International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:7, No:1, 2013

Development of UiTM Robotic Prosthetic Hand

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***Abstract*—**The study of human hand morphology reveals that developing an artificial hand with the capabilities of human hand is an extremely challenging task. This paper presents the development of a robotic prosthetic hand focusing on the improvement of a tendon driven mechanism towards a biomimetic prosthetic hand. The design of this prosthesis hand is geared towards achieving high level of dexterity and anthropomorphism by means of a new hybrid mechanism that integrates a miniature motor driven actuation mechanism, a Shape Memory Alloy actuated mechanism and a passive mechanical linkage. The synergy of these actuators enables the flexion-extension movement at each of the finger joints within a limited size, shape and weight constraints. Tactile sensors are integrated on the finger tips and the finger phalanges area. This prosthesis hand is developed with an exact size ratio that mimics a biological hand. Its behavior resembles the human counterpart in terms of working envelope, speed and torque, and thus resembles both the key physical features and the grasping functionality of an adult hand.

***Keywords*—**Prosthetic hand; Biomimetic actuation; Shape Memory Alloy; Tactile sensing.

I. INTRODUCTION

A MORE recent development in lightweight robotic hand, such as prosthetic hands, has spawned a number of innovations. A lightweight robotic hand with 16 controlled DOF and 32 independent SMA axes was developed by Cho et.al. [1], using a joule heated Segmented Binary Control (SBC) to perform various tasks required for a robotic hand. A coordinate transformation architecture (C-Segmentation) is designed automatically through an algorithm to create a set of desire posture (up to 256 different postures) which able to reduce activation signal dimensionality.

Innovative trend of dexterous robotics multi-fingered hand based on biomemetic initiatives exhibits tremendous effort in the current research activities. For instance a tendon-drive actuation system with biomemetic oriented functionalities has been developed by Bundhoo et. al.[2], for prosthetic and wearable robotic hand applications. A combination between tendon cables and one-way shape memory alloy (SMA) wires is presented to form a set of artificial muscle pairs for flexion and extension of finger joint.

In biomimetic robotic hand and control scheme several research activities have been developed for instance by Seokwon et. al. [3]. With respect to the dexterity and the size suited for human tools, four robotic fingers were built with nine DOFs driven by two linear actuators coupled and linkage knuckles. Tactile sensors are equipped on four fingertips which able to influence toward objects by curved surface workspace in 3D-space.

A concept for controlling a grasp for an anthropomorphic mechatronic prosthetic hand have presented by Wettels et.al. [4], utilizing a biomimetic tactile sensor, Bayesian inference as well as simple algorithms for estimation and control. The grasp control is supported by tri-axial force sensing end-effector for calculation the normal and shear forces at the fingertips so that able to maintain perturbed objects and also prevent slip. In addition to support rapidity and reflexive adjustments of grip, biologically-inspired algorithms and heuristics are used and implemented by on-line.

A new design for a rotary motor-based actuation system for a single revolute joint of a tendon-driven robotic hand has been created by Hellman et. al.[5]. This design is fit to N-type (double-acting actuation) or 2N-type (single-acting actuation) control configurations, where the system possesses a two-stage, zero backlash, pretensioned pulley reduction which enable to control high precision of tendon displacement and force, as well as back-driveability of the motor.

In the case of complex tendon configuration, Sawada et.al. [6], proposed a method of a joint feedback controller for tendon-driven mechanisms (TDMs). This method utilizes a concept of branching tendons in which multiple tendons are connected at a point so that a number of actuators required to create a lightweight robotic mechanisms, such as prosthetic hands, can be reduced. However TDMs with branching tendons is used only for simple adaptive grasping mechanisms due to under-actuation of branching tendons having difficulties in accuracy of control the joint motion.

II. INITIAL PROTOTYPE OF UITM HAND

The first robotic hand developed in Universiti Teknologi MARA (UiTM) consists of five permanent fingers and a palm. In the grasping motions, the thumb comes from the opposite direction to the other fingers to produce a better grip. Each finger is driven by a servo motor, and the rotation is transmitted through a gear belt mechanism. Thus, there are 5 DOF [7]. The motor generates finger movement through three gears in the fingers, one for each member connected with a belt and with a fixed gear on the last segment, as shown in Fig. 1. Exclusion is the thumb with only two members, but the functions and working principle remains the same. Three modes of system control for the robotic hand are possible, i.e. manual control by means of a joystick or a graphical user interface as well as autonomous operation.

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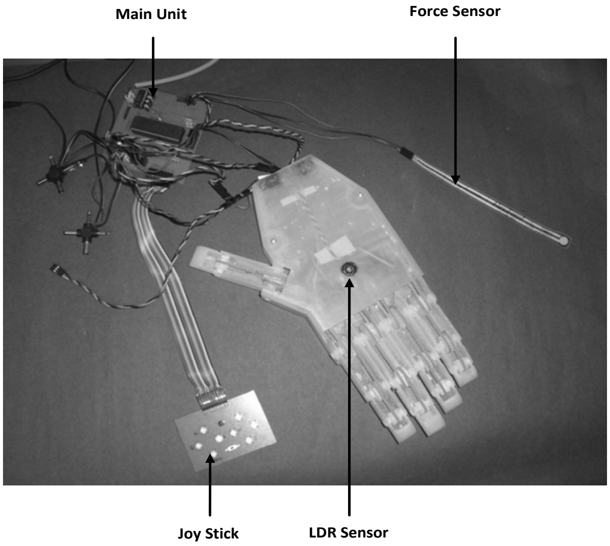


Fig. 1 Initial UiTM Robotic Hand

Joystick control: A joystick is a control board. Pressing the buttons on the board triggers the motion of a motor in the forward or reverse direction. As such a finger is stretched or bent. A switch is used for controlling the power supply and device reset. A red LED indicates the operation state.

Graphical User Interface: A Graphical User Interface (GUI) as shown in Fig. 2 has been developed using Visual Basic.net. Each of the fingers can be controlled individually. Selection of multiple fingers is also possible. Besides, there are two buttons for performing the grasping and release movements. All fingers can operate at the same time and can simulate human hand motion using the GUI.

Autonomous operation: Two types of sensors are used, i.e. a force sensor and a light dependent resistor (LDR). With the LDR added to the palm, it is feasible to detect an approaching object and react on this event with a grasping movement. Programming is downloaded to microcontroller to make each finger to act like human hand. The force sensor will measure the force performed by a finger on a grasped object variable size.

In order to produce a better hand grip, a light dependent resistor (LDR) sensor is added to the palm. The LDR come into operation with the aim to detect approaching objects. The light dependent resistor value changes in relation to the incident light. It is placed in the middle of the palm. Therefore, approaching objects will reduce the incident light and cause a decrease in the resistance. This change will be captured by the micro-controller in the form of a number of voltages provided by the voltage divider. If the object comes closer than this limit, the hand will perform grasping movements.

Additionally, FlexiForce sensors are integrated into the fingertips. Force ranging from 0 N to 15 N is applied during testing to mimic the natural ability of the human fingers in applying force to an object. The sensor acts as a resistor in an electrical circuit that is changing. Resistance change when force is applied to the sensor. The prototype allows grasping objects with all five fingers, as shown in Fig. 2. Tests were carried out with cylindrical objects such as screwdriver. These tests have shown that this system is able to perform gross grasping movements. This initial prototype uses servo motor as the prime mover of the tendons that connects to each cable connection. Finger robot can follow the shape of the object but the griping power generated to the object is not satisfactory.

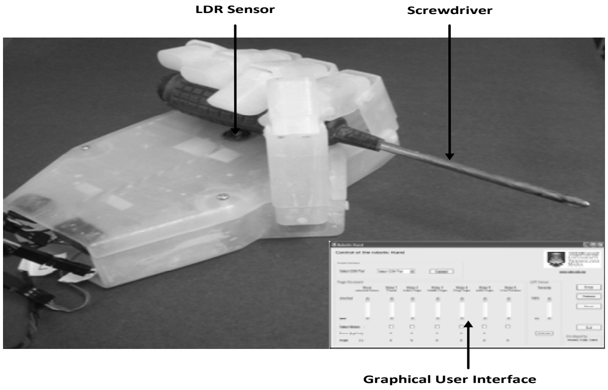


Fig. 2 Grasping of a Screwdriver

Realizing the importance of robotic technology to the amputees, improvements in terms of both actuation and sensing are carried out towards a UiTM robotic prosthetic hand.

III. IMPROVEMENT ON ACTUATION METHOD

Actuators for hand prosthesis must be installed in a confined space and can produce force and stroke which are large enough to allow motion as a means for grasping fingers. Therefore, selection of actuators in prosthetic hands is very important. Some challenges include achieving consistent motion like a natural human hand, light weight, noiseless operation, anthropomorphic size and appearance, agility, compact, controllability, low cost, and safety of the amputees. This part focuses on the factors driving the selection of an appropriate actuator for use in prosthetic hand. Research focuses on the use of two types of SMA wire actuators and a DC motor.

DC motor: DC motor operating noise and limited energy density leads to large motor drive system and heavy weight [8]. Therefore, many researchers started using micro-sized DC motor with a diameter of 6mm to 15mm as a solution to this problem. Commonly used micro-sized DC motors include Faulhaber [9],[10] and Maxon DC motor [11], [12]. The advantage of using DC micro motor is that it can be easily adapted in prosthetic hand because of its small size. In addition, the motor is equipped with a special type of head gear and encoder direction which makes it feasible for precision application. However, DC micro motor is not the best solution for prosthetic hand. This is because a DC motor only offers one DOF. This affects the weight of the hand. In addition, the smaller the diameter of a motor, the lower is the motor torque value.

Shape Memory Alloys: Shape memory alloys are used extensively beginning in 1960 by the U.S. Naval Ordnance Laboratory. Nitinol is an abbreviation to Nickel (NI) Titanium (TI) marine laboratory equipment (NOL) [13]. Nitinol wire is commercially available under the trademark "Flexinol" by Dynalloy. SMA wires are small compared to motors or solenoids, cheap and generally easier to use for a wide variety of applications [14]. SMA has been identified as an ideal candidate to move the finger joints because of its small size, high power to weight ratio and operational similarity to human muscles [15]. In recent years, SMA has attracted the attention of researchers in the field of robotic prosthesis. Some famous SMA actuated prosthetic hand including Hitachi Hand [16], Hands Rutgers [17], Hand SBC [1] and other recorder authors like K. Andrianesis, [18], Beng Guey Lau [12], V. Bundhoo [15].

Hybrid Solution: In order for prosthetic hands to be more viable, a new mechanism should be designed to enhance the ability of the prosthetic hand. The solution is to combine the micro DC motor and SMA wire. The advantage of a hybrid solution is shown in Fig. 3. It improves response and reduces both noise and weight. The SMA wire with a small size and strong actuation force improves the anthropomorphism of the device one step closer to the human hand.

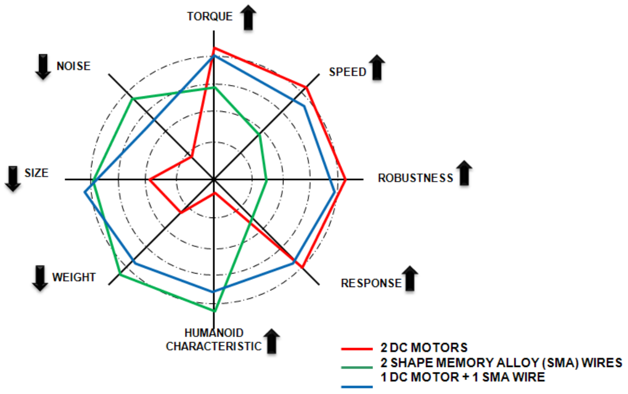


Fig. 3 Advantages of a hybrid actuation solution

The design concept for a hybrid solution is shown in Fig. 4. Small DC motor and SMA wires are used to move the MCP joint and PIP joints independently. SMA wires are integrated into the mechanism of hand prosthesis. DIP joint rotates in correspondence to the PIP joint rotation by means of a mechanical linkage. MCP joint can be rotated without forcing the PIP joint to rotate together.

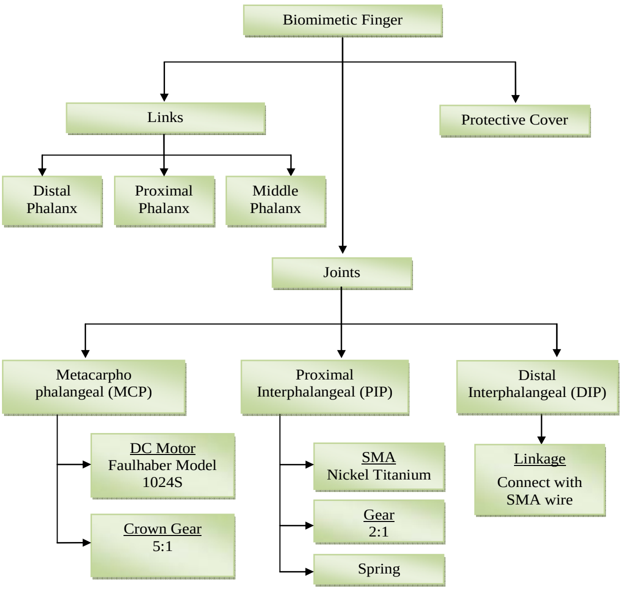


Fig. 4 Design concept of a hybrid actuation solution

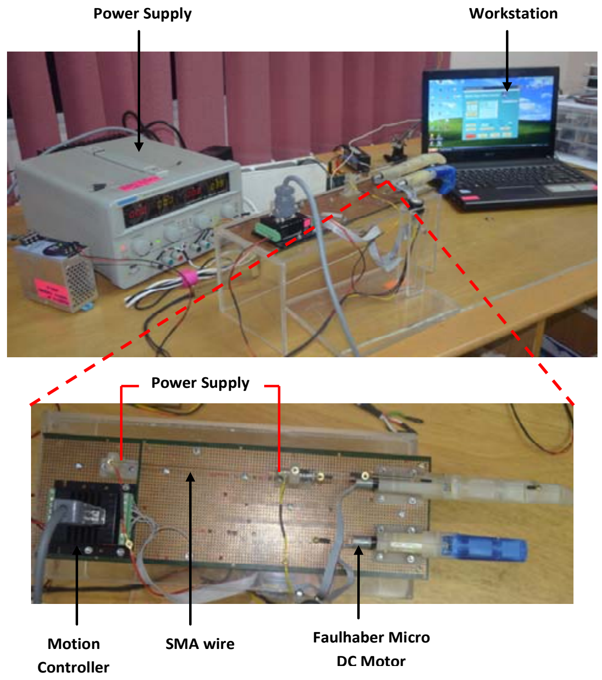


Fig. 5 Experiments setup for testing of a hybrid actuated prosthetic finger (SMA wire and Faulhaber DC Micromotor)

The key task is to ensure that SMA wires produce substantial contraction and stable force. Therefore, tests were carried out to identity the characteristics of SMA wire and to obtain the range of parameters to be used later as actuators in the prosthetic hand [19]. In addition, a finger prototype actuated by SMA wires and Faulhaber DC Micro Motor was developed. The finger prototype and the experimental set-up are shown in Fig. 5. The Faulhaber DC Micromotor is controlled by graphical User Interface (GUI) programmed in

Visual Basic while the SMA wires are controlled by direct current [19]. The results from the testing conducted are shown in Fig. 6. The SMA wire which is 0.381mm in diameter can produce a satisfactory driving force under 10 seconds speed movement with strength of 35N. The SMA wires can also be contracted by 4% of its original length with a direct current input of 2.6A. The Faulhaber DC Micromotor can produce a perfect initiation. Nevertheless, the DC motors also produce a slight noise caused by friction on the surface of the gear which can be avoided by using lubricants.

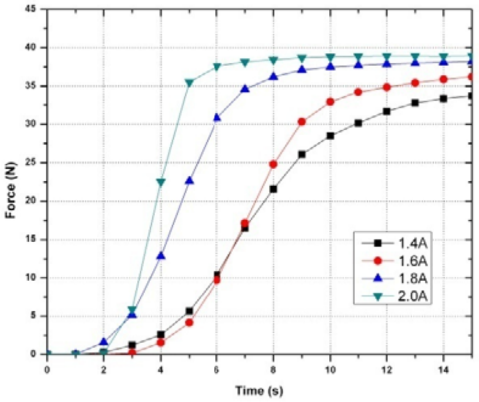


Fig. 6 Force produced by SMA wire during contraction subject to varying input current

IV. IMPROVEMENT ON TACTILE SENSING METHOD

Tactile sensing it is a very important fundamental in humanoid robot as well as prosthetic hand. However, many researchers are not paying much attention on the sensory modality [20]. It is aimed to embed this functionality into the prototype robotic hand. While the prototype is equipped with Light Dependent Resistor (LDR) sensor on its palm, this sensor alone is not able to detect object's slip and makes grasping task impossible to be done. To enable the hand for such tasks, it must be equipped with an array of tactile sensor on the finger tips as well as the finger phalanges area.

A. Quantum Tunneling Composites (QTC) Pills

A new material that is suitable to be used as a sensor transducer for the prototype robotic hand has been identified. The Quantum Tunneling Composite (QTC) is a new material that has promising properties to be used as a tactile sensor. QTC has been used widely for tactile sensing in the Shadow Dexterous Hand [21], [22]. It has the ability to change from a good insulator to conductor by applying force or pressure. With QTC, there is no contact with the individual metal/ carbon particles, but rather the quantum tunneling effect takes place. The more it is compressed, the more particles are brought closer together to reduce the potential barrier and increase the tunneling effects and exponentially reduce the electrical resistance [23]. Among the reasons why this material is chosen in this research is that it is suitable to be used in tactile sensor application. The suitability of this material includes [23]:

a) Mechanically and electrically stable;
b) Exhibit features whose resistance changes with force/ pressure which can be used as a piezoresistive based sensor;
c) Incorporate, coat or impregnate to product surfaces i.e. QTC ink.
d) Form or mold into virtually any size, thickness or shape i.e. QTC pills which make QTC a flexible material.
e) Availability and affordability.

To assist the prototype robotic hand in tactile sensing, preliminary experiments are conducted to explore the properties of this material. This is done on a fanning strip sensor board with different separation paths. Hence, this study aims to ascertain the viability of using QTC for tactile sensing in the setup mentioned. The work also proposes control method for the tactile sensor.

B. Resistivity Properties of QTC

In this part of the study, resistance measurements are carried out, in order to establish the properties of QTC pills material. The resistance behavior of material could be established under different pressures. The experimental setup to investigate the resistance behavior is shown in Fig. 7.

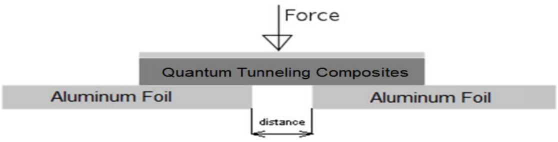
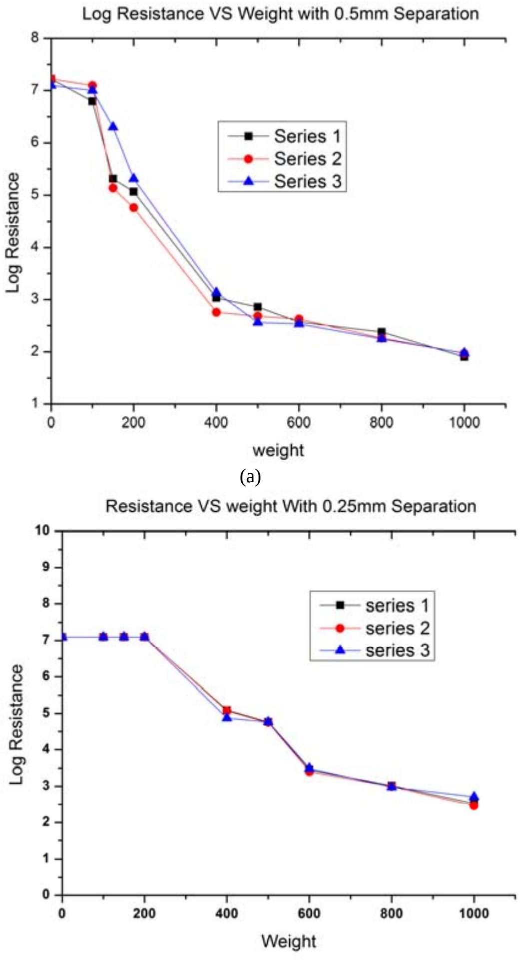


Fig. 7 Experimental Setup

Aluminum foil is used to imitate the conductive environment of the sensor board. The separation distances between the conducting contact surfaces are set at 0.5mm and 0.25mm which actually represents the distance between contact surfaces of the fanning strip. The test will be able to determine which separation distance work more effectively for fanning strip design. A set of two 9mm^2 QTC pills are laid between the aluminum gaps. A transparent film is then used as an insulation material and loads ranging between 100g and 1000g are applied. The resistance changes with load variation are then measured by using a multimeter.

C. Resistivity Behavior of QTC with 0.5mm and 0.25mm Separation Gap

Fig. 8 shows the experimental results of resistivity behavior of QTC between two different separation gaps. This gap will represent the most effective value that can be used in fanning strip design. Both Fig. 8(a) and 8(b) show a higher degree of coincidence with each other. The resistance measurements also show that QTC pills exhibit stable and reproducible values. However, the rate of resistance declining for 0.5mm separation value is more stable as compared to the 0.25mm separation gap at a weight lower than 200g.



(a)

(b)

Fig. 8 Comparation of resistivity behaviour of QTC Pills between 0.5mm and 0.25mm separation gap

V. CONCLUSION

The development of a UiTM robotic prosthetic hand has been presented, focusing on improvements of the actuation and tactile sensing methods. Hybrid actuation solution by combination of a SMA wire and a DC micromotor promises great potential for improvements of actuation in hand prosthesis. Besides reducing the weight of prosthetic hand to a satisfactory level, the noise generated from actuation is also reduced. The force generated by the actuator has been tested and is satisfactory for prosthetic applications. Furthermore, QTC pills are evaluated to be suitable materials that can be used for tactile sensing as it produces stable and reproducible values.

ACKNOWLEDGEMENT

The research team wishes to thank the Ministry of Science, Technology and Innovation (MOSTI) for the financial support and the Research Management Institute (RMI) of UiTM for the support.

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