



MINI ROBOT FINGERS USING SHAPE MEMORY ALLOY

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ABSTRACT

This paper presents the development of an Intelligent Mini Robot Fingers by using the Shape Memory Alloy (SMA). Taking into consideration the advantages of the SMA, a prototype of mini robot fingers is developed which will be actuated by the SMA. The mini robot fingers has 4 fingers with 3 degrees of freedom (DOF) in each finger. Hence, 12 DOFs of robot fingers are developed to allow a greater flexibility. The SMA is an actuator that permits the elimination of motor to control the movement of the robot fingers. In this study, thin SMA is selected due to low resistance, low current requirement and able cooling within a short period. The function of SMA in each finger is similar to the muscle-tendons structure of the human hand. Robot finger flexion is performed by contraction force of SMA using the characteristic of electrical resistance of SMA. The mini robot fingers have articulated fingers with cable tie (as spring) mounted on the backside of each finger. These cable ties provide the necessary, restoring force for SMA contraction as well as open the fingers for relaxation. From experiments, the grip force is 0.2 N, and can support the object up to 20 grams.

Keywords: mini robot fingers, SMA, grip force.

INTRODUCTION

An intelligent robot fingers can be defined as the ability of the robot hand that can mimic the movement of a human hand. A primary target when developing a robot hand is that the grasped object must be safe. An approach by utilizing the Shape Memory Alloy (SMA) can be considered a novel technique to actuate the robot fingers. Many industrial applications consider the SMA such as automotive, consumer electronics, home appliances, aerospace and etc. This project is an attempt to develop a robot fingers by using the SMA. The SMA is embedded in all the finger joints. The SMA acts as an actuator that permits the elimination of motors to control the movement of the robot fingers, it can perform similar to the muscle-tendons structure of the human hand [1]. With its unique ability to contract on demand, SMA (Muscle Wire/Actuator Wire) presents many intriguing possibilities for robotics. SMA is able to contract with significant force, and can be useful in many applications where a servo motor or solenoid might be considered [2].

The prototype of mini robot fingers has four fingers. There are thumb, index finger, middle finger, and ring finger. Each finger consists of 3 DOF which contribute to the total of 12 DOF (almost similar design of robot fingers can be found in [3][4]. Robot fingers flexion is performed by contraction force of SMA using the electric resistance characteristic of SMA. Thin SMA is selected due to low resistance, low current requirement and able cooling within short period [2].

To reduce the amount of SMA use, the mini robot fingers has articulated fingers with cable tie (as spring) mounted on the backside of each finger. These cable ties provide the necessary restoring force for SMA contraction as well as open the fingers for relaxation [5]. This robot fingers is possible perform dexterous hand motions such as tip grasp, and precision grasp. It also suitable applies at many aspect or sector, for instance in medical sector such as taking medicine or gripping pill.

SYSTEM ARCHITECTURE

The block diagram of the mini robot fingers is shown in Figure-1. The SMA is driven by Darlington Transistor Arrays (ULN2003A) which is connected to the Microcontroller (PIC16F877A). The code is programmed using MPLAB IDE software. In this system, PIC16F877A act as a "brain" to drive the SMA to move the fingers.

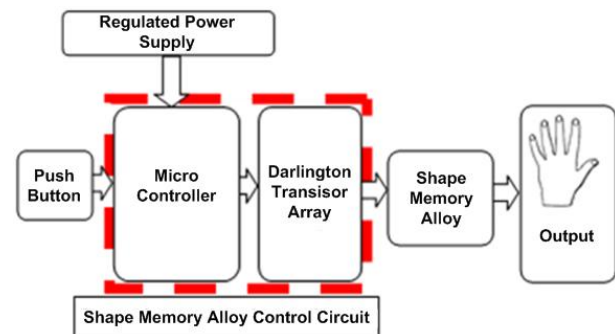


Figure-1. Block diagram of mini robot fingers.

MINI ROBOT FINGERS USING SMA

The development of Mini Robot Fingers by using SMA can be divided in two categories. The first category is the provision of hardware. On the hand, the second category utilized software which will be described in details in this section.

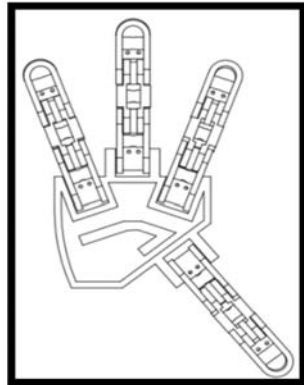
a) Hardware

i. Robot finger design

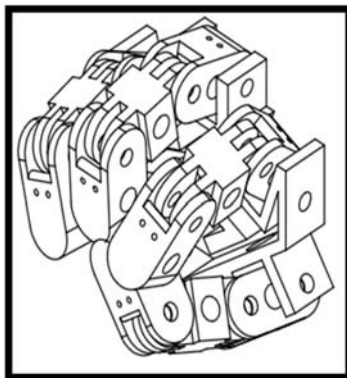
A robot finger is designed by using 2010 software as shown in Figure-2. Specifically, Figure 2(a) exhibits an open view of the robot finger while Figure 2(b) depicts a close view (i.e. a grasping finger). Table-1 shows the size of each finger part. The design of the robot fingers is based on an anthropomorphic shape. The robot fingers



have four fingers which are thumb, index finger, middle finger, and ring finger. All fingers are designed to have the same length [6].



(a) Open View



(b) Close View

Figure-2. Robot finger design.

Table-1. Size of each finger part.

Number	Part	Size (cm)
1	Palm	4.5
2	Upper finger part	2.1
3	Middle finger part	2.4
4	Bottom finger part	2.1

As shown in Figure-3, the mini robot fingers are actuated by SMA which embedded through all the finger joints. As the SMA gets heated (the heat must exceed 70 °C which is transition temperature) from SMA control circuit, SMA will contract the robot fingers to grip an object within 2 sec. The mini robot fingers has 12 DOF where each fingers has 3 DOF. SMA is used to drive the movement to the fingers. Characteristic of the SMA [7] is shown in Table-2.

Table-2. Characteristic of SMA.

Characteristic	Specification
Diameter	0.04 Inch
Resistance	3.0 Ω/Inch
Maximum Pull Force	150 grams
Approximate Current at Room Temperature	180 mA
Contraction Time	1 Seconds
Extention Time	0.8 Second

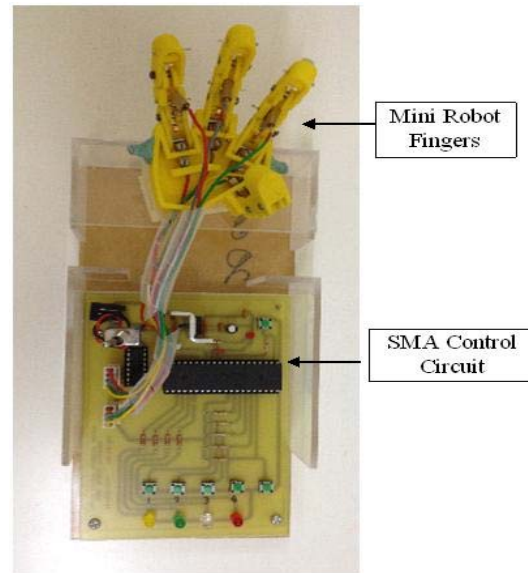


Figure-3. Mechanism of mini robot fingers.

ii. SMA control circuit

In the SMA control circuit, push button act as input component and output component is the SMA. The PCB design is shown in Figure-4. The SMA control circuit Board design consists of Power Supply and Voltage Regulator 7805, Push button, PIC16F877A and ULN2003A.

i Power Supply and Voltage Regulator 7805

DC power supply of 5V is used to supply voltage and current to the SMA control circuit. The voltage regulator 7805 is used to reduce voltage from 12V to 5V to prevent damage on the PIC Microcontroller.

ii Push button

Normally open push button is used to activate the PIC. Push button is giving the signal to the PIC as a switch to control the system. It is open in normal condition but when push button is pressed then it is in activating state. The schematic design for push button is shown in Figure-5.

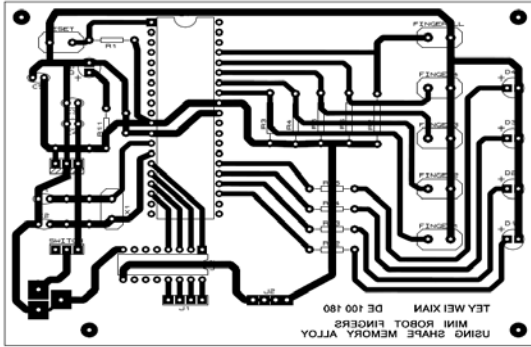


Figure-4. PCB design of mini robot fingers.

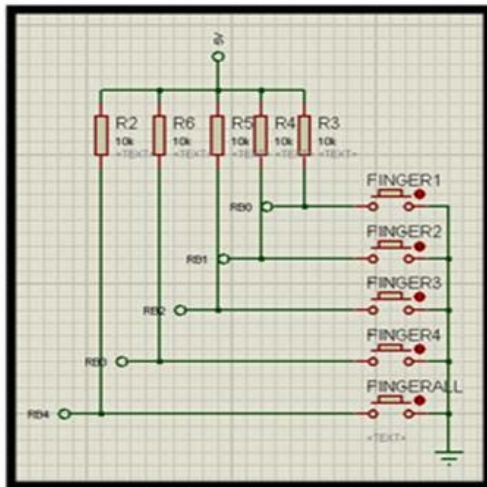


Figure-5. Schematic design for push button.

iii PIC16F877A

PIC16F877A is a main controller in this project. It receives the input signal, process and then generate output signal to the ULN2003A. Crystal oscillator in this project has 4MHz. Besides that, in this project Port B at terminal RB0 until RB4 used as input port for the push button. The port C at terminal RC0 until RC3 used as the output port and connected to ULN2003A to activates SMA. The terminal RC4 until RC7 are connected to LED, which indicate the active Output [8]. When input is generated by pressing the push button RB0, two simultaneous outputs are produce which are LED (RC0) and SMA (RC4). It works the same for other three push buttons. The schematic design for PIC16F877A is shown in Figure-6.

iv ULN2003A

ULN2003A is an array of 7 Darlington transistors, which is a pair in a 16-pin DIP package. Each of its seven inputs on the left side of the chip connects to an output directly opposite on the right. ULN2003A possible to drive loads by connecting outputs from the controller directly to inputs of the ULN2003A with no additional components required [9]. The ULN2003A's

outputs are rated for a maximum load of 500 mA while the whole array can sink as much as a full amp depending on configuration and ambient temperature. The SMA needs about 200 mA to achieve a 1 second contraction, so in this project will use about four output to support the SMA. The schematic design of the ULN2003A is shown in Figure-7.

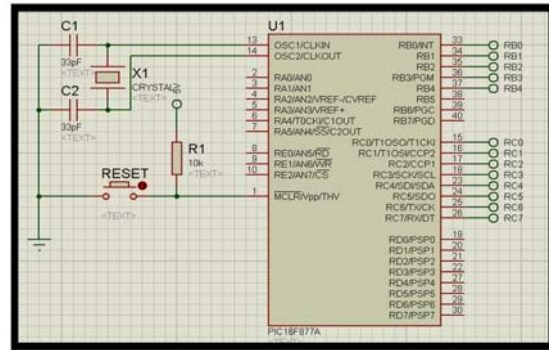


Figure-6. Schematic design for PIC16F877A.

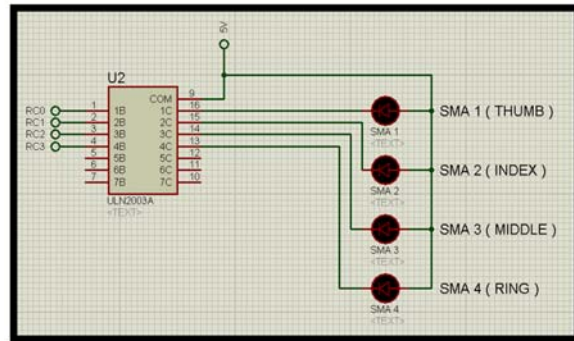


Figure-7. Schematic design for ULN2003A.

b) Software development

The MPLAB IDE, Proteus version 7, and Solidwork 2010 are used to develop the program code, design of mini robot fingers and design of SMA control circuit printed circuit board respectively.

c) System flow chart

Figure-8 shows the project system flow chart. When the SMA controller circuit is switched on, the SMA would be in ready state. There are four push buttons to operate four fingers which is one button for each finger. If any push button is switched on, the SMA will contract and close the respective finger. If the Button A is pressed, then thumb will be activated. If the Button B is pressed, then the index finger will contract until the switch is off. Button C to control middle finger, Button D to control ring finger and Button E to control all fingers. The system will operate until the main switch is turned off.

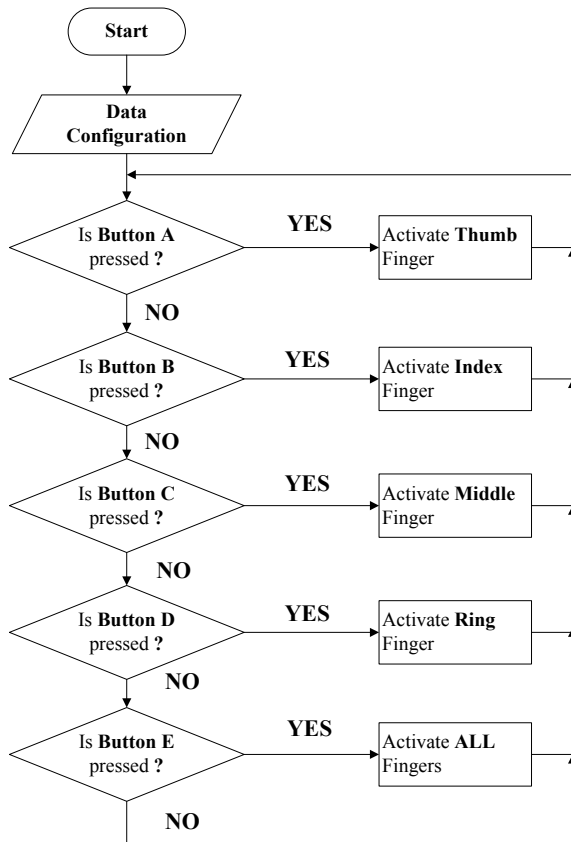


Figure-8. System flow chart.

d) Overall description

Table-3 shows overall description needed in this project. Every single part of this project, encountered and listed depends on demand and usage in this project. With the MPLAB IDE software, programming is downloaded into PIC16F877A and once it is succeed, the board automatically creates independent data transmission between controller and SMA. It makes the robot fingers to operate according to input from PIC16F877A.

Table-3. Overall descriptions mini robot finger.

ITEM	DESCRIPTION
Controller	SMA Control circuit
Actuator	SMA
Software	Proteus 7, MPLAB IDE, Solidwork 2010
Method	Wiring/pulling mechanism

RESULT AND ANALYSIS

The result and analysis of Mini Robot Fingers Using SMA are done according to the actuators which are related to the fabricated board, SMA, and the assembled parts with electronic.

a) SMA control circuit board

The SMA control circuit board with dimension of 12.5 cm x 9.0 cm is shown in Figure-9 and the feature of

each part of the board are labeled and explained in the Table-4. The components had included 12V input socket, power supply and voltage regulator 7805, PIC16F877A, ULN2003A Darlington Transistor, push button and LED indicator and SMA terminal.

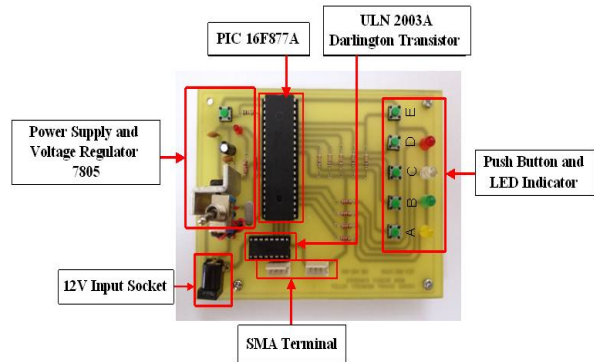


Figure-9. SMA control circuit board.

Table-4. Feature and parts for SMA control circuit board.

Item	Quantity	Function
12V input socket	1	Supply input voltage 12V
Power supply & voltage regulator 7805	1	To regulate voltage to 5V
PIC16F877A	1	As a microcontroller to receive the signal, then process & generate output signal
Darlington Transistor ULN 2003A	1	To step up current & drive SMA
Push button	5	As input
LED	5	As an indicator when push button was pressed
SMA terminal	4	As a port to connect SMA

b) Mini robot fingers prototype

The mini robot fingers prototype is shown in Figure-10. The mini robot fingers have four fingers, there are thumb, index finger, middle finger, and ring finger. The size of all fingers are design to be similar, which is each finger have 6.6 cm length. There have 3 DOF for each finger and total 12 DOF for this project. Based on testing, the maximum movement angle for bottom finger part is 90 degrees, for middle finger part is 45 degrees, and upper finger part is 90 degrees [10]. The movement angle of mini robot fingers is shown in Figure-11.

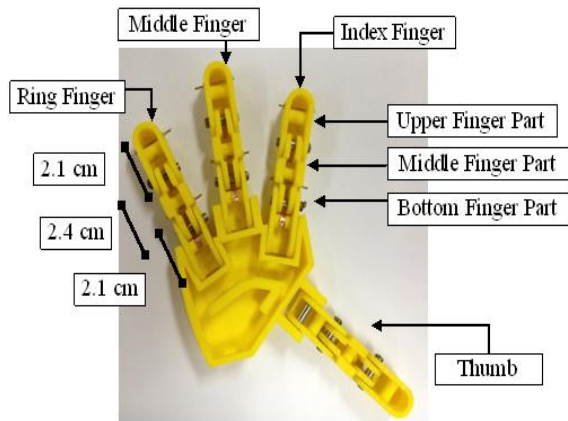


Figure-10. Mini robot fingers prototype.

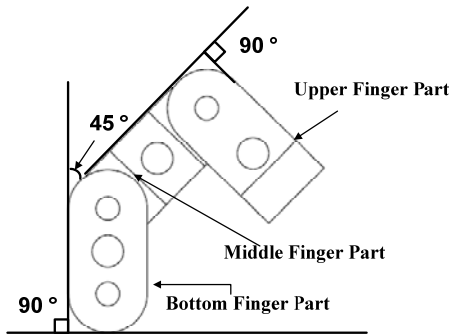


Figure-11. Movement angle for mini robot fingers.

c) SMA output current

According to the characteristic of SMA, the 1 inch (2.54 cm) SMA has resistance value 3.0 Ω [2].

$$\frac{2.54cm}{1.0cm} = \frac{3\Omega}{x\Omega}$$

$$x = \frac{1.0cm}{2.54cm} \times 3.0cm$$

$$= 1.18\Omega$$

Through the calculation above, the various length of SMA has different resistance. Analysis output of SMA current with 4 different length of SMA, which is 3 cm, 5 cm, 7 cm, and 9 cm are carry out. Then, the resistance for 3 cm has 3.54 Ω, 5 cm = 5.9 Ω, 7 cm = 8.26 Ω and 9 cm = 10.62 Ω. As observation, longer SMA will produce higher resistance.

Based on Ohm's Law, V=IR state that the resistance is inversely proportional to current. So, the higher resistant will lower the current. The relationship between length and current of SMA had shown in Table-5 and graph in Figure-12 and Figure-13 respectively.

Table-5. Current used for SMA.

Push Button	Length of SMA			
	3 cm	5cm	7 cm	9 cm
Push Button A*	0.48A	0.38A	0.34A	0.32A
Push Button E	0.29A	0.27A	0.24A	0.21A

* Output of push button A is equivalent with push button B, C, D.

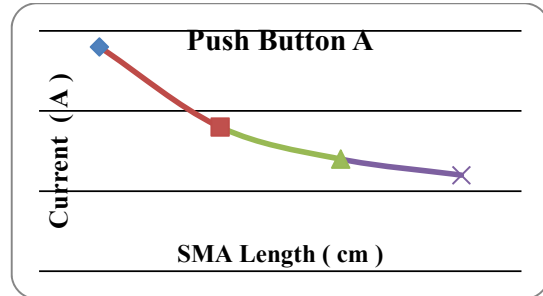


Figure-12. Output of SMA current for push button A.

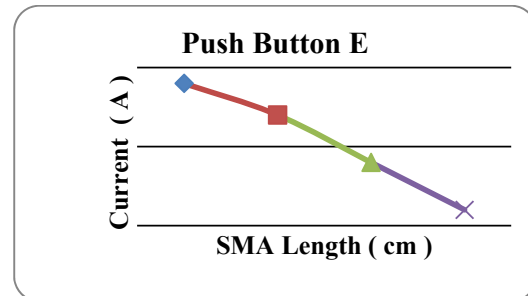


Figure-13. Output of SMA current for push button E.

d) Method connecting between SMA and wire

There are four different ways of connecting between SMA and wires which had been tested during lab experiment session. First method is using solder lead to solder the SMA with the wire. However, the solder breaks due to the heat produce which cause the solder lead to melt. Second method is using PVC connector to screw the SMA tightly and its benefit is during tie will able to correct mistake easier. However, after SMA had been screwed by sharp screw for few times which will breaks the SMA and the attachment failed. Third method is using epoxy to form attachment between SMA and wire. Epoxy is type of glue which is a compound of resin and hardener to form a linkage between the compound structures to form the attachment. However the disadvantage of using epoxy glue is that the heat factor able to melt down the attachment. The final successful method used is by using copper tape attaches around the SMA but as predicted the attachment produced is not tough and able to break with increasing stretching force.

As a way of overcoming all the failure method is do more loops in SMA and the lines are overlap on each other to form multiple lines which able to withstand the stretching force when the fingers moved. Methods using



solder lead, PVC connector, Epoxy glue, Copper tape, are shown in Figur-14, Figure-15, Figure-16, and Figure-17 respectively.

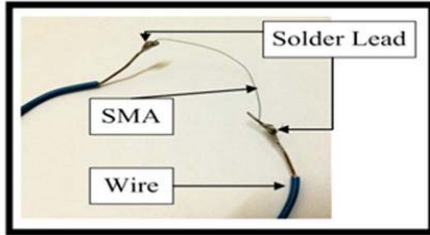


Figure-14. Method using solder lead.

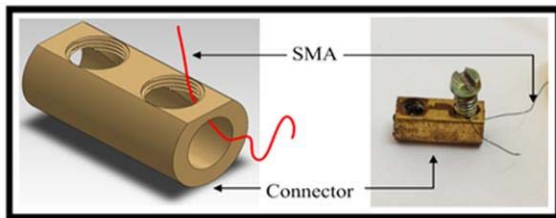


Figure-15. Method using connector.

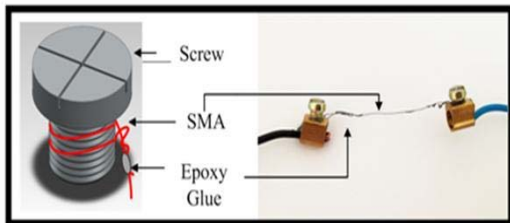


Figure-16. Method using epoxy glue.

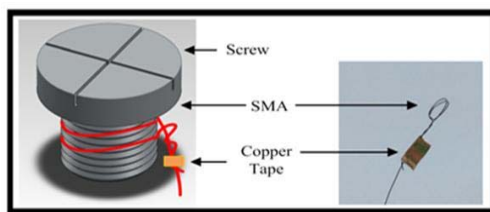


Figure-17. Method using copper tape.

e) Output waveform from ULN2003A

In the analysis section, oscilloscope is used to capture the output voltage waveform. The output waveform includes frequency, period, and voltage peak-to-peak. Based on the theory Electric Power, Power is directly proportional to Voltage and Current ($P=VI$), When the input is given (push button is press), the output voltage will drop as shown in Figure-18. The generated pulses from the hardware are symmetrical every 10 second. The overall waveform from ULN2003A is display as shown in Figure-18.

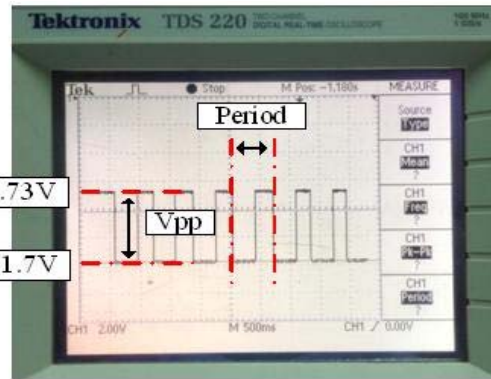


Figure-18. Output waveform from ULN2003A.

Channel 1 = 2.00 V	M = 500 ms	Mean = -6.73 V (Inactive) = -11.7 V (Active)
Vpp = -6.73V - (-11.7V) = 4.97 V	Period = 1.5 × 500ms = 0.75 sec	Frequency = 1 ÷ 0.75 = 1.33 Hz

f) Grip force

Figure-19 is shown the experiment and test of grip force for mini robot fingers. Grip Force test are carried out in order to get the contraction strength of finger. The grip force had measure by Newton Meter with 12 cm of SMA which embedded in finger. The result is 0.2 Newton in first time measure. Then the result 0.1 Newton and 0.2 Newton had been obtained in second test and third test. Average result in this measuring is 0.167 Newton of grip force. The experiment result is shown in Table-6.

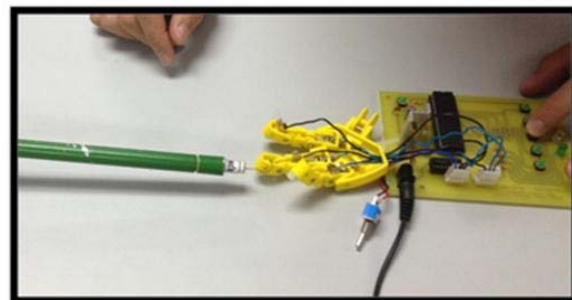


Figure-19. Grip force test.

Table-6. Grip force.

Number of Test	Result (Newton)
1	0.2
2	0.1
3	0.2
Average Force	0.167

CONCLUSIONS

As a conclusion, this project proposed the mini robot fingers like the human hand by using SMA. SMA is



non-classical types of actuation which allow the development of efficient, compact, lightweight and low-cost actuators. The robot fingers before are following the actual size of human hand. Therefore, that hand needs more than 5 strips of SMA to operate or contract. The mini size robot fingers had design with 4 fingers and 3 DOF per finger, it means that only 4 strips SMA used in the robot fingers in this project. This hand only occupied volume about 46 cm³ with 10 cm height, 4.6 cm length and 1 cm wide to be more dexterous. The mini size will offer the hand more portable and flexible. Furthermore, it capable to grip the various shape of objects which are below 20 gram. The mini robot fingers do not only apply in medical sector, but could also contribute in other field such as in industry.

RECOMMENDATION

Since this is the first prototype, this project could be further improved. The mini robot fingers using SMA could be improved by replace a better SMA. The thicker SMA has higher strength, not easy to break while pulling and it also can improve the grip force. The bigger the diameter of SMA will make the connection between wire and SMA become easier. The bigger gap in the mini robot fingers structure will make SMA easier to embed into finger parts. To improve the performance of grasping, SMA should be turning a lot of looping inside the mini robot fingers. In addition, the prototype material should be use heat-resisting material to overcome the high temperature produce by SMA during contraction.

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