Low Cost Functional Electrostimulation

Şule ÖZGÜNER[1], Ömer ALACA[2], Ferdi BAŞKURT[3], Hatice AKMAN[1]

[1] Isparta Uygulamalı Bilimler Üniversitesi Teknoloji Fakültesi, Biyomedikal Mühendisliği Bölümü, Isparta, Turkey
e-posta:suleozguner@gmail.com
e-posta:haticeakman@isparta.edu.tr
[2]Isparta Uygulamalı Bilimler Üniversitesi, Teknoloji Fakültesi, Makine Mühendisliği Bölümü, Isparta, Turkey
e-posta:omeralaca28@gmail.com
[3]Süleyman Demirel Üniversitesi , Sağlık Bilimleri Fakültesi, Fizyoterapi ve Rehabilitayon Bölümü, Isparta, Turkey
e-posta:ferdibaskurt@sdu.edu.tr

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Abstract

Functional electrical stimulation is the stimulation of neurons by electric current in order to perform a functional movement towards daily life activities. Currently, ankle orthoses are used to fix foot status at 90^0 for low foot patients. The orthoses does not supplies a natural gait form as it results with stanble ankle position. The main reason why FES use is not widespread is, that the patients can not afford the costs as it is too high. At this study a low-cost, lightweight, functional electrical stimulation device with heel pressure sensor is designed. Foot pressure sensor is used to control walking. Square wave is used to perform stimulation with arduino nano. This square wave signal is applied continuously at intervals of 200 milliseconds while the foot is up. Square wave is increased with LM2577 integration to input and the voltage of the TIP122 power transistor has been used to control output power. Working volt range can be adjustable between 20-40 Volts with 50 mA current at 20 Hz with response time as 0.8 sn. Low cost FES devices can be used for patients, as it has very positive contributions to human health and increases the quality of life.

Düşük Maliyetli Fonksiyonel Elektrostimülasyon

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Özet

Fonksiyonel elektriksel uyarım, günlük yaşam aktivitelerine yönelik fonksiyonel bir hareket gerçekleştirmek için nöronların elektrik akımı ile uyarılmasıdır. Şu anda ayak bileği ortezleri düşük ayak hastaları için ayak durumunu 900'de sabitlemek için kullanılmaktadır. Ortezler, ayak bileği dik pozisyonu ile sonuçlandığından doğal bir yürüyüş formu sağlamaz. FES kullanımının yaygın olmamasının temel nedeni, hastaların çok yüksek olduğu için maliyetleri karşılayamamasıdır. Bu çalışmada düşük maliyetli, hafif, fonksiyonel, topuk basınç sensörlü bir elektriksel stimülasyon cihazı tasarlanmıştır. Yürümeyi kontrol etmek için ayak basınç sensörü kullanılmıştır. Arduino nano ile stimülasyon gerçekleştirmek için kare dalga elde edilmiştir. Bu kare dalga sinyali, ayak yukarıdayken 200 milisaniyelik aralıklarla sürekli olarak uygulanmaktadır. Girişe LM2577 entegrasyonu ile kare dalga artırılmıştır ve TIP122 güç transistörünün voltajı çıkış gücünü kontrol etmek için kullanılmıştır. Çalışma volt aralığı 20 Hz'de 50 mA akım ile 20-40 Volt arasında, tepki süresi 0.8 sn olarak ayarlanabilir şekildedir. İnsan sağlığına çok olumlu katkıları olduğu ve yaşam kalitesini artırdığı için düşük maliyetli FES cihazları hastalar için kullanılabilirler.

1. Introduction

Drop foot is one of the most common problems in rehabilitation clinics. It is the creeping walking form of the foot due to the inability of the foot muscles. Drop foot patients have difficulty in lifting the foot above at the ankle or cannot lift it at all. In this way, walking becomes difficult, and can cause obstacles during walking and causes fall. Especially in cases where the foot needs to be lifted activities, such as climbing stairs, climbing uphill and walking on soft surfaces are done with difficulty. All these obstacles impair the person's range of motion during their daily life. With the commands from the central nervous system, normal movement is occured with healthy muscles and joints. If a problem has consists at central nervous system, this may result in drop foot. As a result normal gait is disrupted. So the foot hangs from the ankle and cannot perform the dorsal flexion movement, the foot does not touch the ground very securely and the multiple turns continue to rotate correctly.

Drop foot causes deformations in standing shape and appearance over time. The arch of the foot rises and the foot touches the ground from the heel. Wounds or calluses develop due to changing pressure in various parts of the foot. In time, arthritis in the joints of the feet and shape deformation in the fingers occur. There may be swelling due to non-palpable sprains and calls that occur with movement. Drop foot, which has existed for a long time, can sometimes result in shortness on one side. Keeping the foot in the same position continuously causes the achilles tendon to be shortened and the calf tension and pain. These problems in the feet also affect the movements of the knee and hip negatively. There may be problems and pain when the knee joint extends excessively backward over time. These are accompanied by hip fractures.

Functional electrical stimulation (FES) is performed by placing the surface electrodes on the skeletal muscles of the stimulated nerve or muscle. The electrical field between the electrodes stimulates the membrane of the nerve fibers. The stimulus travels along the nerve and reaches the muscle fiber, resulting in contraction [1]. Liberson et al. (1961), first develop FES and focused on this subject and developed commercial products with the data they obtained [2]–[5]. They improved their work by making significant changes on the control system of the FES system[6], [7]. During the swing phase of this system, foot dosflexion was provided by synchronic tibialis anterior muscle stimulation. In FES applications, the increase in walking speed and strengthening of the muscles can be made in a way that the walking pattern is more than normal. In FES applications, the increase in walking speed and strength in the muscles can make the walking pattern much more to normal[8]. Neal and Reswick (1976) reported that inhibition of antagonist muscles in peroneal nerve stimulation and decrease in muscle activities. The evidence for inhibition is not all compatible [9], [10].

Acimovic et al. (1992) developed four-channel stimulation device using microcontrollers. The orthopedic system was based on heel strike and this determines the swing and stance phase. As a result of the studies, 22% improvement in speed, 10% in rhythm and 9% in stride length was achieved during walking [11]. As a similar study, Chou et al. (2011) conducted experiments similar to the mutual arm swing experiments of Malezcik with triceps brachii stimulation [12]. Sabut and Mahadevappa (2008) developed tibialis anterior stimulation using a heel switch during the swing phase in a controlled study they applied to 10 patients with drop foot for eight weeks. Gait improved statistically when using the orthosis device. They achieved an increase of 11.7% in walking speed, 10.8% in rhythm, and 13.3% in stride length. In addition, it has been stated in their studies that there is a 17.7% decrease in the physiological cost index (PCI). In addition to these studies, therapeutic effects such as decreased spasticity, increased range of motion, improvement in blood circulation and reduction of pain were observed [13]. The open loop systems offered so far include the stimulation profile consisting of surface-based and fixed pulse sequences. Halloran et al. (2003) developed a different stimulation method in their study. They developed the stimulation apparatus with heel switch, placed in the body for drop foot with pulse width modulation in both phases of walking. They tested the device for a hemiplegic patient. The stimulator placed in the body. They designed the devices with two channels and with 12-pole nerve cuff electrode for insertion into the peroneal nerve, the initiation of stimulation can be controlled externally. The balance between the channels was mostly achieved by physiological dorsiflexion[14].
Similarly, Breen et al. (2006) developed FES using two switches for heel and nail in their study, and the stimulation timing was set in stages based on walking speed [15]. Lyons et al. (2000) developed EMG-modulated stimulation in their study and tried it in a hemiplegic patient. As a result of this study, a high dorsiflexion width up to 76% (7.68˚) was obtained. In other studies, the rate is generally 53% (4.35˚). The decreased spasticity of the calf muscles during dorsiflexion may have positively affected the result. This approach gives about twice as much to produce dorsiflexion [16].

Keeffe et al. (2003) developed a similar method. it was tested only by healthy individual, it was reported that their study using 47% less stimulation than general methods was more energy efficient [17]. Advanced sensor techniques have entered FES control strategies in the last decade. Stein et al. (2004), tested advanced sensor technologies in their study [18]. Another system with advanced sensor technique is Breen et al. (2009), the system called DuaSTIM is a fully-fledged portable device with dual channel stimulator and advanced sensor techniques [19]. The device control algorithms to correct the drop foot connected to the switches on the foot (heel and nail). It gives free-form stimulation and is generally controlled by different sensors, such as the accelerometer-based stimulator. In the last two decades, heel switch, nerve cuff, and skin mechanoreceptors (natural sensors) have been used to record all responses during walking. In 2005, Hoffer et al. The Neurostep developed one of the first clinical trials with an intramuscular, fully implantable device to correct drop foot. The Neurostep works independently with batteries, sensors and stimulation units, without any external devices. Neurostep is still a medical device under investigation in clinical trials [20].

2. Foot Drop and Fes Overview

Gait disturbances caused by central nervous system damage differ from each other. Spasticity may occur in the muscles or the muscles lost range of motion in a relaxed position. The most common gait disorder is the inability to lift the foot up from the ankle because the muscle that will bring the foot to the upright position, called drop foot, is relaxed and cannot contract. Muscles and nerves are normally intact while standing. There is a damage of central nervous system. Therefore, when the healthy muscle and nerve is electrically stimulated from outside with a device, foot dorsiflexion occurs (Figure 1).

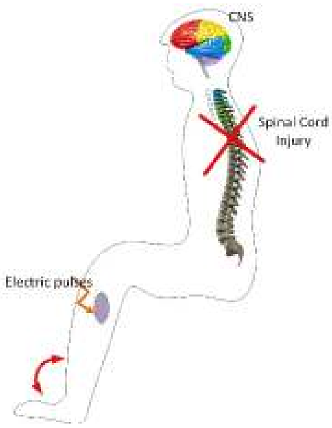

Figure 1. Foot dorsiflexion by the electrostimulation of central nervous system damaged foot drop patients.

During healty walking, the commands received from the central nervous system are converted to normal movement with healthy muscles and joints through the nerves separated from the spinal cord. In drop foot patients problem occurs in any of these structures. So the foot hangs down from the ankle and cannot perform dorsal flexion movement. Moreover, in the stance phase of walking, the foot does not touch the ground very securely and generally tends to turn outwards. Drop foot causes some shape and image deterioration over time. The arch of the foot rises and the foot comes in contact with the ground only from the heel (Figure 2.a). In time, arthritis in the foot joints and deformities in the fingers occur. In the ankle area, swelling due to constant sprains and pain caused by movement may occur. Keeping the foot in the same position constantly causes the Achilles tendon to be shortened and the tension and pain in the calf. These problems also affect the movements of the knee and hip negatively. Problems and pain may occur due to excessive backward stretching of the knee joint over time. Decreased neural conduction may cause muscle wasting (Figure 2.b)

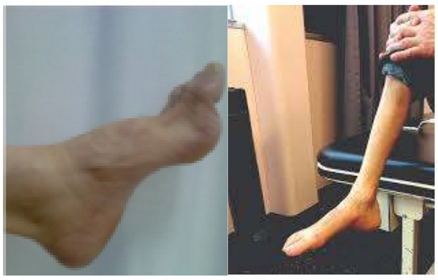

Figure 2. a. Orthopedic disorder due to drop foot [21] b. The patient with muscle loss [22]

Electrostimulator devices, send an electrical stimulation to the nerve passing near the bone called "fibula" in the leg, providing dorsiflexion from the ankle of the foot to supply appropriate phase of walking and preventing the stepping gait (Figure 3.a.). Electrostimulation applications are widely used devices in physical therapy. In this way, by enabling the muscle and nerve to work, further weakening of tissues and muscles is prevented or weakening is slowed down. It strengthens the muscles and protects the joint opening. There types of electrostimulation used.

1) Galvanic current: Direct current is unidirectional, in wave form, there is no change.

2) Alternating Current: It is uninterrupted and bidirectional. Symmetrical or asymmetrical features are occured.

3) Pulsed Current: In pulsed currents, waves can be monophasic and biphasic. Biphasic waveforms can be symmetrical or asymmetrical.

The current density, duration, resting time of the symmetrical ones may change with the decrease in form. Electrolysis products under electrodes does not occur [23].

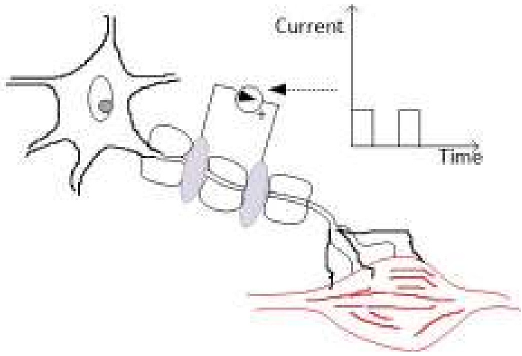

Figure 3. Stimulation of the muscle

In addition to central nervous system disorders, spasticity is a very common muscular disorder. The muscle is constantly tense and the muscle is unable to move. Current treatments have been set up to interrupt the conduction of the involved sinuses. Movement limitation continues to a large extent. When walking is supported by electrical stimulation, partial relaxation is achieved in the muscles after a certain period of time.

Although all cells in our body have membrane potential, only neurons and muscle cells can change their membrane potential. This change is called adaptability. Action to changes in membrane potential called potential [24]. The permeability of the membrane is provided by ion channels called gates. Action potential has three phases. With the opening of depolarization Na^+ channels, Na^+ it is the flow of ions into the cell. Opening of repolarization K^+ channels and K^+ It is formed by the flow of ions outside the cell. Hyperpolarization large number of K^+ It occurs because the channel is open for a few more ms. Impulse transmission is seen at Figure 4. The electrical change in the cell membrane has been demonstrated during period [25].

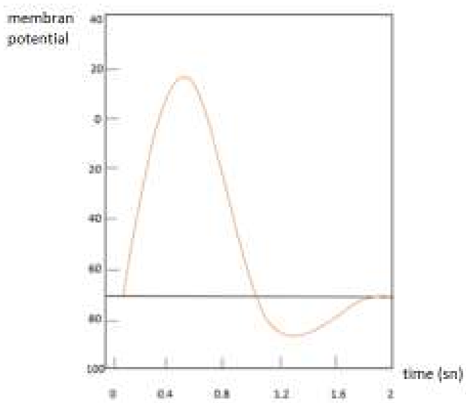

Figure 4. Action potential

3. Materials and Methods

As the patient is insufficient to generate muscle force for the range of motion in the paretic side, the muscle activities are induced by FES designed to assist the patient to generate a natural gait motion with sufficient muscle force and range of motion Functional electrostimulation is performed with the placement two electrode peds. The electrical field between two electrodes simulates the membrane of the nerve fibers. This stimulus travels along the nerve to the muscle and as a result, contraction occurs In the proposed rehabilitation system, ground reaction forces were utilized using force-sensitive resistors (FSR) to determine gait phase and walking speed on the paralyzed side [26] (Figure 5).

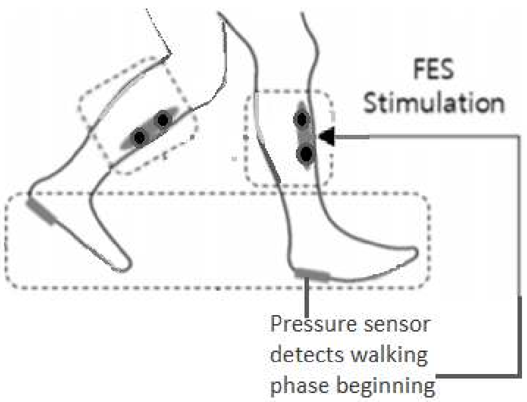

Figure 5. Schematic of the FES control algorithm

Information about the position of the foot was obtained with the help of a 0.6 "force sensitive circular sensor placed at the heel of the foot. When the value from the sensor is read while the foot is on the ground, no signal is applied to the tibialis anterior muscle. The square wave signal is applied to the tibialis anterior muscle according to the value from the pressure sensor. This square wave signal is applied continuously at intervals of 200 milliseconds while the foot is up. Circuit schematic has been shown at Figure 6.

Output voltage values were obtained with the LM2577 boost converter. A 5 volt peak square wave voltage from the output of the arduino microcontroller was given to the LM2577 integrated input and the voltage of the square wave was increased. The simulation program was implemented as at the figure 2. Since the program does not have a library of pressure sensor, a potentiometer is used to read analog values. According to the value taken from the potentiometer, the appropriate value to be applied to the case was obtained from the digital pin that outputs a square wave.

5 volt input signal seen in blue on the oscilloscope output is the output signal that will be applied to the casing. In the simulation, it is seen that TIP122 power transistor is used to control the output signal to be fitted to the case. The circuit designed with this established circuit was designed and operated in a computer environment. At the simulation, an output signal of 20 Hz was received from the square wave digital output pin of the arduino. The 20 Hz output signal is at the level of 5 Volts due to the output amplitude of the arduino. The 5 volt voltage has been increased to 15-35 volts obtained from the LM2577 integrated circuit. The increased voltage is controlled by using an arduino output and a power transistor. The PCB design of the circuit implemented as Figure 7.

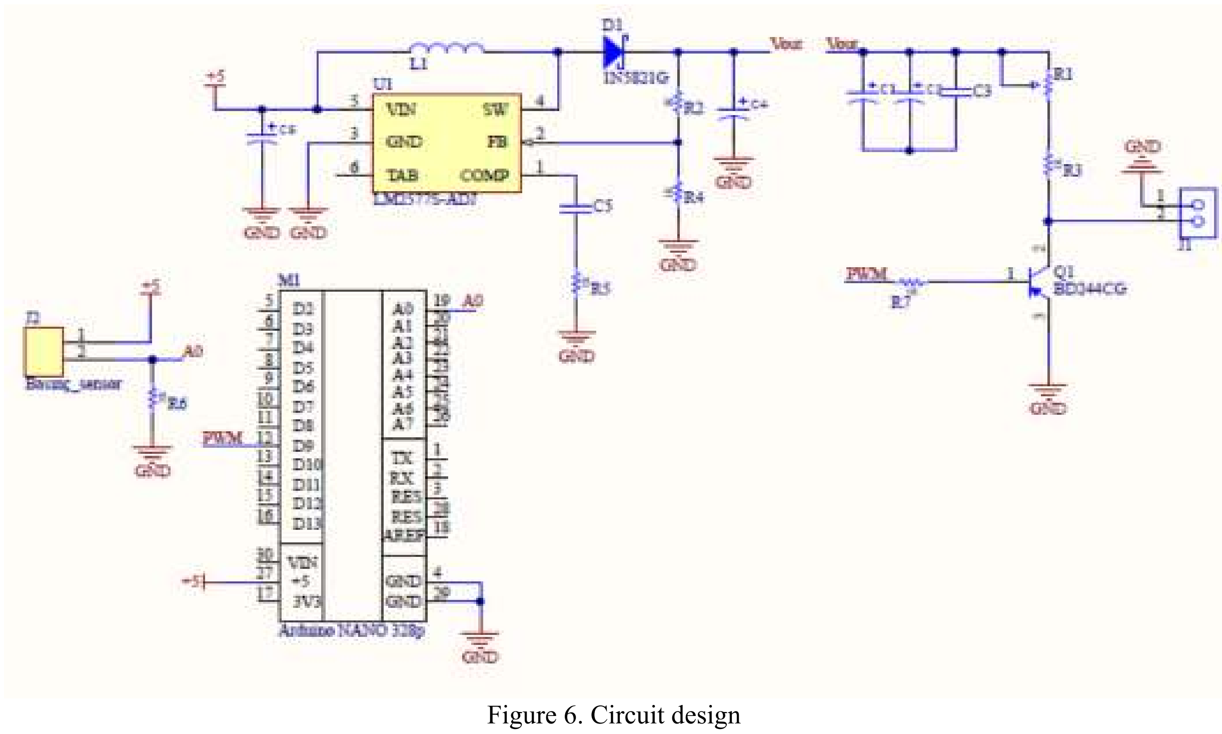

Figure 6. Circuit design

Figure 7. PCB design of the circuit

In order to adjust the output voltage, it have been adjusted with a 3-watt adjustable resistor. TIP122 power transistor is used to control the output signal. Circuit elements with suitable values are preferred to control and adjust the voltage values to be obtained at the output. The input signal obtained with the arduino has been increased up to 40 volts and converted to a format to be applied to the casing (Figure 4). Arduino output signal is at the level of 5 volts. The output signal has been increased to 40 volts with the help of TIP122 transistor, to a level that can stimulate the muscle. The algorithm has been created to be applied at intervals of every 100 ms while the output signal is applied to the casing (Figure 8).

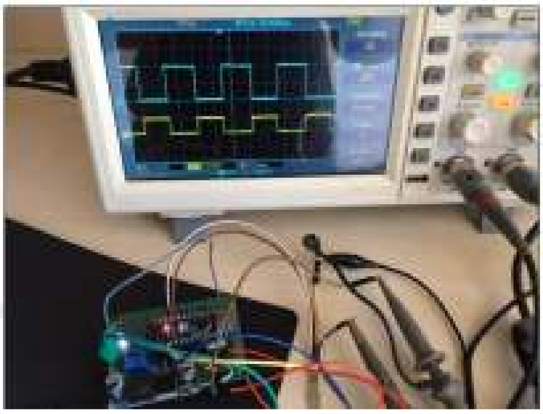

Figure 8. Input and output signals

When the foot rises from the ground, the data from the force sensor is read and the output signal of 40 volt and PWM wave triggers a muscle every 100 ms. This cycle is repeated continuously as long as the walk continues (Figure 5).

The device can adjust the circuit output trigger voltage in the range of 20 - 40 volts. The supply voltage of the device is in the range of 9 - 24 volts. In order to facilitate the use of the device, it will be used with a 9-volt battery in the first stage, and in later stages, the usage time can be extended by using lithium polymer and / or lithium ion batteries with high current capacity. As determined in literature research, the output current works ideally between 40 mA and 100 mA. As a result of experimental studies, it has been determined that it operates at approximately 50 mA levels. The force sensor on the device was placed on the heel of the foot in the desired format, allowing us to get information about the movement of the foot (Figure 9). A more comfortable walking movement is provided for people by triggering the muscle according to the foot movement. Properties of the device indicated at Table 1.

Table 1. Properties of the FES device

Control Data	Foot Pressure Sensor
Voltage Range	20-40 Volt
Signal	Square Wave
Frequency	20 Hz
Weight	200 gr
Current	˜ 50 mA
Response Time	0.8 sn

Figure 9. FES device

4. Results

The device we have developed, an electrical impulse is sent to the nerve passing through the bone called "fibula" in the leg during the appropriate phase of walking. The FES device developed at our study is can be available at low cost and easy to use. The foot provides dorsiflexion from the ankle and the stepage walk can be prevented. Stimulation increases blood flow, increases the activity of neurons and "prevents atrophy'. Electrostimulation treatments are widely used devices. In this way, by enabling the muscle and nerve to work, further weakening of tissues and muscles can be prevented or weakening can be slowed down. At the same time, these stimulations can prevent the deterioration of the foot structure and can be put into normal form. This device, supports feet from outside with stimulation of the muscles to create their dorsiflexion, and to strengthen the muscle. Since the muscles work reversibly, the opposite muscle of the stimulated muscle are relaxed. These reactions can be used for spasticty.

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