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DEVELOPMENT OF A WEARABLE ANKLE REHABILITATION DEVICE FOR PATIENT WITH CALF MUSCLES FLEXIBILITY PROBLEMS

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ABSTRACT

This paper presents the development process and analysis of a wearable ankle rehabilitation device designed for patient with calf muscles flexibility problems. The device is used to help patient in exercising the ankle to strengthen, lengthen and maintain the calf muscles. By using a joystick module to control the actuation of the servo motor, the ankle brace moves the ankle to plantar flexion and dorsiflexion movements. Besides that, MyoWareTM Muscle Sensor is used to generate electromyography (EMG) signal from the calf muscles to monitor the servo motor. Exercising the ankle frequently can increase the calf muscles flexibility. The robotic ankle brace device accommodates the robot-guided at-home therapy requirements and is user-friendly. This allowed patient to perform exercise on the ankle more frequent and the recovery process can be reduced effectively. Other than being used as a treatment, this ankle brace is suitable for daily exercise too.

Keywords: rehabilitation; electromyography; servo-motor; control systems.

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1. INTRODUCTION

Calf muscles are made up of gastrocnemius and soleus muscles which are connected by the fascia to form Achilles tendon at the back of the ankle. When the calf muscles are not flexible, the gastrocnemius and soleus muscles became tight and stiff. Eventually, the Achilles tendon became tight. Calf muscles flexibility problems are usually due to spasticity of the calf muscles.

According to [1], spasticity is a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper-excitability of the stretch reflex, as one component of the upper motor neuron syndrome. According to [2], one of the features of spasticity is that the hypertonia and velocity of the muscle stretch is interrelated. This is meant by the faster the stretches performed, the greater the resistance felt. When the muscles became resistive to stretching and lengthening, two major consequences are faced. First, the muscles remain in a shortened position in long term resulting in changes to the soft tissue and eventually lead to contractures. Second consequence is the restriction to the movement of the body parts. When the calf muscles experienced spasticity, the gait abilities of the patient is affected. Other than gait abnormalities, foot drop, sudden spasms, abnormal posture and increased resistance to the leg movement are some of the situations commonly faced by patient with calf muscles spasticity or calf muscles flexibility problems. The gastrocnemius muscle being the major muscle in powering the motion of the ankle is prone to spasms.

To treat calf muscle spasticity, patient is always subjected to follow up physical and occupational therapy or ankle rehabilitation program. Over the past 30 years, more researches had been carried out to study the treatment effects of ankle braces compared to the research on foot inserts or foot orthoses. The “Rutgers Ankle” is a robotic rehabilitation device developed for home use. This device enables exercising of ankle’s three degrees of freedom while interacting with the virtual environment [3]. In [4] carried out a research to study the effect of calf stretching box usage in increasing the compliance of performing calf muscles exercise and in decreasing the calf muscle tightness and complications as compared to the conventional exercise method. In [5] designed a wearable robotic device using pneumatic artificial muscle actuators for ankle-foot rehabilitation purpose. Pneumatic artificial muscles are used to assist dorsiflexion and plantar flexion as well as inversion and eversion of the ankle. In [6] presented pediAnklebot, an impedance-controlled low friction, back-driveable robotic device that trains the ankle of neurologically impaired children of ages 6-10 years old. Another ankle rehabilitation robotic device available is developed by [7]. This device is to address the need to deliver intensive passive and active movement training in acute stroke using a wearable ankle robotic device.

The cited studies and references therein emphasize on various designs of ankle brace for rehabilitation purpose. As year goes by, the ankle brace became more advance. However, the cost of owning the device is expensive and the direction of usage is complicated making it not suitable to be used at home plus professional guidance is crucial.

In this paper, the design of the ankle brace is made to be suitable for robot-guided at-home therapy and user-friendly. The cost of the production is maintained at minimal. The robotic ankle brace is to be used to move ankle to plantar flexion and dorsiflexion. As such, the purposes of this study is to design a wearable ankle rehabilitation device for patient with calf muscles flexibility problems to carry out physical therapy treatment by using Arduino Uno. Hence, to verify the designed device as the real system by acquiring real time data of the electromyography (EMG) signal from the calf muscles using MyoWareTM Muscle Sensor and MATLAB® and Simulink®. Lastly, to analyse the functionality of the ankle brace device with the joystick and its suitability for the robot-guided at-home therapy purpose.

2. METHODOLOGY

The development of robotic ankle brace device is divided into there phases which are the development of mechanical part, design of electrical network and the formulation of software. The first phase involves the mechanical development of the ankle brace. Afterward, the electrical circuitry is designed in the second phase. Then, the software is formulated in the third phase.

Fig. 1 shows the conceptual block diagram of the hardware part. Practically, patient pushes the joystick to produce demand input to be compared with the sensed signal from the

MYoWare Muscle Sensor. The error signal is used to by the processor to actuate the servo motors [8]. Technically, the ATmega328P that behaves as the microprocessor will detect the signal from the joystick and converted it into pulse signal. The pulse signal is delivered to the servo motors to generate a rotational mechanical movement.

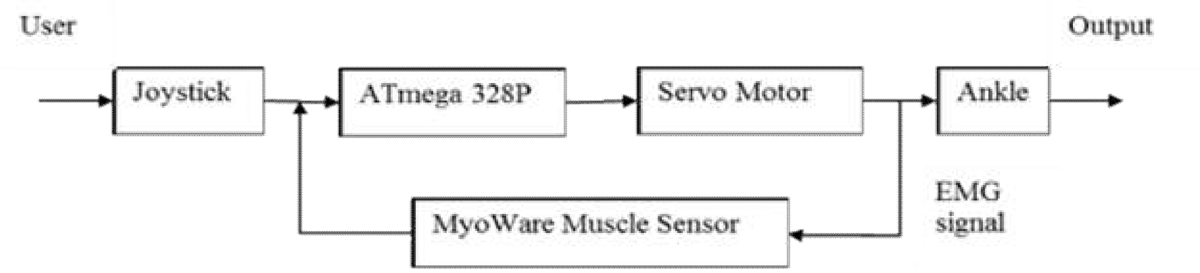
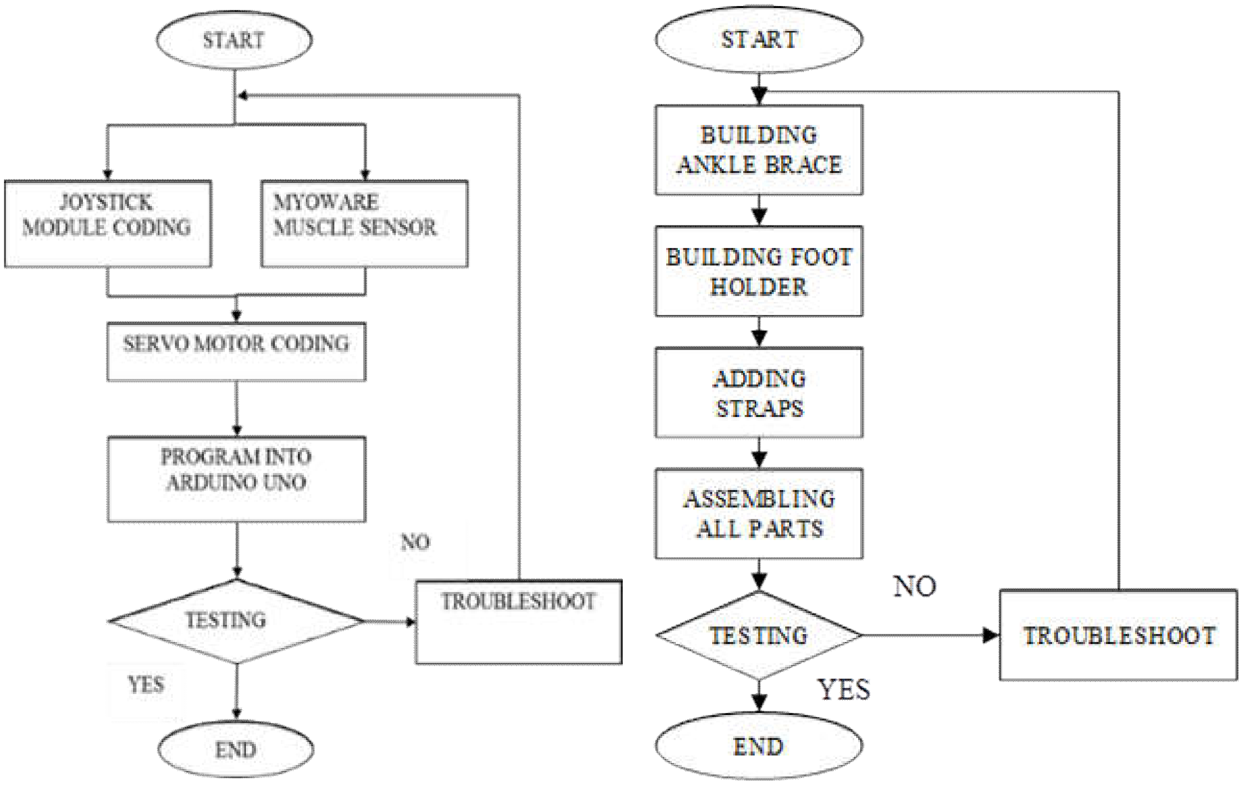


Fig.1. Block diagram of the device

Fig. 2(a) shows the flowchart for software development. Initially, the program for joystick module and servo motor coding is written in Arduino IDE. The MyoWareTM Muscle Sensor is also used to obtain the EMG signal of the calf muscle. MATLAB® and Simulink® is used to obtain the data. The threshold value is determined and is set to hold the servo motors rotation. Then, the program is compiled and uploaded into ATmega328P in Arduino Uno [14-15]. The program is tested to ensure the system run according to the requirements. To determine the motor position is a crucial task in this study. The motor must run precisely in accordance to the range of motion of the ankle. The range of motion of the ankle for every individual may vary due to many circumstances. However, the acceptable values for a normal range of motion of the ankle is 0° to 50° for plantar flexion and 0° to 20° for dorsiflexion [9].



(a) Flowchart of software development Flowchart of mechanical part development

Fig.2. Flowchart of the study

Fig. 2(b) depicts the development process of mechanical part. The mechanical part is referring to the ankle brace equipped with adjustable straps and foot holder. First, the ankle brace is built. Then, the foot holder is added. The foot holder is designed to be in two degrees of freedom, dorsiflexion and plantar flexion. Next, the adjustable straps to hold the ankle and foot in place are added to the brace. All parts were assembled and secured properly. The assembled brace was then tested for its functionality. It is then undergoes troubleshooting repeatedly until it runs without backlashes and almost frictionless. This criteria is the necessity criteria in order to ensure smooth operating of the device without exogenous disturbances and uncertainties. This issue was also highlighted by [10].

Fig. 3 shows the schematic circuit diagram for the control apparatus of the wearable ankle rehabilitation device. The inter-connected network involves the joystick, MyoWareTM Muscle Sensor, servo motors and the ATmega328P. Three light-emitting diodes have been added to the system to indicate the direction of movement of the ankle brace actuated by the servo motors.

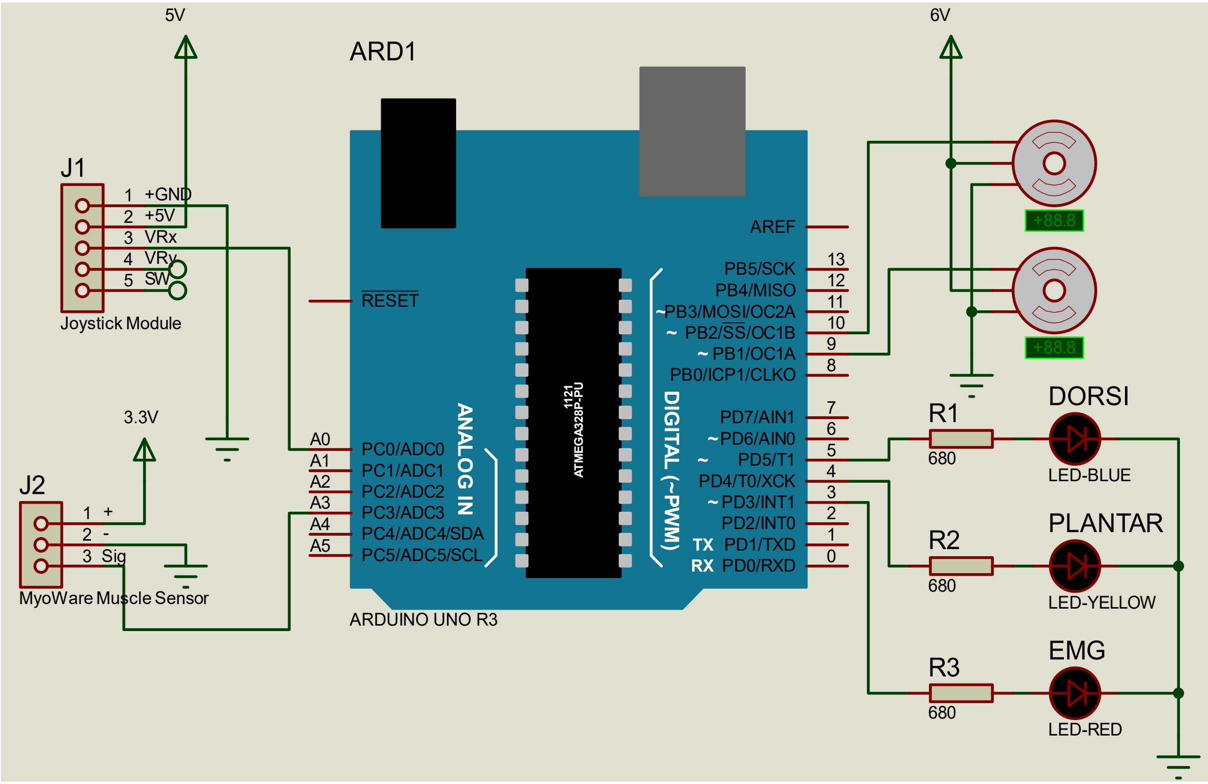


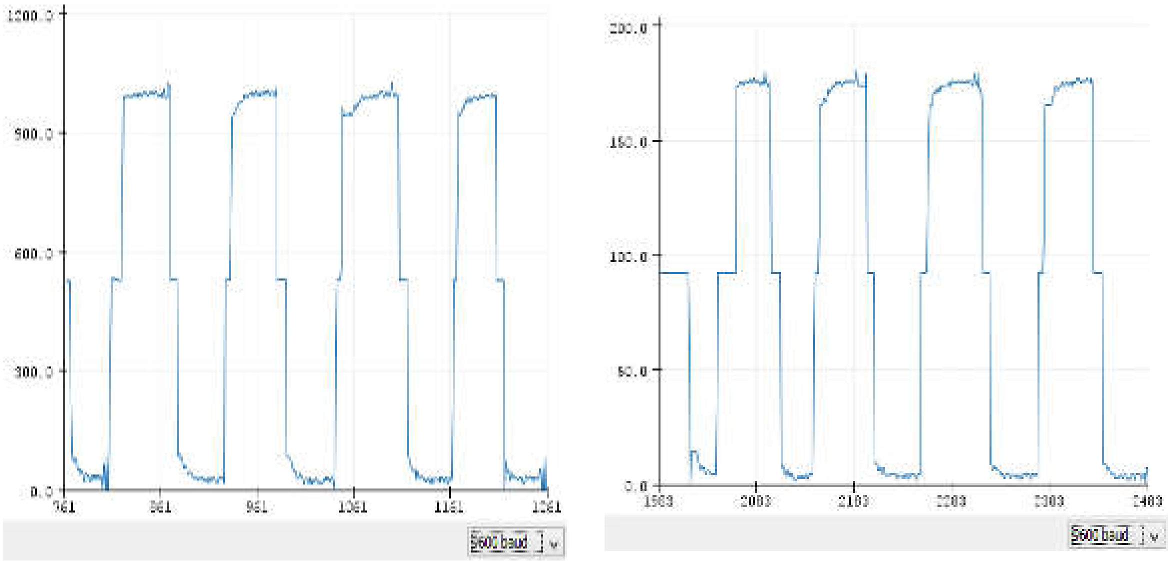
Fig.3. Schematic circuit diagram

3. RESULTS AND DISCUSSION

The joystick module produces a varying output ranging from 0 to 1023 count when the joystick moves to the x-axis and z-axis direction. Test is carried out to determine the output value so that it can be used to control the servo motor. Right-ward movement of joystick gives minimum 0-count while left-ward movement gives a maximum 1023-count. When the joystick is at initial position, the output value is recorded at 520-count. When the joystick is pressed, the servo motor return to its original position after being held by the EMG signal.

To calibrate the servo motor with the joystick output, the minimum and maximum pulse width of the motor needs to be determined since the servo motor rotates according to the duration of the applied pulse. The minimum pulse width is 550µs. When 550µs pulse is injected to the servo motor, the servo motor rotates to 0˚. The maximum pulse width is set at 2400µs. When 2400µs pulse is injected to the servo motor, the servo motor rotates to 180˚. Using the minimum and maximum pulse width, the servo motor is mapped to the joystick output value that is 0 to 1023-count, so that 0-count output gives 0˚ rotation and 1023-count gives 180˚ rotation.

Fig. 4(a) shows the real-time data obtained from the joystick. Fig. 4(b) shows the real-time daya from the servo angle after the mapping process. It can be observed from the signal that the servo motor angle varies according to the output value from different position of joystick. Table 1 tabulates the pulse width of the servo motor at different angles. The pulse width values are used to control the actuation of servo motor to the desired smaller angles. According to [11], the normal range of motion of human ankle in dorsiflexion is 0˚ to 20˚ and for plantar flexion is 0˚ to 50˚. In this study, the servo motor is set to rotate at 60˚ in every direction. The ankle is assumed to be at 0˚ when the servo motor is at 90˚ position. When the servo motor revolve to 30˚, the ankle will revolve to 60˚ in dorsiflexion. When the servo motor revolve to 150˚, the ankle will rotate around 60˚ in plantar flexion.



(a) Joystick output value after mapping (b) Servo motor angle after mapping

Fig.4. Real-time data for joystick output value

Table 1. Pulse width for specific angle

Servo Angle (˚)	**Pulse Width (μs)**
30	855
90	1475
150	2090

Fig. 5 shows the EMG signal when the calf muscle is at rest. The signal is seems to be almost constant when there is no movement of the leg. In this configuration, the EMG signal is used to measure the muscle activity. The MyoWareTM Muscle sensor is connected to the

Biomedical Sensor Pad to detect the EMG signal. The sensor pad is placed on the skin directly on top of the muscle of interest. Then, by using MATLAB® and Simulink® [13] environment, the analogue value of the EMG signal can be generated as shown in Fig. 6. Literally, Fig. 6 plots the EMG signal obtained when the ankle is moving in dorsiflexion and plantar flexion repetitively. When the ankle has reached the maximum range of motion in both movements, the EMG signal peaks at maximum. The peak of the signal occurs when the ankle is stretched to its maximum range of motion. This action triggers the threshold value to stops the servo motor from rotating any further in order to prevent ankle injury.

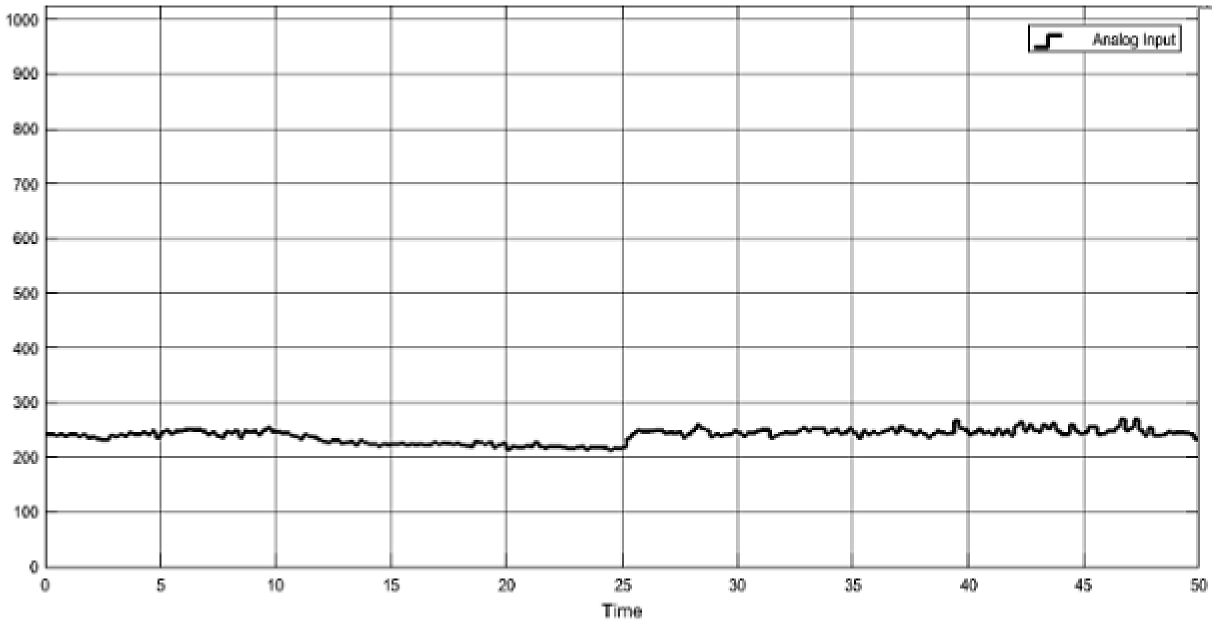


Fig.5. EMG signal when the calf muscle is at rest

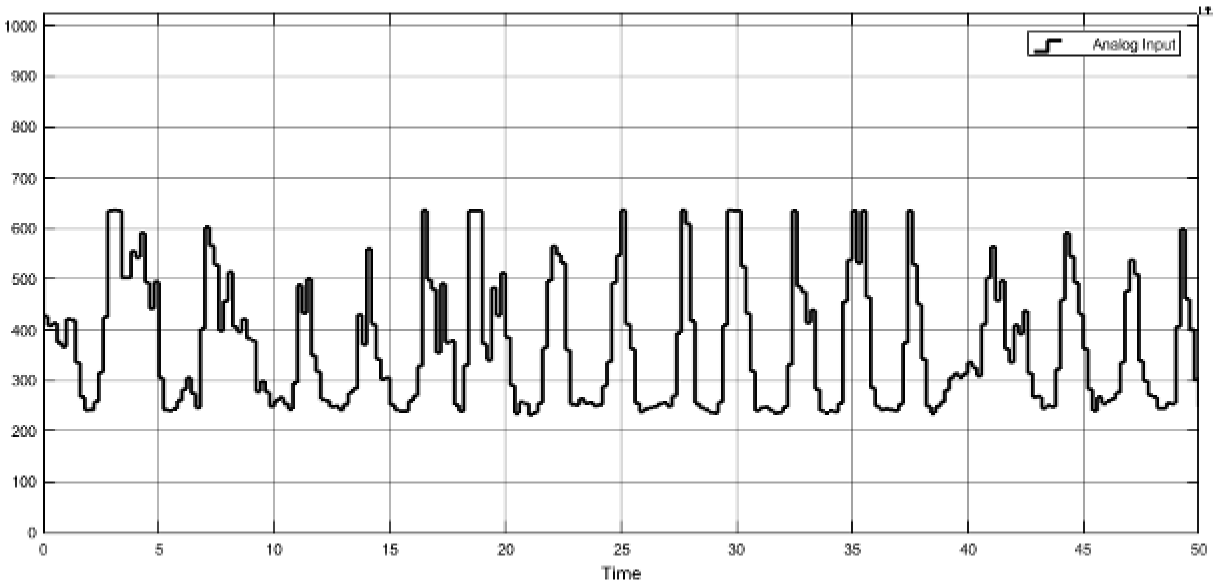


Fig.6. EMG signal when the ankle is moved in plantar flexion and dorsiflexion

Fig. 7 shows the servo motor angle when the ankle is stretched to its maximum range of motion. The servo motor stops from actuate further and held still the position. Before mounting the servo motor and the circuit to the ankle brace, the threshold value is tested on the circuit and identified by an LED. When the joystick is moved, the servo motor actuated as programmed. When the ankle is moved in dorsiflexion manually until it reaches maximum range, the LED turned on indicating the EMG [12] signal has reached the threshold value and the servo motor stopped actuating.

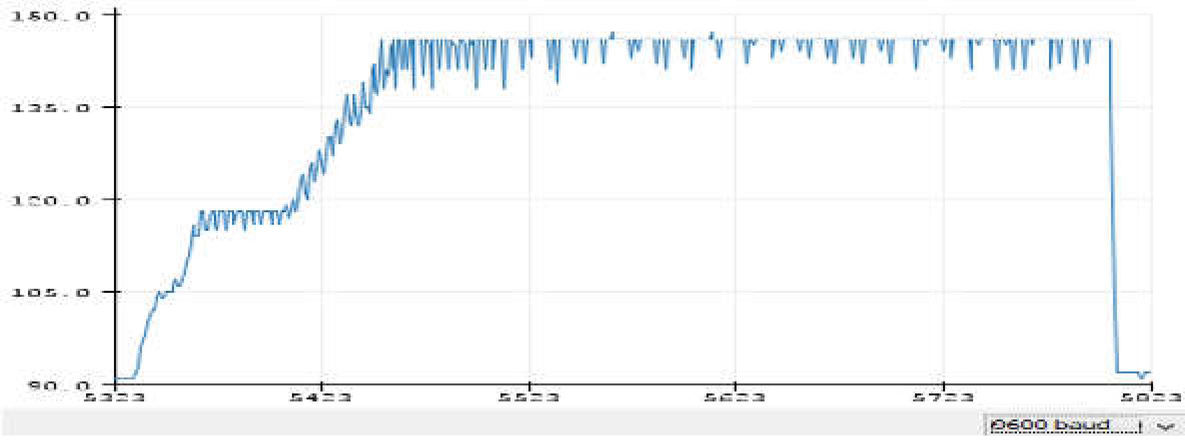


Fig.7. Servo motor angle

4. CONCLUSION AND SUGGESTION

Calf muscles play a very important role in human everyday life. Disruption of its function may affect human in many ways. One of the most extreme effect is gait abnormalities. Thus, it is very important to protect the calf muscles. Exercising the calf muscles maybe an effective treatment for patient with calf muscles flexibility problem, but it can also help to maintain the muscles and prevent future muscle disorder conditions from occurring. With the technologies advances, it is believed that in future there will be more and more modifications on current device to produce the best fit device for ankle rehabilitation purpose. This study is one of the effort made to open up research and development in this field. However, there are a few limitations which were identified during the development of the ankle brace. These limitations open up new avenue to researchers to ponder and researching further. The main limitation is the insufficient torque provided by the servo motor. The ankle brace device could not be tested out properly on real human ankle as it unable to overcome the joint resistance torque.

Besides that, the Biomedical Sensor Pad that is used to connect the MyoWareTM Muscle Sensor with the muscle is not reusable. Moreover, sensitivity of the sensor pad reduces significantly after use. Since the power supply for the ankle brace is obtained from the batteries, the functional time is limited as batteries may drained very fast. In future, it is recommended to select a servo motor which can provide large torque so that it can overcome the joint resistance torque. Besides that, rather than using disposable Biomedical Sensor Pad, a reusable electrode can be used. It can be custom made according to required specifications. Other than that, the power supply of the ankle brace should be replaced with a rechargeable battery or renewable power sources. It is also recommended to implement an angle sensor and LCD display so that user can keep track of the ankle range of motion after using the ankle brace device.

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