Microcontroller-based assistive device for training weak biceps brachii muscle

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Abstract. A person with a certain degree of biceps brachii muscle weakness will not be able to move the lower hand. The muscle needs contraction and relaxation practice regularly to avoid the condition getting worse. An electromyography-based assistive device has been developed. It uses biopotential signals from biceps brachii muscle when contracted and relaxed to control the elbow flexion and extension movement of the weak hand. The device uses a Muscle Sensor V3 module to sense the muscle biopotential signals, and also an Arduino Nano 3.0 microcontroller module and a servo motor to control the elbow movement. The elbow movement is limited to 90° to its maximum degree of movement at 170°. It is the range of elbow movement that used in a method to work out the biceps brachii muscle. The starting process needs to adjust elbow position manually using potentiometer to 90° angles. This device can work properly when stimulated by the biceps brachii muscle biopotential signals and produce as low as 0.0977V at the input of the internal ADC of Arduino Uno 3.0 when the muscle contracted and lower than that voltage when it relaxed. The device consumes low power to operate at 0.374watts.

1. Introduction
Weak arm muscles are a condition that occurs when the performance of the biopotential signal of the arm muscles weakens [1-3]. One of the causes of muscle weakness is the plexus brachii injury, which is injury or trauma that occurs in the plexus brachii [4]. The weak arm muscles can also occur due to excessive muscle performance, lack of exercise, muscle pulling due to the absence of warm-up before exercising, and because the nerve performance is not optimal due to myelin narrowing. This condition causes a decrease in muscle strength and sensation in the arm, resulting in a reduction of functional activity of the arm [1].

Patients with weak arm muscles need to practice arm movement regularly, with the help of a therapist and independently, to keep the arm muscles from deteriorating further do to lack of functional activity of the arm [1, 4]. In this study, an assistive device was made to move the forearm based on the stimulus signal from the upper biceps to produce elbow flexion and extension movements in the angles of its range of motion (ROM) [2, 5-6]. This assistive device aims to help improve the motor function of the arm and its surrounding muscles [7-10]. This assistive device is designed to be able to move the arm when holding a load with a specific weight, so that it can be used to support the activities of the patients with weak arm muscles such as carrying a hand back.
2. Materials

2.1. Electromyogram

The electromyogram of the biceps brachii muscle can be read by placing a pair of surface electrodes on the biceps brachii muscle as shown in figure 1 [11-12]. One other electrode is placed in the position of the tendon muscle in the back arm as the reference point.

![Figure 1. The surface electrodes position on biceps brachii muscle.](image)

The electromyogram of the biceps brachii muscle has dominant frequency range between 20 – 500Hz, and the amplitude range is between 0 – 5mV [3, 5]. The condition of the weak muscles will cause the electromyogram obtained to decrease in amplitude [1-3].

2.2. The muscle’s biopotential sensor module

The Muscle Sensor V3 is a sensor module that can detect the motoric muscles biopotential signals, and convert it to electric voltage in the range of 0 – 5volts. The Muscle Sensor V3 in sequence is constructed of an instrumentation amplifier, rectifier, analog filter circuits, and an end amplifier circuit. The module size is quite small, with the size of 1 inch square (1 x 1 inch).

The electromyogram obtained from the instrumentation amplifier output is forwarded to the rectifier so that only positive signals will be processed further. The gain adjustment of the second stage amplifier circuit uses a potentiometer, to produce gain in the range of 0.002 to 20,700 times. The supply voltage of the module is between ±3.5V to ±18V.

3. The hardware design method

Figure 2 shows the shape design of the assistive device and figure 3 shows the hardware block diagram. Currently the intention of the assistive device is for the arm. The servo motor will rotate the forearm plate down and up to produce elbow extension and flexion movement.

This assistive device that utilizes motor movement control has two modes (the manual and the electromyography mode), which is selected using a toggle switch. The manual mode is done by rotating the potentiometer, and the electromyography mode with a reading of the biceps brachii muscle contraction and relaxation. The manual mode is needed everytime the device is turned on, to adjust the forearm plate position so that the elbow of the arm forms an angle of 90° as the starting position of the servo motor.

The assistive device is then sets to the electromyography mode. One cycle of contraction and relaxation of the biceps brachii muscle will stimulate the servo motor to move the forearm plate down, to produce the elbow extension movement, until the elbow forms a maximum angle of 170°. A moment later the motor will moves upward and creates elbow flexion movement, to return to its original position with 7°/s speed.

There is a limit switch on the device to prevent it from overextension due to the ROM of the hand. The switch will cut the power off when the unit is overextended, so the motor stops working. This switch will prevent the servo motor from going out of control, and the angle of the elbow is always between the angle limit of 90° – 170° [2, 5-6].
Figure 2. The device physical design.

Figure 3. The block diagram of the designed system.

Figure 3 shows the block diagram of the electronic part of the device. The Muscle Sensor V3 senses the voltage potential of the biceps brachii electromyogram then amplifies the signal and at the same time filters the noise to produce an analog signal between 0 – 5V. An internal ADC of ATmega328P of the Arduino Nano 3.0 microcontroller changes the analog signal into digital. The amplitudes of the digital signals are used as the stimulus to control the motion of the servo motor that placed on the outer side of the elbow hand plate, as seen in figure 2. The AMS 1117 feeds the power to the servo motor, the Arduino Nano 3.0 module, the LCD to display information, and to the
The power of the entire system comes from two 9V batteries to produce bipolar voltage of ±9V电压 to supply power and the Muscle Sensor V3 module.

3.1. The microcontroller and i/o

An ATmega328P based microcontroller is the base of the Arduino Nano 3.0 module, which is the primary controller of the system. Table 1 is the connection of the I/O pins to the external devices. The microcontroller receive two analog input signals, they are from the Muscle Sensor V3 module output when in the electromyography mode, and from the potentiometer when in the manual mode, that will be converted to digital signals by the internal ADC of ATmega328P. The amplitudes of the digital signals are used as the stimulus to control the servo motor movement. The motor speed is regulated using the pulse width modulation (PWM) method.

| Pin  | Connection                               | Function                                      |
|------|------------------------------------------|-----------------------------------------------|
| A0   | The Muscle Sensor V3 module              | To convert the analog output voltage of the    |
| A1   | The Potentiometer                        | Muscle Sensor V3                               |
| A4   | I2C serial data (SDA)                    | To send data to the LCD                        |
| A5   | I2C serial clock (SCL)                   | To send data to the LCD                        |
| D2   | The toggle switch                        | To choose modes (the manual mode or the       |
|      |                                          | electromyography mode)                         |
| D9   | The servo motor and the limit switch     | To control ON/OFF the servo motor              |
| D10  | The servo motor                          | To control ON/OFF the servo motor              |

The Arduino Nano 3.0 module also receives signals from the two limit switches of the overextension prevention. All three functions to connect/d disconnect the power supply line to the parts of the device. The main toggle switch is for the primary power connection to the main power supply to the device, while the mode motor toggle switch is for the connection of the motor servo to the power supply. One LCD (16 x 2 characters) is the only display for the mode and condition of the system. The data communication between the microcontroller and the LCD is via serial communication lines.

3.2. The mechanical design

The design of the device warrants the ability to move the forearm with a maximum arm mass of 1 kg; therefore a minimum torque of 2.6Nm (Newton meter) is required. In this study, a MG996R Servo Continuous 360° servo motor is sufficient.

Figure 2 illustrates the physical shape of the device. The size of the upper arm plate and forearm plate is 20cm x 8cm and 26.5cm x 8cm. Both plates are connected by a series of gearboxes to increase the servo motor torque. The gearbox system in figure 4 consists of 4 gears; each with the number of teeth as follows: gear 1 (A) 11 teethes, gear 2 (B) 65 teethes, gear 3 (C) 11 teethes, and gear 4 (D) 65 teethes.
Figure 4. The gearbox system design.

The gearbox system causes one full rotation of the gear C to gear D on the output of the servo motor to produce 35 times full rotation of the gear B to gear A in the input section. This gearbox system produces higher servo motor torque and a more efficient motor control.

4. The software design method

The Arduino Nano 3.0 will read the toggle switch condition when it connected to the power supply. The device will be in the manual mode when the position of toggle switch produces a low logic signal so that the servo motor movement is controlled by the potentiometer value. The device will be in the electromyography mode if the mode toggle switch produce highs logic signal so that the servo motor movement is controlled by the amplitude of the output signal of the Muscle Sensor V3 module.

At the initial condition, the system must be in manual mode. The user adjusts the potentiometer to move the forearm plate into a comfortable position with the device strapped to the arm. The next step, the user adjusts the potentiometer again to move the forearm plate to an angle of 90°. After these processes, the user changes the mode toggle switch into the electromyography mode for the treatment process. The analog voltage outputs of the potentiometer and the Muscle Sensor V3 module are then converted to 10 bits digital signals by the internal ADC of the ATmega328P microcontroller IC. The ADC convertible analog input range is 0 – 5V. The ADC is set to work in free running mode at its highest speed.

The electromyography mode is designed to read the analog input signals 24 times, then taking the average voltage to stimulate the control of the servo motor movement. This method is intended to reduce the noise of the electromyogram signal readings obtained. The microcontroller will activate the servo motor to rotate the forearm plate to produce an elbow extension movement when the average voltage measured exceeds the specified threshold. The process continues until the elbow forms an angle of 170° based on the timer. The servo motor speed is set at 7°/s in the setting of the servo motor movement. The threshold voltage is determined based on the measurement of the electromyogram peak amplitude of the prospective user when contracting the biceps brachii muscle. The procedure to stimulate the servo motor movement is the user needs to contract the biceps brachii muscle for a moment, and then relax. The servo motor will rotate until the elbow forms an angle of 170°, then after 3000ms it will rotate backward to its initial position that the elbow forms an angle of 90° to produce the elbow flexion movement with the same speed as the elbow extension movement. The system will be idle for 4 seconds before start reading a new electromyogram to stimulate the next process cycle.

The manual mode is designed so that the potentiometer rotary direction will produce the same direction of the servo motor rotation. The LCD functions to display the mode status selected at that time.

5. Results and discussions

5.1. The electromyogram signal measurement

The measurement aims to study the electromyogram peak amplitudes of subjects with normal arm muscles and a subject with arm muscle weakness by contracting their biceps brachii muscles. The electromyogram is obtained when the subject performs contraction and relaxation of the biceps brachii
muscle. The participants as the measurement subjects were 9 (nine) male undergraduate students (subject 1 to subject 9) with normal right arm muscles, and one male adult participant with weak right arm muscle condition (subject 10) who had biceps brachii arm circumference ≤ 26cm when relaxation.

Figure 5 and 6 show the electromyogram of a participant with normal arm muscles. The measurements show that the voltage decreases when the biceps brachii muscle relax, and the voltage increases when the muscle contract. Figure 5 shows the electromyogram peak was 0.0311V\text{p-p} that produced when the subject relaxes the biceps brachii muscle, and figure 6 shows that the peak signal was 0.6622V\text{p-p} when the muscles contracted.

Besides, the subjects biceps arm circumference while the muscle relaxed and contracted also observed. Figure 7 and 8 compare the measurement results from normal subjects and a patient with arm muscle weakness. In figure 7, the graph of biceps arm circumference when biceps muscle contracted (continues line) shows a significant difference between normal subjects and the patient, while biceps muscle relaxed (dash line) did not show a significant difference. Figure 8 shows the electromyogram rms (root mean square) voltage of the subjects when biceps brachii muscle contracted. It shows that the electromyogram rms voltage of a person with normal biceps brachii muscle is higher than that whose experienced weak arm muscles.

**Figure 5.** The electromyogram output of the Muscle Sensor V3 module from a subject when the biceps muscle relaxed.

**Figure 6.** The electromyogram output of the Muscle Sensor V3 module from a subject when the biceps muscle contracted.

**Figure 7.** The comparison graph of biceps arm circumference measurement results from normal subjects and a subject with arm muscle weakness when the biceps muscle contracted.

**Figure 8.** The rms voltage of the electromyogram measurement results from normal subjects and a subject with arm muscle weakness.
5.2. The power consumption measurement

Table 2 is the measurement result of the power consumption of the system, which is the observation of the current and the voltage measured at the main power supply. There are three parts of the system that consume power which is the switch 1, the relay for EMG 1 with positive polarity and the relay for EMG 2 with negative polarity. The table shows that the highest power consumption (at 0.374 watts) occurs when the power switch is on and at standby mode.

| Switch/relay position | Device phase | Current (mili ampere) | Voltage (volt) | Power consumed (watt) |
|-----------------------|--------------|-----------------------|----------------|----------------------|
| Switch 1              | Stand by     | 48                    | 7.8            | 0.374                |
| Relay EMG 1 (+)       | Stand by     | 9                     | 9.62           | 0.087                |
| Relay EMG 2 (-)       | Stand by     | -9.5                  | -9.57          | 0.091                |

5.3. The system performance testing to subject with muscle weakness

This test is carried out with the supervision of a licensed physiotherapist at a local hospital. The subject is a 35 years-old patient with a nerve narrowing – better known as impingement syndrome. The narrowing of the nerve weakens the patient’s arm muscles strength. Figure 9 shows the patient while wearing the device. The total mass of the device at 1kg; it does not overload the patient’s arm, and is quite comfortable to wear.

![Figure 9. The photograph of a patient with weak biceps brachii muscle when wearing the device.](image)

The physiotherapist observes the work process of the device and the results of testing and provides responses that this short-term arm elbow aid is useful to help train the people with weak arm muscle. But periodic and continuous exercise, and balanced with physiotherapy in the long-term needs to be done to achieve maximum results.

6. Conclusion

The dimension of the device only fits for a person with the maximum upper arm circumference of 26cm when the biceps brachii muscle relaxed and the maximum arm mass of 1kg. The total weight of this assistive device is 1kg so that the user can wear it comfortably for short-term elbow movement therapy or daily activities. The device is designed to be used on the right hand. The maximum power consumed by the device when stand by is quite small, which is equal to 0.374 watts, making it suitable for using batteries as the power supply.

The device can detect the electromyogram of the subjects with normal biceps brachii muscle, and also those with weak arm muscles. It depends on the amplitude of electromyogram received by the ADC. The amplitude measured should be lower than the threshold at 0.0977V when the muscle relaxed, and higher than that threshold when the muscle contracted. The electromyogram signal can trigger servo motor control to produce the elbow extension and flexion movements. The servo motor with the gears ratio of 1:35 of the gearbox can withstand the expected load with smooth rotation.
movement, and control the servo motor to form the elbow angle of $90^\circ$ in the flexion movement, and it will form the elbow angle of $170^\circ$ at the end of the extension movement.

7. References

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