A Low Cost Anthropomorphic Prosthetic hand Using DC Micro Metal Gear motor

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***Abstract*—This research focus on developing of low cost anthropomorphic prosthetic hand using DC micro metal gear motor. The DC metal gear motor is selected as actuator because it is easy to find, low cost, and light weight. The prosthetic hand is based on 3D printed material that enables it light weight, low cost, easy to manufacture and easy to maintain. The mechanism of the hand is based on the tendon spring mechanism. The prosthetic hand has five degree of freedom (DOF) and two joints in each finger. For performing the activities of daily living (ADLs), the hand is designed with seven grip patterns. Based on the experimental results in grasping test and writing test on the white board, the hand can be used as low cost prosthetic hand replacing the passive prosthetic hand that has been available on the market.**

Keywords—low cost; DC motor; prosthetic hand; anthropomorphic

I. Introduction

The research of robotic hand has grown significantly especially in the development of robotic prosthetic hand ranging from research hand to commercial hand. The available prosthetic hand in the market with great features is very expensive that make it only certain people can buy it. The purpose of this research is to develop a low cost prosthetic hand using widely used mechatronics components. The hand must be easy to manufacture, and easy to maintain with the available component in the market. The prosthetic hand also must be able to perform activities of daily living (ADLs) such as take, grasp, and hold an object.

Some researches about prosthetic hand significantly increased in the size, weight, and anthropomorphism. The prosthetic hand is used to replace the lost hand especially for transradial amputation. In order to the prosthetic hand can move using command from the remaining muscle of the amputee, the hand must read the muscle activities by using sensor. The most widely used sensor for reading the muscle activities is electromyography (EMG) sensor. Some research hands use pattern recognition method of the EMG signal to distinguish the hand movement or gesture. One of common pattern recognition method in the EMG signal recognition is neural network [1,2]. This method is difficult to implement in the prosthetic hand control system due to the limitation of hardware memory in the microcontroller. The simple control algorithm is developed in this research using the same EMG or potentiometer signal to drive several grip pattern of prosthetic hand.

Some open source hand is available today to reduce the cost and to increase manufacturability. Open source prosthetic hand based on 3D print are widely used Ada Hand [3] from Open Bionics and Dextrus [4] from Open Hand Project. The state of the art prosthetic hands commercially available are Vincent Hand [5], Michelangelo [6], Bebionic [7], and iLimb [8]. They have great performance in ADLs especially for object grasping manipulation but they are still very expensive.

In this paper, the research goal is try to develop an affordable five DOF robotic prosthetic hand using widely used low cost DC metal gear motor incorporating tendon-spring mechanism. The proposed of the prosthetic hand must be able to grasping task with various objects and perform activities of daily living (ADLs). Based on the ref [9], the most used grasping pattern is power grip followed by precision grip. The prosthetic hand is designed with seven grip pattern to perform object grasping manipulation.

II. Prosthetic hand Design

In this paper, five degree of freedom (DOF) prosthetic robotic hand was proposed and designed using commonly used DC motor. Each finger comprises of two joints and one DC Micro Metal Gear motor. As summarized in Table I, many of robotic prosthetic hand have five DOF and six DOF. The thumb has one DOF or two DOF. The five DOF is selected because it can do sufficient ADLs, reduce the complexity of mechanism design, and also reduce the manufacture cost. Most of prosthetic hands implement linkage and spring-tendon mechanism. The proposed prosthetic hand is named AstoHand v.1.

The distal interphalangeal (DIP) joint was designed with fixed angle at 20 degrees. Where the metacarpo-phalangeal joint (MCP) and proximal inter-phalangeal (PIP) joint can be rotated from 0 degree to 90 degrees. A torsional spring is used in the middle of 1 mm shaft. The shaft is utilized as joint in each finger.

The tendon-spring mechanism is connected to DC Micro Metal Gearmotor. For finger flexion or closing mechanism of the fingers, the DC motor rotates and pulls down the finger. For the extension or opening the finger, the DC motor rotates in counter direction and the spring-torsion will move the finger.

The hand is designed using SolidWorks Computer Aided Design (CAD) software. SolidWorks is utilized because of easy to use and operate. The solid model of prosthetic hand design can be exported into SimMechanics model for 3D animation and kinematics analysis purposes. The 3D CAD model of the prosthetic hand cover can be seen in Fig. 1. In order to the proposed of prosthetic hand has the same size and weight with the natural human hand, all of mechatronics component has are designed to fit into the hand. Five DC motor are placed in the palm. Arduino Nano microcontroller, PCB, and driver motor are place in the back cover of the hand. The battery is placed on the socket or out of the hand.

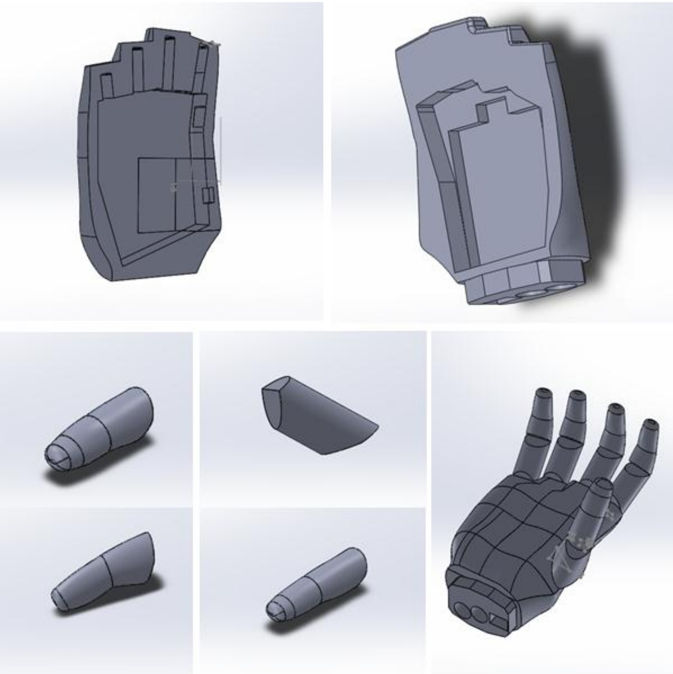

Fig. 1. Finger, palm, and hand design in SolidWorks.

After the 3D model is developed in SolidWorks, the model needs to be printed using 3D printer. The hand is made from PLA (Polylactic Acid) material. The material is selected due to lightweight property. The 3D hand model of this prosthetic hand is inspired by Ada Hand from Open Bionics. The 3D print results of palm, back cover and the fingers are shown by Fig. 2. The length of each finger is summarized in Table I. The length of distal medial in index, middle, and ring is designed with the same length. The final assembly if proposed prosthetic hand, sensor, and battery are shown in Fig. 3.

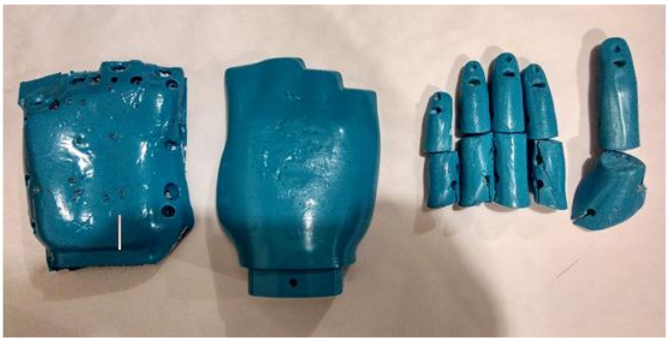

Fig. 2. The Developed prosthetic hand.

TABLE I. THE FINGER LENGTH OF PROSTHETIC HAND

Fingers	Distal Medial (mm)	Proximal (mm)
Thumb	61	40
Index	41	42
Middle	41	44
Ring	41	42
Little	34	34

The size of the prosthetic hand is 180 mm in length, 85 mm in width, and 50 mm in thick. The overall mass of the prosthetic hand is 261 grams. The size, shape, and weight of the prosthetic hand approach with the human natural hand. This is very lightweight prosthetic hand, when the user/transradial amputee used it as prosthetic hand, the user can manipulate object grasping task without feels fatigue. The general characteristics comparison of AstoHand v1.0 can be summarized in Table 2. Based on the Table II, the mass of available robotic hand varies from 261 gr to 760 gr.

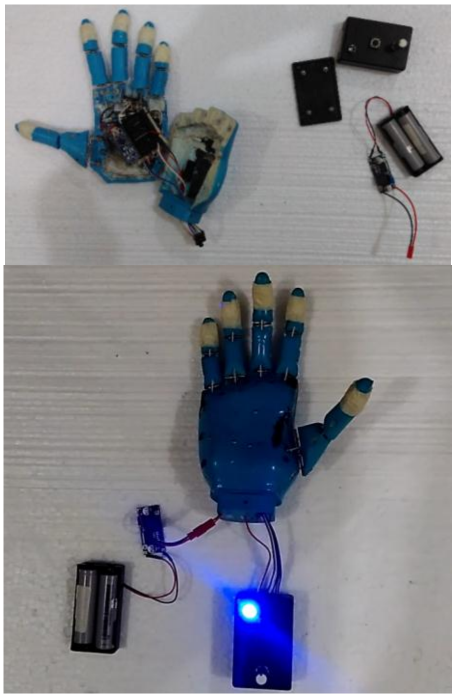

Fig. 3. Complete hardware system of robotic prosthetic hand.

TABLE II. GENERAL CHARACTERISTICS OF SOME PROSTHETIC HANDS

Hand	Develo-per	Mass (g)	Size (length x width x thickness, mm)	Numb. of Joint	DOF	Numb. Of Actua-tor	Motor Actu-ator Type	Joint couple method
Asto Hand v.1 (2016)	Dipone-goro University	261	180 x 85 x 50	10	5	5	DC Motor	Tendon - spring
Ada Hand (2016) [3]	Open Bionics	380	215x 178 x 58	10	5	5	Lead screw	Tendon
Dextrus (2013) [4]	Open Hand Project	428	205 x 88 x 45	15	6	6	Ten-don DC Motor	Tendon
Vincent Hand (2010) [5]	Vincent system	-	-	11	6	6	worm gear Motor	Linkage
Michelan gelo (2012) [6]	Otto Bock	420	-	6	2	2	-	Cam design to all finger
Bebio-nic (2011) [7,10]	RSL Steeper	495-539	198 x 90 x 50	11	6	5	Lead Screw Motor	Lingkage
Bebio-nic v2 (2011) [7,10]	RSL Steeper	495-539	190-200 x 84-92 x 50	11	6	5	Lead Screw Motor	Lingkage
iLimb (2009) [8,10]	Touch bionic	450-615	180-182 x 75-80 x 35-41	11	6	5	worm gear Motor	Tendon
iLimb Pulse (2010) [8,10]	Touch bionic	460-465	180-182 x 75-80 x 35-45	11	6	5	worm gear Motor	Tendon

III. HARDWARE AND SOFTWARE SYSTEM

In this section, the hardware and software will be presented and discussed. The main hardware components in in the hand are Arduino Nano microcontroller, using DC micro metal gearmotor, PCB, and motor driver. The control algorithm and operation system of the robotic prosthetic hand are developed in MATLAB/Simulink environment.

The utilized five DC micro metal gear motors is shown in Fig. 4. The total mass of the motor is 45 gr. L293D Dual H-Bridge is used to control the direction of rotation and angular speed of motor. The general properties of this motor can be summarized in Table III. This motor is selected as an actuator in the prosthetic hand because it gives enough torque to drive the fingers with tendon spring mechanism. Furthermore, the motor consume low energy when the motor is run.

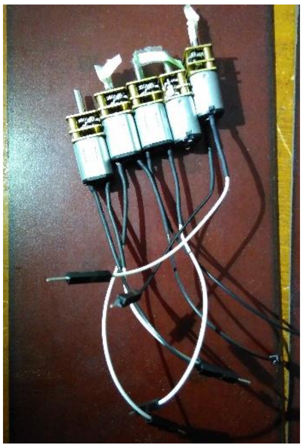

Fig. 4. Five DC micro metal gearmotor GA12 N20 as actuators.

TABLE III. DC MICRO METAL GEARMOTOR PROPERTIES

Properties	Values
Working voltage	2 – 6 V
Current consumption with load	40 mA
Current consumption with no load	360 mA
Maximum angular velocity	300 rpm @ 6VDC

For the brain of the prosthetic hand, Arduino Nano is chosen because it is an open source and open hardware platform. Moreover, Arduino Nano can be programmed using widely used computational software like MATLAB/Simulink. It has 32 KB flash memory for saving the operation program of prosthetic hand. It also has 14 digital input output (DIO) pin which make it suitable for controlling five DC motor as actuator. Two 18650 Li-Ion batteries is employed in the hand as power source of the motors, RGB LED, driver motor, and Arduino Nano microcontroller. The battery is arranged in series. Each battery has voltage of 3.7 V and capacity of 2425 mAh. Before the power from battery goes to the motor and micro controller, it passes to step down LM2596 for converting the voltage from input with 3-40 V to output 1.5-35 V. The selected output voltage is 5 V.

Fig. 5. 18650 Li-Ion battery.

The total mass of the hand excluding the battery and sensor is 261 gr. The most weight of the prosthetic hand component is 3D print material and the tendon spring-mechanism of the hand which can reach to 70 % of overall prosthetic hand weight.

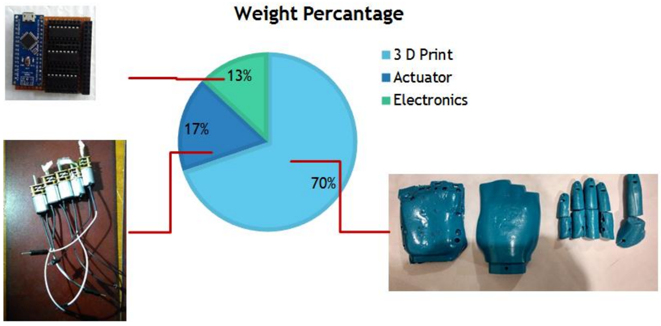

Fig. 6. Mass percentage of the proposed prosthetic hand.

For the operation of prosthetic hand, the control algorithm is developed in Simulink as can be seen in Fig. 7. The block is embedded into Arduino Nano using Simulink Support Package for Arduino that can be freely downloaded on MathWorks Website. The electromyography (EMG) or potentiometer can be used as sensor input to the hand system. The sensor output is red using Analog input Block. The digital input is used to read the tactile switch state for selecting the seven grip patterns. The counter computation is used for running the loop of seven grip patterns. The motor rotation direction is determined by using digital output block and the angular speed is controlled using PWM output block. The flow chart of the AstoHand v.1 operation system is depicted in Fig. 8. The current grip pattern is indicated by the color of RGB LED. AstoHand v.1 can communicate with computer via serial USB. The communication is based on an 115200 baud rate, 8 bit word, 1 stop bit, and no parity.

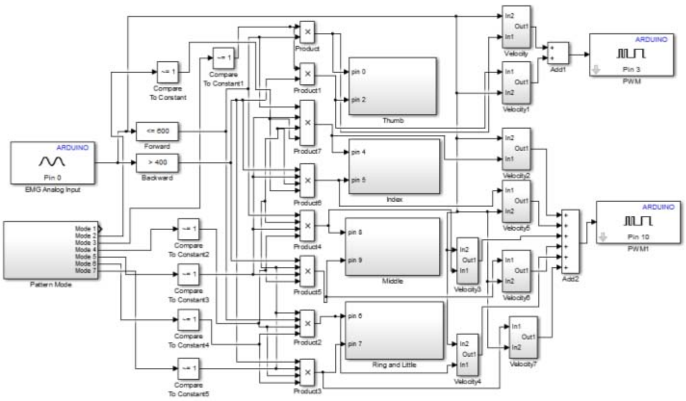

Fig. 7. Embedded block diagram of prosthetic hand control.

IV. Experiments and Results

After assembly process of prosthetic hand main parts, the proposed hand is tested in grip pattern, grasping, and writing test. In the grip pattern test, the hand is tested to perform seven grip patterns using potentiometer as signal input. Based on the experimental result shown in Fig. 9, the prosthetic hand can successfully perform seven grip patterns. The seven grip patterns are power grip, index, hook, pinch, peace, tripod, and active thumb. The running current grip pattern is indicated with the corresponding RGB LED on the back cover of the prosthetic hand.

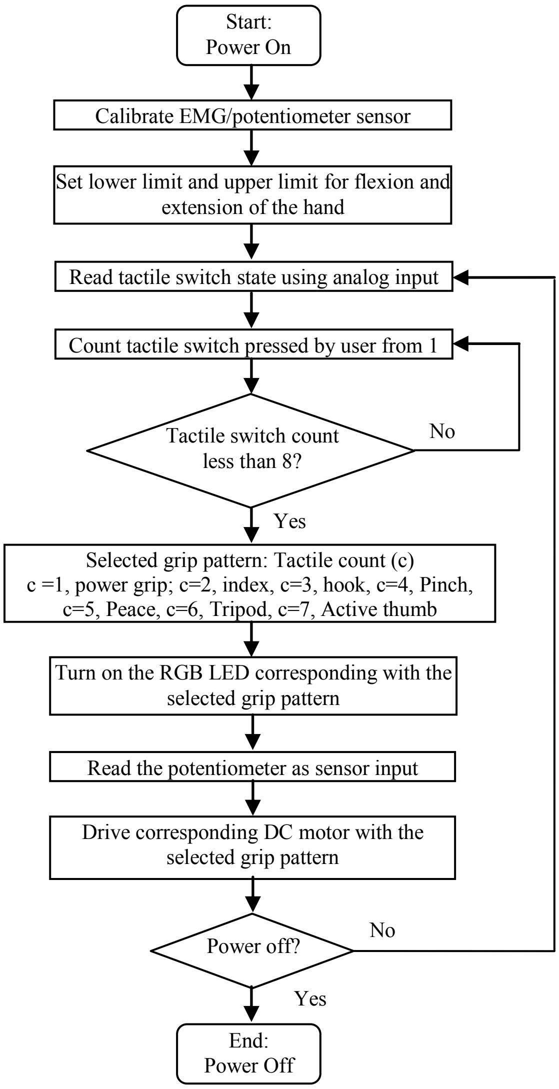

Fig. 8. AstoHand v.1 operation system.

Seven grip patterns as shown in Fig. 9 are selected because it can perform activities of daily living (ADLs) such as grasping and hold various shape and size of the objects. In the next test, the proposed prosthetic hand is tested to take, grasp, and hold six objects. Based on the experimental result as shown in Fig. 10, the prosthetic hand can stably grasp various objects such as water in the bottle, water in a cup, glue gun, screwdriver, TV Remote, and pliers. In the final test, prosthetic hand is tested to take and grasp the black marker then write the words “Asto Hand v10” on the whiteboard. The prosthetic hand can successfully write the word using black market as shown in Fig. 11. The performance of the proposed prosthetic hand can be seen online on YouTube at https://www.youtube.com/watch?v=qg3TugzrXFI.

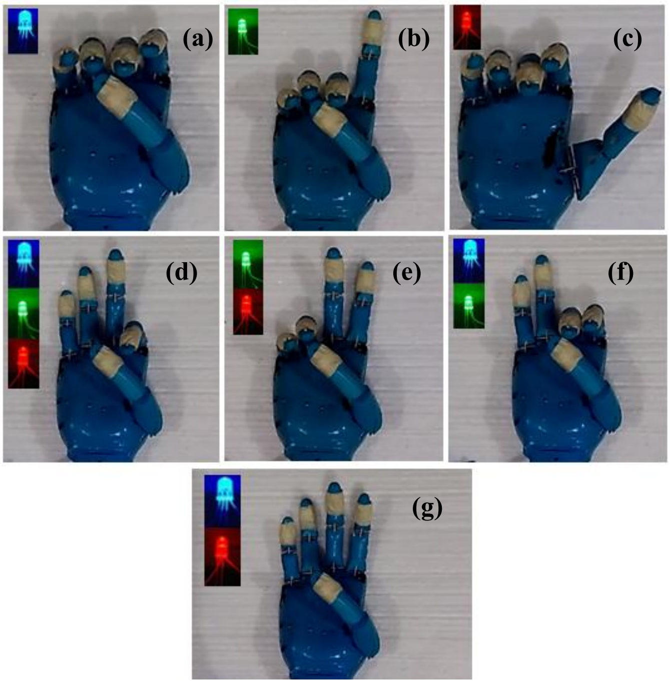

Fig. 9. Grasping pattern of proposed prosthetic hand: (a) Power grip, (b) index, (c) hook, (d) Pinch, (e) Peace, (f) Tripod, (g) Active thumb.

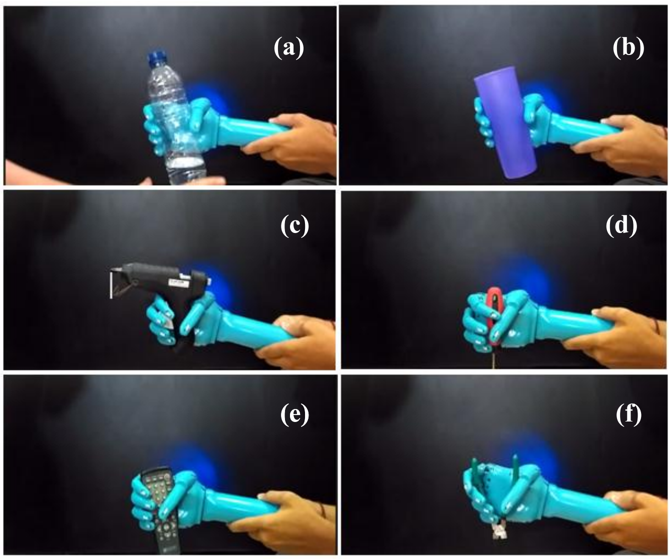

Fig. 10. Various objects grasping of robotic prosthetic hand: (a) Water in the bottle, (b) Water in a cup, (c) Glue gun, (d) Screwdriver, (e) TV Remote, (f) Pliers

V. CONCLUSIONS

The proposed of the prosthetic hand has 261 grams in weight. The DC motors as actuator give the hand lightweight structure and low cost prosthetic hand. This hand can be used as prosthetic hand for transradial prosthesis because of its size and weight which approach the human hand. The prosthetic hand also has seven grip patterns that enable it to do activities of daily living (ADLs). The grip pattern can be selected by pressing the tactile switch. The corresponding RGB LED will turn on to indicate the selected current grip pattern. Based on the experimental on gripping task, the prosthetic hand can stably grasp and hold six objects ranging in size and shape. The hand can also do a writing test on whiteboard. Based on the experimental results, the hand can be used as low cost prosthetic hand replacing the passive prosthetic hand that available on the market. For further development, the hand will be integrated with socket, and 3D Animation.

Fig. 11. Sequence images of writing test.

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