Design of The Bionic Robot Hand with Electromyography Smart Sensor based on MATLAB/Simulink

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***Abstract*— High-torque servo motors are frequently employed as actuators in bionic robot hands, which constitute a type of exoskeleton robot. However, the high torque increases the price of the servo motor. This study develops a low-cost bionic robot arm, which replaces the servo motor by a DC motor. The DC-motor actuator is controlled by a fuzzy logic control system that provides human heuristic knowledge. Based on this knowledge, the robot hand can lift, hold, receive, and retrieve desired objects. The robot arm is equipped with electromyography that detects the electrical potential caused by the contraction of the arm muscles. The magnitude of the output voltage depends on the amount of movement in the muscle part measured by the muscle sensor, which detects the electrical activity in the muscle. The robot moved from 0° to 90° in less than 1.96 s.**

***Index Terms*— fuzzy logic control, bionic robot hand, electromyography sensor, dc motor**

I. Introduction

Paralysis is the inability to move all or part of the body. Paralysis of the arm can occur through genetic predisposition, accidents, or illness. To overcome the body's inability to move or function, robotics researchers have developed exoskeleton robots that provide support structures outside the body [1]. A hand-like exoskeleton robot is an assistive device that helps to regain the function of the arm. The most suitable kinematics for biped robots with low power consumption have been developed via simulations [2]. An exoskeleton robot is supported by an electric motor, pneumatics, lever, hydraulic system, or a combination of technologies that enhance the strength and endurance of the limbs. The exoskeleton arm is an anthropomorphic outer-mechanical structure that transfers mechanical power from itself to the human arm [3]. Such devices allow physiotherapy rehabilitation and provide passive therapy to stroke victims, avoiding spasticity in their joints [4]. In clinical trials, passive robotic therapy more effectively improved the rehabilitation of shoulder and elbow movements in patients with spastic hemi-paresis when compared with traditional physiotherapy [5].

When equipped with a bionic robot hand, the weak and paralyzed patients can regain independent life and continue their daily activities [6]. The elbow arm robot developed by Evison uses Dynamixel MX-28T servo motors that input a heavy sensor (load cell sensor) and output 2.5 Nm of torque [7]. As the load driven by the servo motor increases, the DC motor must output more torque, which increases the cost of the servo motor. Such costs inevitably increase the price of the exoskeleton robot. To reduce the cost to consumers, a robot with an inexpensive exoskeleton arm is imperative. In this research, the servo motors are replaced by a DC motor, providing a low-cost exoskeleton arm robot.

Fuzzy logic, introduced by Prof. Lotfi A. Zadeh in 1965, is based on the methods and principles of human reasoning. The main objective is to provide a foundation for reasoning estimates using improper propositions based on the fuzzy set theory. Similarly, classical reasoning infers appropriate propositions based on the classical set theory. Unique among computing approaches, a fuzzy logic system simultaneously handles numerical data and academic knowledge [8]. In principle, fuzzy algorithms overcome the limitations of Boolean binary logic, which allows only two statement conditions (true or false). Fuzzy algorithms cope with conditions that are intermediate between the "yes" or "no" statements, and describe these mid-conditions as mathematical formulations [9].

In the present study, the DC motor that replaces the servo motors is driven by a fuzzy logic control program [10]. Fuzzy controllers provide a formal methodology for representing, manipulating, and applying human heuristic knowledge [11]. To model biological muscle, the DC motor is controlled by both a proportional integral–derivative (PID) controller and an auto-regressive neural network [12].

The bionic robot hand with motion input was developed using electromyography (EMG), which records the reaction of an arm muscle. The reaction signal is forwarded to the microcontroller while the DC motor actuates the robot. The muscle sensor measures the electrical activity of the muscle, so the magnitude of the output voltage depends on the amount of movement in the measured part of the muscle. As mentioned above, the DC motor is controlled by a fuzzy logic algorithm. The

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program is created in MATLAB/SIMULINK software interfaced by an Arduino mega 2560 board. The control system on the elbow of the exoskeleton arm robot is expected to regulate the DC motor motion. The movement of the bionic robot hand follows the muscle reaction in the arm. Previously, PID control has achieved object pick-up by a five-fingered gripper [13],[14].

II. Method of Research

A. Description of Research

Before constructing the exoskeleton robot, we must know its structure. The design of bionic robot hand was created based on the hand human structure as shown in Fig.1 a). The robotic structure of the exoskeleton arm is based on the upper arm and forearm. Fig.1 (b) shows the robot simulation was created as a three-dimensional in 3d Inventor Auto desk software. The sizes of the robotic structures are based on anthropometric data collected from several samples.

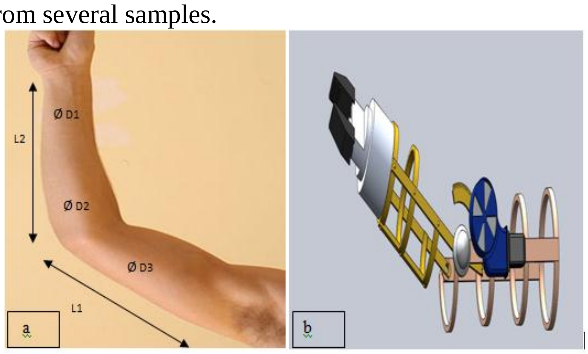

Figure 1. Mimicry of exoskeleton robot: (a) human arm picture [16] and (b) Design robot prototype in 3D-Inventor by authors.

B. Research Procedure

The control system of this robot was created in MATLAB/SIMULINK. The control system accepts the data from the EMG sensors and angle-position sensors as inputs, and outputs the voltage that regulates the direction of motor rotation. The EMG sensor data were obtained while lifting the arm upwards and downwards. The angle-position sensors determine the angles made by the arm during the up–down movements. Fig. 2 is a sequence of work systems from the authors for the design of a control system with a muscle sensor on a bionic robot hand

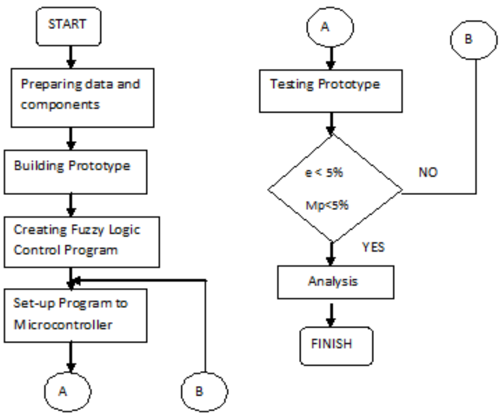

Figure 2. Flowchart of the research.

C. Testing Procedure

The muscle strength was measured by MyoWare EMG sensors (Advancer Technologies) as shown in Fig. 3

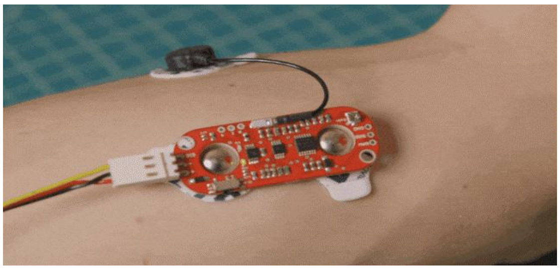

Figure 3. Position of the Electromyography sensor on the human arm [17].

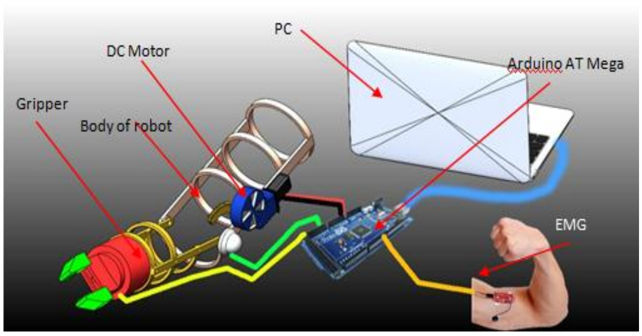

Figure 4. Schematic of the bionic robot experiment.

Fig. 4 shows the schematic of control system of bionic robot hand using Myoware EMG sensor. The EMG sensor analyzes the electrical activity and issues an analog signal representing the hardness of the muscle contraction [15]. The signals of muscle contraction or relaxation are converted into a set of numbers from 0 (total relaxation) to 1024 (maximum contraction). The numbers generated by the EMG sensor are stored in the MATLAB Workspace.

The first step of the proposed methodology builds the prototype of the robot exoskeleton as show in Fig. 5. The DC motors are the high-torque DC motors installed in car-wiper systems.

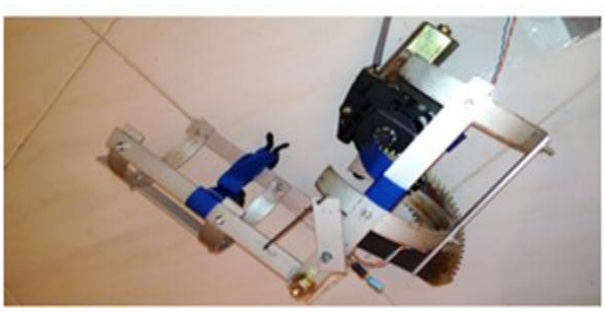

Figure 5. The real bionic robot hand prototype.

Fuzzy logic is available in the MATLAB toolbox. Researchers can map the voltage input to the DC motor and specify the angular tolerance in the arm motion. The fuzzy logic program regulates the motor rotation under the voltage setting. The input to the fuzzy logic program is the difference between the muscle signals and the actual angular motion of the arm. Panels (a) and (b) of Fig. 6 show the member function and output of the fuzzy logic, respectively, and Fig. 7 shows the rule scheme of the fuzzy logic.

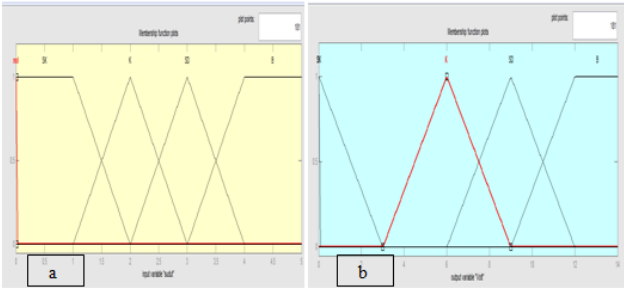

Figure 6. Input and output functions of the fuzzy logic program

The input angles mapped by the fuzzy logic ranged from 0° to 5°. The input and output membership functions were both divided into 5 categories, namely, Zero, Very Small (SK), Small (K), Medium (SD), and Large (B). The fuzzy logic output ranged from 0 to 12 volts.

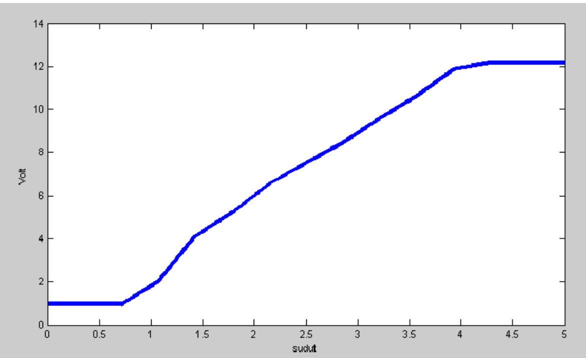

Figure 7. Rules of the developed fuzzy logic program.

After pairing the fuzzy logic rules of the MF inputs and MF outputs, the arm angle inputs are graphically mapped to the voltage signals. When the angular error exceeds 4, the voltage is 12 volts. In contrast, when the angle error value is less than 4, the voltage drops to near zero (reflecting the negligible error). Fuzzy logic governs the control system of the exoskeleton robot. Meanwhile, the DC motor control created in MATLAB/SIMULINK mimics the servo-motor control system, which ensures that the angle position formed by the output of the motor shaft matches the provided input angle.

The fuzzy logic control system built in the MATLAB/SIMULINK program is shown in Fig. 8. A tolerance of 2% is applied to accommodate the gap between the gears in the motor.

The robot hand system determines the motor rotation by fuzzy logic. The Arduino board is commonly employed as the driver of servo and other DC motors. This control system drives both the speed and direction of the DC motor rotation, ensuring that the angle formed accords with the given reference angle. The support package for the Arduino hardware is already provided in the Simulink toolbox.

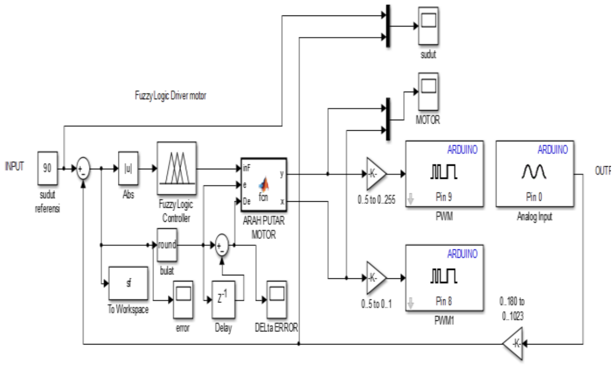

Figure 8. Block diagram of the bionic robot hand.

III. Results and Discussion

During testing, the prototype was interfaced to a computer that displayed the robot's responses on the screen. The robot responses were then subjected to a transient response analysis implemented by the researcher. In the first test, the reference angle was 90°. The test was run for 10 seconds without a load mass. Fig. 9 compares the robot responses with and without the fuzzy control system.

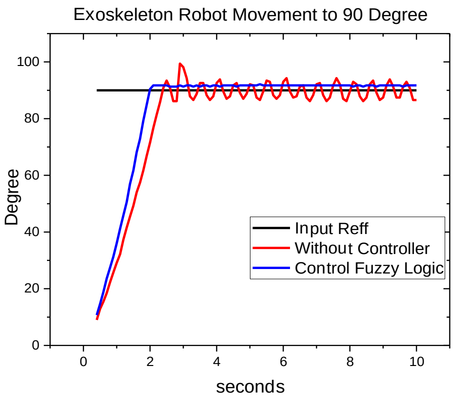

Figure 9. Motion responses of the exoskeleton arm robot.

When the control system was omitted, the DC motor exhibited an oscillatory instability. In the absence of rotational speed control, the motor is controlled only by the direction of the motor movement. The reference angle 90° was reached after 2.38 s, and the top of the first time was reached at 2.52 s. The maximum angle was 99.4°. In contrast, the DC motor governed by the fuzzy control system was stable with no oscillations, and the angle remained within the tolerance. The fuzzy control also accelerated the time to reach the reference angle 90° (from 2.38 to 1.96 s). The first peak was reached at 2.1 s, and the maximum angle was 91.71°.

As shown in Fig. 10, the fuzzy logic control system regulates both the voltage and angular speed of the DC motor. The system provides a large angular speed to the DC motor when the error or angle difference is excessive, and a small (near-zero) angular velocity when the error decreases. By convention, the clockwise and counterclockwise rotations of the DC motor are assigned as positive and negative angles of the motor rotation, respectively.

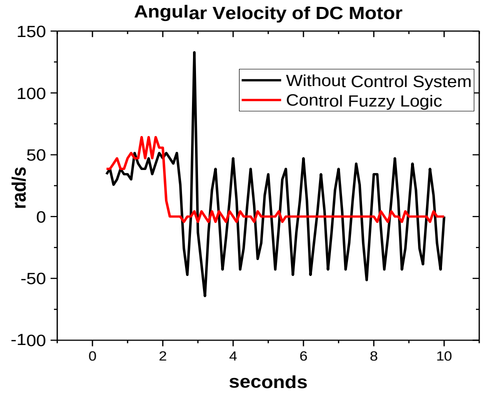

Figure 10. Angular velocity of the DC motor under the fuzzy logic control

Fig. 11 shown the error defines the deviation of the output angle from the reference angle. In the uncontrolled system, the errors oscillated like the responses themselves, and were maximized at 9%. The fuzzy logic reduced the error to 1.9%, within the stipulated tolerance of 2%. As mentioned above, the error tolerance allows for the gap in the gear box of the DC motor.

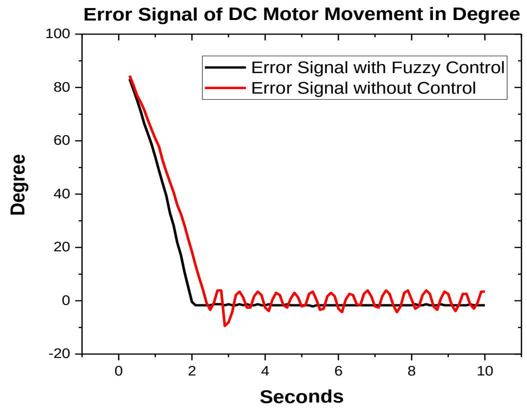

Figure 11. Error signals in the DC motor responses.

Fig. 12 shows the results in the form of theta angles (degree) that have followed the reference input provided. Overall, the fuzzy logic control system improved the transient responses of the DC motor.

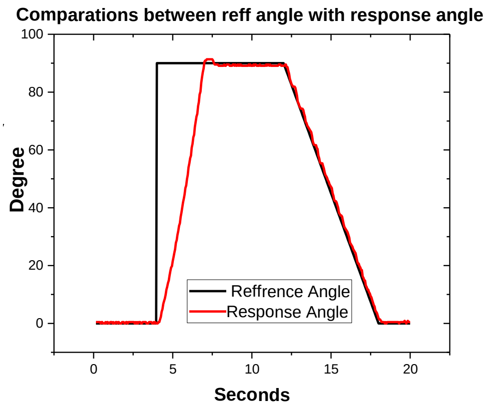

Figure 12. Response of the exoskeleton robot to angle variations.

The responses of the exoskeleton arm robot under the three loads are plotted in Fig. 13.

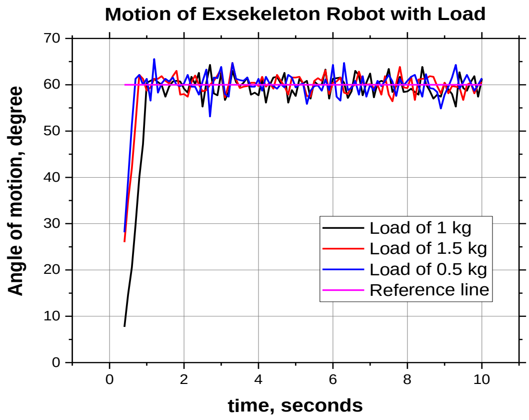

Figure 13. Robot responses under varying loads.

In the next test, a load was mounted on the end of the robot arm. The load was varied as 0.5, 1.0, and 1.5 kg. The reference angle was 60 ° and the test time was 20 s. As shown in the Fig. 13, the exoskeleton arm of the robot oscillated under each load. This instability is caused by the gap in the gear, which causes angular deviations from the reference angle. Therefore, the error is inherently large.

The error signals in Fig. 14 are the differences between the input value and the actuator value. The errors oscillated along with the robot responses. To reach stability, the error must be negligible or within the tolerance value.

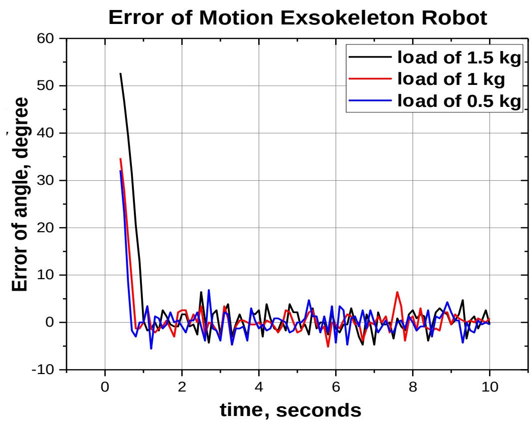

Figure 14. Error signals in the DC signals under different loads.

IV. Conclusion

This study developed an exoskeleton robot in which the usual servo motor was replaced by a DC motor. The motor movement was controlled by a fuzzy logic program, which is easily designed and implemented in MATLAB/SIMULINK. By virtue of the fuzzy logic system, the DC motor was a suitable substitute for the more expensive servo motor.

The responses of the robot were displayed on the robot response graphs, which appear in MATLAB's workspace window after completing the prototype test in

MATLAB/SIMULINK. Under the fuzzy logic control, the robot moved from 0° to the reference angle (90°) in less than 1.96 seconds, and plateaued at 2.1 s. The maximum angle was 91.71° with an error of 1.9%, within the specified tolerance of 2%.

In future work, the authors will develop a complete bionic robot hand with a five-fingered gripper. The movements of the gripper fingers will mimic those of human fingers. The robot motion will be governed by an intelligent control.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, W.W. and T.G.T.N.; methodology, W.W, T.G.T.N., I.N.B.; software, W.W., and I.N.B.; validation, W.W., T.G.T.N. and I.N.B.; formal analysis, W.W.; investigation, W.W. and I.N.B.; resources, W.W.; data accurate, W.W.; writing—original draft preparation, W.W.; writing—review and editing, W.W. and T.G.T.N.; visualization, W.W.; supervision, W.W.; project administration, I.N.B.; funding acquisition, W.W.

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