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MINIATURE TWO-FINGERED ROBOT HAND DRIVEN BY MUSCLE WIRES ACTUATORS

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Abstract

In this research, a modified artificial hand with direct control has been designed using electrical artificial muscle wires that receive direct sensory impulses through human hand instead of using the mechanical action to open and close this artificial hand. Each finger is designed as a chain and its movements achieved through the conventional arrangement control of the electrical muscles wires. The results indicate that it is possible to design an artificial hand using electrical muscle wire for control it with high accuracy.

Keywords: Muscle Wires, Shape Memory Alloy, Robotics Hands.

1. Introduction

Much work over the recent years have been involved in the creation of a humanoid hand, where degrees of freedom and size of the hand and forearm are designed to be as close as possible to human proportions. Over time various hands were built from a simple 2 finger system without a thumb, all the way to an almost exact replication of a human hand, comprising of 4 multi-jointed fingers and a thumb. Several forms of actuation have been used in these hands such as electrical revolute motors, DC motors, pneumatic actuators and pneumatic muscles.

Human being has been developing variety of robots. Before the 1970, the Industrial robot for simple work in plant were mainly developed Then, the robots have been Improved and multi-functionalized with the progress of technology. Recently, they have extended their fields and uses. Particularly the humanoid robot technology attracts high attention of public. The humanoid robot has a high flexibility, so they can work in human environment. The manlike robot such as the humanoid robot is expected to realize novel concepts as tele-existence and coexistence of the human being and robot. There have been several robotic hand implementations that subscribe to different levels of anthropomorphism. Thus, researchers have since modified commercially available versions of some these original designs to incorporate more elaborate sensing techniques. Human being usually contacts with the external environment with his hand. The robot also needs the hands the end-effecter to interact with the object. The robot hand is divided into three categories: mechanical gripper, special purpose hand, and universal hand . The former two types are for the limited use, so their form is not generally manlike. They are often used for industrial robots. On the other hand, the humanoid robot has the last type of robot hand because it requires handling the various types of objects steadily and smoothly. The universal hand can also be used for other purposes such as tele-operation in space environment and in hazardous environment and tele-surgery. Therefore, the development of universal robot hand has been an interesting topic among researchers, and a lot of sophisticated robot hands have indeed developed all over the world [1].

Ikuo et al. [1] developed a robot hand having equal number of DOF to human hand. The method uses restoring force of elastic element as driving power for grasping an object, so that the hand can perform the soft and stable grasping motion with no power supply. In addition, all the components are placed inside the hand It had equal number of joints and DOF to human index finger, and it was also equal in size to the finger of average adult male. The performance of the robot finger was confirmed by fundamental driving test. Jessica Lauren Banks [2] investigated the problem of a tactile sensing platform for anthropomorphic manipulation through the fabrication and simple control of a planar 2-DOF robotic finger inspired by anatomic consistency, self-containment, and adaptability. The robot was equipped with a tactile sensor array based on optical transducer technology whereby localized changes in light intensity within an illuminated foam substrate corresponds to the distribution and magnitude of forces applied to the sensor surface plane. The integration of tactile perception was a key component in realizing robotic systems which organically interact with the world. Such natural behavior was characterized by compliant performance that could start internal, and respond to external, force application in a dynamic environment. However, most of the current manipulators that support some form of hap tic feedback either solely derive proprioceptive sensation or only limit tactile sensors to the mechanical fingertips. Peter Scarfe and Euan Lindsay [3] presented the design and implementation of a low-cost air muscle actuated humanoid hand as shown in Figure [1]. It is developed at Curtin University of technology. This hand offers 10 individually controllable degrees of freedom ranging from the elbow to the fingers, with overall control handled through a computer GUI. The hand was actuated through 20 McKibben-style air muscles, each supplied by a pneumatic pressure-balancing valve that allows for proportional control to be achieved with simple and inexpensive components. The hand was successfully able to perform several human-equivalent tasks, such as grasping and relocating objects.

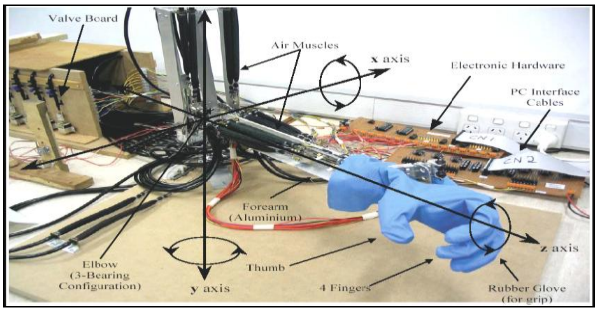

Fig. 1. The Physical Hand and Arm Comprises 4 Fingers.

Touch Bionics [4] developed the i-LIMB Hand as shown in Figure[2]; It was a prosthetic upper limb device with five Individually powered digits. This replacement hand looks and acts like a real human hand and represents a generational advance in both bionics and patient care. The Touch Bionics i-LIMB Hand was developed using leading-edge mechanical engineering techniques and is manufactured using high-strength plastics. The result was a next- generation prosthetic device that is lightweight, robust and highly appealing to both patients and healthcare professionals.

Fig. 2. i-LIMB Hand

Lillian Y. Chang and Yoky Matsuoka [5] , presented ACT thumb kinematics model that unifies several studies from biomechanical literature. They also validated the functional consistency (i.e. the nonlinear moment arm values) between the cadaveric data and the ACT thumb. This functional consistency preserves the geometric relationship between muscle length and joint angles, which allows robotic actuators to imitate human muscle functionality.

Tetsuya Mouri, etal [6], presented a newly developed anthropomorphic robot hand called KH Hand type S, which has a high potential of dexterous manipulation and displaying hand shape, and its master slave system using the bilateral controller for five-fingers robot hand. The robot hand was improved by reducing the weight, the backlash of transmission, and the friction between gears by using elastic body. A. H. Arieta1, et al., [7], described an electrically powered prosthetic system controlled by electromyography (EMG) signal detected from the skin surface of the human body. The research of electrically powered prosthetic systems is divided into two main subjects. One is the design of the joint mechanism. This mechanism includes mechanical torque-velocity converters and a mechanism to help the proximal joint torque by distal actuators. The other subject is the recognition of the EMG signal. For the discrimination of many patterns and nonlinear properties of the EMG signal, they propose a controller based on a simple pattern recognition information process. The system also drives 12 servomotors to move the adaptive joint mechanism.

Kenji KANEKO, et al. [8], presented a development of multi-fingered hand, which is modularized and can be attached to life-size humanoid robots. The developed hand has a four fingers with 17 joints, which consist of 13 active joints and 4 linked joints. A miniaturized 6-axes force sensor is newly developed and is mounted on each fingertip for improving the manipulability. A main node controller with I/O, motor drivers, and amplifiers for 6-axes force sensors are also newly developed. These components are equipped in the hand for modularization. The developed hand is designed so about realize about 8 [N] forces on the pad point of stretched finger, supposing transmission efficiency of drive system is 55 [%]. In this study, the mechanisms of hand module, its specifications, and electrical system is also introduced.

2- Prostheses for Partial Hands

The fundamental difference between a reconstructed hand and any present-day hand prosthesis lies without direct sensation in the latter. Although the wearer of a modern hook or artificial hand may receive indirect sensory impulses through shoulder harness or cine plastics muscle pin, the conventional arrangement constitutes only a crude and inefficient signal system which must be supplemented and directed by sight. A hand Prosthesis is of little use in the dark. In contrast, there is the exquisite appreciation we receive from the normal hand by feeling. By light touch, coarse touch, response to heat or cold and compass-point discrimination, we appreciate texture, and by muscle, joint, and tendon sense we appreciate size and shape. By combining these sense impressions in our cerebral cortex in the opposite parietal lobe, we can identify from memory an object held in the hand. This is stereo gnosis, a phenomena replaced by no artificial hand now available. Figure[3] gives some prostheses for the partial hand

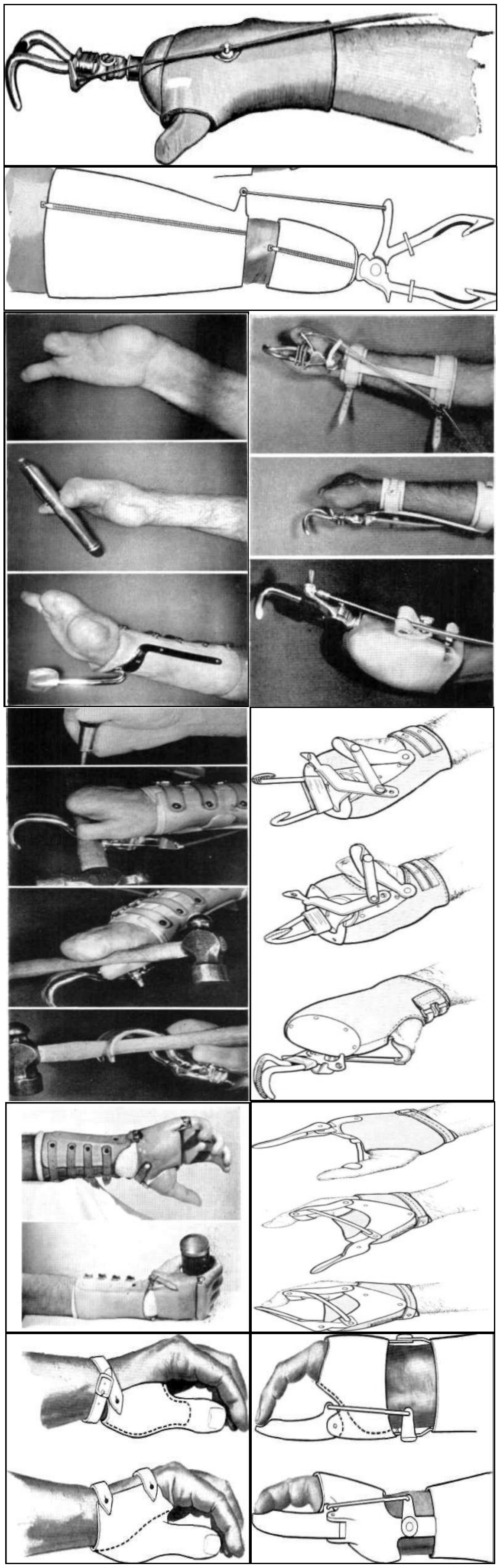

Fig. 3. The Management of the Nonfunctional Hand-Reconstruction vs. Prosthesis [9].

3- Experimental Work:

The mechanism could be divided into two parts, the mechanical and the electrical part.

A. Mechanical Part:

The process of constructing the hand from mechanical view is developed from simple one to respectively complex one as shown in Figure [4] where they are designed experimentally depending on the trail and error.

Figure [4-a], demonstrates the first proposed simple gripper, which consists from two fingers, each with two phalanxes. The phalanxes connected together through nails. Each phalanx made of simple wood. The motion of each finger is accomplished by one muscle wire (actuator) and one elastic spring to return the moved phalanx back. With this configuration of the gripper, a problem is appeared, that is since each finger has the two movable phalanxes, and the friction between phalanx and nail are respectively high, therefore the motion is inaccurate and inhomogeneous. Also finger is endurable.

Figure [4-b]. a developed form of the gripper, where it consists of two fingers. each of them composed of three phalanxes. The fingers constructed of chain covered by plastic shield where the shield is cut into three parts to separate three phalanxes to generate a motion as far as similar to human finger motion. It is required to move each phalanx independently, and that may be through connecting each phalanx with independent MW. MW connected to a corpus of T-square as shown from the figure. T-square used to observe the amount of motion or extraction of the MWs. Also each phalanx is connected to plastic spring and the spring connected to the T-square. The springs are guided through eye-bolts riveted to the plastic shield. One problem developed here is that the independency of phalanxes is unapproved, that is because there is a leakage developed between the chain and plastic shield, and because of the incorrect connection of plastic springs to the T-square.

From the above discussion the problem appeared need solutions. The solution is developed by building the two fingers with three independent phalanxes for each as shown in Figure [4-c].

(a)

(b)

(c)

Fig. 4. The Proposed Mechanical Hands.

It is aimed to have a humanlike hand, and this of-course is very difficult because the mechanism of human hand work the complex one from other mechanical parts of the human body .The human hand consists of fingers and each one is of three phalanxes, and each phalanx may be work independently. Something like this mechanism is ought to get, at least for one or two fingers.Each phalanx connected to independent tendon that will be connected to the muscle wire needed to activate it. So there will be three MWs for each finger alone to have a good catching, these fingers must be durable and reliable, therefore each finger constructed from the components shown in Figure [5].

Figure [5], shows the components: chain, needles, elastic springs, and tough plastic tendon. The chain mechanism is like bon mechanism in human hand, and the needles work as stops to prevent excessive backward motion, the elastic springs are needed to retrieval phalanxes to their original positions after removing the muscle wire activation. Finally the elastic tendons are used as the same one in human hand. The constructed finger is shown in Figure [6].

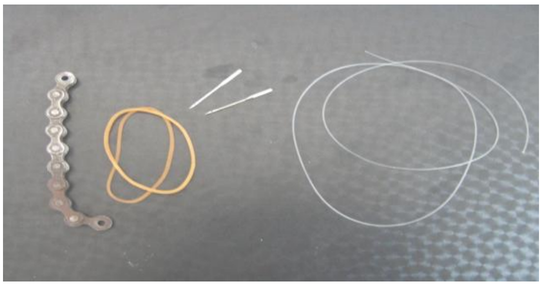

Fig. 5. The Components of a Single Finger.

Fig. 6. The Constructed Finger Design.

In this research, it is also used other different parts which are simpler than the previous one, they are shown clearly in Figure [7], which are available in the markets. They are used to show the control strategy of activation the smart hand using the muscle wires.

(a) (b)

Fig. 7. Ready Hand Parts.

From Figure[7 a and b], two types of ready grippers used and they are different from the direction of motion viewpoint, to show clearly the advantages and disadvantages of using the MW to open the gripper or use it to close(catch) the gripper.

B- Electronical Part:

The electronic part of activation the muscle wire is not very difficult, but as the number of MWs used increases, the complexity of the electronic circuit will increase, and so on. Muscle wire must be activated with Pulse-Width-Modulation (PWM) signal (i.e. ON-OFF) to prevent the overheating case of the MW . In other ward, MW under activation must be putting under cycling (heating and cooling). It is possible to get PWM signal simply through out using 555 integrated circuit. A schematic of activation electronic circuit shown in Figure [8].

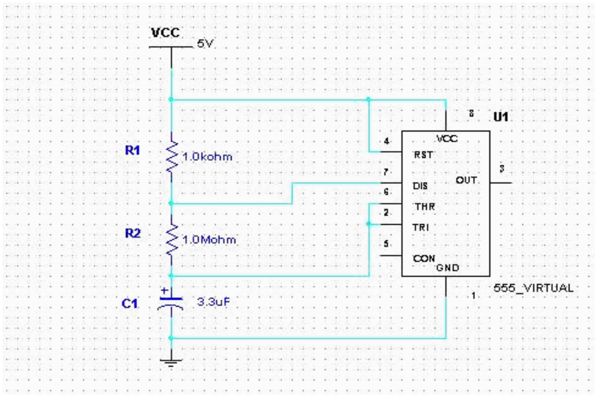

Fig. 8. A Schematic of the Activation Circuit of a Single MW.

The 555 integrated circuit U1, is a popular chip that contains over 40 transistors, resistors, and diodes. Turning its output (pin3) on and off according to the values of R1, R2, and C1, as showed by the following equation:

TON=0.69(R1+R2)C1

TOFF=0.69R2C1

The PWM signal is shown in Figure [9].

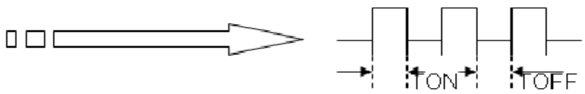

Fig. 9. PWM Signal.

In this research a lot of MWs used to perform the desired function, and since each MW needs respectively large amount of current which is the recommended current required to activate the MW (sometimes current reaches 1 amp, and/or more depending on the length and cross-section area of the MW used) [4], driver used to supply the MWs. Number of power transistors may be a good choice. A microcontroller used to select the required MW(s) depending on the previous condition. It had been also designed the driving circuit that containing the microcontroller which is AT89C51 version and shown in the overall circuit in Figure [10].

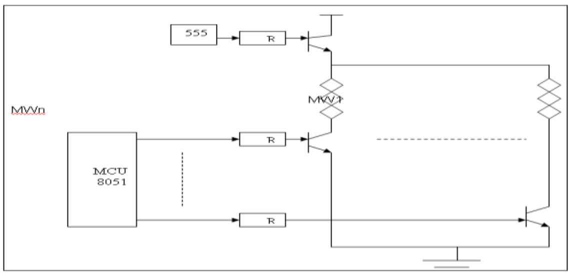

Fig. 10. Control cct of Activation and Selection of MWs.

C- Control strategy

Any muscle wire with a given length has a resistance that changes with length (i.e. the resistance of the MW is a function of its length) [4], and since each MW with a specific diameter needs a recommended current to be activated, the voltage required changes with MW length also. That means a MW with a given length will contracts by a constant length (MAX. 8% of its original length), and this is a problem appearing in the control system, where to control the motion of the system, the input to the actuator (here MW) must be as a parameter, whereas here the input to the MW is a constant voltage (the recommended one to activate the MW). One of the proposed solutions to this problem in this research is to connect several MWs have the same length in a series sequence and separated electrically as shown in Figure [11].

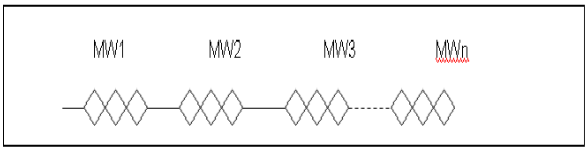

Fig. 11. Schematic of MWs Connection in Series.

As shown from Figure [11], the activation of one MW will contact or pull the hand with a specific length (5% of its length which is the recommended). to duplicate contraction, that needs activate two MWs and so on. To increase the accuracy and smoothness of motion, large number of MWs with respectively small length will be required. As a case study, four MWs with length 20 cm each and of the same diameter (100 micrometer) used to control the motion of the gripper showed in Figure [12].

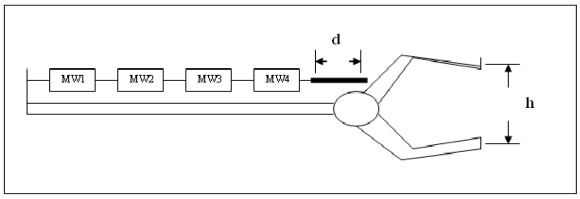

Fig. 12. Schematic of Gripper Controlled by MWs Actuators.

From Figure [12] the relationship between the generated distance (d) due to MWs activation and the gripper head (h) is calculated practically and gives the graphical relation as shown in Figure [13].

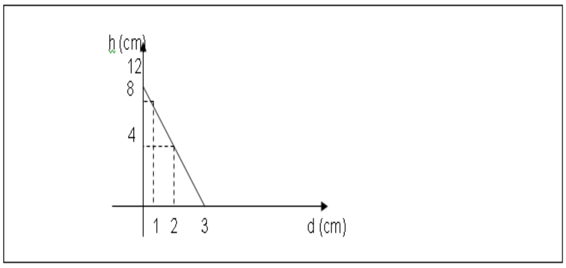

Fig. 13. Graphical Relationshp between d and h of Fig. 12.

The relation mathematically is:-

$$h= 12- 4d \qquad ...(1)$$

The value of (d) depends directly on the number of activated MWs, where activation one MW of 20cm length will generates distance of 1cm (5% of MW length), and as shown in Figure [12] the gripper head will reduces to 8cm. Since the motion of each MW is constant, then the control strategy that established here is by using ON-OFF algorithm, and so practical & theoretical results took to this algorithm which is explained in Table [1].

Table 1
Practical and Theoretical Results of Controlling Gripper Catching.

MWs	Theoretical		Experimental	
	d (cm)	h (cm)	d (cm)	H (cm)
All MWs =OFF	0	12	0	12
MW1=ON, Others=OFF	1	8	0.5	10
MW1=MW2=O N	2	4	1.75	5
MW1=MW2=M W3=ON	3	0	2.75	1.08
ALL MWs =ON	4	0	4	0

From Table [1], it is clearly seen that there is a difference between theoretical and practical results, and that difference starts larger, then smaller and finally die out. This because the activation of one MW will affect the lengths of others not activated MWs, and the effect reduced each time increasing the number of activated MWs. Note that this problem may be possible prevented by putting stops to each MW extreme that is nearer to the gripper side.

There are other solutions proposed and may be used, like arranging all MWs in parallel form with different length or arranging them in different angles with same lengths and other more depending on the idea researchers may have and that of course depends on the common sense not a general way.

It is required also in this research to make the motion of the proposed hand imitate the motion of human hand (i.e. to be what attributed {smart hand} is), and this is possible through making the following process, which had been done in this research:

1. Taking a variable resistance (or pot). This potentiometer assembled by a specific mean with human hand as shown in Figure [14].
2. The output voltage of the pot is changed with human hand motion. Since the experiment of the mentioned study consists of four MWs of 20 cm length each(i.e. four separated motions), therefore four values of output voltage which is related to four constant motions of human hand must be considered here. Another think must be considered here, is that the imitation must as closed to human hand as possible. From Table [1], since practical results of gripper head is different from theoretical; therefore the human hand head must be similar to practical values of gripper head. So the values of the potentiometer output selected as shown in Table [2].

Fig. 14. A Human Hand Composed with a Potentiometer.

Table 2
Selection of Specific Values of Pot o/p in Hexadecimal

Exp gripper h (cm)	h of human hand	Potentiometer output Voltage (hexa)
12	12	00
10	10	07
5	5	1F
1.08	1.08	3F
0	0	FF

From Table [2], the values of the potentiometer are taken in hexadecimal because it is the values that are dealt here when talking about control as will be show. And this values are took with respect to the human hand head practically when the output of the pot connected directly to the ADC0808 (Analog-to -Digital converter) , which has the resolution of 8-bit.

D- Controller

Table [2] Shows that the voltage of pot(Vo/p) is less than 07H, then do nothing, and when 07H<=(Vo/p) <=1FH then activate one MW as following:

0 MWs
00H<=(Vo/p) <07H
1 MWs
07H<=(Vo/p) <1FH
2 MWs
1FH<=(Vo/p) <3FH
Number of activated MWs= 3 MWs
3FH<=(Vo/p) <FFH
4 MWs
(Vo/p) <=1FH

The previous conditions must be controlled accurately and that is possible using a control program.

E-Control Program

Control program (controller) is built in a microcontroller IC AT89C51 version using assembly language. It is clearly described in the following flow chart shown in Figure[15]:

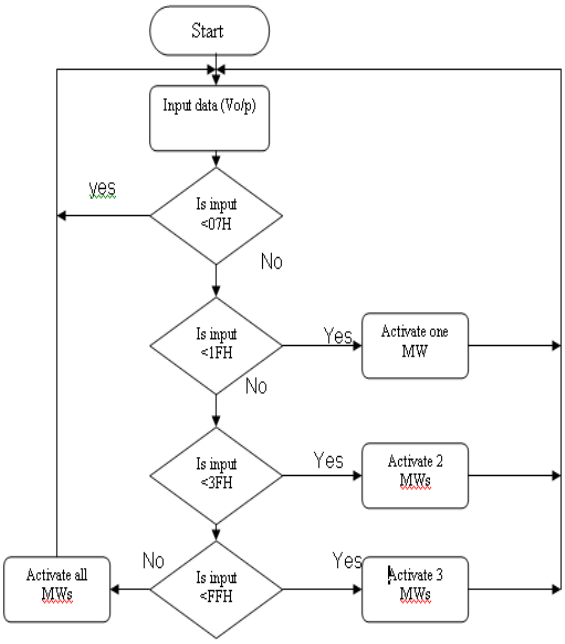

Fig. 15. The Flow Chart of the Control Program.

The electronic circuit is shown in Figure [16] and is described clearly in a block diagram shown in Figure [17].

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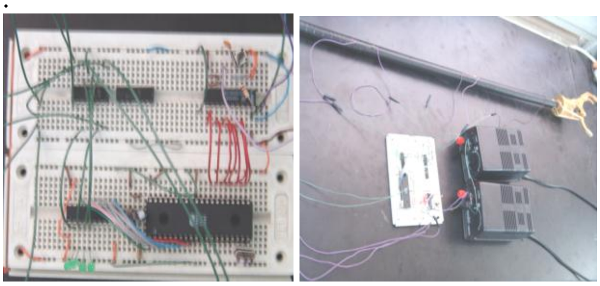

Fig. 16. Control Circuit.

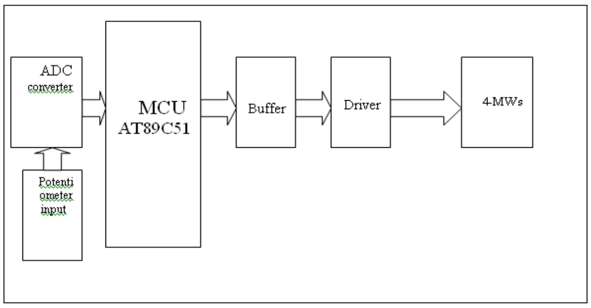

Fig. 17. Block Diagram of the Control Circuit.

To discuss the force generated on the proposed hand, it must first to analyze the force generated by a single activated muscle wire. Fortunately, it is well known that the recommended recovery weight for a single MW (which is generated from applying a recommended current) of 100μm generated about 1500 N when activated. Since the MWs of the proposed hand connected in series, the effort (force) therefore is duplicated simply through activation more MWs as shown clearly in Figure [18].

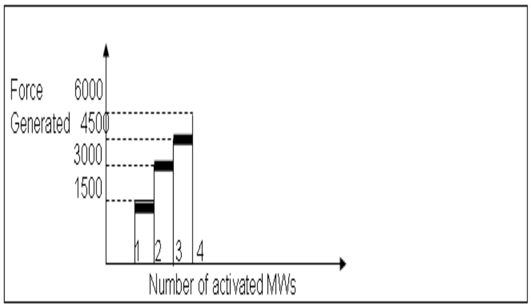

Fig. 18. Force Generated as a Function of no. of Actived MWs.

4-Conclousion

In this study the design for a two fingered hand actuated by electrical artificial muscles is presented. Four experimental prototypes of a hand were described and used to evaluate the design. A modified hand with direct control has been designed using electrical muscle wires that receive direct sensory impulses through shoulder harness instead of using the mechanical action to open and close the hand. Each finger is designed as a chain and its movements achieved through the conventional arrangement control of the electrical muscles wires. An important aspect of the rapid prototype technique was used that this hand will be fabricated in one step, without requiring assembly, while maintaining its desired mobility. The use of muscle wires actuators combined with the rapid fabrication of the non-assembly type hand; reduce considerably its weight and fabrication time. This will make it very useful to be used for applications requiring low weight

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يد انسان آلي صغيرة ثنائية الأصابع تقاد بواسطة مشغلات الأسلاك العضلية

عبد السلام العامري، بهاء ابراهيم كاظم، يعرب عمرناجي
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الخلاصة

في هذا البحث تم تصميم يد اصطناعية يتم التحكم بها بشكل مباشر عن طريق أسلاك عضلية اصطناعية كهربائية تأخذ إشارة تفعيلها مباشرتا من اليد البشرية بدلا من فعل ميكانيكي لأجل فتح و غلق هذه اليد الاصطناعية. كل إصبع مصمم من سلسلة ميكانيكية يتم تحريكها من خلال ترتيب تقليدي للسيطرة على العضلات الاصطناعية الكهربائية.لقد وضحت النتائج العملية و النظرية انه من الممكن تصميم يد اصطناعية يتم التحكم بها باستخدام أسلاك عضلية اصطناعية كهربائية و بدقة عالية.