Faculty of Engineering

FUNCTIONAL ELECTRICAL STIMULATION (FES) STUDY FOR FOOT DROP REHABILITATION BY ARDUINO NANO ATMEGA328P

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Bachelor of Engineering

Electrical and Electronics Engineering

with Honours

2022

UNIVERSITI MALAYSIA SARAWAK

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FUNCTIONAL ELECTRICAL STIMULATION (FES) STUDY FOR FOOT DROP REHABILITATION BY ARDUINO NANO ATMEGA328P

MUHAMMAD NAZREEN BIN ULIA @ MOHD SAZALI

64961

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ABSTRACT

A foot drop occurs when a person is unable to lift the front of their foot because the muscles in their foot are either too weak or too paralyzed to do so. The tibialis anterior (TA), the extensor hallucis longus (EHL), and the extensor digitorum longus (EDL) are the three muscles that are damaged by this condition. Electromyography is used to record the activity of the muscles (EMG). It is based on the observation that when a muscle contracts, blood flow increases to that muscle. This project proposed the design of Functional Electrical Stimulation (FES) device with a microcontroller, Arduino Nano ATmega328p, and a Transcutaneous Electrical Nerve Stimulation (TENS) unit. This device allows a person with foot drop to have access to an FES device at a price that is more affordable. A real-time EMG signal of TA muscle is acquired and filtered directly using 2nd order low pass Butterworth filter to clean the signal. The FES device will focus on the muscle problem that the foot drop which is the tibialis anterior (TA). The next stage is performing research on the detection and classification technique of EMG. The techniques are various and choosing the suitable technique can aid in the preprocessing of the raw signal. The microcontroller will be programmed and respond accordingly based on the preprocessed EMG signal. Tests will evaluate the accuracy and runtime of the device in detecting and activating the muscle. Four subjects are chosen with diverse characteristics including age, weight, height and body mass index (BMI). As a whole, this research has resulted in the FES device a successful implementation because the TENS delivers a shock to the TA when it is relaxing and turns off when it is contracting.

ABSTRAK

"Foot drop" merupakan salah satu penyakit yang berlaku apabila seseorang tidak dapat mengangkat bahagian hadapan kakinya kerana otot di kakinya sama ada terlalu lemah atau lumpuh. Tibialis anterior (TA), extensor hallucis longus (EHL), dan extensor digitorum longus (EDL) adalah tiga otot yang terkesan oleh keadaan ini. Elektromiografi (EMG) digunakan untuk merekodkan aktiviti otot. Ia berdasarkan pemerhatian bahawa apabila otot mengecut, aliran darah meningkat ke otot tersebut. Projek ini mencadangkan reka bentuk peranti Rangsangan Elektrik Berfungsi (FES) dengan mikropengawal, Arduino Nano ATmega328p dan unit Rangsangan Saraf Elektrik Transcutaneous (TENS). Peranti ini membolehkan seseorang yang mengalami "foot drop" mempunyai akses kepada peranti FES pada harga yang lebih berpatutan. Isyarat EMG masa nyata otot TA diperoleh dan ditapis terus menggunakan penapis Butterworth lulus rendah pesanan kedua untuk membersihkan isyarat tersebut. Alat FES akan memfokuskan kepada masalah otot tibialis anterior (TA). Peringkat seterusnya ialah menjalankan penyelidikan mengenai teknik pengesanan dan pengelasan EMG. Tekniknya adalah pelbagai dan memilih teknik yang sesuai boleh membantu dalam prapemprosesan isyarat mentah. Mikropengawal akan diprogramkan dan bertindak balas dengan sewajarnya berdasarkan isyarat EMG yang dipraproses. Ujian akan menilai ketepatan dan masa jalan peranti dalam mengesan dan mengaktifkan otot. Empat subjek dipilih dengan ciri yang pelbagai termasuk umur, berat, tinggi dan indeks jisim badan (BMI). Secara keseluruhannya, penyelidikan ini telah menghasilkan peranti FES sebagai pelaksanaan yang berjaya kerana TENS memberikan kejutan kepada TA apabila ia berehat dan dimatikan apabila ia mengecut.

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EMG	-	Electromyography
FES	-	Functional Electrical Stimulation
AFO	-	Ankle Foot Orthosis
TENS	-	Transcutaneous Electrical Nerve Stimulation
TA	-	Tibialis Anterior
EHL	-	Extensor Hallucis Longus
EDL	-	Extensor Digitorum Longus
GM	-	Gastrocnemius Medialis
GL	-	Gastrocnemius Lateralis
RF	-	Rectus Femoris
SM	-	Soleus Medial
SL	-	Soleus Lateral
PL	-	Peroneus Longus
PB	-	Peroneus Brevis
H	-	Hamstring
MH	-	Medial Hamstring
VL	-	Vastus Lateralis
VM	-	Vastus Medialis
BF	-	Biceps Femoris
S	-	Semitendinosus
FSR	-	Force Sensitive Resistors
IMU	-	Inertial Measurement Unit

Chapter 1

INTRODUCTION

1.1 Overview

This chapter is discussing the framework of the study. In this chapter in which including the project background, problem statements, project objectives, scope of work for the research and project outline.

1.2 Background

The lower limb from the knee to the ankle is referred to as the leg. They offer assistance and a variety of movements. There are five regions in each leg known as upper leg (femur bone), knee (patella), lower leg (tibia and fibula), ankle and foot [1]. The tibia and fibula are two bones found in the lower leg. The tibia, or shinbone, is the bigger of the two bones. The fibula is smaller and thinner compared to tibia. It can be found on either side of the leg. Figure 1.1 shows the lower limb bones.

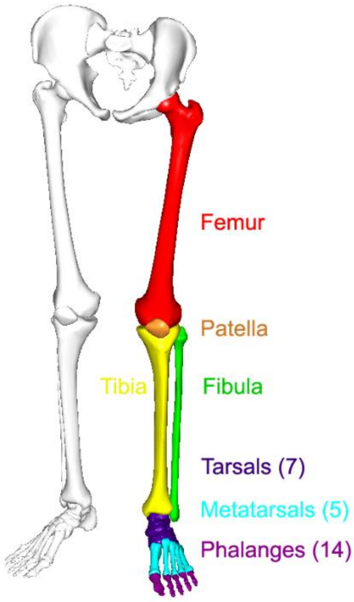

Figure 1.1 Lower limb bones [2]

The lower leg has several muscles that work together to move the foot and ankles such as gastrocnemius, soleus, plantaris, tibialis anterior, tibialis posterior and peroneus [3]. Figure 1.2 illustrates the muscles of lower limb.

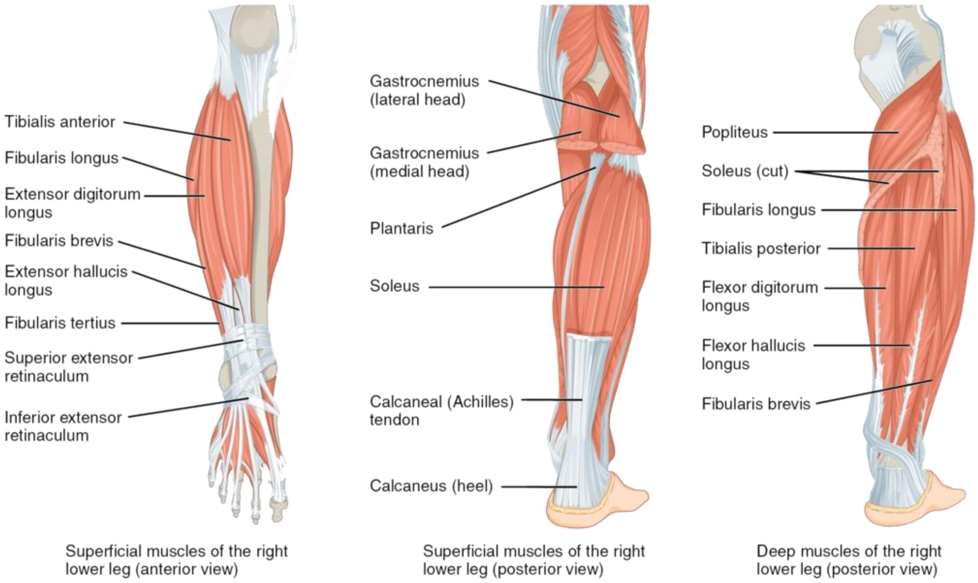

Figure 1.2 Lower limb muscles [4]

The foot is essential for human motions such as standing, walking, running, jumping, and balancing, as well as absorbing power from body components above it. The skeleton of the foot is separated into three parts: the tarsus, metatarsus and digits [5]. The talus, calcaneus, navicular, cuboid, and three cuneiform bones make up the tarsus, which is made up of seven bones. The digits are produced by the phalangeal, which is made up of five metatarsals. The primary foot muscles are including extensors, flexors, tibialis posterior, tibialis peroneal and tibialis anterior [5]. Shown in Figure 1.3 is the skeleton of foot.

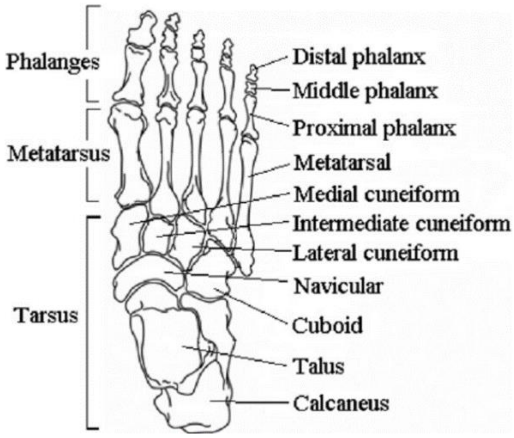

Figure 1.3 Foot bones [6]

Humans have gait which is known as a pattern of limb movements produced during walking or a walking style [7]. Walking is a common activity of daily living and at the same time a very complex one. As shown in Figure 1.4 is the gait cycle of normal person. When walking, it might cause a person to drag their foot on the ground. This condition is known as foot drop. They may need to raise their knees higher than normal to minimize dragging their toes or make a wide arc to swing their leg.

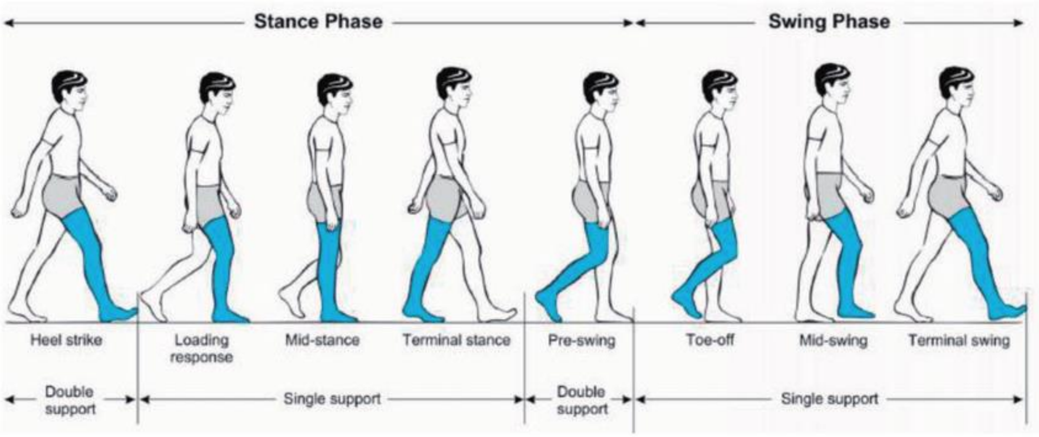

Figure 1.4 Gait event [8]

Foot drop is caused by a muscular issue caused by difficulties with the common peroneal nerve or paralysis of the muscles across the lower leg's anterior area [9]. Foot drop can result from a direct impact to the back of the knee, cerebral palsy, muscular dystrophy, stroke, as well as multiple sclerosis. A notable weakening of ankle and toe dorsiflexion can be classified as this condition. The tibialis anterior, extensor hallucis longus and extensor digitorum longus are the dorsiflexors of the foot and ankle. Figure 1.5 demonstrates the muscles causing foot drop and Figure 1.6 shows the gait cycle for individual with foot drop.

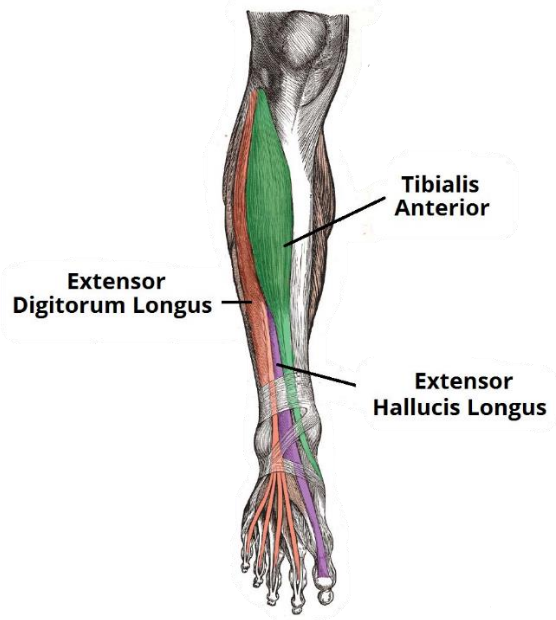

Figure 1.5 Muscular groups that affect foot drop [10]

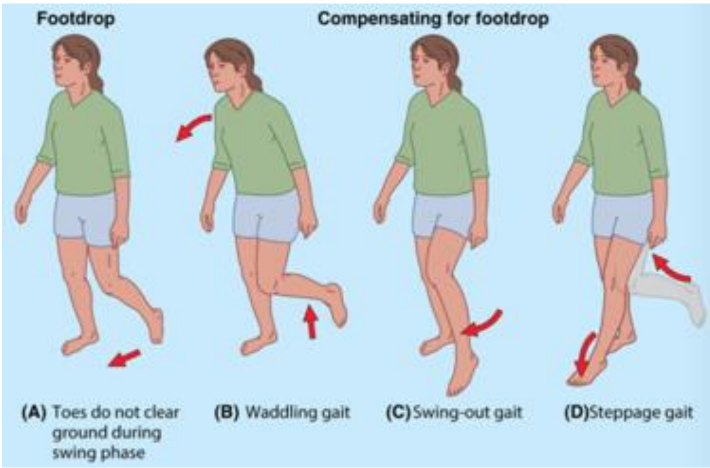

Figure 1.6 Foot drop gait cycle [11]

1.3 Problem Statement

The movement of our muscles is recorded using electromyography (EMG). It is based on the observation that when a muscle contracts, a burst of electric activity is created, which transmits into underlying tissue and bone and could be recorded from nearby skin regions. The quantity of muscular contraction and the number of contracted muscles is both linearly related to EMG activity. In other words, the greater the strength of the muscular contraction and the greater the number of active muscles, the greater the measured amplitude. Interference, background spikes, Gaussian noise, motion artifact, or powerline interference are all common sources of contamination in raw EMG obtained from human muscles. It is necessary to identify, deconstruct, analyze and classify the recorded EMG signal before developing a FES.

Functional electrical stimulation (FES) is the application of tiny electrical pulses to muscles in order to regain or restore their function. Many FES devices have an external tiny electrical box known as the neuromuscular electrical stimulator unit, wires that extend from the box and transmit the electrical impulse, and an electrode to which the wires are connected. Other FES devices employ wireless connections that send electrical impulses through radio waves. The electrodes activate the muscles that are being stimulated. It is one of the most expensive treatments compared to AFO. The cost of owning FES will be greatly reduced by combining low-cost goods like Arduino or Raspberry Pi with a transcutaneous electrical nerve stimulation (TENS) device to build a FES product.

Prototype test is an essential stage of the product development and design process. Testing and assessment merely verify whether the product will perform as expected or whether it need modification. Therefore, the developed FES should be evaluated its performance to identify any flaws so that improvements can be made. A more accurate and functional FES device could be created as a result of the improvements. The enhanced FES could be used as a low-cost solution for foot drop rehabilitation.

1.4 Objectives

The following are the project's objectives:

- To preprocess raw EMG of tibialis anterior muscle by using suitable technique.
- To develop a FES with microcontroller and TENS.
- To evaluate the performance of the developed FES

1.5 Scope of Work

The project is focusing on the development of functional electrical stimulation (FES) which is operating by using a microcontroller and transcutaneous electrical nerve stimulation (TENS). The Arduino IDE and Fritzing are two of the software applications that are being utilized in this project. The Arduino IDE is used to code the microcontroller and to apply filter to the signal received. The Fritzing is used in the process of designing the circuit for the FES device. The project will not include real procedural data collection and only focus on the tibialis anterior (TA) muscle. The electromyography (EMG) sensor is going to be used to collect the data on the muscle signals. Furthermore, the FES device functionality will focus for adult users only. This is due to different age range have distinct muscles activation.

1.6 Project Outline

The project report is structured into three chapters: introduction, literature review, and methodology. The first chapter discusses the project background, problem statements, project objectives, scope of work for the research and project outline.

Chapter 2 of this project consists of the literature review of the project. Mainly, the research study on related topics. In the beginning of the chapter, foot drop syndrome is defined along with the muscle affecting the foot drop and the treatment for the syndrome. Following that, the terms Functional Electrical Stimulation (FES) and Transcutaneous Electrical Nerve Stimulation (TENS) are discussed, as well as their applications. The final section of this chapter compares preprocessing techniques used by past researchers as well as existing FES devices used or developed by earlier researchers.

The methodology of the project is covered in Chapter 3. This chapter covers the research methodology, experimental design, procedures and equipment of the project including Gantt Chart for FYP1 And FYP2. Other than that, the concept of the project will be included in this chapter.

Chapter 4 of this project contains three parts of results and discussion. The first part is the preprocessed EMG signal. This part consists of several graph of filtered signal using three type of filtering. The second part is hardware and software development. This part explains and show the complete FES device and the code that running the device. The very last step is the evaluation of the device. The purpose of this evaluation is to test how well the device works with a variety of users.

Chapter 5 consists of the conclusion for this project and recommendation to improve the device for future work.

Chapter 2

LITERATURE REVIEW

2.1 Overview

This chapter discusses a basic explanation and definition of foot drop, as well as the muscles that cause foot drop and the treatment for the syndrome. The concepts of Functional Electrical Stimulation (FES) and Transcutaneous Electrical Nerve Stimulation (TENS), as well as their application, are explained after that. Finally, past study of preprocessing techniques will be compared, as well as the FES devices used by other researchers.

2.2 Foot Drop

Foot drop refers to the inability to elevate the front half of the foot. According to Nori and Strenski [9] , foot drop is a sensation of weakness experienced when attempting to lift the foot and/or toes upward. When walking, a person with foot drop may notice that the front of their foot drags on the ground. On the affected side, the leg is raised higher than usual to allow the toes to clear the surface [12]. Foot drop is an indication of a neurological, muscular, or anatomical issue and is not a disease. It can affect either one or both feet simultaneously [13].

2.2.1 Muscles

During normal gait, leg consists of various muscles and each muscle performs different activities. Figure 2.1 shows an overview of lower-limb muscle control during gait in a simplified format. Referring to the black region of the model, the tibialis anterior (TA) is just begin its activity to prepare for the first swing phase at the completion of the stance phase. The TA will not active during initial to middle of swing phase in those with