Designing One Degree of Freedom Nursing Robot for Stroke Rehabilitation

Nurul Muthmainnah Mohd Noor, Muhammad Haziq Suhaimi

Fakulti Kejuruteraan Mekanikal, Universiti Teknologi MARA, Cawangan Pulau Pinang, Kampus Permatang Pauh, 13500 Permatang Pauh, Pulau Pinang, Malaysia.
nurul.muth@gmail.com

Abstract. Rehabilitation training is a method of post-treatment for physically injured part of body especially the stroke patients. The training task such as massage and repetition exercises are needed to help them to have a normal life as before by a physiotherapist. The physiotherapist or physical therapy is a person who has experienced to treat disease or injury by physical methods. Therefore, a main objective of this paper is to develop a nursing-care robot system that can assist the stroke patient in doing daily activities. A one-degree of freedom nursing robot was designed based on the right-hand bicep using CATIA software. This robot was associated with the electromyography (EMG) sensors in order to collect the data from the muscle contractions. Meanwhile the EMG sensor is a muscle sensor that detect an electrical potential between the two-contraction flexion or extension muscle using the polymer Ag/AgCl coated electrodes. Then, the data from the muscle was sent to the Arduino microcontroller to control the servo motor. The different angle of servo motor can give the direction of movement of the nursing-care robot. The nursing robot was activated by electrical potential from the contraction of the muscle. The value of servo angle from 0 to 100 degrees angle made the robot will move up and down. The movement of robot in up and down direction is likely same as the therapist assistance doing to their patient. The size of robot is about 600 mm X 100 mm length and width and then was fabricated using 3D printer with one degree of freedom (DOF). The limitation of this project is focusing only the hand right hand bicep brachii muscle physiotherapy exercise.

1. Introduction

In industrial revolution 4.0, using robotics and automation is a method in solving the various problems especially in rehabilitation purposes. Most of these problems are relatively related to the repetitive and time-consuming tasks such as the muscle rehabilitation or physiotherapy exercises [1, 2]. The patient needs to regain their fully functional part of body that was injured by assisted with the rehabilitation training. Therefore, it requires the patient to meet a physiotherapist in few times either weekly or monthly [3]. This may give some trouble to some patient who has limited time to meet the schedule of appointment for rehabilitation exercises [4]. Other problems also need to be considered is the patient’s health condition, attention and effort in an intensity and task-orientation of the training. Intense repetitions of coordinated motor activities constitute a significant burden for the therapists assisting
patients [5]. The idea to solve these problems is designing an automated robot that can assist the rehabilitation exercises without any physiotherapist and can be done by himself/herself.

Robotic devices with the ability to perform repetitive tasks on patients are advanced devices and called as rehabilitation robot. Most of these robotic devices are already used in the clinical practice as well as the clinical evaluation. It can support and enhance clinicians’ productivity and effectiveness as they try to facilitate the individual’s recovery. The demand for caregivers and rehabilitation services are growing apace with the aging population. Therefore, a new approach is needed to improve the effectiveness and efficiency of rehabilitation to assist in the recovery process. There are two types of rehabilitation robot from the mechanical design point of view: end-effector based robots, and exoskeleton-type robots. One of examples of end-effector based robots is MIT-MANUS. This robot is will interact with subjects at the end of robot arm, which is based on different size body [6]. While exoskeleton-type robots can resemble human anatomy and apply torque to specific joints that can be used for rehabilitation training. Most of prosthesis robot and robot-aided rehabilitation are used the EMG signals to trigger and control the movement of robots. The EMG signals reflect the activities of the muscles and generate the formation of muscle force. These robots were designed like human’s joints and could be worn by the human operators as an assistive device.

Therefore, in this study, the myo-electrically controller of robotic system based was designed and evaluated its effect during rehabilitation training. This project hopefully can help the stroke patient can regain his/her injured back to the normal life.

2. Electromyography (EMG) Biopotential Sensor

EMG is a method of biopotential sensor for measuring muscle activities in human [7]. This method is an active topic to be improved for accurate results. One of the different with EEG signal is EMG signal is harvested from the muscle voluntary contraction, meanwhile EEG signal from the brain [8]. A vast analysis of EMG and its information can provide an accurate picture of the function of individual muscles during voluntary movement. By using EMG, the mechanical function of a muscle or the muscle kinematics is determined by the electrical potential of the muscle, not by its mechanical events of a contraction [9]. The EMG signal can be read in amplitude information that sent via electrodes attached on the target muscle. Therefore, the amplitude information then can be manipulated to vary device control [10]. Using EMG signals, the system can predict the intention movement of certain movement in order to perform a task [11].

In this project, a MYOWARE muscle sensor from Advancer Technologies was used. The MYOWARE board acts by measuring the filtered and rectified electrical activity of a muscle with output 0 - 5 Volts depending on the amount of activity in the targeted muscles [12]. Figure 1 shows the position of 24 mm diameter biomedical pads (electrodes) that attached to the MYOWRAE board. The electrodes are coated with polymer silver chloride electrode (Ag/AgCl) to read the electrical potential difference [13]. The advantage of using MYOWARE muscle sensor is that the output signal gained was in filtered and rectified signal. Hence, reducing the time to convert raw signal into filtered signal. In addition, the position and orientation of pin A and pin B need to be aligned with the muscle fibres’ orientation. Incorrect positioning of electrodes will reduce the strength and quality of the sensor’s signal. The summary of the position of electrodes can be seen in Table 1.
Figure 1: Position of the electrodes [8].

Table 1: Position of electrodes and its pin.

| Point | Pin    | Position                                  |
|-------|--------|-------------------------------------------|
| A     | Middle | Above the midline of the biceps brancii   |
| B     | End    | Below the midline of the biceps brancii   |
| C     | Reference | Elbow side                               |

3. Electromyography Data Acquisition

3.1 EMG data acquisition from Arduino Serial plotter

In this experiment, the Arduino serial plotter was used to acquire the muscle signal. The movement of flexion and extension of the elbow joint were recorded until the subject reached full range of motion (ROM) for each movement. The experiment setup for this project as shown in figure 2, where the electrodes were placed on the user’s bicep brancii. Then the electrodes were connected to the pins on MYOWARE sensor board. The sensor board then connected to the Arduino NANO microcontroller.

From the data acquired based on EMG signals towards the movement of the user’s arm, the pattern of signal was classified. There are only two movements involved which are flexion and extension of muscle. The movements of the arm were needed to be actuated separately. Therefore, an algorithm was developed by using the two different conditions based on the movement of the arm either in extension or flexion. These both conditions were making the system can be repeated the process for a few times same as the manual training exercise. The flow of algorithm can be seen in figure 3.
3.2 Design exoskeleton arm using CATIA software

In designing the exoskeleton of nursing robot, a few factors are considered such as weight, size and strength as well as the ergonomics. The exoskeleton dimensions were designed based on the 50th percentile male manikin according to right-hand side (RHS) arm measurements which includes the average size of a human arm. Therefore, the exoskeleton can be fitted for average human population. This exoskeleton was designed using CATIA software. In this software, the strength of exoskeleton can be found by doing the simulation. Figure 4 shows the illustration of exoskeleton that attached to human by CATIA software.

Figure 3: Flowchart of algorithm.
Meanwhile, figure 5 shows the full assembly the exoskeleton of nursing robot. It consists of four major parts. The major parts of exoskeleton structure are upper arm, lower arm with forearm placeholder and two gears. The upper arm part was designed to put the mechanical and electrical components such as Arduino NANO. The lower arm part with forearm placeholder was designed to assist the forearm of the user and act as a supporter for the arm. There are two gears – driver and driven gears were attached to the servo motor and the lower arm part respectively. The gears were linked using 6 mm width timing belt. The mechanism of single degree of freedom (SOF) was located at the elbow joint, which the robot will rotate. The size of the exoskeleton was 600 mm X 100 mm length and width respectively.

3.3 Fabrication of exoskeleton
In figure 6 shows the fabricated exoskeleton of nursing robot. The material used was Acrylonitrile Butadiene Styrene (ABS) plastic and fabricated using 3D printer. The product is twenty-percent infill with the total weight of 167 grams. Table 2 shows the description of the parts consist in the nursing robot.
4. Results and Analysis

4.1 Exoskeleton Finite Element Analysis (FEA)

In designing the nursing robot, a few analyses need to be considered in order to achieve the objective. One of analyses in this project is to identify the maximum yield strength of the product design. Using CATIA software, the method of finite element analysis (FEA) was conducted. In this simulation, the load needs to be chosen as well as the direction of force. In this analysis, the most concerned problem was whether the exoskeleton parts can support the weight of the user’s arm. Referred at anthropometric data adapted in Principle of Biomechanics in 2009, an average value for 50th percentile male upper limb weighs around 3.70kg while 95th percentile weigh about 4.33kg. Therefore, to exceed any additional weight, 10kg weight or 100 N force was applied at vital points that seemed to be vulnerable to bear the load. The result of analysis can be seen in figure 7 and figure 8.
In Figure 7, it shows a simple 100 N force analysis exerted at the forearm placeholder. This analysis simulates force exerted from the weight of the forearm of the user. The Von Mises Stress shows the maximum stress was 15.2 MPa. While in Figure 8 shows the maximum stress was 3.43 MPa.

Based on Table 3, the data was recorded based on the Von Mises value. The yield strength of common Acrylonitrile Butadiene Styrene (ABS) is about 40 MPa. Meanwhile, the maximum stress for lower part and upper part were 15.2 MPa and 3.43 MPa respectively. Both maximum values did not reach the ABS yield strength. Therefore, the design should be able to withstand any force applied on the exoskeleton such as the forearm mass. The summary has been recorded in Table 3.

| Item                        | Lower part       | Upper part       |
|-----------------------------|------------------|------------------|
| Force (N)                   | 100              | 100              |
| Point of force exerted      | Forearm placeholder | The exoskeleton joint hole |
| Maximum yield stress (Pa)   | 15.2x10^6        | 3.43x10^6        |
| Minimum yield stress (Pa)   | 220              | 14.5             |

Figure 7: The lower part of exoskeleton.

Figure 8: Von Mises Stress on upper part of exoskeleton.
4.2 Electromyography data acquisition results

The data of EMG is collected on the bicep muscle by using Arduino software serial plotter. The subject was asked to extend the arm during sitting on the chair. This condition is called relax condition. Meanwhile, the subject was needed slowly raises his forearm in the flexion position until reach the maximum flexion and then slowly lowering the forearm to its original position. The value of EMG can be seen in figure 9.

![Figure 9: The data EMG signal from using serial plotter.](image)

Figure 9 shows the EMG signal plotted in voltage value. When the subject flexed his forearm, the muscle value or EMG value increases but not directly proportional to the elbow angle. This shows that the EMG value only concern about the contraction strength when flexing or relaxing the target muscle. The overall reading was satisfied showing that the muscle sensor can be used in the project.

In this project, there are three subjects involved, which are two males aged 24 and 28 while the other female aged 23. Figure 10 shows the signal response by the serial plotter of the nursing robot for the three sets of movement (extension – flexion - extension). The blue graph indicates the muscle value was needed to manipulate the servo angle (green graph). The EMG value was varied for every subject. This is because everyone has their own muscle values. The sudden raised of signal gained between point 80 and point 100 was caused by the subject touched the electrode while the system was tested. The mean value was gained by adding the maximum and minimum EMG values then divided by 2.

![Figure 10: The EMG values with servo angle.](image)

Table 4 shows the results of the EMG values for each subject and the servo angle actuated based on their EMG value. The EMG value acquired can be divided into the maximum, the minimum and mean EMG values. Based on the results recorded, the highest value among the subject’s average mean EMG value was 3.16 V and the lowest was 1.774 V.
Table 4: The subjects' details

| Details               | Subject 1 | Subject 2 | Subject 3 |
|-----------------------|-----------|-----------|-----------|
| Age                   | 23        | 24        | 28        |
| Gender                | Female    | Male      | Male      |
| Max EMG value (V)     | 248       | 435       | 264       |
| Min EMG value (V)     | 88        | 240       | 192       |
| Mean EMG value (V)    | 168       | 337.5     | 228       |
| ROM flexion, degree   | 100       | 100       | 100       |
| ROM extension, degree | 0         | 0         | 0         |

Meanwhile Table 5 shows the sequences of input and output in the both flexion and extension of the elbow joint that obtained from the test. In flexion movement, the servo motor rotated from 0° to 100° degree when the muscle value was higher than the mean value and when the muscle value lower than mean value, the servo motor maintains in the position. However, in the extension movement, the servo motor rotated from 100° to 0° angle when the muscle value was lower than mean value and motor stopped when the value of angle is more than 100°.

Table 5: The array of nursing robot system.

| Movement  | Input (muscle value) | Output (servo actuation) |
|-----------|----------------------|--------------------------|
| Flexion   | 1                    | 1                        |
|           | 0                    | 0                        |
| Extension | 1                    | 0                        |
|           | 0                    | 1                        |

5. Conclusion and Recommendations
In this project, the Arduino microcontroller-based nursing robot for rehabilitation purpose was developed and fabricated using the 3D printer respectively. Based on finite element analysis using CATIA software, the nursing robot was designed according to human kinematics motion especially the movement at the elbow joint. Therefore, from the result, it can conclude that the nursing robot is successfully fabricated and suitable to be used for both male and female. It can replace the human job by using this robot. The exoskeleton design also meets the desired yield stress within the forearm mass. The limitation of the nursing robot is that it is applicable only to be used at the right-hand side of the upper limb. This is because, the servo angle needs to be calibrated as the left and right arm are on the opposite side. Several improvements can be considered in the future development. For example, the product can be used on both sides of arms. Graphical user interface (GUI) can also be added to increase the user interaction with the product and track the user’s exercise routine.

References
[1] S. Bhattacharyya, and D. N. Tibarewala, "Motor imagery, P300 and error-related EEG-based robot arm movement control for rehabilitation purpose,” Med Biol Eng Comput, p. 1007–1017, 2014.
[2] H. Bastiaens, G. Alders, P. Feys,S.Notelaers, K. Coninx, L.Kerkhofs, V. Truyens, R. Geers, and A. Goedhart, “Facilitating robot-assisted training in MS patients with arm paresis: a procedure to individually determine gravity compensation,” in Proceedings of the 12th IEEE International Conference on Rehabilitation Robotics (ICORR ’11), pp. 1100–1105,
Zurich, Switzerland, July 2011.

[3] P. Maciejasz, J. Eschweiler, K. Gerlach-Hahn, A. Jansen-Troy, and S. Leonhardt, “A survey on robotic devices for upper limb rehabilitation”, Journal of Neuro-Engineering and Rehabilitation, vol 11(3), pp: 1-29, 2014.

[4] J. R. Octavia, P. Feys, and K. Coninx, "Development of Activity Related Muscle Fatigue during Robot-Mediated Upper Limb Rehabilitation Training in Persons with Multiple Sclerosis: A Pilot Trial," Multiple Sclerosis International, vol. 2015, p. 11, 2015.

[5] H. I. Krebs, and B. T. Volpe, “Rehabilitation robotics”, Hand Clin Neurol, vol: 110, pp: 283-294, 2013

[6] R. Song, K. Tong, X. Hu, and W. Zhou, “Myoelectrically controlled wrist robot for stroke rehabilitation,” Journal Neuroeng Rehabil, Vol: 52, 2013.

[7] R. G. Whittaker, "The fundamentals of electromyography," Practical Neurology, vol. 12, p. 187–194, 2012.

[8] A. T. Poyil, F. Amirabdollahian, and V. Steuber, "Study of Gross Muscle Fatigue During Human-Robot Interactions," The Tenth International Conference on Advances in Computer-Human Interactions, pp: 187 – 192, 2017.

[9] A. Basteris, S. M. Nijenhuis, A. H. Stienen, J. H. Buurke, G. B. Prange, and F. Amirabdollahian, "Training modalities in robot-mediated upper limb rehabilitation in stroke: a framework for classification based on a systematic review," Journal of Neuro-Engineering and Rehabilitation, vol. 11, no. 1, 2014.

[10] L. Grover, A. Arcelus, R. Wang, R. Huq, K. Zabjek, and D. Hebert, "Investigation of EMG Fatigue Patterns While Using an Upper Limb Rehabilitation Robotic Device," in Proceedings of the RESNA 2013 Annual Conference, 2013.

[11] M, Yamik, B. Purohit, and K. George, "Electromyography (EMG) sensor controlled assistive orthotic robotic arm for forearm movement," Sensors Applications Symposium (SAS), pp. 1-4, 2017.

[12] S. Didier, D. F. Stegeman, and J. H. van Dieën, "Redundancy or heterogeneity in the electrical activity of the biceps brachii muscle? Added value of PCA-processed multi-channel EMG muscle activation estimates in a parallel-fibered muscle," Journal of Electromyography and Kinesiology, vol. 23, no. 4, pp. 892-898, 2013.

Acknowledgement
This research was supported by Universiti Teknologi MARA, Cawangan Pulau Pinang. I also would to thank my final year student who involved this project by providing his expertise, knowledge and time.