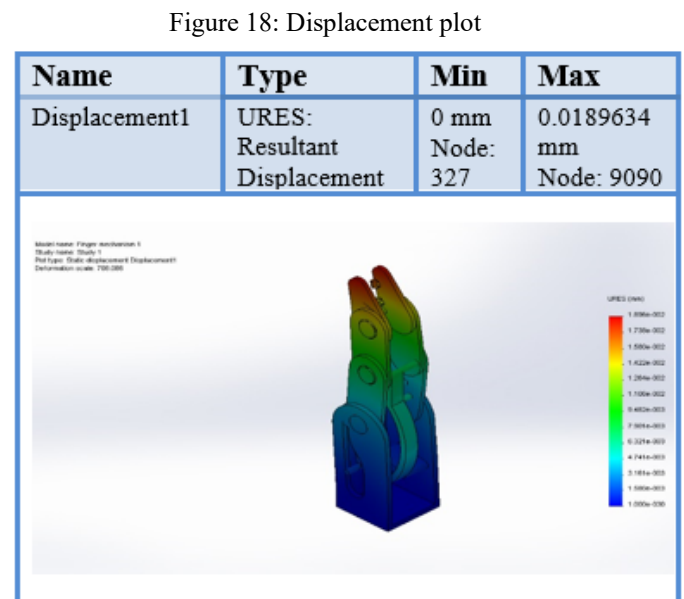


Figure 18: Displacement plot

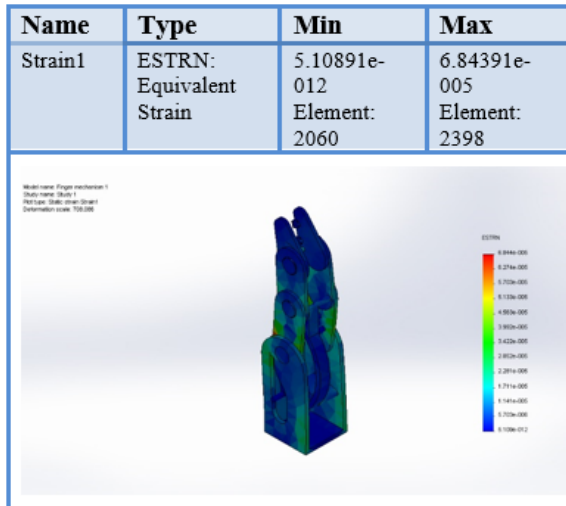


Figure 19: Strain plot

#### IV. CONCLUSION

The idea behind under-actuation in grasping is to use an ingenious mechanical system that can adapt to the shape of the object automatically. The three-fingered robot hand actuator is embedded in the link; hence, the finger becomes compact, simple in mechanism and lightweight. Its design and control issues are described using a PIC 18F4520 micro-controller with three servo motors as the actuators and a PID control technique is implemented in this work to minimize errors or to ensure that the effective grasping of various objects is achieved. From the test conducted to demonstrate the functionality of the multi-finger robot hand, it can be observed that the robot hand has shown its ability to grasp various objects firmly. It can also be concluded that the multi-finger robot hand developed is functional.

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