Anthropomorphic transradial myoelectric hand using tendon-spring mechanism

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TELKOMNIKA, Vol.17, No.1, February 2019, pp.537~548
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v17i1.11600

Anthropomorphic transradial myoelectric hand using tendon-spring mechanism

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Abstract

In the developing countries, the need for prosthetic hands is increasing. In general, transradial amputee patients use prosthetic hands that are passive like a body-powered prosthesis. This research proposes a low-cost myoelectric prosthetic hand based on 3D printing technology. Hand and finger size were designed based on the average size of human hands in Indonesia. The proposed myoelectric hand employs linear actuator combined with the tendon-spring mechanism. Myoelectric hand was developed with five modes of grip pattern to perform various objects grasping in activity of daily living. Control strategy had been developed for controlling the motion of flexion and extension on the hand and saving the energy consumed by the actuators. The control strategy was developed under MATLAB/Simulink environment and embedded to Arduino Nano V3 using Simulink Support Package for Arduino Hardware. Surface electromyography (EMG) sensor was used in this research for reading the muscle activity of the user/wearer. The proposed myoelectric hand had been tested in object grasping test and was implemented on a study participant with transradial amputee.

Keywords: *3D printing, low-cost, myoelectric, prosthetic hand, tendon-spring*

1. Introduction

Myoelectric prosthetic hand is a wearable robot that resembles human hands and can move like a human hand such as taking, grasping, holding, and putting an object. Due to limitations in performing activity of daily living by a handicapped person, the myoelectric prosthetic hand becomes a device needed by handicapped persons. With a myoelectric prosthetic hand, people with disabilities can be helped in carrying out their normal activities. In developing countries, the widely used prosthetic hands are still passive prosthetic hand or body-powered prosthetic hand. Recently, the myoelectric hand manufacturers that are available in the market today include Bebionic [1], ILimb hand [2], Michelangelo hand [3], and Vincent Hand [4]. These hands are high-end products of myoelectric hands and have great performance and reliability. These prosthetic hands are highly expensive for people in developing and underdeveloped countries. The hands employ tendon and linkage as the joint connection to the actuator. DC motor is widely used in the myoelectric hand as an actuator. The myoelectric prosthetic hand also incorporates non-backdrivable mechanism to maintain high grip forces without consuming current from battery [5].

Currently, low-cost myoelectric prosthetic hands based on 3D printing technology are available on the market. The low-end product based on 3D printing technology of myoelectric hand is proposed for achieving the affordable hands and lightweight. The commercially available low-cost myoelectric prosthetic hands are Ada Hand [6], Dextrus hand from Open Hand Project [7], Exiii Hackberry [8], and Brunel Hand from Open Bionics [9]. These hands employ tendon mechanism and DC motor [6, 7], [9] for actuating the flexion and extension of the fingers. While Exiii Hackberry uses linkage and servo motor. Researchers in universities have developed myoelectric prosthetic hand by using 3D printing technology. The material used for the hand will be affordable and lightweight. The studies of myoelectric prosthetic hands based on 3D printing have been proposed by some universities such as Tact [10], Rehand [11], Smart Hand [12], Keio Hand [13], AstoHand [14, 15], UC Softhand [16], ISR-Softhand [17], and other prosthetic hands [16-22]. The mass of the hands on those research works are less than 500 grams.

Received June 20, 2018; Revised October 4, 2018; Accepted November 6, 2018

In this research, a low-cost anthropomorphic myoelectric hand based on 3D printing technology was developed using tendon-spring mechanism. Feedback control strategy was developed for controlling the finger flexion and extension of five grip pattern modes. The feedback control strategy aimed to reduce excess power usage during myoelectric hand performing finger flexion and extension motion. Linear actuator with potentiometer feedback incorporating non-backdriveable mechanism was utilized as the actuators. The proposed myoelectric hand was tested in various object grasping test using selected EMG sensor. The hand was used to pick and grasp a fragile object like an egg by using human visual feedback.

2. Design and Control of Myoelectric Hand

In the finger design, as shown in Figure 1, the distal interphalangeal (DIP) joint was set with a fixed angle with 20 degrees. The proximal interphalangeal (PIP) joint and metacarpophalangeal (MCP) joint can be freely rotated from 0 degrees to 90 degrees. In the PIP and MCP joint, a shaft with one mm in diameter is employed as a revolute joint in the finger. Torsion spring is attached on the middle shaft on the PIP and MCP joints. The dimension of each finger can be summarized as shown in Table 1. The 3D mechanical design of the proposed myoelectric hand is developed by using SolidWorks computer-aided design (CAD) software. It is selected in this design phase because the CAD software is easy to use and operate. The final design in the CAD software can be exported easily in the .stl format. The format is used for 3D rapid prototyping using 3D print technology.

Table 1. Finger Dimension of the Proposed Myoelectric Hand

Fingers	Distal and Medial (mm)	Proximal (mm)
Thumb	62	32
Index	40	32
Middle	43	32
Ring	41	32
Little	40	27

In the design of the proposed myoelectric hand, the hand is the development of previous robotic hand model that uses tendon-spring mechanism, and AstoHand V1.0 [14], as well as AstoHand V2.0 myoelctric hand [15]. This research developed a myoelectric hand named 'AstoHand V3.0'. In this myoelectric hand, all five linear actuators, Arduino Nano, motor drivers and PCB should be able to fit into the myoelectric hand. AstoHand V3.0 is designed approaching the average size and the weight of the human hand. The final proposed myoelectric hand is shown in Figure 2. In this hand, the control strategy will be developed for controlling the finger motion and saving the energy consumed by the five linear actuators.

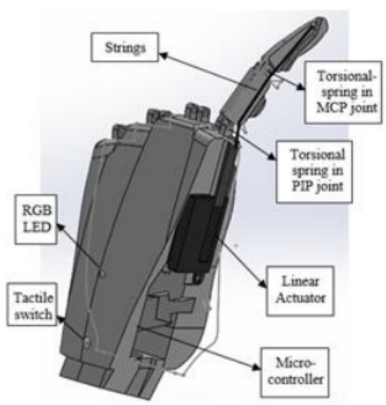


Figure 1. 3D CAD design and tendon-spring mechanism of myoelectric hand

Figure 2. The final prototype of the proposed low-cost myoelectric hand

In this research, the myoelectric hand has five grip patterns i.e. power grip, tripod, precision closed, hook, and active index to perform object grasping in the activity of daily living. The command for each grip pattern uses the same EMG signal for finger flexion and extension. To select the grip pattern, user can touch the tactile switch on the back cover of the hand. The current working active grip pattern is indicated by an RGB LED that lights up according to the selected grip pattern. On-off control is employed for controlling the stroke displacement of the actuators with the allowable steady-state error tolerance of less than 0.55 mm as shown in Figure 3. Because the actuator system utilizes the non-backdrivable mechanism, the proposed control can maintain high grip forces and stop consuming the current from the battery.

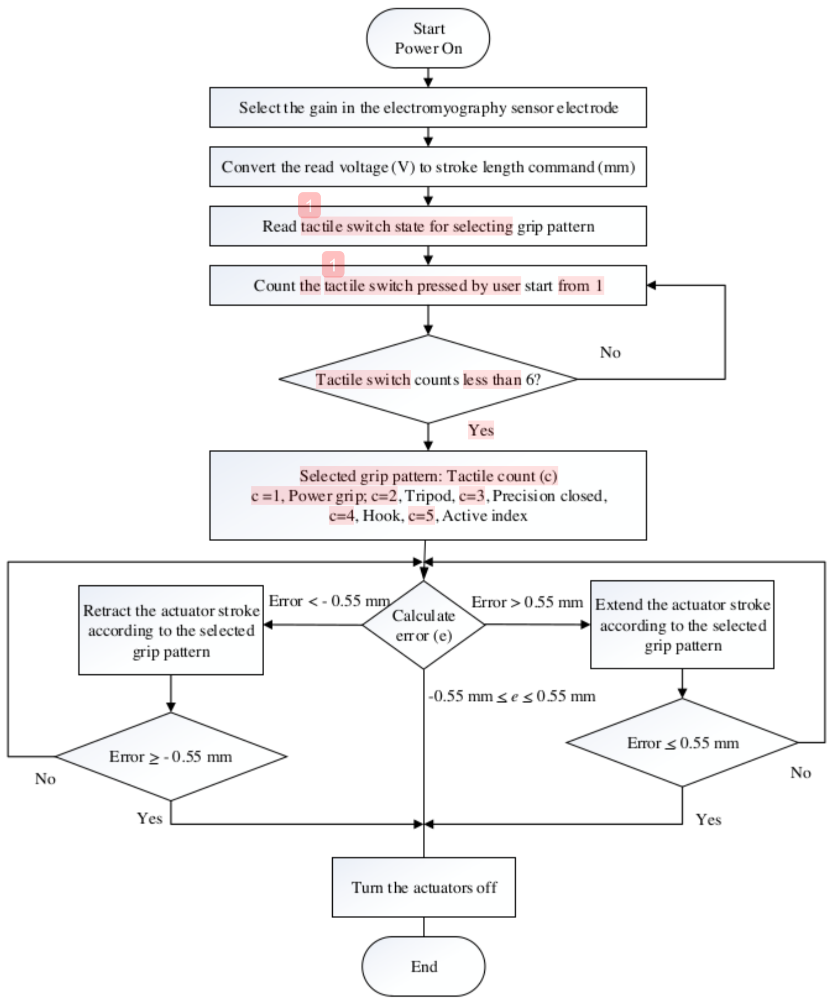


Figure 3. The proposed control strategy for the myoelectric hand operation system

The control strategy as shown in Figure 3 is developed under MATLAB/Simulink software. The developed block diagram of the myoelectric hand operation system is presented as show in Figure 4. The voltage input read from the EMG sensor is filtered using a first-order low-pass filter. The block diagram is embedded into Arduino Nano using Simulink Support

Package for Arduino Hardware. The package can be downloaded freely on the MathWorks website. The block diagram of the operation system can run in real-time on Arduino Nano with the sampling rate of 50 Hz.

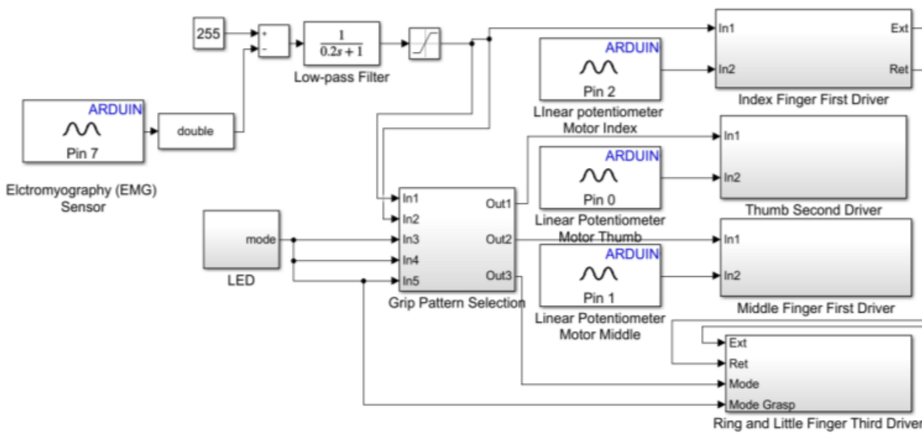


Figure 4. Proposed control strategy developed in MATLAB/Simulink environment

Figure 5 is the block diagram of feedback control algorithm as shown in Figure 3 on the proposed myoelectric hand using EMG as an input command signal. The electrical signal of the user muscle is read by the EMG sensor which gives the voltage output signal, then multiplied by a gain into the value of the command X reference. The value of the X reference is the value of the stroke displacement length that is commanded to the linear actuator. The value of the X reference then is given to the control algorithm. It becomes the value of the commanded stroke displacement of the linear actuator. Linear potentiometer in the linear actuator is used to measure the stroke displacement. The steady state error (e) allowed in the feedback control is less than 0.55 mm. The stroke length of linear actuator can extend from 0 to 20 mm.

The electromyography (EMG) sensor used in this study comes from RSL Steeper, the UK. The EMG sensor can capture a low muscle signal. It has proportional control and built-in gain adjustment. The sensor requires voltage from 5 V to 19 V. The resulted signal from the EMG has been amplified, rectified, and smoothed. The EMG sensor is placed in normal healthy hands as shown in Figure 6. It shows that the user performs the flexion motion on the hand. Flexion and extension motion on the hand is read by EMG sensor and then the signal is used to drive the myoelectric hand. The used voltage from EMG sensor is below 1.4 volts. The EMG signal is filtered using first-order low-pass filter before it is processed by feedback control. The acquired and processed EMG signal is presented in Figure 7. The selected linear actuator is Actuonix PQ 12-P with the maximum stroke length of 20 mm. The technical specification of the utilized linear actuator is summarized as show in Table 2.

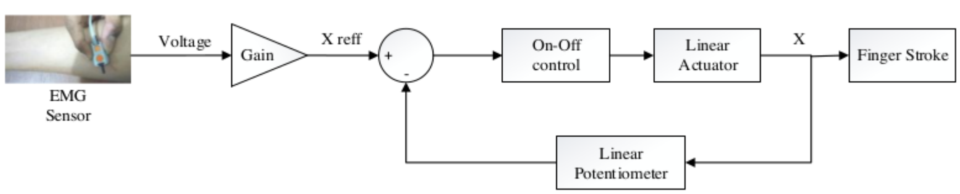


Figure 5. Block diagram of the feedback control of myoelectric hand for finger flexion and extension

Table 2. Technical Specification of the used Linear Actuator PQ 12-P [23]

Properties	Value
Peak power point	15N @15mm/s
Peak efficiency point	8N @20mm/s
Max speed	28 mm/s
Max force	18N
Max sideload	5N
Back drive force	9N
Max. Operating Voltage	6V
Gear ratio	30:1
Stroke sensor	Linear potentiometer
Mass	15gr
Stall current	550mA @6V

Figure 6. Electromyography sensor placement

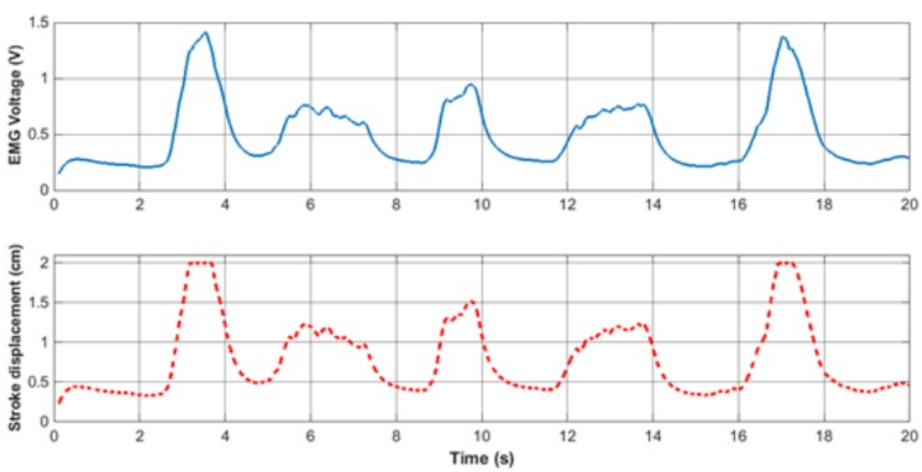


Figure 7. Acquired EMG signal and stroke displacement command on the linear actuator

3. Results and Discussion

In this section, the proposed control strategy of five grip pattern mode will be tested experimentally. The developed feedback control will be tested using step and trajectory tracking command input. The efficiency of control strategy will be performed with voltage drop monitoring when the myoelectric hand is driven every minute. Five grip pattern mode will be implemented and tested by using normal healthy hand. Various object grasping tests will be conducted by using normal healthy hand incorporating five developed grip pattern. In the final test, AstoHand V3.0 myoelectric hand will be employed on the study participant with transradial amputation.

3.1. Control Performanceub

In the input command test in the form of step input and trajectory tracking, the sampling rate is 50 Hz. The maximum voltage given to the linear actuator is 5 V. L293D Motor Driver IC is used for reversing the polarity of the DC motor to retract or extend the stroke of the linear actuator. Based on Figure 8, it can be seen that there is a delay from response to command less than 0.3 seconds. This can be due to the voltage applied to the Actuonix PQ 12-P linear actuator of 5 Volts, while the maximum voltage that can be applied to the linear actuator is 6 Volts. In the test of the input step with a command from 0 to 10.25 mm, the time constant is about 0.6 seconds. The initial stroke position of the linear actuator is 1.75 mm. The steady state error of feedback control that has been developed is less than 0.5 mm. The steady state error is less than the allowable steady-state error criteria in the proposed feedback control as shown in Figure 3. The proposed control has a good performance result to be implanted on the AstoHand V3.0 myoelectric hand for controlling the finger flexion and extension.

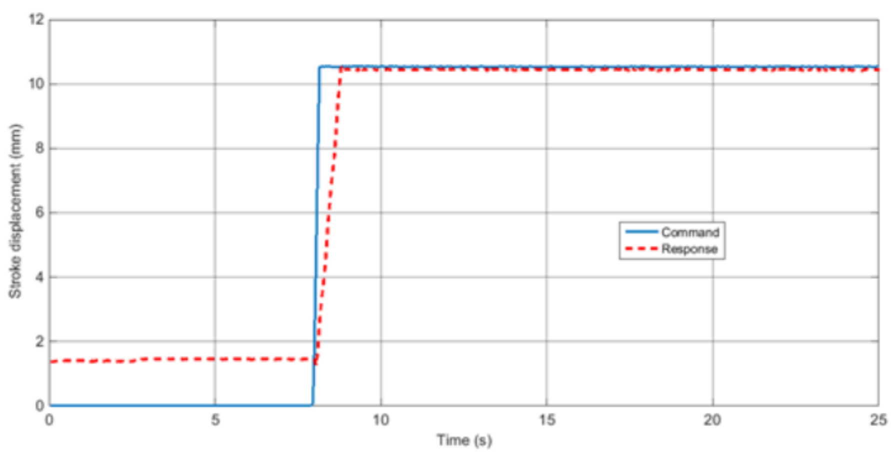


Figure 8. Performance of the proposed control with step command

In this test, the initial stroke position of the linear actuator is 1.3 mm. Based on the test result as shown in Figure 9, the stroke displacement command has been successfully followed by stroke displacement response signal in the form of a trajectory tracking of the Actuonix PQ-12 linear actuator. This test result from the figure proves that the proposed control has successfully performed a stroke displacement position control that can be used to adjust the stroke length of the Actuonix PQ-12 linear actuator according to the length of the given stroke length command. There is still a delay when the response signal follows the command, this happens because the voltage given in this test is 5 Volts. The larger the stroke displacement length command, the greater is the time constant that occurs. Larger time constant occurs when the stroke is retracted. The resulted steady-state error in the trajectory tracking is relatively low that is less than 0.5 mm. When the steady-state error reaches below 0.55 mm, the motor will be turned off by the controller.

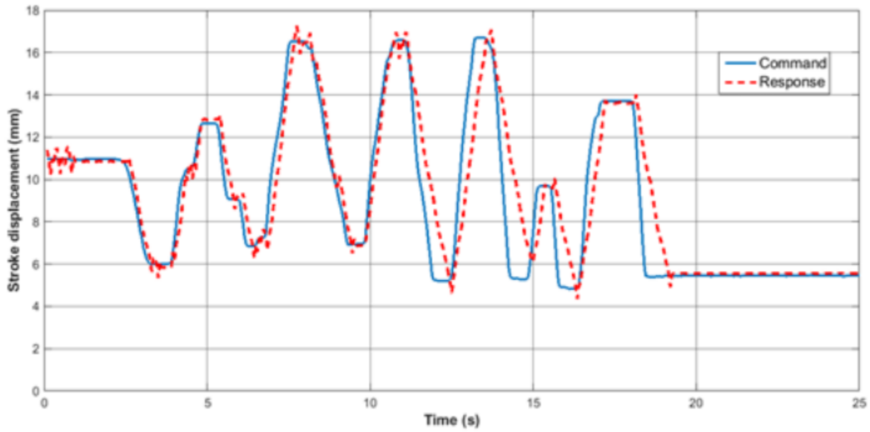


Figure 9. Performance of the proposed control with trajectory tracking command

In the voltage drop test, it is aimed to test the proposed control as presented in Figure 3 for reducing the power consumed by myoelectric hand. The AstoHand V3.0 myoelectric hand is turned on for 60 minutes. The hand is commanded to perform finger flexion and extension movements on the fingers simultaneously every second. In the test, the hand performs finger flexion and extension movements 60 times for one hour. The voltage value on the myoelectric hand battery is acquired and recorded every second. In the study, two 18650 rechargeable Li-Ion batteries that are connected in series connection are used as a power source of the myoelectric hand system. The batteries are used to power the Arduino Nano microcontroller, five linear actuators, three L293D motor drivers, an RGB led, and an EMG sensor.

Figure 10 shows the voltage drop every second for 60 minutes on the myoelectric prosthetic hand batteries. In this test, the initial voltage value is 7.80 Volts. Then in the first minute, there is a voltage drop to 7.79 Volt. Until in the 60th minute, it is obtained that the final voltage value is 7.66 Volt. Based on the test in Figure 10, the voltage drop on the myoelectric hand that is used every second for one hour is 0.14 Volts. Based on the result from the test, it proves that the proposed feedback control embedded in the myoelectric hand system serves to reduce excess power usage during myoelectric hand when it performs finger flexion and extension motion.

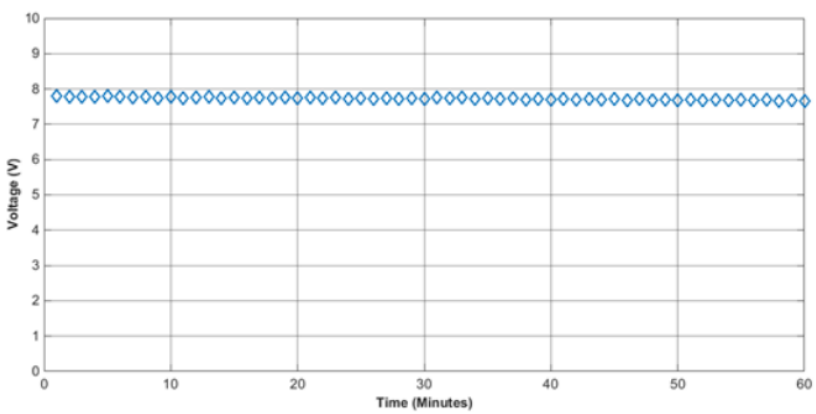
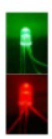


Figure 10. Voltage drop test result on the battery

3.2. Object Grasping Test

In the grasping test without objects, the motion is conducted to find out the five of the grip pattern modes can run as expected. There are five grip pattern modes developed on the proposed myoelectric hand as shown in Table 3. The table shows the first mode with red LED indicator can perform power grip motion which is expected to replace the grip function of the lost human hand. The second mode with green LED indicator can perform tripod motion which is expected to replace the function of grasping small objects or writing on the paper. Then the third mode with blue color LED indicator can perform precision closed motion which is expected to replace the function of taking flash disk or necklace. The fourth mode with the green and red LED color indicator can perform hook motion which is expected to perform the function to carry goods such as lightweight bag or case. The fifth mode with blue and green LED color indicator can perform active index movement which is expected to replace index fingers function to press keyboard or to take compact disc.

Table 3. Five Grip Patterns on the Proposed Myoelectric Hand

Mode	Grip pattern	Result		
1	Power grip			
2	Tripod			
3	Precision closed			
4	Hook			
5	Active index			

After conducting the motion test on five different grip patterns, the myoelectric hand will be tested to grasp various objects ranging in weight, size, and shape. The signal input for grasping various objects comes from a study participant with normal healthy hand as shown in Figure 6. The various objects grasping test results can be seen in Figure 11. The power grasp mode applies the maximum force on the myoelectric hand. This mode is selected for grasping the objects such as drinking water in a glass or plastic bottle. The tripod mode is selected to pick and grasp objects such as flash disk, soldering iron, and marker pen. Hook grip mode is utilized to pick and grasp a bag and a book. Finally, the active index mode is selected to press the keyboard. Based on the object grasping test results, the five developed grip patterns can successfully grasp an object ranging in size, shape, and weight. The performance of the AstoHand V3.0 in various object grasping test can be seen online at https://www.youtube.com/watch?v=rJRc9wr5a1k&t=2s.

Figure 11. Various object grasping test

Asto Hand V3.0 is employed to pick and to grasp a fragile object like an egg. The input signal comes from the study participant with normal healthy hand. Visual feedback from the user is used in order that the egg does not break when it is grasped by myoelectric hand because the myoelectric hand does not have force feedback closed-loop system. The result of the egg grasping test is shown in Figure 12. Based on the test, AstoHand V3.0 myoelectric hand can successfully pick and grasp an egg by using visual feedback from user/wearer. In the final test, AstoHand V3.0 myoelectric hand is applied on the study participant with transradial amputation. The study participant wears AstoHand V3.0 as shown in Figure 13. In the test, the batteries are placed outside of the myoelectric hand. Five developed grip pattern modes are tested by the study participant. The input of the signal for driving the myoelectric hand comes from the remaining muscle on the study participant's hand. Based on the test result, the study participant can stably use the myoelectric hand. The performance of the myoelectric hand implemented on the transradial amputee can be seen at https://www.youtube.com/watch?v=Rs8M4LTIK8Q&t=62s. The comparison of our AstoHand V3.0 with other low-end and high-end myoelectric hands is summarized in Table 4.

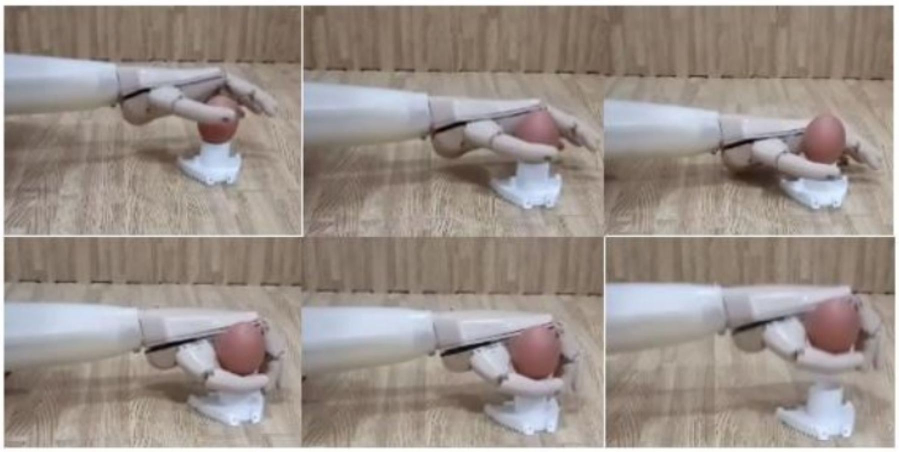


Figure 12. Sequence images of fragile object grasping test

Figure 13. AstoHand V3.0 implemented on the study participant with transradial amputee

4. Conclusion

In this study, a low-cost anthropomorphic myoelectric prosthetic hand with five degrees of freedom (DOF) has been designed and manufactured as a wearable robot for transradial amputee. The proposed myoelectric prosthetic hand is equipped with five grip pattern modes for grasping various objects. The proposed control has good performance result on the AstoHand V3.0 myoelectric hand for controlling the finger flexion and extension motion using EMG sensor as an input. When the steady-state error reaches below 0.55 mm, the DC motor in the linear actuator will be turned off by the controller. The proposed feedback control strategy can reduce excess power usage during myoelectric hand performing finger flexion and extension motion.

2
Based on the test result, the five developed grip patterns can successfully grasp an object ranging in size, shape, and weight. AstoHand V3.0 myoelectric hand can successfully pick and grasp a fragile object like an egg by using visual feedback from the user / wearer. The study participant with transradial amputation can stably use the myoelectric hand. In the future research, the proposed myoelectric hand will be developed incorporating force feedback control for grasping fragile objects. Provide a statement that what is expected, as stated in the "Introduction" chapter can ultimately result in "Results and Discussion" chapter, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

Table 4. The Comparison of the Proposed Hand and Commercially Available Myoelectric Hand

Prosthetic hand	Developer	Mass (gram)	Dimension (mm)	Number of Joint	DOF	Number of Actuator	Actuator Type	Joint connection
AstoHand V3.0 (2018)	Undip	375	175x85x 52	10	5	5	DC Motor Lead Screw	Tendon-spring
AstoHand V2.0 (2016) [15]	Undip	430	180x85x 50	10	5	5	DC Motor Lead Screw	Tendon-spring
AstoHand V1.0 (2016) [14]	Undip	261	-	10	5	5	Micro Metal Gear Motor	Tendon-spring
Vincent Hand (2010) [4]	Vincent system	-	-	11	6	6	DC Motor Worm Gear	Linkage spanning
iLimb (2009) [2]	Touch bionic	450-615	182x75x 41	11	6	5	DC Motor Worm Gear	Tendon
iLimb Pulse (2010) [2]	Touch bionic	460-465	182x75x 45	11	6	5	DC Motor Worm Gear	Tendon
Bebionic (2011) [1]	RSL Steeper	495–539	198x90x 50	11	6	5	DC Motor Lead Screw	Linkage
Bebionic v2 (2011) [1]	RSL Steeper	495-539	200x92x 50	6 11	6	5	DC Motor Lead Screw	Linkage
Michel-angelo (2012) [3]	6 Otto Bock	~ 420	-	6	2	2	-	Cam design to all finger
Ada Hand (2016) [6]	Open Bionic	400-430	185x85x 50	10	5	5	DC Motor Lead Screw	Tendon
Exii hand (2015) [8]	Handii eng	-	-	13	5	5	Motor-worm gear & Servo motor	Linkage
Brunel Hand (2017) [9]	Open Bionic	371	198x127x 66	9	5	4	DC Motor Lead Screw	Tendon

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ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

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2	Rifky Ismail, Mochammad Ariyanto, Kharisma A. Pambudi, Joshua W. Syafei, Gilar P. Ananto. "Extra robotic thumb and exoskeleton robotic fingers for patient with hand function disability", 2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), 2017 Publication	1%
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anthropomorphic robotic hand driven by modified glove sensor and integrated with 3D animation", 2016 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES), 2016
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