UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF A WEARABLE ANKLE REHABILITATION DEVICE FOR PATIENT WITH CALF MUSCLES FLEXIBILITY PROBLEMS BY USING ARDUINO UNO

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electrical Engineering Technology (Industrial Automation and Robotics) with Honours.

by

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DECLARATION

I hereby, declared this report entitled "Development of A Wearable Ankle Rehabilitation Device for Patient with Calf Muscles Flexibility Problems by Using Arduino Uno" is the results of my own research except as cited in references.

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Date : ……………………………………………………….

APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering Technology (Industrial Automation and Robotics) with Honours. The members of the supervisory are as follow:

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(Project Supervisor)

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(Project Co-Supervisor)

ABSTRAK

Kespastikan merupakan faktor utama masalah fleksibiliti otot betis. Kespastikan ialah suatu situasi di mana otot betis mengalami kontraksi secara berterusan. Hal ini akan menyebabkan otot menyusut dan akhirnya akan mengganggu gaya berjalan seseorang dan akibat lain yang berkaitan. Untuk merawat kespastikan, pesakit menjalani program pemulihan yang menawarkan fizikal terapi yang melibatkan penggunaan pelbagai peralatan robot atau peranti. Walau bagaimanapun, peralatan yang sedia ada masih mempunyai kelemahan dan banyak perbaikan dan pengubahsuaian diperlukan untuk meningkatkan keberkesanan rawatan. Tujuan projek ini adalah untuk mereka bentuk peranti pemulihan buku lali yang boleh dipakai oleh pesakit yang mempunyai masalah fleksibiliti otot betis untuk menjalankan fizikal terapi dengan menggunakan Arduino Uno. Peranti ini mudah digunakan dan tiada bantuan daripada pihak ketiga diperlukan untuk mengendalikan peranti ini. Pendakap buku lali yang digunakan adalah murah dan sesuai untuk pelbagai saiz pergelangan kaki. Motor servo akan dipasang pada pendakap tersebut untuk membantu menggerakkan buku lali. Untuk mengawal pergerakan motor, modul joystick akan digunakan. Dengan menggunakan MyoWare™ Muscle Sensor, signal elektromiografi boleh diterima dah digunakan untuk mengawal pergerakan motor servo bersama dengan modul joystick. Pendakap buku lali robotik tersebut adalah mesra pengguna dan memenuhi keperluan konsep terapi berpandukan robot dan konsep terapi di rumah. Dengan menggunakan pendakap ini untuk melakukan senaman regangan buku lali yang melibatkan dorsiflexion dan plantar flexion, tempoh pemulihan pesakit boleh dikurangkan dengan berkesan. Ia juga dapat mengurangkan risiko mengalami masalah fleksibiliti otot betis.

ABSTRACT

Spasticity is the most common factor of calf muscles flexibility problems. It is a condition where the calf muscles continuously experiencing contractions. This will result in fixed contracture of the muscles which eventually will result in gait abnormalities and other related consequences. To treat spasticity, patient undergoes rehabilitation program which offers physical and occupational therapy which involves usage of various robotic equipment or device. However, the existing equipment are still lacking and many refinement and modification are needed to increase the effectiveness of the treatment. The aim of this project is to design a wearable ankle rehabilitation device for patient with calf muscles flexibility problems to carry out physical therapy by using Arduino Uno. This device is easy to be used and no assistance from a third party is needed to operate the device. The ankle brace is low in cost and suitable for various sizes of ankles. A servo motor is mounted onto the ankle brace to help in moving the joint. A joystick module is used to control the actuation of the motor. By using MyoWare™ Muscle Sensor, the electromyography (EMG) signal is obtained and used to control the servo motor together with the joystick module. The robotic ankle brace device accommodates the robot-guided at-home therapy requirements and is user-friendly. By using this device to perform ankle stretching exercises involving dorsiflexion and plantar flexion, patient recovery process can be reduced effectively. It also reduces the risk of experiencing calf muscles flexibility problems.

DEDICATION

To my beloved parents
To my supervisor, Dr. Sahazati Binti MD. Rozali
To my co-supervisor, Dr, Aliza Binti Che Amran
To my lecturers
And not forgetting to all my friends.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

EMG	-	Electromyography
STJ	-	Subtalar Joint
LED	-	Light-Emitting Diode
EEG	-	Electroencephalography
ECG	-	Electrocardiography
PWM	-	Pulse Width Modulation
ADC	-	Analogue-to-digital Converter
DAC	-	Digital-to-analogue Converter
I/O	-	Input/Output
UART	-	Asynchronous Serial Communication Interface
DMA	-	Direct Memory Access
USB	-	Universal Serial Bus
IDE	-	Intergrated Development Environment
LCD	-	Liquid-Crystal Display

CHAPTER 1

INTRODUCTION

1.0 Introduction

The background of this project related to calf muscles flexibility problems and the treatment available including the equipment used for rehabilitation purposes, problem statement, objectives, and conclusion will be explained in this chapter. An overview for this project and the content of the report will also be included in this chapter.

1.1 Background

Calf muscles flexibility problems usually occur due to spasticity of the calf muscles. Spasticity is defined as a condition in which certain muscle continuously experiencing contractions. If muscle contractions are not treated, fixed contracture may occur causing the muscle to be permanently shortened. Spasticity can be ranged from slight muscle stiffness to spasms that come and go, to permanent contracture. Scientifically, spasticity occurs due to imbalance signal from the central nervous system to the muscles because of injury or disease that damages parts of the brain or spinal cord. Some of the common neurological conditions that may lead to spasticity are cerebral palsy, traumatic brain injury, stroke, multiple sclerosis and spinal cord injury. Thus, spasticity of the calf muscles can be defined as condition when the calf muscles are continuously contracted causing stiffness and tightness in the muscles and a wide range of involuntary muscle spasms (Bandi and Ward, 2013).

Gait abnormalities, foot drop, sudden spasms, abnormal posture and increased resistance to leg movement are some of the symptoms that are associated with spasticity of calf muscles. Resistance to leg movement may refer to restriction of ranges of dorsiflexion and plantar flexion ankle movements compared to a normal range of motion. These ankle movements play a very crucial role in helping human to walk, run or jump.

Fortunately, spasticity can be treated with appropriate treatments such as physical and occupational therapy, medications, surgery or a combination of these treatments (Richardson, 2002). Stretching, muscle group strengthening and range of motion exercises to prevent muscles from contraction, preserve flexibility and range of motion are all categorized as physical therapy. These exercises should be performed frequently as suggested by the physical therapist. On the other hand, occupational therapy includes usage of splints, casts or braces on the affected area for proper limb positioning and maintaining flexibility and range of motion. A physical and occupational therapist needs to provide patients with guidelines on how to perform these exercises as well as the direction to use the suitable equipment due to the complication of the equipment.

To date, various devices have been developed to make the therapy session more effective and easier. Ranging from an exoskeleton robot to the arm or leg stretching device and even prosthetics or orthotics, the rehabilitation program attended by the patients have been more enjoyable and the outcome of the implementation is also positive. However, there are still spaces available for refinement and modification so that the devices available in the future are really effective and affordable to be used. It has to be fit for robot-guided at-home therapy usage.

1.2 Problem Statement

Physical and occupational therapy is one of the most common rehabilitation treatment for patients with calf muscles flexibility problems. Even with existence of various robotic ankle brace devices that are meant to make the therapy process more enjoyable and easier, the assistance of the physical and occupational therapist is still very crucial during the therapy. Patients need to be under close surveillance of the therapist when performing the ankle stretching exercises and when using the robotic ankle brace device at the rehabilitation centre. Besides that, the price of the robotic ankle brace device used for the therapy are too costly to be owned by the patients and the direction of the usage are too complicated. Hence, this will restrict the patients from carrying out the therapy program at home which will actually make the recovering and treatment process slower and less effective as it can be.

1.3 Objective

The purposes of this project are as follow:

a) To design and develop a wearable ankle rehabilitation device for patient with calf muscles flexibility problems to carry out physical therapy treatment by using Arduino Uno.

b) To verify the designed device on the real system by acquiring real time data of the electromyography (EMG) signal from the calf muscles using MyoWare^{TM} Muscle Sensor and MATLAB® and Simulink®.

c) To analyse the functionality of the ankle brace device with the joystick and its suitability for robot-guided at-home therapy purpose.

1.4 Work scope

The wearable ankle rehabilitation device will be built using Arduino Uno as the microcontroller board for programming the circuit and a joystick module to act as a controller for the device. To program the board, Arduino IDE software will be used. The ankle brace will be designed so that it is adjustable for all sizes of ankle and servo motors with suitable torque will be used to move the ankle for stretching purposes. The MyoWare^{TM} Muscle Sensor will also be used to convert the muscle activities into electromyography (EMG) signal so that it can be used to prevent over-stretched ankle. The cost of the device will be maintained at minimal. This device is solely built for passive ankle stretching exercises which involves dorsiflexion and plantar flexion movements and not active exercise. These movements are very useful for improving calf muscles flexibility.

1.5 Organisation

This report focuses on the development of a wearable ankle rehabilitation device for patient with calf muscles flexibility problems. The first part of the report focuses on the introduction of calf muscles flexibility problems and its treatment. Then, the problem faced by the patients undergoing the treatment will be discussed followed by the introduction on the ankle device to be built. Next, we will review some background information from previous projects in literature review. This is followed by the methodology to be used during the development of the device. Next, analysis will be carried out on the product and the results will be discussed. Finally, conclusions and recommendations are made.

1.6 Conclusion

The project background, objectives, problem statement, scope of the project and organisation of the report had been explained above. This chapter has also stated the problem to be solved and how the project is carried out.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter gives a review of a wearable ankle rehabilitation device for patient with calf muscles flexibility problems using Arduino Uno microcontroller and the uses of MyoWare^{TM} Muscle Sensor to detect the electromyography (EMG) signal of the muscles. The main source of the study was taken from journals, conference papers, books, articles and websites. Each source is chosen according to the relevance of the project scope.

2.1 Calf muscles flexibility

Calf muscles are made up of gastrocnemius and soleus muscles which are connected by the fascia (connective tissue) to form Achilles tendon at the back of the ankle. When the calf muscles are not flexible, the gastrocnemius and soleus muscles are tight and stiff. This lead to tightness in the Achilles tendon too. This situation always occurs due to spasticity of the calf muscles. When the calf muscles are tight, the ankle cannot move properly, especially in the motion of dorsiflexion.

2.1.1 Leg anatomy

According to Figure 2.1, the foot is divided into three segments which are the posterior segment (ankle), middle segment (mid-foot) and anterior segment (five metatarsals and 14 phalangeal bones).

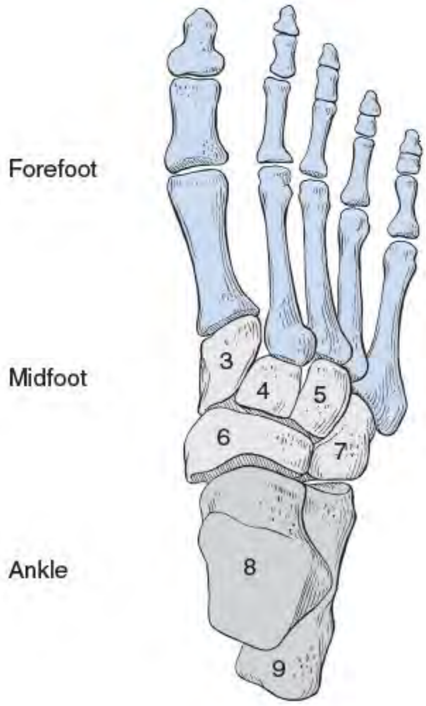

Figure 2.1: Three segments of the foot (posterior, mid-foot and forefoot segment) (Ombregt, 2013)

The posterior segment or ankle is made of the connection between foot and the leg. The ankle joint is a hinge joint formed by the bones of the lower leg consists of the tibia, fibula and bone of the foot, talus. The basic movements that the ankle can make are dorsiflexion and plantar flexion through an axis that passes transversely through the body of talus. Other than that, are eversion which is turning of the sole of the foot so that it moves outwards and face laterally and inversion which is turning of the sole of the foot so that it moves inwards and face medially.

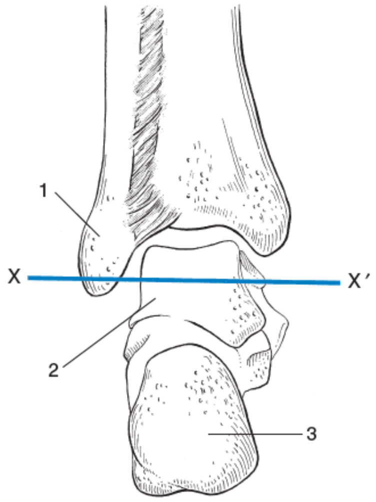

Figure 2.2: Axis of plantar flexion and dorsiflexion [X-X’] (Ombregt, 2013)

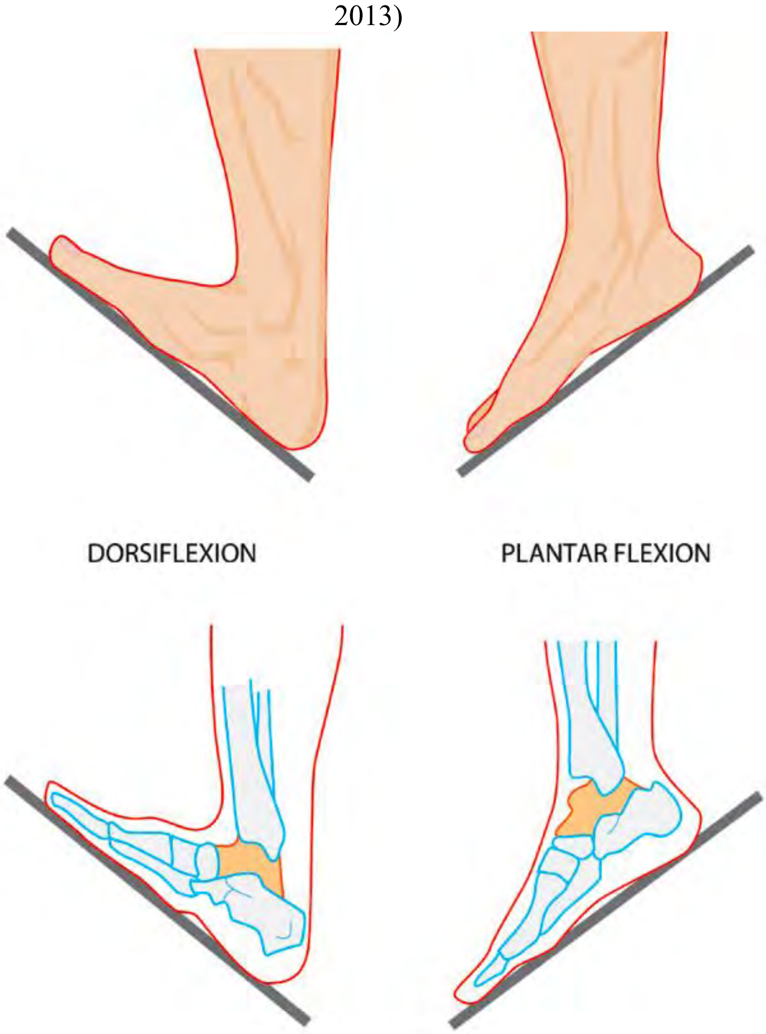

Figure 2.3: The foot during dorsiflexion and plantar flexion (Silas Carey, 2016)

The gastrocnemius muscle is the bulging shape of the calf. It is a muscle located at the back of the lower leg. The gastrocnemius and soleus muscles make up the calf. The soleus is the flat muscle underneath the gastrocnemius muscle. These two muscles are connected by the connective tissue called fascia to form the Achilles tendon which is the strongest and thickest tendon in the human body. The gastrocnemius and soleus muscles are in charge of plantar flexing the foot at the ankle joint and flexing the leg at the knee joint. The gastrocnemius is majorly involved in running, jumping and other fast movements of the leg while the soleus is majorly active when standing still. The gastrocnemius muscle is more prone to spasms.

The range of motion of the ankle for every individual may varied due to many circumstances. However, the generally accepted values for a normal range of motion of the ankle is 0° to 50° for plantar flexion and 0° to 20° for dorsiflexion (Quinn, 2016).

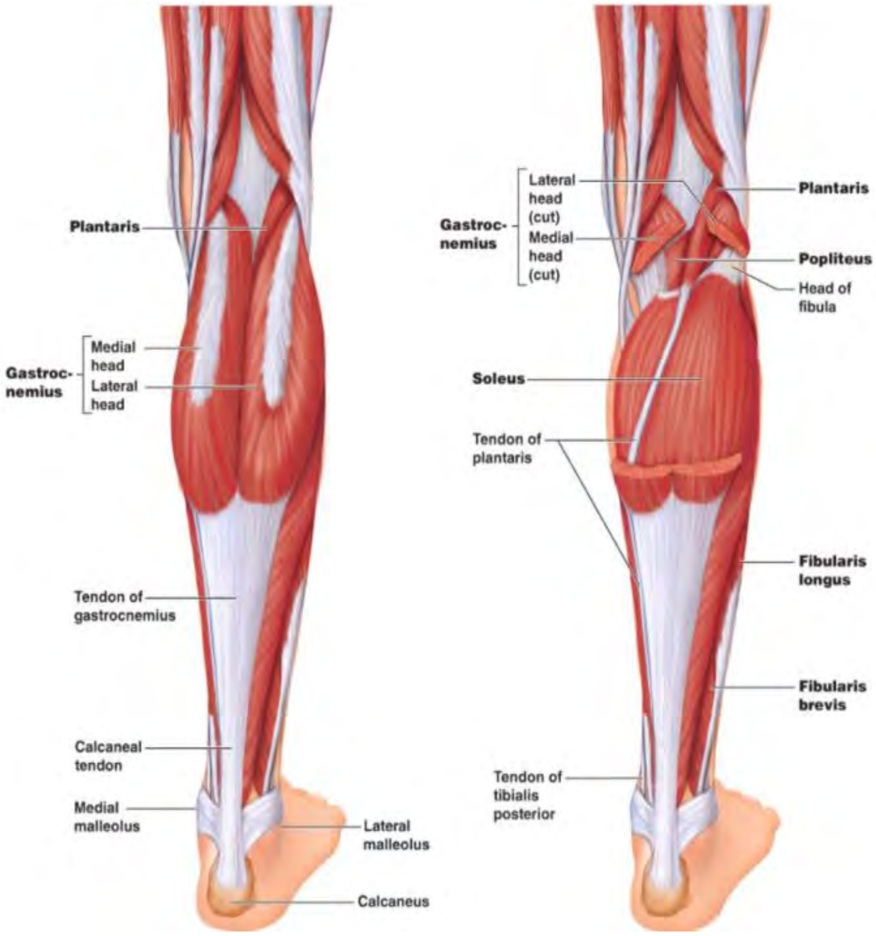

Figure 2.4: The gastrocnemius and soleus muscles (Silas Carey, 2016)

2.1.2 Spasticity

Many had attempted to define the meaning of spasticity. However, spasticity was first described by Lance (1980) as:

‘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.’

Later, Young (1994) redefined spasticity by adding neurophysiological elements to it as:

‘A motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes that results from abnormal intra-spinal processing of primary afferent input.’

Based on the two definitions above, it can be said that the definition given by Lance only valid for spasticity during passive movement where it is the movement conducted by someone else on the patient’s body.

According to Barnes and Johnson (2001), 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 muscle become resistive to stretching and lengthening, there will be two major consequences faced. First, there will be chances that the muscle will remain in a shortened position in long term and may result in changes to the soft tissue. This will eventually lead to contractures. Second, there might be restriction to the movement of the body parts.

Similarly, according to Bandi and Ward (2013), spasticity can be life-threatening and may lead to disabling and risky consequences. They claimed that spasticity is a physiological consequence of an insult to the brain or spinal cord. This muscle over activity may cause muscle and soft tissue contracture if it is not treated.