DEVELOPMENT OF WIRELESS MICROCONTROLLER BASED FUNCTIONAL ELECTRONIC STIMULATION DEVICE FOR DROP FOOT CORRECTION

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

Drop foot syndrome is general term for difficulty lifting the front part of the foot from the ground which is a common problem that can lead to falls, trips and injuries in human life. It is usually neuromuscular disorder that cause peroneal neuropathy between the neck and the fibula. In other words drop foot problem is the loss of communication between the the peroneal nerve and central nervous system which is enables the foot to make dorsiflexion . The patient cannot move his/her foot upward the ankle or toes. Foot drop correction is generally achieved by electric stimulation of the common peroneal nerve by sending a series of pulses at a given amplitude, duration and frequency . For this purpose a wireless programmable microcontroller based, low-power, low-cost, battery operated, high performance and portable electronic stimulation device has been developed.

The stimulator has been designed to make correction on the foot drop syndrome, which is called wireless FES device. In the traditional FES systems, sensors are placed inside the shoe sole which are connected to a stimulator device using lead wires or cables. One of the biggest disadvantages of the cabled systems is the cable complexity, and also device giving discomfort to the patient during the walking, because of the cables around the shoe and the foot. The system designed by the author is wireless and was developed by removing this cables from the device and by using Radio Frequency (RF) transmitter/receiver pair to connect the sensors to the stimulator device. For this reason, the patients can use this device more comfortably, and easier. In the design of the wireless FES device, a force sensitive sensor, programmable microcontroller, transmitter, receiver and electrodes are used. Stimulation amplitude, duty cycle, and frequency of the output waveform can easily be adjusted by using switches. Also design has been developed further by the addition of another second in-sole foot sensor underneath the metatarsal heads so that device enabled reliable sensing in addition to walking on straight surfaces during the stair climbing. The cost of the overall system is very low, because during the development process standard microcontroller development systems, standard electronic equipments and standard wireless components were used which are easily found in the market.

Keywords: Drop foot syndrome, foot drop, drop foot correction, wireless microcontroller based stimulation, peroneal nerve stimulation, FES device.

ÖZET

Düşük ayak sendromu , ayağın ön kısmının zorlukla yerden kaldırılmasının genel bir terimi olup insan hayatında düşmelere, tökezlemelere ve yaralanmalara sebebiyet veren yaygın bir sorundur. Genel olarak boyun ve fibula arasındaki peroneal nöropatiye neden olan bir nöromüsküler hastalıktır. Başka bir deyişle düşük ayak sorunu peroneal siniri ile merkezi sinir sistemi arasındaki iletişim kaybından dolayı,ayak bileğin bileğinin dorsifleksiyon yapamamasıdır. Bu hastalar ayağını ayak bileğinden yukarıya doğru hareket ettiremez. Ayak düşmesi genellikle peroneal sinirine belirli bir genlikte ve sıklıkta bir dizi elekktrik uyarımı göndererek düzeltilebilir. Bu amaçla kablosuz programlanabilir, düşük-güçte, düşük maliyetli, bataryalı, taşınabilir ve yüksek performanslı bir stimülatör dizaynı geliştirilmiştir.

Kablosuz FES cihazı olarak tanımlan stimülatör, düşük ayak sendromu düzeltmek için tasarlanmıştır. Geleneksel sistemlerde, ayyakabı içerisine yerleştirilmiş olan bir kuvveteduyarlı sensörün sayesinde hastanın adımları algılanmaktaydı ve bir kablo vasıtasıyla mikroişlemci destekli cihaza verilmekteydi. Kablolu sistemlerin en büyük dezavantajları ise ayakkabıdan cihaza bağlanan kablonun yürüme esnasında hastaya rahatsızlık vermesi ve kablo karmaşıklığına sebep olmasıydı. Kablosuz FES sistemi geliştirilerek sensörler ve cihaz arasındaki kablo ortadan kaldırılmış ve Radyo Frekansları(RF) ile alıcı/verici kullanılarak kablosuz iletişim hattı sağlanmıştır. Böylece hastalar bu cihazı daha kolay ve daha rahatça kullanabilmektedirler. Kablosuz FES cihazı tasarımda kuvvete duyarlı sensörler, programlanabilir mikroişlemci, verici, alıci ve elektrotlar kulanılmıştır. Uyarım frekansı ,pals genişliği ve dalga çıkış genliği cihaz üzerindeki düğmeler kullanarak kolayca ayarlanabilir. Ayrıca dizayn dahada gelştirilerek ikinci bir kuvvet ölçüm sensörü ayağın metatars başlarının altına eklenmiştir böylece cihaz düz yüzeylerde yürüme ek olarak merdiven tırmanma sırasında güvenilir algılama sağlamıştır. Tasarımın genel sistem maliyeti düşüktür bunun sebebi tasarım esnasında kolayca piyasada bulunan standart mikroişlemci sistemleri, standart elektrikli ekipmanları ve standart kablosuz bileşenleri kullanılmasıdır.

Anahtar Kelimeler: Ayak düşmesi, düşük ayak, düşük ayak düzeltmesi, kablosuz mikrokontrolör tabanlı uyarım, peroneal sinir uyarımı, FES cihazı

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INTRODUCTION

1.1. What is Functional Electronic Stimulation

Functional electronic stimulation (FES) is one of the most rapidly growing areas in biomedical engineering. FES has been developed to help patients with neurological disorders, including foot drop, to move more easily and comfortable. FES system works by producing muscular contractions which is mimic natural voluntary gait movement by supplying electric pulses to the nerveous system to stimulate paralayzed muscles either externally (across the skin) or directly (if implanted) (Horsley,2012).

In other words, FES is a technique that causes a muscular contractions through the use of an electric pulses. The human body naturally uses electrical currents to make body parts move . When a part of the body needs to move, the brain sends electric pulses to the nerves. The nerveous system, acting like electrical wires, relay these pulses to the muscles, directing them to contract(muscle contraction). This muscle contraction causes the body parts to move in a controlled, deliberate way. For example ; the elbow, ankle or finger joints movements. FES allows muscles that have been partially paralyzed or paralyzed by stroke to move body parts again or to make foot drop correction. In a case of any disability like a stroke or any neurological diseases, some of these electrical signals do not function as well as they should. In such cases FES is required to stimulate nervous system to sends electrical signals to muscle contraction (Retrieved January 6, 2014, from http://strokengine.ca/intervention/admin/patient/FES%20Upper%20ExtremityFamily%20 Information.pdf).

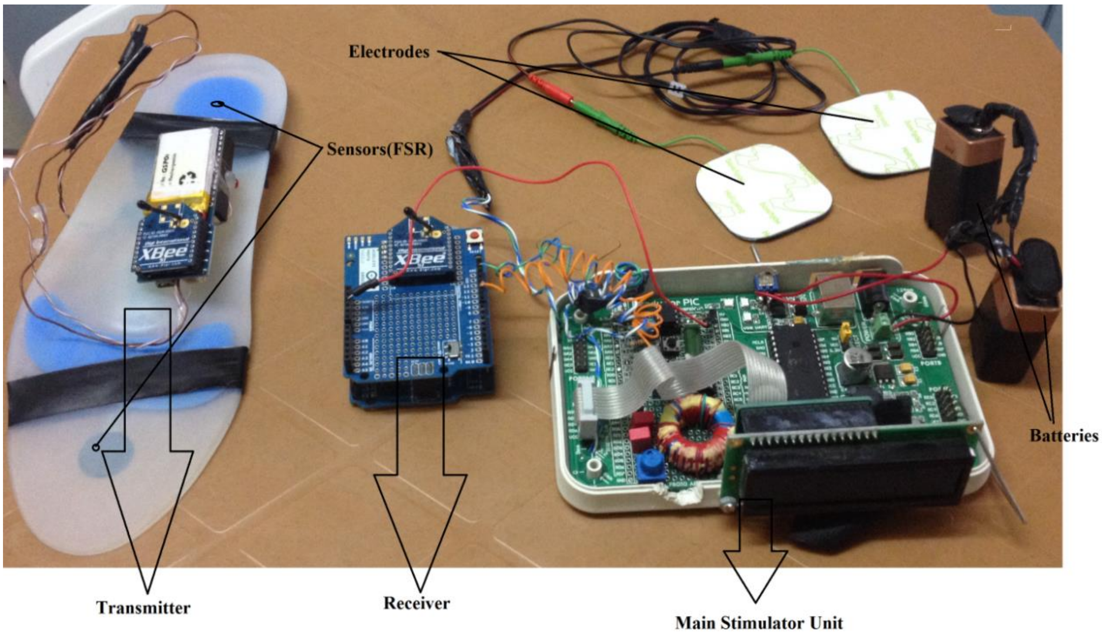

Figure 1.1. Wireless Microcontroller Based FES Device

1.2. What is Drop Foot

Drop Foot, sometimes called dropped foot or foot drop, is a general term for difficulty lifting the front part of the foot . Drop foot is a common problem in people suffering from stroke, (MS)multiple sclerosis, cerebralpalsy, or SCI where some of the motor functions are lost. In other words foot drop is a neuromuscular disorder that effects the gait performace , significantly. A healthy gait or a normal walking pattern depends on biomechanical and nervous system features. Drop foot is identified by the disability to lift the front part of foot(toe up) when it is brought forward during the gait swing cycle, resulting in the foot being on the ground all the time. This condition is due to the loss of communication between the the peroneal nerve and central nervous system which causes lack of activity in the ankle dorsiflexion. Previous studies show that , regular use of a drop foot stimulator strengthens the activation of motor cortical areas and residual descending connections (Everaert *et al.*, 2007).

1.3. Literature Review FES

Functional electronic device was initially referred to as Functional Electrotherapy by Liberson in 1961. The first real effort was made by him to supply electronic stimulation as an aid to recover function in a disabled persons. Liberson designed portable FES device to treate foot drop by stimulating the peroneal nervce of hemiplegic patients suffering from drop foot during gait,which is basically an electronic devices that can generate pulses with the correct amplitude ,ferquency and duration in order to stimulate the damaged nerves externally.In this condition ,a heel switch located under the feet of a patient's shoe, would activate a FES system worn by the patient (Liberson *et al.*,1961).

In a typical application ,external electrodes , energized by an electronic device are placed above the peroneal nerve. During wallking the heel switch triggered stimulation then the pulses generated at the correct times cause the tibialis anterior muscle to be contracted (dorsiflexion of the foot) during swing phase of the gait cycle and hence help the patient prevent it from dragging on the ground and lift the foot (Broderick *et al.*,2008).The new design was simple but ingenious stimulator started a new field of rehabilitation of paretic patients which is defined FES system. Since then, multi-channel, dual-channel and one- channel. Electrical stimulators have been designed, that generate stimulation via implantable electrodes or transcutaneous, cutaneous. This designe used in subjects with head trauma ,MS and stroke to enable opening of spastic hand and correct unnatural walking pattern (Hart *et al*., 2006).

In SCI patients electric stimulaion is used for walking and standing. In tetraplegic patients electric stimulaion enables functional grasping by the paralysed hands. Electronic stimulation has been used also for pain relief systems. TENS, correction of healing of pressure sores and juvenile-scoliosis , vascular wounds and ulcuses (Retrieved January 6, 2014, from http://ifess.org/proceedings/IFESS1998/IFESS1998_065_Stanic.pdf).

FES can be applied using external, percutaneous, or implanted electrodes.In external application, a pair of self-adhesive electrodes are placed on and near the peroneal nerve in the leg. The actual points of placement are important as it affects the strength and efficiency of the stimulation and the patient comfort level. In the case of percutaneous FES, an electrode is placed under the skin and close to the peroneal nerve with the aid of a needle. Percutaneous FES is more effective than the external FES but its placement may require medically qualified staff. Percutaneous FES is also prone to infection and it is difficult to keep it in place for long times. Implanted FES is based on placing the electrodes under the skin permanently by a small surgery. In some applications, the actual stimulation device may also be implanted under the skin. Although this is suitable for long term use, it has the disadvantages that as with the percutaneous FES, qualified medical staff is required to implant the device and as with any type of surgery there is always the risk of infection (Broderick *et al.*, 2008). A comparison of percutaneous and external stimulators during gait in a case report of a child with hemiplegic cerebral palsy . The rise in dorsiflexion was greater with percutaneous stimulators (Pierce *et al.*, 2004).

External FES remains the preferred mode of stimulation in the clinical settings A trial contains hemiparetic, ambulatory and 32 chronic patients each with a single foot drop. They received either physiotherapy or FES treatment sessions. In conclusion patients in the electronic stimulation group walked significantly faster, more effective and efficiently with the common peroneal stimulators than patients in the physiotherapy group.On the other hand, there is no improvement in these parameters was measured in the FES group when the stimulator was not used (Seifart *et al.*, 2009). The effect of FES on gait in spastic cerebral palsy. Clinically significant improvements occurred in three of the eight children (Postans *et al.*, 2005). The effects of external FES applied to the gastrocnemius-soleus complex. The authors concluded that FES is effective in increasing impulse during thepush-off phase of the gait cycle, but not in decreasing stiffness (Ho *et al.*, 2005).

The orthotic versus therapeutic impacts of Functional Electronic Stimulation devices was compared by the Van der Linden et al., In this study FES suplied to the ankle dorsiflexors and quadriceps in fourteen children with cerebral palsy. For the orthotic impact of FES, a statistically significant effect was found for the measurement of the deviation of overall gaitcycle pattern from the normal. FES to the dorsiflexors ensued in a statistically significant orthotic effect on peak dorsiflexion in swing phase and the foot-floor angle at first contact. This study showed that FES implemented to the dorsiflexors ensued in significant improvements in the gait cycle of patients with CP. On the other hand no long-term treatment effect of using FES was found (Van der Linden *et al.*, 2008).

In another research the therapeutic and orthotic impacts of a drop foot electronic stimulator on gait performance of subjects with chronic non-progressive (stroke) and progressive (MS) disorders was compared. As a result shown that, bothgroups had an orthotic benefit from FES however the therapeutic impact ended for a shorter time in progressive disorders (Stein *et al.*, 2010).

In a systematic study of investigators the improvement of gait cycle in stroke patients with foot drop during the (peroneus)peroneal nerve stimulation. As a result of the studies investigators suggested that there is positive orthotic impact of FES on walking speed (Kottink *et al.,* 2004).

1.4. Why Use FES Device?

The researchers discuss functional interventions based on motor learning and brain plasticity basis. Researchers specify the ultimate aim of the rehabilitation is to test and design interventions after resultant in deterioration benefits sufficiently robust to be reflected in functional activity and further in participation of life role.The Activity of the central nervous system dependent the basis principles and plasticity, of the learning of are shown below ;

- Close to natural gait
- Improve the life quality
- Activation of muscles during walking
- Focused caution in movement
- Repetition of requested gait
- Specificity in Practice and Training

The results of the investigations have shown that recovery is supported by motor experience. Also repetition of movements has been determined as a key in relearning of motor principles (Popovic and Sinkjae, 2007). Functional electronic stimulation may simplify motor recovery with joint and muscle afferent feed-back with repetitive of the human movements (Kroon *et al.,* 2005). Peripheral stimulation can effect reorganization in the brain. The afferent nerves and efferent nerves input from movement simplified by FES can play an important role as a reminder on “how to perform movement properly” (Hara, 2008).

Researchers aid Stimulator as obtaining the learning principles of motor for gait with respect to the literature, stimulator has been developed to treat unnatural gait tone, paralyzed muscles, in-coordination of motion, gait problems(foot drop patients). It can closely increase the motor gait components . It does supply the “practice of close-to-normal movement and repetition of that practice” (Daly and Ruff, 2007).

1.5. The Purpose of the Thesis

The purpose of this thesis is to improve walking ability of patients who live with drop foot condition due to spinal cord injury (SCI), Multiple Sclerosis (MS)**,** head injury, stroke, Cerebral palsy (CP) or other neurological disorders by using a wireless microcontroller based FES device. Drop Foot is a condition characterized by weakness or paralysis of the muscles involved in lifting the front part of the foot so foot drop can leads trips, falls, slow inefficient walking and difficulty in walking. Therefore to solve all these indicated negative impacts on the patients, a microcontroller based wireless FES device has been developed. In other words a microcontroller based wireless FES device is designed to stimulate electrical pulses on the paralyzed muscles to restore muscular contraction in this way FES can be improved the patient's gait performance and also it solves the cable complexity and foot sensors wire discomfort with the design of wireless system.

The wireless FES device has been designed according to the main requiremets that will satisfy the followings:

- Low-cost
- Low power consumption
- Battery operated
- Easy to Portable
- Wireless communication
- Stand-alone with no external support, e.g. for configuration ...

1.6. Brief Operation Of The Wireless FES Device

Force sensitive resistors are placed inside the patient’s shoe (insole) where a transmitter is also placed. The receiver is attached to a microcontroller based electrical stimulation circuit . When the patient tries to walk and lifts his or her foot, the receiver side senses the trasmitted signal and sends a triggering signal to the stimulation circuit (or the controller). The controller then sends a stimulus signals to patient’s peroneal nerve at the feet so that stimulation starts and the patient can walk. When patient’s foot strikes to the ground stimulation is stopped automatically by microcontroller.

1.7. Thesis Layout

This thesis consist of 5 Chapters.

Chapter 1 is the introduction part and provides literature review about the topic.

Chapter 2 is analyzes the foot drop problem and contains general information about the components, and benefits of the typical FES devices.

Chapter 3 gives information about the hardware and software of the microcontroller based wireless FES system in details.

Chapter 4 presents the test results , future work and recommendations about the thesis.

Finally, Chapter 5 is the conclusion

CHAPTER 2

ANALYZING THE DROP FOOT, GAIT CYCLE, AND THE COMPONENTS OF THE FES DEVICE

2.1. Diagnosis of Drop Foot

The first diagnosis of the drop foot frequently is define in routine physical examination of people. Such diagnosis can be specified and confirmed by a persons that experts in the health fields such as these medical professionals are ortopedist, physiatrist, neurologist, podiatrist,neurosurgeon or thopedic spine surgeon. A person living with drop foot will have difficulty walking on patients heel. Therefore a simple test of asking the patient to dorsiflex may explain diagnosis of the foot problem. This is measured on a 0-5 scale that observes mobility. The lowest point zero will determine the highest point ad whole paralysis five , will determine whole mobility. On the other hand there are other trials that might aid to define diagnosis. These testing introduce an magnetic resonans imaging ,computed tomography , EMG or MRN to assess the surrounding areas of paralyzed nerves and the paralyzed nerves them-selves, respectively. The nerve that communicates to the muscle sytems that move the foot is the peroneal nerve. This nerve trigger the anterior muscles of the leg that are used in dorsiflexions. The muscle that are used in plantar flexion are triggered by the nerve in tibia and often develop tightness in the presence of drop foot. Paraesthesia in the lower leg, particularly on the top of the ankle and foot, also can cause foot drop, while it isn’t related every time (Retrieved January 6, 2014, from http://en.wikipedia.org/wiki/Foot_drop).

2.2. Pathophysiology of Drop Foot

Neurologic disorders are all reason of the foot drop disease , it should be approached using a localization focused approach before etiologies are conceived by the medical professionals. Mostly, drop foot is the result of neurological lesions which are effecting the muscular contraction, only rarely is the non-functionality of the muscles or diseased muscles. In other words Dropped foot is the inability to dorsiflex . The source for the neurologic impairment can be central or peripheral. Dropped foot is rarely the result of a pathologsiology including the muscles or bones which make up the lower leg. The anterior tibial is the muscle that picks up the foot. It is triggered by the deep fibular peroneous which branches from the sciatic nerves. The sciatic nerve exits the lumbar plexus with its root arising from the 50 lumbar nerve space. Occasionally, spasticity in the muscles opposite the anterior tibialis exists in the presence of dropped foot, making the pathology much more complicated than dropped foot . Isolated foot drop is mostly a flaccid conditions. Foot drop is diverse from foot slap, which is the audible slapping of the foot to the ground with every step that exits although the foot initial contact to the ground on each step, while they frequently are synchron. Also treated systematically, possible lesion sites causing foot drop as explained below:

1. Peroneal nerve; (-chemical, mechanical, disease)
2. Genetical disease;
3. Neuromuscular disease;- affecting the muscles or affecting their direct nervous system control
4. Sciatic nerve;(-direct trauma, iatrogenic)
5. Lumbosacral plexus;- lumbar plexus,sacral plexus,pudendal plexus causes sensory deficits, and loss of motor control .
6. Nerve roots(L5)
7. Spinal cord; (Tumor,poliomyelitis)
8. Stroke, TIA, tumor;
9. Nonorganic;
10. Syndrome of the Cauda Equina. (Spinal cord injury reason of the nerve impingement);
11. An others(multiple sclerosis, trauma, motor neuron disease, diabetes, and side effects of the alcohol or drug.(Retrieved January 6, 2014, from http://en.wikipedia.org/wiki/Foot_drop).

2.3. Foot Biomechanics

The "biomechanics" word was coined in 1899 by Nikolai Bernstein. Biomechanism is the study of the function and structure of biological systems such as plants,animals,humans, organs, and cells by means of the science methods of mechanics.Biomechanics is related to engineering and motion of bodies, because it frequently uses conventional engineering sciences to investigate the biological systems. Some examples of Newtonian mechanics or materials sciences can supply correct approximations to the mechanics of many biological systems. Most notably mechanical engineering is applied mechanics, it is discipline such as structural analysis, continuum mechanics, mechanism analysis, kinematics and dynamics which are play important role in biomechanic studies (Retrieved January 6, 2014, from http://en.wikipedia.org/wiki/Biomechanics).

In other words mechanincs is the branch of physics related with the motion of bodies, in case of biomechanics, the bodies are living as bio = life. So, foot biomechanics basically, relates to the study of foot movements and the effects of muscles and gravity on its skeletal structure. A foot can dorsiflex (move upwards) and plantarflexion (downwards); Adduction (horizontally inwards) and Abduction(horizontally outwards); Eversion (twist outwards) and Inversion (twist inwards) (Retrieved January 6, 2014, from http://www.docpods.com/what-are-orthotics).

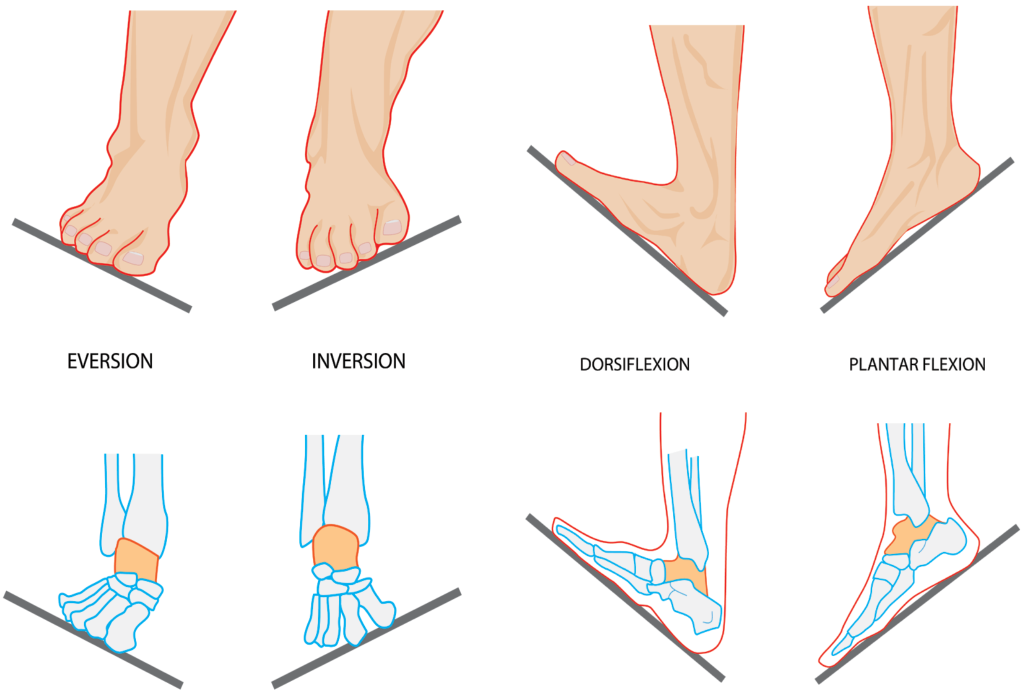

Figure 2.1. Four Different Foot Movements.

These movements may occur alone or in combination. Supination & Pronation are the 2 definitions used to determine a combination of these body motions which are shown in following figure. Supination is a inward & downward motion of the foot containing plantarflexion, (inversion & adduction of the foot) . Pronation is the outward & upward motion of the foot containing dorsiflexion,(eversion & abduction) (Retrieved January 6, 2014, from http://www.docpods.com/what-are-orthotics) .

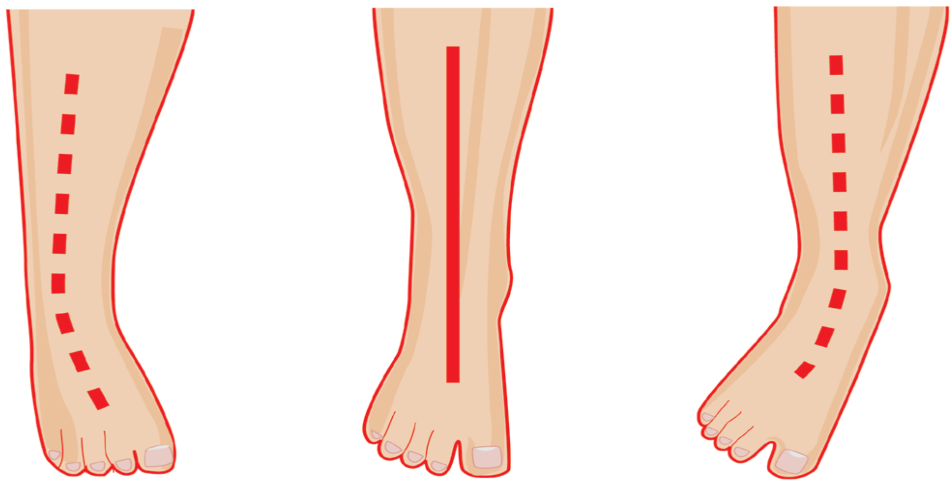

Figure 2.2. Upward & Outward, and Downward & Inward Foot Movements

2.4. The Gait Cycle

Human gait cycle consist of one full step that begins with, when the heel of one foot lifts from the ground and ends with , when heel of the same foot touches to ground again. It consist of two phases swing phase and stance phase . In other words Locomotion is a complex function. The movements of the lower limb during walking on a level surface may be divided into alternating swing & stance phases. The stance phase begins with heel strike, when the heel strikes the ground and begins to assume the body's full weight, and ends with push-off from the fore foot. The swing phase begins after push-off, when the toes leave the ground, and ends when the heel strikes the ground. Walking is a remarkably efficient activity, taking advantage of gravity and momentum so that a minimal of physical exertion is requisite .During the gait swing phase contains nearly 40% of the walking cycle and the stance phase, 60% of the walking cycle. In running, the time and percentage of the gait cycle represented by the decrease in stance phase (Retrieved January 6, 2014, from https://www.inkling.com/read/essential-clinical-anatomy-keith-moore-4th/chapter-5/walking-the-gait-cycle).

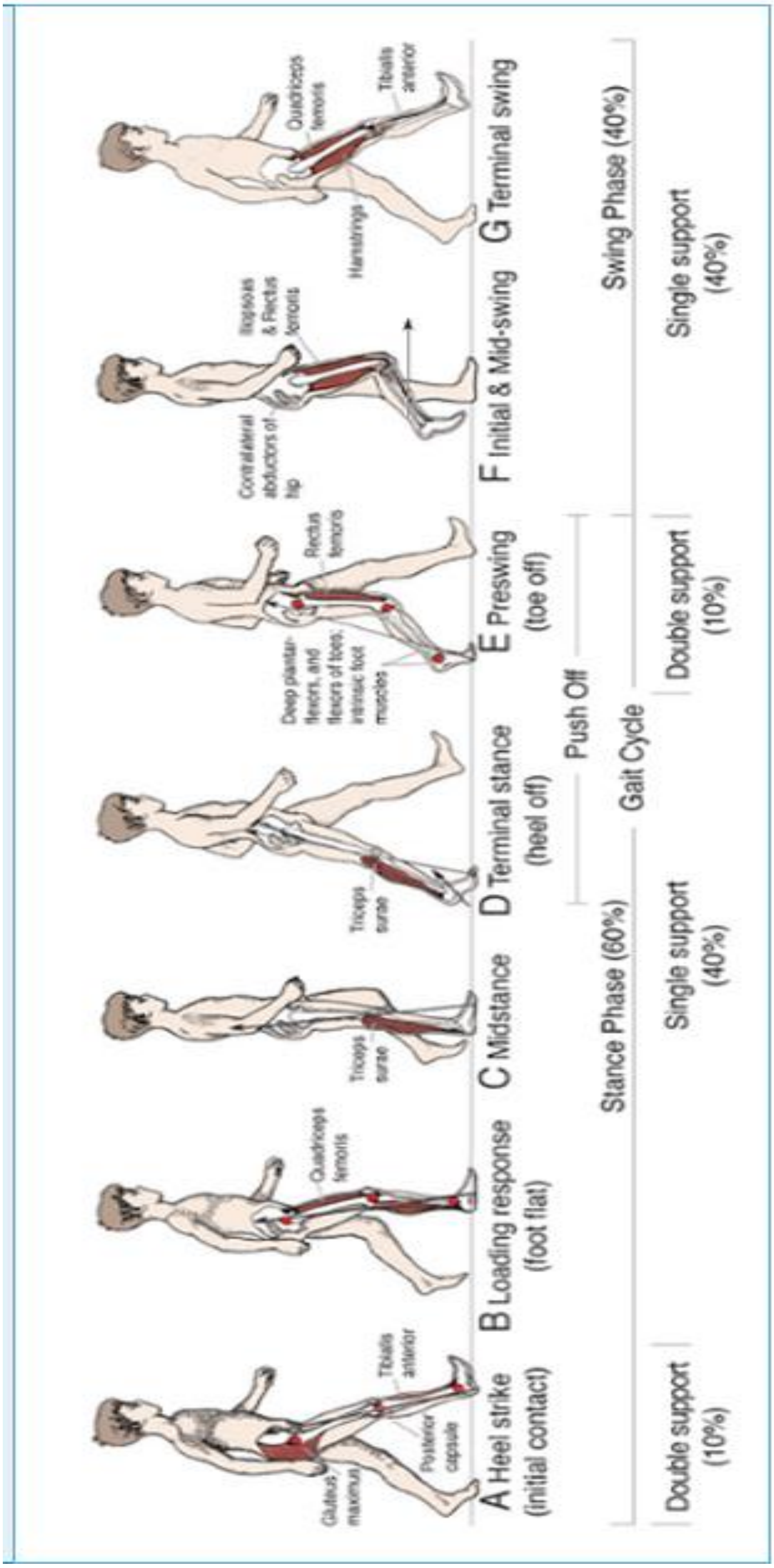

Figure 2.3. Typicall Eight Phases of the Gait Cycle

(Retrieved January 6, 2014, from https://www.inkling.com/read/essential-clinical-anatomy-keith-moore-4th/chapter-5/walking-the-gait-cycle).

Phase of Gait		Mechanical Goals	Active Muscle Groups
STANCE PHASE	Heel strike (initial contact)	Lower forefoot to ground	Ankle dorsiflexors (eccentric contraction)
		Continue deceleration (reverse forward swing)	Hip extensors
		Preserve longitudinal arch of foot	Intrinsic muscles of foot
			Long tendons of foot
	Loading response (flat foot)	Accept weight	Knee extensors
		Decelerate mass	Ankle plantarflexors
		Stabilize pelvis	Hip abductors
		Preserve longitudinal arch of foot	Intrinsic muscles of foot
			Long tendons of foot
	Midstance	Stabilize knee	Knee extensors
		Control dorsiflexion (preserve momentum)	Ankle plantarflexors (eccentric contraction)
		Stabilize pelvis	Hip abductors
		Preserve longitudinal arch of foot	Intrinsic muscles of foot
	Terminal stance (heel off)	Accelerate mass	Ankle plantarflexors (concentric contraction)
		Stabilize pelvis	Hip abductors
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot
			Long tendons of foot
	Preswing (toe off)	Accelerate mass	Long flexors of digits
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot
			Long tendons of foot
		Decelerate thigh; prepare for swing	Flexor of hip (eccentric contraction)
SWING PHASE	Initial swing	Accelerate thigh, vary cadence	Flexor of hip (concentric contraction)
		Clear foot	Ankle dorsiflexors
	Midswing	Clear foot	Ankle dorsiflexors
	Terminal swing	Decelerate thigh	Hip extensors (eccentric contraction)
		Decelerate leg	Knee flexors (eccentric contraction)
		Position foot	Ankle dorsiflexors
		Extend knee to place foot (control stride); prepare for contact	Knee extensors

Table 2.1. Muscular Activities During Gait Cycle (Rose *et al.*, 1994).

2.4.1. The Normal Gait Cycle

The natural gait cycle is as shown below in sequencely;

Swing Phase: During the movement it defined as the period of time when the foot is not in contact with the ground. In those cases while the foot never leaves the ground (foot strike), it can be defined as the phase when all portions of the foot are in forward motion.

Initial Contact : The point in the gait cycle where the foot initially makes contact with the ground; this specifies the beginning of the stance phase. It is suggested that heel strike not be a term used in clinical gait analysis as in many circumstances initial contact is not made with the heel. Suggestion: Should use foot strike.

Terminal Contact : The point in the gait cycle while the foot leaves (foot-rise) the ground: this specifies the beginning of the swing phase or end of the stance phase . Additionally referred to as foot rises or foot off . Toe off should not be used in situations where the toe is not the last part of the foot to leave the ground (Retrieved January 6, 2014, from http://en.wikipedia.org/wiki/Biomechanics).

2.4.2. Gait Cycle Of Dropped Foot Patients

Drop foot gait cycle requires more exaggerated phases as explained below in sequencely;

Dropped Foot Swing Phase: During the walking cycle if the foot happens to be the affected foot, there will be greater flexion at the knee to accommodate the disabilty to dorsiflex. This increase in knee extension will cause a stair climbing movement.

Dropped Foot Initial Contact: First contact of the foot that is in movement will not have natural heel toe foot strike. Instead of the foot may either slap the ground or the overall foot may be located on the ground all at once.

Dropped foot Terminal Contact: Terminal contact that is observed in patients that have dropped foot is quite different. Since patients tend to have weakness in the affected foot, they may have the disability to support weight of body. Frequently, a cane or walker will be used to assist in this aspect.

The part of the dropped foot gait cycle that introduces most dorsiflexion of the muscle would be Heel Contact of the foot at ten percent of Gait Cycle, and the overall swing phase, or between sixty-hundrend percent of the Gait Cycle. This is determined as a Gait Abnormalitie(Retrieved January 6, 2014, from http://en.wikipedia.org/wiki/Biomechanics).

2.5. What Are The Benefits of FES Device?

Trials have shown that stimulation for foot drop can lead to the following benefits:

- Provides more natural walking pattern
- Regenerated walking speed
- Increased independence during daily activities
- Walking becomes less tiring
- Improved self confidence and safety with a reduced incidence of falls
- Increased independence during daily activities and ability to walk longer distances
- Reduced spasticity and Curative effect
- Walking becomes easier on uneven surfaces

This impact might not relate with every users or be stable. Many Foot drop patients resulted that these benefit supply them to enjoy a better qualification in life & gait cycle . The evidence from these studies was reviewed by the National Institute for Health and Clinical Excellence . Their published guidance states that dropped foot electric stimulation is a effective and safe treatments. The "National Clinical Guideline for Stroke" reported by the Royal College of Physicians also recommends dropped foot electric stimulation (Retrieved January 6, 2014, from http://www.differentstrokes.co.uk/content/ helpingyou/ professionals/Adult%20info/FES.pdf).

2.6. Main Components OF a Typical FES Device

Functional Electronic Stimulation systems must meet specific design requirements to supply orthotic or therapeutic impacts and to help patients. To function as a take-home device, FES must be easily operable,be safe, portable, comfortable and so that users can wear the device without any help or with minimal assistance or aid. The interface must be as ergonomic as possible to enable patients with minimize poor eyesight or dexterity to use the device without any difficulty. Most surface FES systems follow a standard electronic design structure, similar to that originally proposed by author , system consisting of sensors , stimulating parts, user interface ,clinician interface and electrodes In general, modern FES devices consist of five main parts these are shown below (Ilic *et al.,* 1994).

- Sensors: To detect gait events
- Stimulating Unit: Provides electrical pulses to a certain nerve points.(digital controller, a high voltage or current generation and switching circuitry, and battery).
- Clinician Control Unit: Clinician enables the stimulation features to be set for the user.
- User Control Unit: To change the output amplitude, frequency and duration settings for specific user requirements.
- Electrodes : Placed on peroneal nerve which is used to apply stimulus to the patient.

Figure 2.4. shows the block diagram of a typical modern FES device which are included the basic elements of the FES designing.

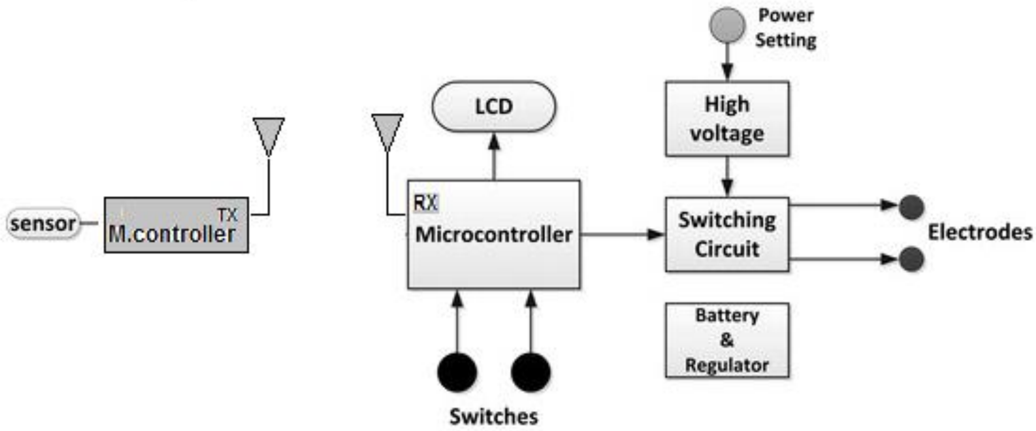

Figure 2.4. A block Diagram of a Typical FES Device

2.6.1. Sensors

Sensors are the basic requirements of the FES devices to determine the patient's activities. All FES systems consit of various sensors to detect activities when the stimulus should be applied to the paralyzed muscles .Some commonly used sensor types are shown below:

- Force Sensitive Sensors or Force Sensisitve Resistor (FSR)
- Push Button Switches
- Tilt Sensors
- Goniometers
- (EMG) Electromyography Sensors
- Accelerometers
- Gyroscopes

2.6.1.1.Force Sensitive Sensors (FSR)

Force sensitive sensor are also known as force sensitive resistor these sensors consist of a conductive polymers, which changes resistance in a presumable manner following application of force on its surface. FSR sensors are in-shoe sensors and are fitted to an in-sole to detect movements of the foot . The controller assembly is usually kept in the pocket or is attached to a belt around the body and these sensors are normally connected to the microcontroller with a pair of wires or connection can be established via wireless system. When the heel rise is detected with a wired or wireless system , the status of the input pin changes at the microcontroller input and this applies stimulation to the peroneal nerve of the limb (Retrieved January 6, 2014, from http://home.roboticlab.eu/en/examples /sensor/force).

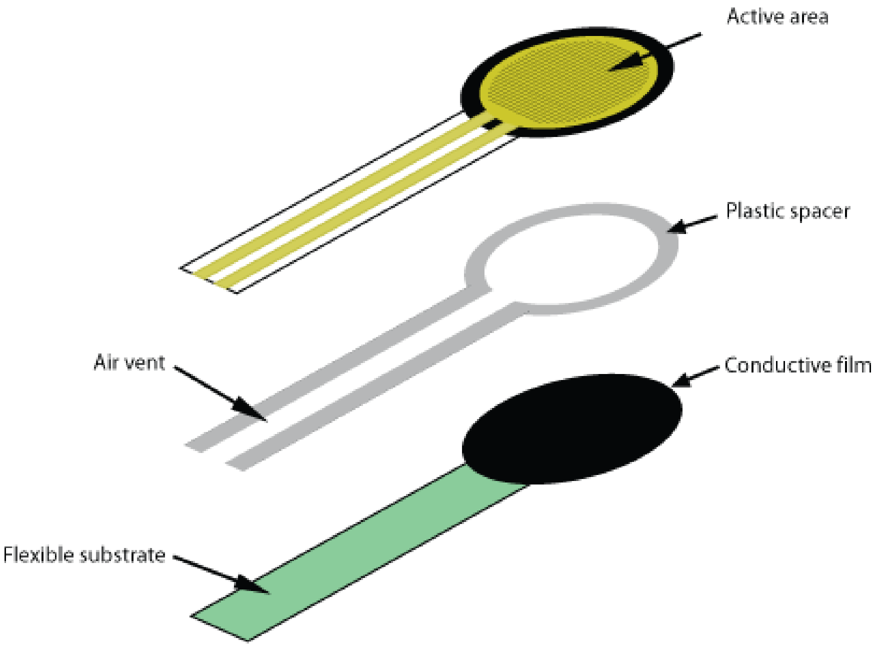

Figure 2.5. Force Sensitive Resistors

FSR sensors are rectangular or round shaped flexible resistance devices whose resistance changes with the applied pressure on its surface. These resistive sensors are generally used with a potential divider resistor networks such that the output voltage is either low or high depending upon whether or not pressure is applied on the sensor (Griethuysen *et al.*,1971).

2.6.1.2. Push Button Switches

Push-button switches are all low-cost and simple devices which are in demand qualities in modern FES devices. On the other hand, all in-shoe sensors affected long term reliability problems. The repeated application and removal of force on these sensors cause the sensor material to break and the sensor can lost their functions, although these problems can be reduced by careful placement and packaging of the sensors. Another disadvantage of in-shoe sensors is the requirement to use long wires to connect the sensor assembly to the digital controller. Unless the sensor wires are routed properly such wires may cause discomfort and difficulty in movement to the user. It is however possible to design in-shoe sensors using wireless systems as was done in this design , where the foot movements are transmitted to the controller using low-cost wireless with a transmitter and receiver technologies such as RF or the Bluetooth systems (Retrieved January 6, 2014, from http://parallax.com/product/28036).

2.6.1.3. Tilt Sensors

Tilt sensors is a simplified accelerometer that can be found in various shapes and sizes and they are small two state devices which change state when tilted. These sensors are generally based on the movement of liquid (e.g.mercury) to make short circuit a pair of contacts when tilted. When tilt sensors are compared with the in-shoe sensors they have advantages over in-shoe as they do not suffer from reliability problems when used repeatedly, and they can be miniaturized, which is a desirable property in FES applications. But, like the in-shoe sensors these devices are not intelligent as they provide only high/low (logic 1-0) type of output (Prieto *et al.*, 1993).

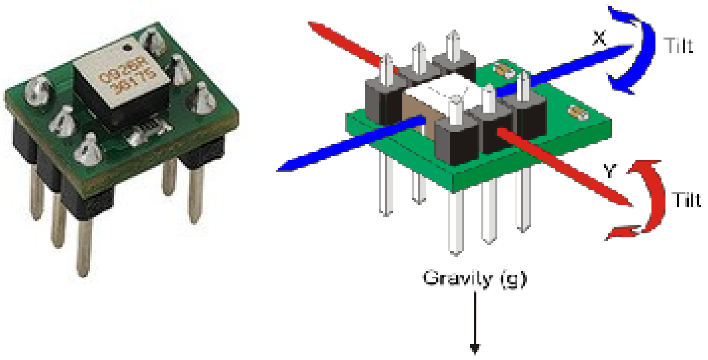

Figure 2.6. 4-Directional Tilt Sensor

2.6.1.4.Goniometers

Goniometers sensors are used to measure 1D or 2D angular displacements (angles). it can be used on most body joints e.g. knee, hip, ankle, shoulder, spine and elbow angles.These sensors are used successfully in FES devices to measure the knee angle and trigger the stimulation of FES device (Kostov *et al.*, 1995). Some investigators used goniometers to measure kinematic variables as an inputs at the ankle, knee, and hip joints with a fuzzy model so that to determine the gait cycle (Chizeck, 1997).

Figure 2.7. Flexible Goniometer

2.6.1.5. (EMG) Electromyography sensors

Electromyography (EMG) sensors are used to measure electric potential of muscle activities by using electrodes in FES devices. EMG sensors output very low analog voltages that specify muscle activity. The main problem with EMG sensors is that it may be difficult to generate a measurable EMG electric potentials on the damaged limb. As a result of Naomi and William's research it is also difficult to process the EMG signals as special digital signal processing algorithms are required to remove stimulus artifacts and generate useful electric signals in spinal cord injured (Chesler *et al.*, 1997).

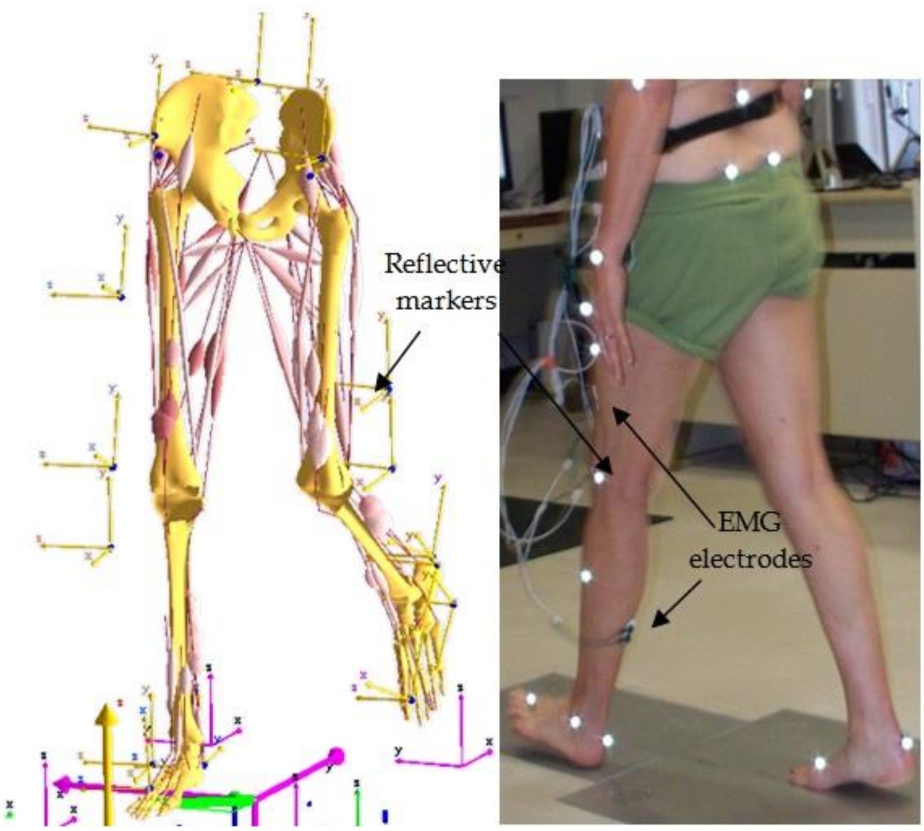

Figure 2.8. Model of the Lower Extremity With Muscles Included and Actual Subject with EMG Electrodes Attached.

2.6.1.6.Accelerometers

Accelerometers are inexpensive electronic devices. These devices are used to measure the magnitude and direction of acceleration in one to three linear axes (x, y, z) . These are tiny microchips that mostly generate analog or digital voltages for each x,y,z direction . They are proportional to the magnitude of the acceleration experienced by the FES device. Several researchers they have been recommended to use, accelerometers as FES sensor devices instead of in-shoe sensors. Accelerometers are mostly placed on the waist, on the knee, or on the lumbar region. Accelerometers are intelligent sensors as they can be used to sense the acceleration as well as the movement and the velocity of the leg in any direction in x,y,z, axes (Williamson and Brian, 2000).

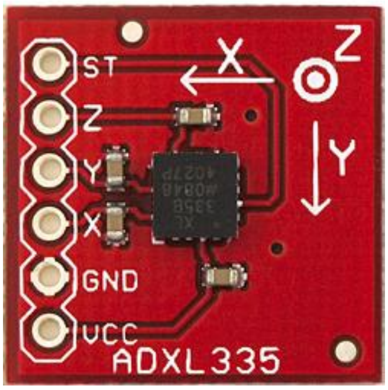

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Figure 2.9. Triple Axis Accelerometer

2.6.1.7.Gyroscopes

Gyroscopes are tiny (MEMS) Micro-Electro-Mechanical Systems devices which are used to measure angular velocity , this device do not have a fixed reference, and only measure changes. MEMS are determined as devices that converts energy from one form to another form. In these case of microsensors, the device basically converts a measured mechanical signals into an electric signals. Pappas et al. have reported the successful use of gyroscopes as sensors in FES devices. Gyroscopes are usually used with other sensors, such as with force sensitive resistors and with accelerometers. As a result of research the quantitative motion analysis during walking of the affected and nonaffected sides indicated that the use of the combined in-sole and electric stimulation device showed that significant improvement in the kinematics of gait at the affected limbsides. This stimulation system and combined sensor has the potential to serve as a walking aid for rehabilitation training or continued use in a wide range of gait disability after SCI, brain injury, stroke, or any neurologic disorders (Pappas *et al.*, 2004).

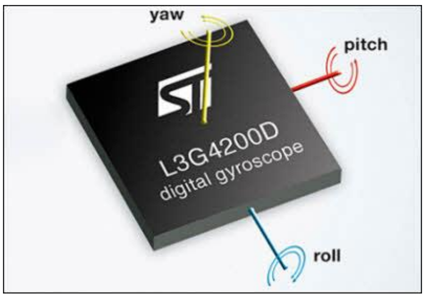


Figure 2.10. 3-Axis Digital Gyroscope.

2.6.2. Stimulating Unit

Stimulating units provides electrical pulses to a certain nerve points during the gait. Simply stimulation unit is reasponsible from generation of stimulus signal. The controller sends a stimulus signal to patient's peroneal nerve so that stimulation starts and patient can walk. When patient's heel strikes to the ground stimulation is stopped by microcontroller. The stimulation unit consist of digital controller, a high voltage or current generation and switching circuitry, and battery which are described below (Ilic *et al.*, 1994).

2.6.2.1. Digital Controller

The main objective of the digital controller is to generate pulses at the output with the specified frequency and pulse duration. Also, digital controllers must do the timing control, user interface control, and gait detection. All digital controller based FES devices consists of a microcontroller, which is fundamentally a single chip computer. There are some components that affect the choice of a suitable microcontroller, such as the data memory, size of the program ,power consumption, built-in clock, interrupt logic, and timer. Since electrical stimulation devices are easly portable and are used in daily activities, long battery life is one of the most important factor that impact the choice of the microcontroller and interface circuitry. The total power consumption can be reduced by the choice of low power elements wheresoever possible. For example, if LCD used it can be turned OFF during normal operation to save device energy . The timing of the output pulses are transmitted out using the built-in microcontroller timers. Generally more than one timer is needed to create pulses with the required duration and frequency. Interrupt capability is also an important parameter in the choice of the microcontroller since accurate timing is mostly handled by using the timer interrupt mechanisms. The chosen microcontroller must also have additional input-output ports, for example to drive an external display such as an LCD, and also to accept inputs from sensors and various switches that may be used to configure the device for specific user needs.There are lots of microcontroller families that can be used in FES manufacturing as long as they provide the fundamental needs which are summarized above. Some examples are the PIC series of microcontrollers, 8051 & 68HC11 series of microcontrollers, Atmega 328 series of microcontrollers, BX-24, and so on. Some microcontroller examples that have already been generated in electronic systems are: Microchip Technology's PIC16F84, Freescale 68HC11,Analog Devices ADuC831, and BX-24 (Breen *et al.*, 2009).

Figure2.11. 18 Pin PIC16F84 Microcontroller

2.6.2.2. High Voltage & Switching circuit

In response to signals which is detected from the sensors, the microcontroller provides the required stimulus current (output waveforms) at the correct times as low level output voltages for stimulation. The High Voltage & Switching circuit is then controlled to increase this stimulus current or voltage to the required level. Switching circuit generally consists of a DC to DC converter and transformers to convert low voltage level to the high voltage level, for example; + 9 V to + 80 V. The output of FES devices can be either constant voltage or constant current. In a constant voltage device, the pulse amplitude is around 80 V and the skin resistance increases if the current is lowered. Constant current devices supply around 120 mA current and they are less affected from changing of skin resistance . The output waveform from the FES devices is a pulse with a changeable pulse-duration and frequency. The pulse shape can be monophasic, take sahpe from positive pulses only, symmetric or asymmetric biphasic, where the pulses are both positive and negative with no gap in between them, and symmetric biphasic with inter pulse intervals. The pulse duration between 50 μs − 1 ms, and the pulse frequency in most devices change between 1 − 100 Hz (Dimitrijevic *et al.*, 2002).

Figure 2.12. MC34063 8 Pins DC to DC Converter 3.0-40V Output Current 1.5A

2.6.2.3.Power Supply (Batteries)

The electrical current of the FES device is created by a small battery powered electronic circuits. The stimulator are portable and they are powered using either normal or rechargeable batteries. Patient safety is an important parameter when the batteries are charged while the device is worn by the patient movement. Because the FES devices are used repeatedly during the gait they should be designed to increase battery life so that they can be used for long periods . While design of the FES device, careful choice of a low-power components and low-power microcontroller will result in long battery life. Some FES systems for example “Parastep” make external belt worn rechargeable battery to power the system for long period, while some other systems use single use or disposable batteries for example” WalkAide” for protection. While using an external battery might provide longer period during use of device, and also batteries are heavy and it is not practical to carry them long time (Retrieved January 6, 2014, http://www.walkaide.com/en-US/support/Documents/ ClinicianManual.pdf).

Figure 2.13 9V Rechargeable Battery

2.6.3.   Clinician Control Unit

The clinician control unit enables the stimulator parameters to be set for the patients. It is also interfaces with the clinician’s programmer, clinicians do adjustments that are automatically stored in the patient’s records, to observe gait history and monitor patient accordance with the FES device. In addition, displays (LCD) are usually provided to make the device user-friendly, to see such changes in frequency, output amplitude and duration settings on the device (Retrieved January 6, 2014, from http://uk.farnell.com/ mikroelektronika /mikroe-55/display-board-lcd-2x16/dp/2281679).

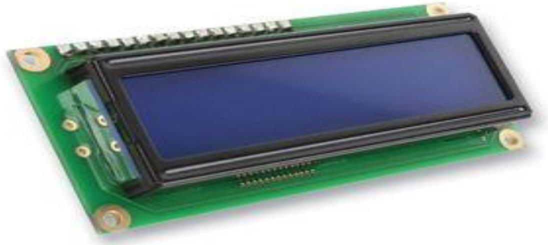


Figure 2.14. 2X16 LCD Display Board.

2.6.4. User Control Unit

The user control unit enable users to control the on-off switch, intensity and also to adjust the output amplitude, frequency and duration settings for specific requirements of the patients. In addition the resistance of the muscular contraction is controlled by the pulse amplitude,duration and frequency of the stimulus generated by FES devices.

User Parameters for Frequency Pulses

- Patients reguire a high enough, fusion frequency, to create a smooth contraction. It must produce too low and series of twitches.
- Temporal summation is the cumulative effect of stimuli repeated in a short time interval
- If the applied stimulus frequency is high , it effects the muscles contraction more stronger and at the same time it result with quickly increase in muscle fatigue.
- The minimal stimulation frequenc rate to achieve fused muscle response are generally between 12-15Hz.
- Normal ideal muscular stimulation frequency for lower extremity between 18-25 Hz for the upper extremity is 12-16 Hz (Sheffler and John, 2007).

User Parameters For Pulse Amplitude and Duration

- Spatial summation (action potential of neuron) is the impact of increas in activated motor unit number, to increase the strengthness of musclar the contractions.
- Increasing in pulse duration or pulse amplitude increases the number of motor units and axons activated because of the effect of a larger charge and resulting electric field being manufactured. This reproduces in the strengthness of muscular contraction and increase the muscle activation area.
- Amplitude over motor threshold also stimulate small diameters of unmyelinated C fiber which causes pain.
- Pulse rate interval between 400-200, 300 micro second is the suitable value. (Bogey and George, 2007).

2.6.5. Electrodes

The generated electrical pulses from FES device is transmitted on the paralyzed muscles by conductors. The electrode cable is rubber or plastic insulated flexible silver or copper wire. The thick-ness of the wire depended on the amount of current to be carried by the conductors, the thicker the conductor means conductor can carry a larger value of current so conductivity and current-carrying amount is directly proportional to each other. Electrode wires may be a uni-form color-coded or color according to the function of electrodes. Generally color coding of the cables are as follows, the wire to the positive electrode is anode, and to negative electrode is conventionally black colored which is cathode.

Figure 2.15. Color Coding of the Electrode Cables

An electrode pad's medium that get into touch between the cable from the FES devive and the patient's body . It usually introduces a good conductor materials that form and shape can be adapted to conform to shape of the body. Also mediums include metal foil (electrode conductors are generally made by an zinc alloy, tin & lead), water, moist pad, or flexible silicone or carbon pad.

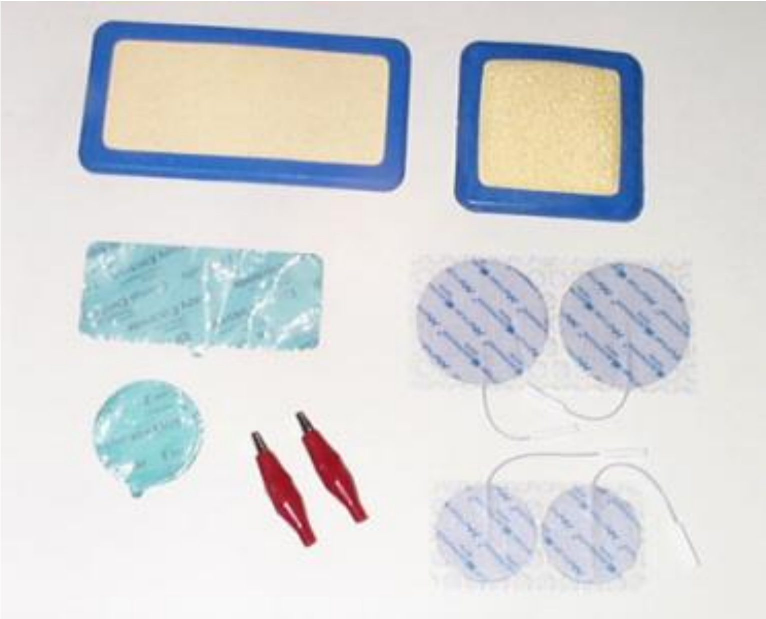


Figure 2.16. Flexible Electrode Pads

Electrode pads are generally produced in pairs, of equal size. The current density of the two equal size of electrodes are distributed equally between them during the electrical stimulation. If one pad is twice as large as the other is, the current density under the smaller one will be twice as great as that under the larger. As the current spreads between two electrodes pads, across the body, its density must progressively decrease so that midway between them the density is the least. The closer the electrodes are to one another, the greater the density of the current that passes between two electrode pads. The higher the current density means that the greater effect on the tissues stimulated.The electric current transmitted throughout the cable length after all cause to breaks in the cable at the sites and to some crystallization of the conductor (conducting wire) while the most bending or movement of the wires occurs, at both ends of the connections which is generally close to the electrode connection (Retrieved January 6, 2014, from http://www.advtherapy.net /html/estim.pdf)

CHAPTER 3

THE DEVELOPED MICROCONTROLLER BASED WIRELESS FES SYSTEM

3.1. Overview

The stimulator has been designed to correct the drop foot problems in the human body which is programmable and microcontroller based wireless FES system . During the design of wireless FES device the following parameters were considered; device must be low-cost, operate with low power, battery operated, easily portable, can communicate wirelessly, stand-alone with no external support, for example configuration mode.

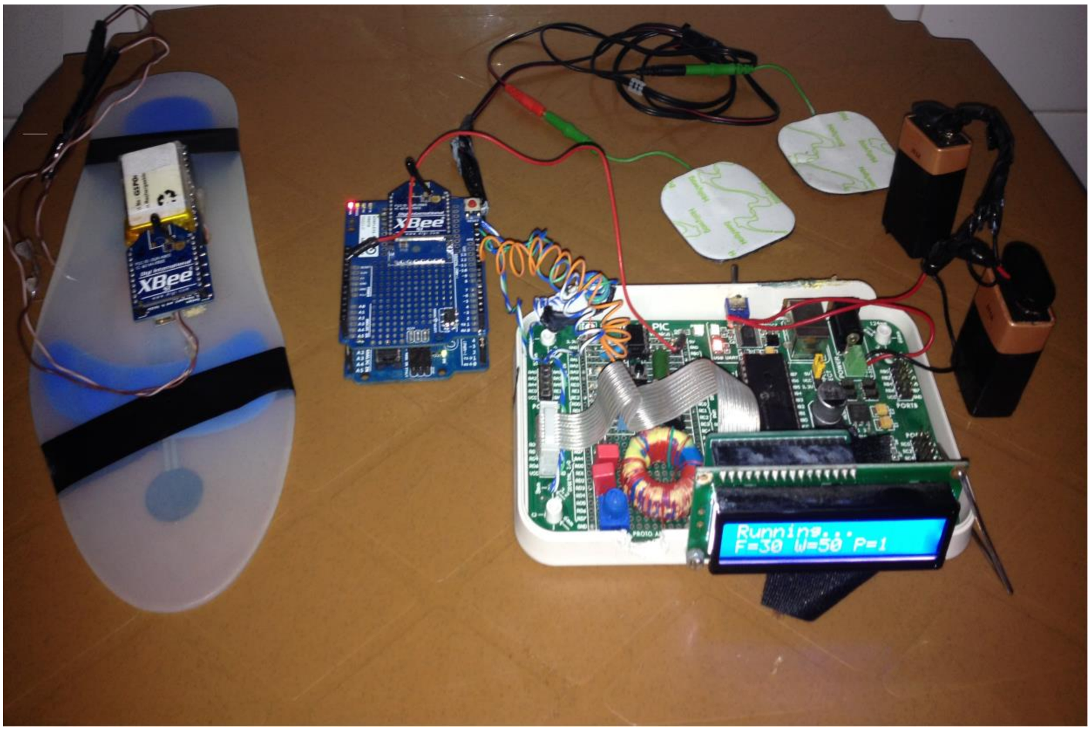


Figure 3.1. The Wireless Microcontroller Based Fes Device

The FES designe consist of a microcontrollers, force sensing sensors, electrodes, and wireless system. This chapter gives detailed information about the design of the wireless FES device. The algorithm, hardware, software and also circuit diagram of the wireless FES device has been described in details in the following sections.

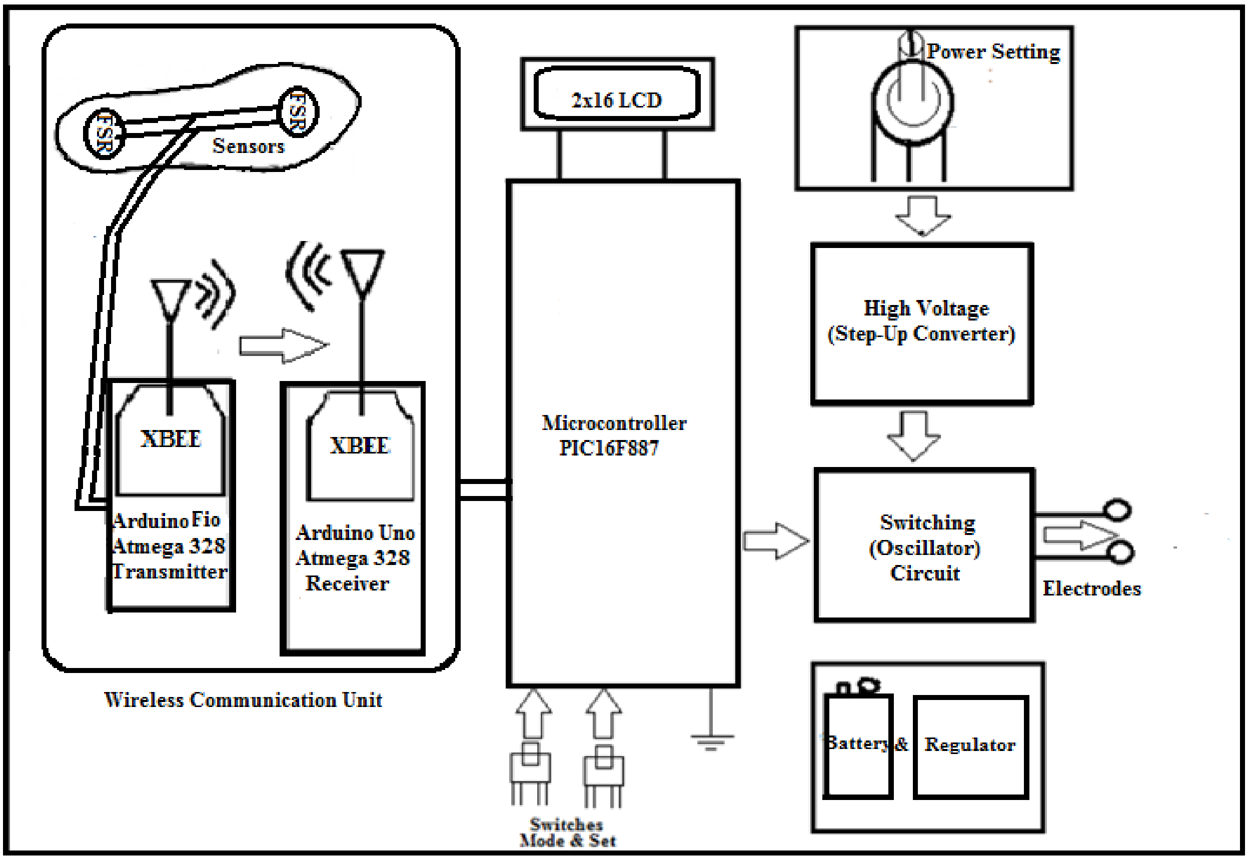


Figure 3.2. The Block Diagram of Wireless Microcontroller Based Fes Device

As shown in Figure 3.2 the block diagram of the wireless microcontroller based FES device consist of several blocks. As mentioned in previous sections system works with microcontrollers, force sensing sensors, electrodes,and wireless units. The force sensitive resistors are placed inside the patient's shoe (insole) which is transmitter side of the wireless communication unit . When patients tries to walk and lifts foot from the ground , transmitter detects this movement and sends signal to the receiver side after that this signal flows on the PIC16F887 microcontroller. Then controller sends a stimulus signal to patient's peroneal nerve at the foot, so that stimulation starts and patient can walk. When patient's foot strikes to the ground stimulation is stopped by microcontroller. The definition of the each bolck is given in details in the following section.

3.2. Hardware & Operation Of The Wireless FES device

The FES hardware is designed around " Ready for PIC" development board, it is developed by the MikroElektronika company. Ready for PIC board based on PIC16F887 controller which is supported with Arduinos for wireless communication. Arduino wireless communication unit based on two ATmega328 microcontroller.

As mentioned above the system consist of two type of microcontroller. First microcontroller is PIC16F887 (40-pin) which has a low-power consumption and it is specified as a nanoWatt technology chip. Second microcontroller is ATmega328 (28-pin) this is the wireless unit of the system which is easily connect on a computer with a USB cable and it simply power it with a battery or AC-to-DC adapter to get started also .

An MC34063 type DC to DC (converter chip) switching regulator is used together with a trasformer to increase 5V DC to 80V DC voltage level . This voltage is used at the source input of a power MOSFET switch. The switch is controller by microcontroller. Pulses at the required frequency and pulse-width are generated by the microcontroller and these pulses are used to switch the MOSFET ON and OFF. The Drain output of MOSFET drivers a pair of electrodes connected to the patient. The wireless part of the system working with two xbee modules they are connected on the two arduino. During the stimulation these modules used RF technology for communication between the arduinos. First microcontroller is arduino Fio it is transmitter side of the communication part which is sense the feet when lifts from the ground and transmit this signal to the second arduino its name is arduino Uno which is called receiver side of the communication then main microcontroller PIC16F887 sense the signal coming from the receiver side and starts the stimulation.

The main differenece of the design from the others are; it has no cable complexity problem this problem solved by wireless system by using transmitter and receiver units. Normaly FES systems uses only one sensor under the feet .The Wireless FES developed further by the addition of another in-sole force sensing sensor underneath the metatarsal heads to enable exact sensing during stair climbing. Pappas et al. Reported that only the front side of the foot is normally placed on the step during stair climbing, when the heel remains in the air, hence making the detection unfeasible with one sensor only. [69] In this context there are two force sensitive resistor(FSR) placed in-sole in wireless FES device. First FSR is placed front side of sole (under toe) and second FSR is placed under the heel so without using it straight surfaces it can be use while climbing the stairs. In older FES systems FSR placed under the heel so system can only detect the heel strikes in straight surfaces but in new design system detects whole foot actions.

3.2.1. The Circuit Diagram Of The Wireless FES Device

The circuit diagram of the stimulator consist of several components as shown in Figure 3.2. The description of each component is given below in details.

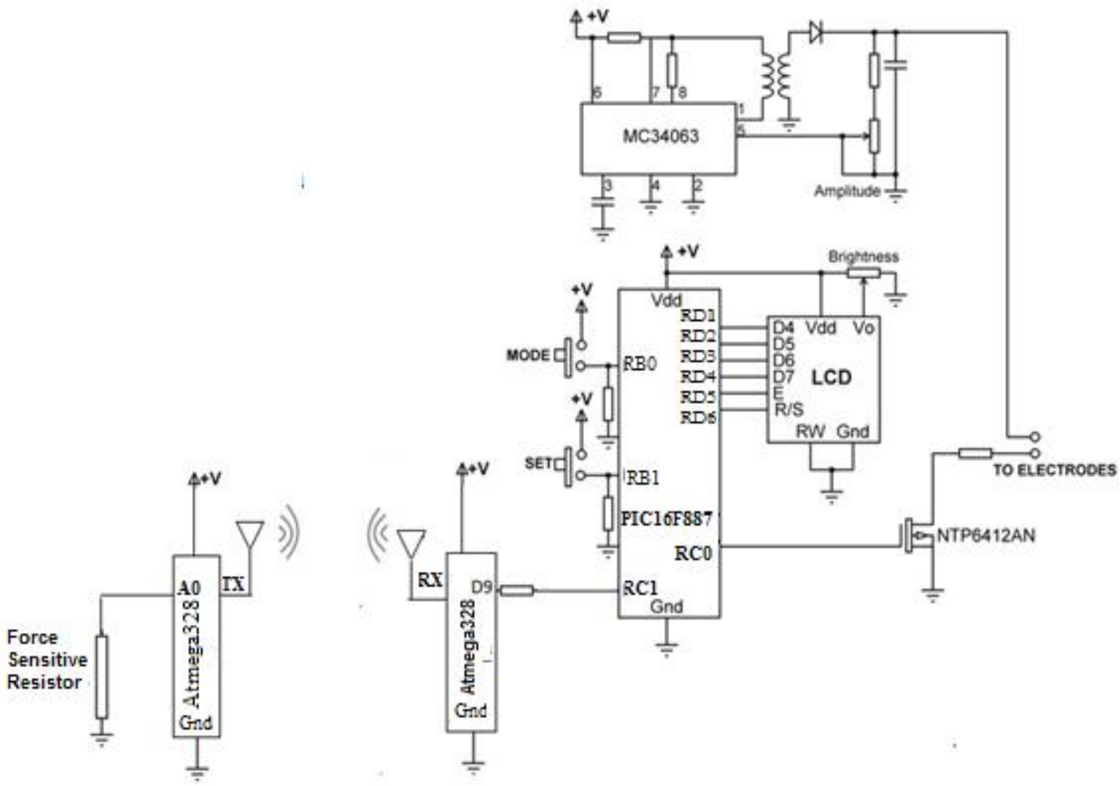


Figure 3.3. Circuit Diagram Of Wireless FES Device

The circuit diagram of the FES device is simple and is shown in the Figure3.3. FSR type sensors are used in the design in order to make the cost as low as possible and also to make the design simple. The two FSR are connected analong input pin A0 of the arduino Fio which is transmitter side of the wireless communication unit, due to the movement of the foot, the electric currents passing through the sensor than this current enters analog input pin A0 of controller so current converted into the digital signals. Then the converted signals flows on the Tx pin of the arduino Fio and transmitted to the arduino Uno which is called receiver side of wireless communication unit of the FES device. After that the recieved signal flows on the digital input pin of arduino Uno D9 which is connected to the interrupt input pin RC1 of the microcontroller PIC16F887 through a resistor. Two push-button switches named SET and MODE are connected to port inputs RB1 and RB0 respectively, and are used to configure the operational parameters, such as the pulse-width, operation profile , and the frequency. The LCD, can remove during the normal process and it is only used for configuration which is connected to PORTD of the PIC16F887 microcontroller. The switching regulator is used to generate high voltage , by using the MC34063 type of DC to DC converter which is used together with a trasformer to increase the voltage . The pin 5 of the DC/ DC converter is connected to the 100k potentiometer. It is used to adjust output voltage amplitude up to 80 volts . RC0 output pin of the microcontroller is used to turn ON and OFF the output voltage through a

NTP6412AN type high voltage MOSFET switch. It is possible to remove the configuration switches and the LCD, and for example connect the device to a PC for configuration. It was on the other hand one of the requirements to make the device to be stand-alone it self and low-cost as it was mainly advantage of the system.

3.2.2. Ready for PIC Board

Ready for PIC board is a compact development equipment for 40 pin PIC microcontrollers. The board by default is equipped with PIC16F887 MCU placed in a DIP40 socket but it does provide connection holes to place a 28-pin device. The preinstalled bootloader or an external programmer must be use to program the MCU . For using an external programmer, user must do a few adjustments on the board. Four 2×5 male header pins are available on the board for easy connection and access a to the MCU input/output pins. The on-board FT232RL chip make a USB to asynchronous serial data transfer interface so that the MCU can communicate with a PC through a virtual COM port by using a USB cable. The board has two LEDs marked with Tx and Rx so that blink when data transfer is active via UART USB module . The power supply of the board can also be used with a 3.3 V type PIC microcontroller. There is an on-board jumper which is provide voltage selecting between 3.3 V and 5 V for the MCU (Retrieved January 6, 2014, from http://embedded-lab.com/blog/?p=3635).

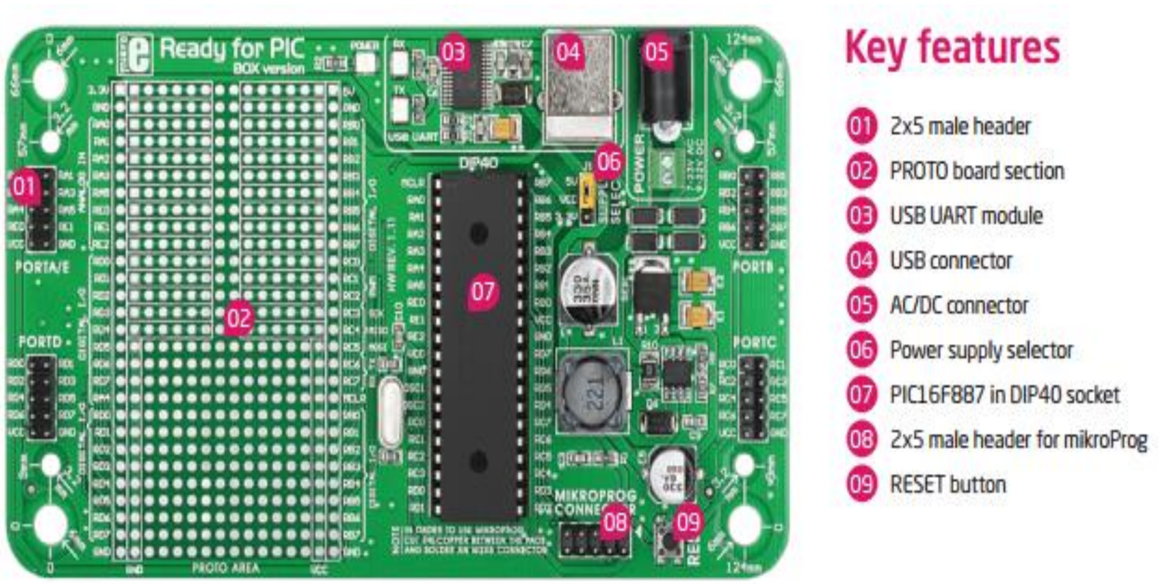


Figure 3.4. Ready for PIC Board

3.2.2.1. Microcontroller Processinng

Processing is an open source software development environment designed for simplifying the process of creating animations , digital images , and interactive graphical applications. It is free to download and operates on Windows, Linux, and Mac platforms. The

Processing IDE has the same basic structure as that of the Arduino IDE and is very easy to use. The programming language is so simple that can easily create an interactive graphics with just a few lines of code. Processing Serial library that will allow to transfer data between the PC and the Ready for PIC board. The firmware for PIC16F887 is written in mikroC Pro for PIC (Retrieved January 6, 2014, from http://embedded-lab.com/blog/?p=3635).

Programing with Boatloader

Bootloader program is required for programming microcontroller on the Ready for PIC board which is pre-instaled in to MCU memory. To transfer the hex files from a PC to MCU you need to use mikro Bootloader (bootloader software) program. After downloading the bootloader program it receives new program data externally via some communication means and writes that data to the program memory of the processor so program can work on PIC. (Retrieved January 6, 2014, from http://www.mikroe.com/downloads/get/1692/).

- Step-1 Choosing COM port

First of all change settings menu selected on boatloader than USB COM port is detected (such case COM8) Baudrate to set 115200 and lastly OK button is clicked.

Figure 3.5. Selecting COM ports On Boatloader

- Step-2 Connect PC to MCU

Reset the board and click on “Connect with MCU” with in 5 second time fare to force the PIC into boatloader mode.

- Step-3 Browse for HEX file

Click on Browse for hex than select hex file which will be uploaded to MCU memor and select desired .hex file from the folder list click on Open button

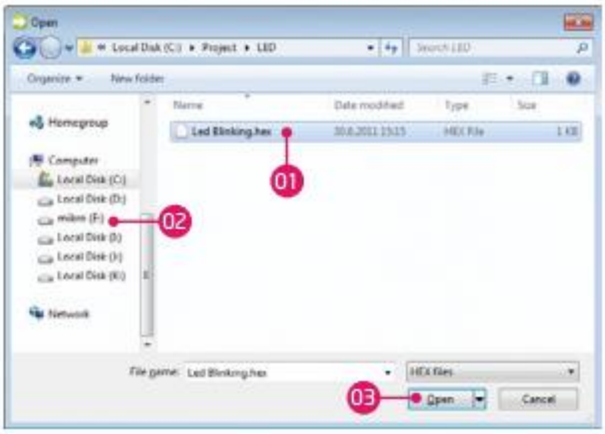


Figure 3.6. Selecting the Hex. file

- Step-4 Load your Hex-file
- Step-5 Start Boatloading

To start loading of the hex file transfer from a PC to microcontrole click button must be pressed also you can see hex file uploading process on via progress bar.

Figure 3.7. Begin Uploading & Bootloading Progress Bar

3.2.3. The PIC16F887 MCU

The PIC16F887 type controller is a production of Microchip which is built on Ready for PIC board. It is a feature that almost all the modern microcontrollers modules should be, and practical modality in such application as the control of different processes in industry, measurement of different values etc. because of high quality , wide range of application, low power consumption, low price and easy availability are important factor in preference of the controller. PIC16F887 microcontrollers are pre-programmed by an UART bootloader firmware and thus eliminate the requirement of the external programmers. The on-board USB-UART module allows the serial data transfer between the PIC and a PC using an USB cable. It has also got a reasonable size prototyping area to add more functionalities to the board as required (Retrieved January 6, 2014, from http://www.mikroe.com/chapters/view/16/).

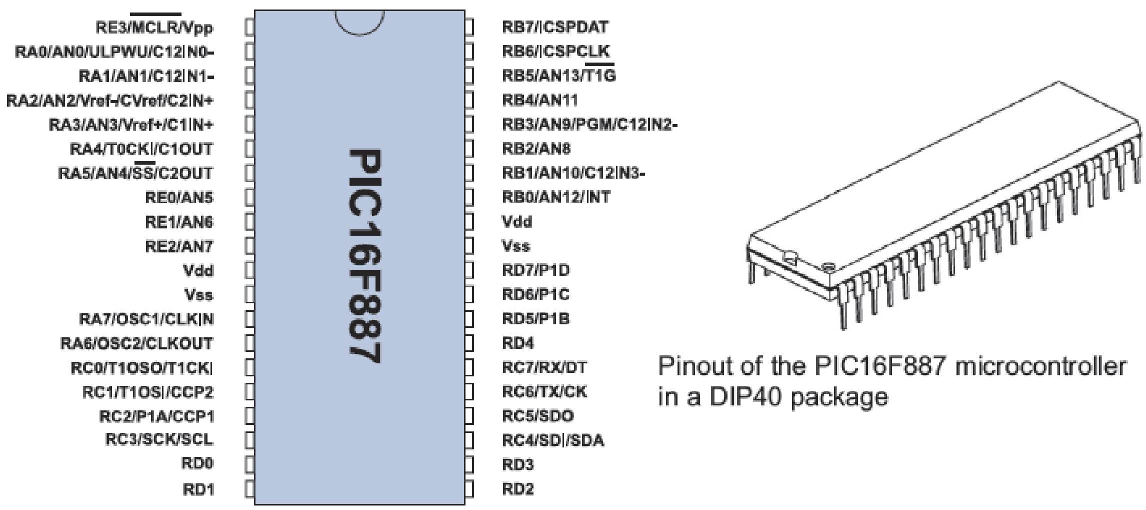


Figure 3.8. PIC16F887 Pin Configuration

3.2.3.1. Memory Of PIC16F887

The PIC16F887 has three types of memory ROM, RAM and EEPROM. All of them will be separately discussed since each has specific functions, features and organization.

- **ROM Memory**

ROM memory is used to permanently save the program being executed. This is why it is often called ‘program memory’. The PIC16F887 has 8Kb of ROM (in total of 8192 locations). Since the ROM memory is made with FLASH technology, its contents can be changed by providing a special programming voltage (13V).

- **EEPROM Memory**

Similar to program memory, the contents of EEPROM is permanently saved, even when the power goes off. However, unlike ROM, the contents of EEPROM can be changed during the operation of the microcontroller. This is why this memory (256 locations) is perfect for permanently saving some of the results created and used during the operation.

- **RAM Memory**

This is the third and the most complex part of microcontroller memory. In this case, it consists of two parts: general-purpose registers and special-function registers (SFR). All these registers are divided in four memory banks to be explained later in the chapter.Even though both groups of registers are cleared when power goes off and even though they are manufactured in the same manner and act in a similar way, their functions do not have many things in common (Retrieved January 6, 2014, from http://www.mikroe.com /chapters/view/16/).

3.2.3.2. The Basic Features of PIC16F887

- ❖ RISC architecture (Reduced Instruction Set Computer)
  - ✓ Only 35 instructions
  - ✓ All single-cycle instructions except branches
- ❖ Operating frequency 0-20 MHz
- ❖ Precision internal oscillator
  - ✓ Factory calibrated
  - ✓ Software selectable frequency range of 8MHz to 31KHz
- ❖ Power supply voltage 2.0-5.5V
  - ✓ Consumption: 220uA (2.0V, 4MHz), 11uA (2.0 V, 32 KHz) 50nA (stand-by mode)
- ❖ Power-Saving Sleep Mode
- ❖ Brown-out Reset (BOR) with software control option
- ❖ 35 input/output pins
  - ✓ High current source/sink for direct LED drive
  - ✓ software and individually programmable pull-up resistor
  - ✓ Interrupt-on-Change pin
- ❖ 8K ROM memory in FLASH technology
  - ✓ Chip can be reprogrammed up to 100.000 times
- ❖ In-Circuit Serial Programming Option
  - ✓ Chip can be programmed even embedded in the target device
- ❖ 256 bytes EEPROM memory
  - ✓ Data can be written more than 1.000.000 times
- ❖ 368 bytes RAM memory
- ❖ A/D converter:
  - ✓ 14-channels
  - ✓ 10-bit resolution
- ❖ 3 independent timers/counters
- ❖ Watch-dog timer
- ❖ Analogue comparator module with
  - ✓ Two analogue comparators
  - ✓ Fixed voltage reference (0.6V)
  - ✓ Programmable on-chip voltage reference
- ❖ PWM output steering control
- ❖ Enhanced USART module
  - ✓ Supports RS-485, RS-232 and LIN2.0
  - ✓ Auto-Baud Detect

- ❖ Master Synchronous Serial Port (MSSP)
  supports SPI and I2C mode

3.2.4. Wireless Communication Unit

The FES Wireless communication unit based on the ATmega328 controller, it is working with two xbee module which are connected on two arduino board. During the stimulation these modules used RF technology for communication between them. The Communication unit consists of two parts which are receiver and transmitter part. Arduino Fio is used in the transmitter part of the communication unit which sense the feet when lifts from the ground and transmit this signal to the receiver part. Receiver part of the communication unit formed by Arduino Uno. The incoming signal on receiver part detected by the main microcontroller PIC16F887 and controller sends stimulus signal to the patient's peroneal nerve which is connected with pair of electrodes on the limb so that patient can walk. After the foot strikes to the ground, transmitter(Arduino Fio) stops to send stimulus signal to the receiver (Arduino Uno) so that stimulation would stopped.

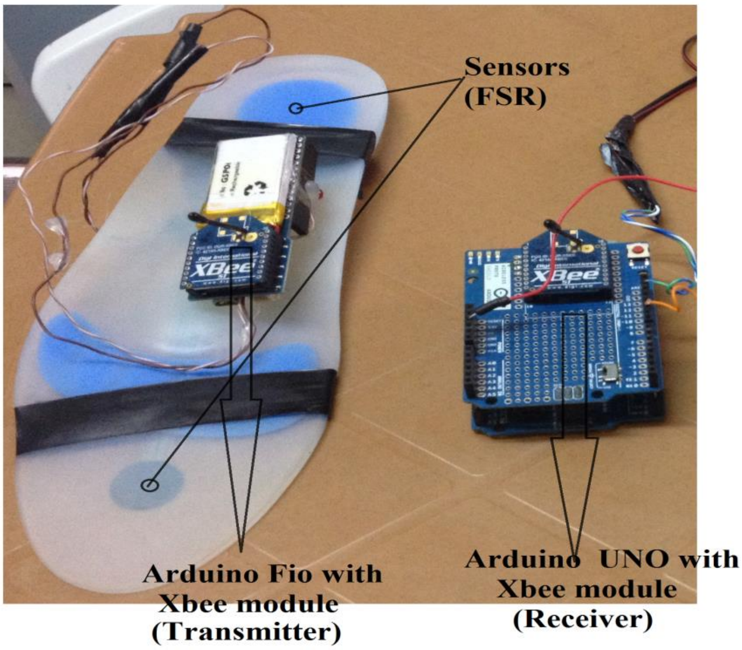


Figure 3.9. The Communication Unit Arduino Fio(left) & Arduino Uno(right).

3.2.4.1. Xbee RF Module

XBee RF modules are used in designe of the wireless communication unit which are connected on Arduino Uno and Fio boards they are allow very reliable and easy to communicate between the microcontroller systems , computers, and serial ports. These modules are embedded solutions providing wireless end point connectivity to the devices. XBee modules use the IEEE 802.15.4 network protocol for fast point to point , multipoint or peer to peer networking and support the individual needs of low cost, low power consumption between wireless sensor network also they are developed for high-throughput application requiring presumable communication timing and low latency .

Figure3.10. 1mW XBee (Wire Antenna)

XBee is the brand name which is coming from Digi International company .These RF modules can all be used with the minimum four number of connections power 3.3volt, data in/data out (UART), and ground with other recommended lines being Reset and Sleep. In addition most XBee families have some other input/output, analog/digital, flow control, and indicator lines built in.

- **The Basic Features of Xbee Module:**

- 3.3V & 50mA
- 250kbps Max data rate
- 1mW output (+0dBm)
- 300ft (100m) range
- Wire antenna
- Fully FCC certified
- 6 10-bit ADC input pins
- 8 digital IO pins
- 128-bit encryption
- Local or over-air configuration
- AT or API command set

- **Xbee Programing**

Xbee RF modules needs to be used X-CTU terminal program to setup wireless communication between the two XBee radios to talk each other. For Xbee to arduino interface or Xbee to Xbee talks, a terminal X-CTU program required to be used. Although other terminal programs might work as well, X-CTU software was designed specifically for the Xbee, and in addition to its terminal functions, it also has functions for saving, writing, reading, and testing signal strength the state of the XBee, and updating firmware. (Retrieved January 6, 2014, from http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/ point-multipoint-rfmodules/ xbee-series1-module #overview).

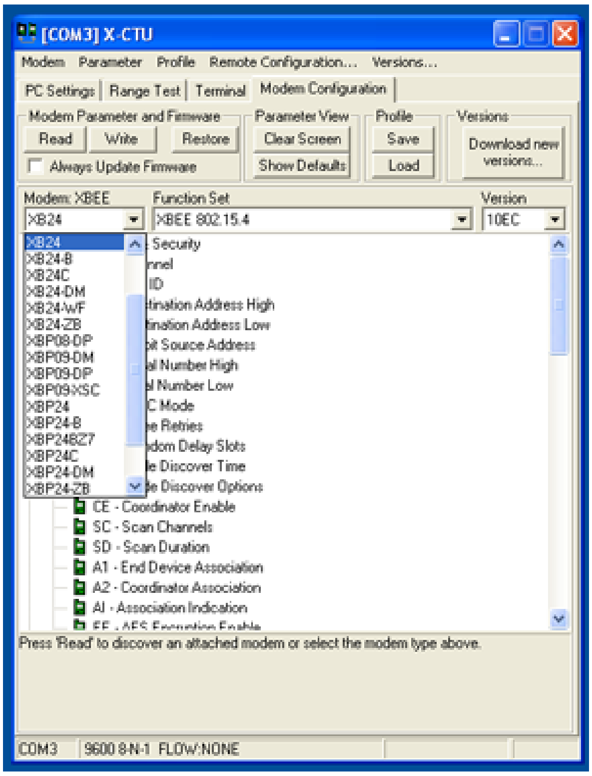


Figure 3.11. Xbee X-CTU Program

The X-CTU program is run on the PC while connected to a X-Bee via a serial port. X-CTU program is a Windows based application provided by Digi company. This program is designed to interact with the firmware files found on Digi's RF products and to provide a simple to use graphical user interface to them. X-CTU is designed to function with all Windows based computers. X-CTU program can be downloaded from "Digi.com". After installing the program, the following steps should be applied.

Step 1. Connect XBee to PC with USB Adapter
Step 2. Click on the correct serial port , set the right "Baud" and API Mode (its off in this case)
Step 3. Click on Test / Query
Step 4. Go to Configuration of modem and click on "Read".Program gives the current Modem type , Function Set , and Version
Step 5. Change the Function Set to API mode , and the Version for this Function Set will change to the latest one automatically
Step 6. Modify the (BD) - Baud Rate to "7 - 115200"
Step 7. Check "Always update firmware" then click on "Write.

When all these steps applied on X-CTU program , XBee modules will be ready for communication between each other. (Retrieved January 6, 2014, from http://examples. digi.com/get-started/configuring-xbee-radios-with-x-ctu/).

3.2.4.2. Arduino Uno

The Arduino Uno boards are equipped with Atmega 328 type of miccontroller . It has 14 digital Input and Output pins (six of them used as a PWM output), a USB connection, 6 analog inputs, a power jack, a 16 MHz ceramic resonator, an ICSP header, and a reset button. It contains all needed to support the microcontroller; it is easy to connect it on a computer with a USB cable or power it with a Analog to Digital battery & adapter or to get started the board.

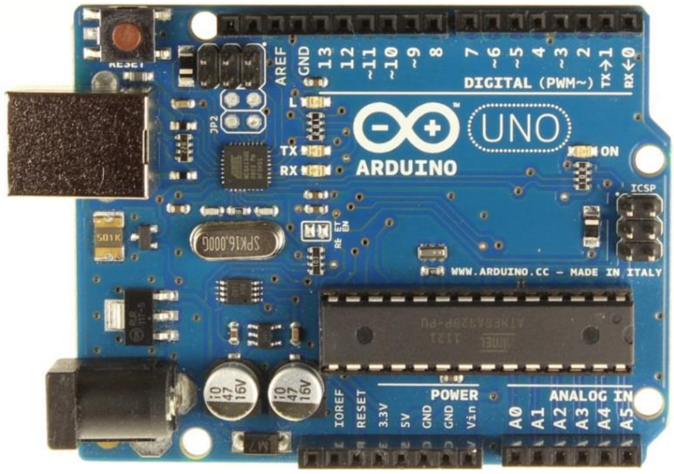


Figure 3.12 Arduino Uno board

The board can be powered via the USB connection or with an external power supply. The Arduino uno board operatable with the   external supply voltage between 20-6 volts. If supplied voltage is less than seven volts, on the other han , the five volts pin may supply less than five volts and the board might unsuitable. If supplied voltage more than 12V, the voltage regulation might be damage and overheat the microcontroller or the circuit elements. The convenient range is between 7 to 12 volts ,also the technical information of arduino uno board as given below;

- **The Basic Features of Arduino Uno Board**

Operatable Voltage	5V
Input Voltage	7-12V
Input Voltage (limit)	6-20V
Digital Input / Output Pin	14
Analog Input Pin	6
DC Current per Input/Output Pin	40 mA

DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

- **Memory**

The Atmega 328 has 32 kb.It also has 2 KB of 1 KB of SRAM and EEPROM

- **Input and Output**

Each of the 14 digital pins on the Arduino Uno can be used as an input or output, using pinMode(), digitalWrite(), anddigitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data.
- External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analogWrite() function.
- SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).
- LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:
- TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.
- AREF. Reference voltage for the analog inputs. Used with analogReference().
- Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board (Retrieved January 6, 2014, from http://arduino.cc/en/Main/arduinoBoardUno).

- **Arduino Uno Communication**

The Arduino Uno has a number of facilities for communicating with a computer, another Arduinos, or other microcontrollers. The Atmega 328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The

Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB to serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).
A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.
The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus;

- **Programming**

The Arduino Uno can be programmed with the Arduino software it is available on “http://arduino.cc/en/Main/Software” web adress. After program is dowloaded from the web by selecting "Arduino Uno from the Tools > Board menu (according to the microcontroller on board) programming can be done. The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows programmer to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol.

- **Software (Automatic) Reset**

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of theATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.
This setup has other implications. When the Uno is connected to either a computer running Linux or Mac OS X, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Arduino Uno. While it is programmed to neglect malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line;

- **Protection From the USB Overcurrent**

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from short circuits and overcurrents. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to.

- **Physical Characteristics of The Board**

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Four screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins (Retrieved January 6, 2014, from http://arduino.cc/en/Main/arduinoBoardUno).

3.2.4.3. Arduino Fio

The Arduino Fio is trasmitter part of the FES wireless communication unit it has two force sensitive resistor located inside the sole. The first sensor is located under the heel and second senssor is located front part of the feet (under toe)also this sensor powered by 3.3volts .When patients lifts his/her feet current flows through the force sensitive sensor and reaches to the analog input pin A0 so that signal can detected by the receicer part.

Arduino Fio designed by Shigeru Kobayashi and this board manufactured by SparkFun Electronics company, it is a microcontroller board based on the ATmega328P type of microcontroller which is runs at 3.3V source voltage and 8 MHz. It has 14 digital I/O pins ,8 analog inputs, an on-board resonator, a reset button, and holes for locating pin headers. It has connections for a includes a charge circuit over USB and Lithium Polymer battery source. An XBee socket is available on the bottom of the board (Retrieved January 6, 2014, from http://arduino.cc/en/Main/ArduinoBoardFio).

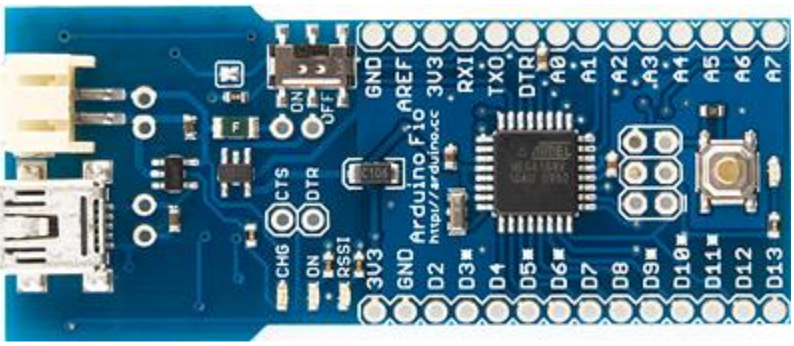


Figure 3.13. Arduino Fio

- **The Basic Features of Arduino Fio:**

Microcontroller	ATmega328P
Operating Voltage	3.3V
Input Voltage for charge	3.7 – 7V
Input Voltage	3. 35 - 12V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Clock Speed	8 MHz
EEPROM	1 KB
SRAM	2 KB
Flash Memory	32 KB (of which 2 KB used by bootloader)

- **Memory**

The ATmega328P has 32 KB of flash memory for storing code (of which 2 KB is used for the bootloader). It has 2 KB of SRAM and 1 KB of EEPROM .

- **Input and Output**

Each of the 14 digital pins on the Fio can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead()functions. They operate at 3.3 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- Serial: RXI (D0) and TXO (D1). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the DOUT and DIN pins of the XBee modem socket.
- External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analogWrite() function.
- SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.
- LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- I^2C: 4 (SDA) and 5 (SCL). Support I^2C (TWI) communication .

There are couple of another pins on the board:

- AREF. Reference voltage for the analog inputs. Used with analogReference().
- DTR. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

There are also 8 unsoldered holes on the board:

- BAT + and BAT -. To be connected to a battery. CHG 5V and CHG -. To be connected to charging terminals.
- SW. Connected to the power switch on the board. Typically used to add an external power switch.
- CTS. Connected to the #CTS/DIO7 pin of the XBee socket. Typically used to do sleep control for a XBee modem.
- DTR. Connected to the #DTR/SLEEP_RQ/DI8 pin of the XBee socket. Typically used to do sleep control for a XBee modem.

➢ **Arduino Fio Communication**

The Arduino Fio has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328P provides UART TTL serial communication, which is available on digital pins 0 (RX) and 1 (TX). The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino Fio board via an external serial connection.

➢ **Physical Characteristicsof Arduino Fio**

The dimensions of the Fio PCB are approximately 1.1" x 2.6"(66 x 28 mm) (Retrieved January 6, 2014, from http://arduino.cc/en/Main/ArduinoBoardFio).

3.2.4.4. The ATmega328 Microcontroller

The single chip Atmega 328 type of controller designed by the Atmel company and it is production of mega AVR series. Atmega 328 controller is preferred due to the system designe is simple, low-powered, low-cost .The high performance Atmel 8bit AVR RISC based microcontroller combines 1 KB EEPROM, 32 KB ISP flash memory with read-while-write capabilities, 23 general purpose Input & Output lines , 2 KB SRAM, three flexible counters/timers with compare modes, 32 general purpose working registers, external & internal interrupts, serial programmable USART, a byte oriented two wire serial interface, SPI serial port, six-channel ten-bit A/D converter , programmable watch dog timer with internal oscillator, and it has five software selectable power saving mode. The MCU operating voltage between 5.5-1.8 volts, Temperature range: -40Â°C to 85Â°C. By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed (Retrieved January 6, 2014, from http://www.popsci.com/diy/article/2013-01/program-arduino-few-simple-steps).

Step1
Firstly arduino software package program is downloaded from the arduino download web page to operate the system after program must be install to begin it .

Step2
Connect arduino to the USB port of the computer. This may require a specific USB cable then reconfigure the port.

Step3
Set the board type and the serial port in the Arduino Programmer.

Step4
By using one of the preloaded programs microcontroller can tested also arduino written codes is named in sketches. Click the upload button to load it. The arduino should begin responding to the program.

Step5
After writing the new codes by using arduino programming language to create new sketchs, the compilling sketch tests the program if is it correct or incorrect and also shows the wrong codes so that when program is ready it can load to the arduino. An arduino sketchs generally formed in 5 parts: a headline defining the sketch and its author; a section describe variables; a setup routine that adjust the initial cases of variables and operates beginning code; a loop routine, which is add the main code that will execute continiously until the program stop running the sketch; and a section where the list can do other functions that operates during the setup and loop routines.All arduino codes or sketches must contains loop routines and the setup .

Step 6
Once the programmer have uploaded the new sketch to the arduino, disconnect it from the computer and integrate it into the project as directed so after all circuit desing is completed on the board it is ready for use .

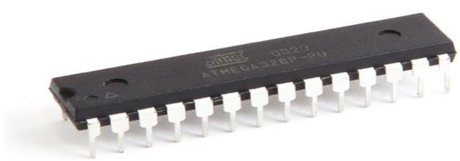


Figure 3.14 Atmega 328 Microcontroller

3.3. FES Algorithm and Software

The Wireless FES system consist of two software program , first program for main controler unit to supply required stimulus signal second program for wireless communcation unit to transmit incoming signal from the foot to the stimulator by using the trasmitter and receiver parts. The first software of the FES device has been developed using the mikro C PRO for PIC language on Ready for PIC board . This is popular high-level C programming language for microcontrollers, developed by mikroElektronika. The second software of the wireles unit has been developed on arduino Uno and arduino Fio boards. The Arduino programming language is a simplified version of C/C++.The software consists of two functionally separate modes: Running mode, and Configuration mode.

3.4. Configuration Mode

The configuration mode enables patients to control the intensity, on-off switch and also to adjust the output amplitude, frequency ,duration and the user profile settings for specific parameters.Two push button switches are , MODE and SET used to adjust these requirements. While operating FES device the configuration mode is entered by pressing the MODE switch while turning the power ON. The frequency and pulse duration can be adjusted respectively between, 5 - 200 Hz, and 50 - 1000 µs, in addition patients can be selected 5 user profiles on device. During the configuration mode the LCD is connected to the device so that patient can see frequency and Amplitude selections on device . By using the rotary potentiometer amplitude pulse can be set between 0-80 volts .The configured parameters are stored in the EEPROM non-volatile memory of the microcontroller.

3.5. Running Mode

The FES algorithm is based on 4 states which is described below . After the first configuration is done FES device is ready for use, so once the device is configured with the required parameters the program will run the system automatically. Although the foot switches(FSR) have two states. The states and the transition between these states are described as follows:

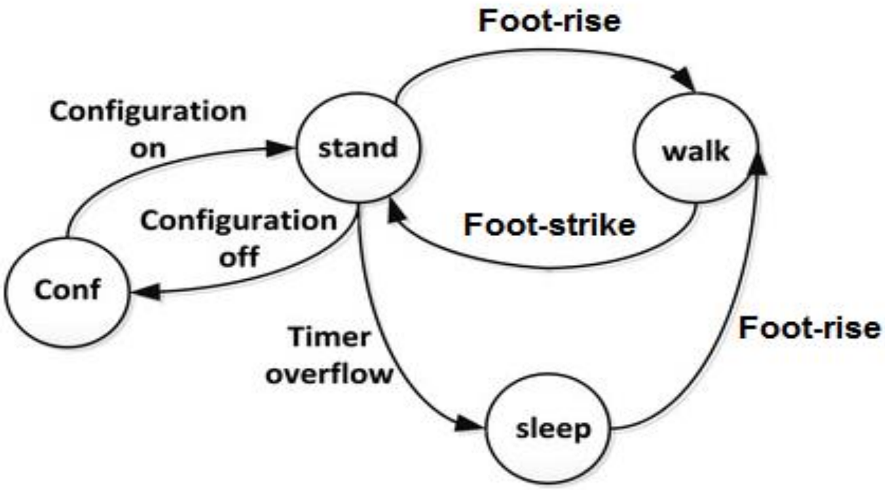


Figure 3.15 Operational States of FES

The FES device states, and transition between the states are operating at a frequency of 11.0592Mhz. A MC34063 type DC/DC converter chip is used together with a transformer to step up the 5 volt DC to 80 volts DC during the walking. This voltage is used at the source input of a power MOSFET switch. The switch is controlled by the controller. In Walk State pulses at the required frequency and pulse-width are generated by the microcontroller and these pulses are used to switch the MOSFET ON & OFF. The Drain output of the MOSFET drives a pair of electrodes which are connected to patient's peroneal nerve at the feet.

- **Stand:** The two force sensitive resistor are placed inside the patients sole which is transmitter part. In the stand state if any force is applied on any of two force sensitive resistor , receiver sends signal to the microcontroller so that stimulator turns to OFF position.

- **Walk:** In this state if patient lift his/her foot from the ground or foot- rise is detected by the device , system is activated so stimulator becomes in ON position. In otherwords while patients tries to walk and lifts his/herfoot , the transmitter sends Rf signals to the receiver part. In foot-rise position receiver generate 5 volts otherwise 0 volts, then this generated signal is sent to the microcontroller based controller therefore controller sends a stimulus signal to the patients peroneal nerve at the feet so that patient can walk. After the foot strike is detected, device automatically turns to the stand state and the stimulation is stopped by the microcontroller.

- **Sleep:** While in the Stand state inactivity of FSR or pre-specified duration has occurred sytem reached to sleep state. In this state sytem gets self-protection to minimize energy expenditure so that the microcontroller is virtually shut down and system operates with an low current (the current consumption is only 30 nA in sleep mode). After the foot-rise is detected FES device automatically returns to the Walk state.

- **Configuration :** If the MODE switch is pressed in the Stand state ,the configuration state operates the sytem so it enables the FES device to be re-configured without having to cycle the power switch. By using a Program Description Language (PDL) the operational structure of the software is described in the following figure.The stimulation algorithm practically compose the base of the program.

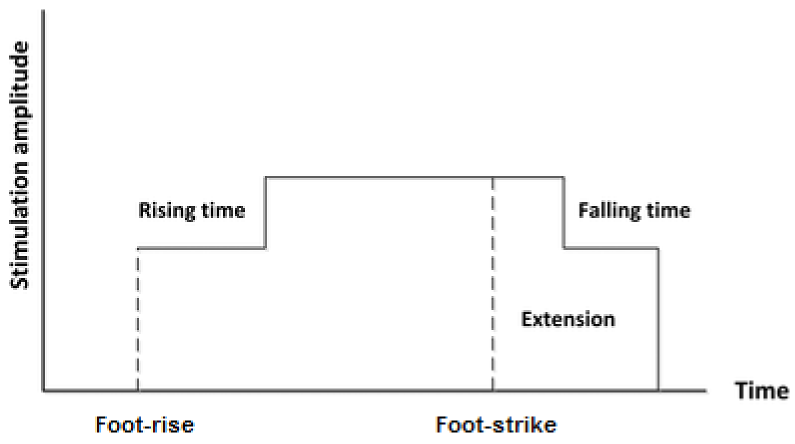
```
BEGIN
        Set stimulation OFF
        DO FOREVER
                IF Foot-rise THEN
                        Clear Timer
                        Set Stimulation ON
                ELSE
                        Increment Timer
                        Set Stimulation OFF
                        IF Timer overflow THEN
                                SLEEP
                        ENDIF
                ENDIF
        ENDDO
END
```

Figure 3.16 The Fes software in Porgram Deccription Language

When there is no activity on a pre-specified period of time or in other words force is applied on any FSR during the Stand state, the processor is forced into Sleep mode. When the foot-rise is detected by the processor ,sytem automatically exits from the Sleep mode than program turns to the Walk state. The required user paremeters pulse duration and pulse frequency are provided by using in interrupt mode of two timers of the microcontroller. One timer adjusts the pulse duration and another one adjusts the pulse frequency rates. End of the configuration begins with the running mode. The program runs continuously. The Foot Switches(FSR) are checked by microcontroller . If the patient lifts his/her foot then stimulation starts with ten selected frequency, pulse-width and the profile. Then stimulation stops after the foot strike where the patient presses on his/her feet to the ground.

3.6. Stimulation Algorithm

The Functional Electronic stimulation algorithm is a simplified version of the stimulation envelope used in the Odstock dropped foot stimulator (ODFSIII) ,the stimulation envelope contains time dependent sections: ramp up,ramp down, midband, and extension. All of these are well known that during a normal stride(gait) the electrical activity of muscles are increased progressively just after foot-rise until it reaches to a maximum level. After the foot-strike also stimulator is due to prolong the electrical stimulus. In wireless FES design, a rectangular envelope is used with the essential parameters as shown in Figure 3.18 whenever the foot-rise is detected, lower stimulation amplitude is applied during the rise time and then the amplitude is increased to the maximum following the rise time. At foot-strike, the normal amplitude time has been extended by an amount which is named the extension time. After all this extension time of the stimulation is reduced for a time equal to the falling time(when foot touches to the ground), therefore stimulation is stopped . Some investigators notice using exponential envelopes rather than linear ones to get better approaches to the normal muscle activity and natural stride (Hart *et al.*, 2006).



Figuren3.17 FES Stimulation Envelope

In wireless FES device 5 selectable and configurable profiles have been described with different timing requirements that may suitable for different users. These profile timing selections are shown below in the table .Various type of experiments applied on drop foot patients these showed that different patients may require different selectable and configurable profiles.

	Rising Time	Falling Time	Extension Time
Profile 1	0	0	0
Profile 2	2	2	1
Profile 3	2	3	1
Profile 4	3	3	2
Profile 5	4	3	1

Table3.1 Stimulation Profile Timings (in seconds)

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1. Results

This section gives information about the test results of the wireless FES device.The Wireless FES device has been tested at the Near East University Training and Research Hospital. The Near East University Training and Research Hospital as the first and only private university hospital in North Cyprus and also the largest hospital in Middle East. NEU Hospital has a 56,000 square-meter closed area with 209 private, single patient rooms, 8 operating theatres, 17-bed Neonatal Intensive Care Unit, 30-bed Intensive Care Unit an large modern laboratory where a wide array of medical and experimental tests can be carried out, and a cutting-edge diognostic imaging center (Retrieved January 6, 2014, from http://neareasthospital.com/about-us/).

Figure 4.1. A Photograph During The Hospital Trials

The foot drop tests have been carried out at Physical Medicine and Rehabilitation Department under the Faculty of Medicine with the real patients. In the traditional FES devices the sensor wires do cause discomfort and cable complexity to the patients as these wires were coming from the shoe sensors to the waist of the patient but in new design has been solved this problem with the help of trasmitter and receiver parts so that replacement of the wires with the wireless technology has been provided more comfort to the patients.

The wireless FES device has been tested on thirteen patients. Five patients suffering from stroke and eight patients suffering from the Multiple sclerosis (MS). These patients had been receiving physiotherapy in NEU rehabilitation center since a certain time. As the part of physiotherapy, during the tests the normal walking pattern of the each patients have been observed (without FES) by Dr. Pembe Hare YİGİTOĞLU and physiotherapists then wireless FES device main unit together with the receiver part has been connected to the patients waits and transmitter part has been put in-shoe after then electrodes connected to the peroneal nerve. With the help of FES device ten patients could use properly their affected legs and significantly walked faster and more efficiently than before. Three patient with stroke could not benefit from the FES device because of first patients has a different anatomical position of the peroneal nerve , the second patient has a semi paralyzed situation and other patient did not respond to the stimulation even at higher amplitude settings as a result of serious damage to the peroneal nerve.

4.2. Future Work and Recommendations

Although the designed FES working satisfactorily, during the future developments simulator will provide more effective results. New technological FES designs are all based on microcontrollers where the technology evolves the size is getting smaller than before every time. Also these developments can lead cost reductions in the future . Today's designs are based on the current technology, by using different type of intelligent sensors with wireless communication systems between different parts of the device, such as using tilt, gyroscopes or accelerometers with RF and Bluetooth communication systems.

WalkAide Products, worked by Weber et al they are produced to be highly successful accelerometer based electronic stimulator devices with no external components or wires , and by using a cuff it is directly applied to the leg, so that simulator can be single whole with the electrodes by using the cuff systems (Weber *et al.,* 2005).

In european countries implanted stimulators one of the new development in recent years. In implantable applications electrodes are surgically implanted to the leg therefore patients no need to find the right place as surface electrodes. Electrodes are fixed to the nerve and skin is not stimulated so that less skin and sensation problems occurs . Always the risk of infection is an important problem in implanted designs. In the future expected that new biocompatible materials, will overcome these challanges. The FES device has been manufactured for experimental purposes currently the cost of the prototype between $150-$200. Our goal is after the further development of the device it might be included in the market in this way device can help more patients with low budgets who suffer from foot drop problems.

CHAPTER 5

CONCLUSIONS

The designed microccontroller based wireless FES device has been successfully applied and tested on real patients suffering from foot drop at the the NEU Training and Research Hospital by using a Ready for PIC board based on PIC16F887 and arduino wireless unit based Atmega 328 microcontrollers. The wireless FES device has been solved the cable complexity and foot sensors wire discomfort with the design of wireless system. Also design has been developed further by the addition of another second in-sole FSR sensor underneath the metatarsal heads so that device enabled reliable sensing in addition to walking on straight surfaces during stair climbing . Microcontroller based wireless Fes device has been restored muscular contraction by stimulating electrical pulses on the paralyzed muscles and also improved the patient's gait performance.

The stimulator power consumption is very low because of the special design. While the patient is waiting in the foot-strike position, the processor shuts off system and system enters the low current sleep mode with practically no current consumption. As soon as an activity has been detected, the FES automatically wakes up and stimulation starts again with detection of the foot-rise, thus reducing patient interaction. The cost of the overall system is very low. Because of during the designing process the standard microcontroller development systems and electric equipments also standard wireless components were used which are easily found in the market. The developed FES system is practical and programmable so it can be improved by modifying the program functions. Further trials will be carried out at the Near East Hospital with real drop foot patients before the system is designed and accepted for patient use.

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APPENDIX A

The Wireless Microcontroller Based FES Device Footaid Program Codes In Micro C For PIC16F887 Controller

/*****
The pin connections of the microcontroller are described as follows:

RB0 - MODE push-button switch

RB1 - SET push-button switch

PORT D - LCD connections

RC0 - Output from the microcontroller to the Gate of the MOSFET

RC1 - Transmitted signal from the Foot switch or (FSR) . Although the foot switch output is connected on the transmitters (in-sole sensor) analog input pin A0. it is connected to a digital input of the microcontroller via a potential divider resistor which is comes from the receiver part of the wireless communication.

The configuration is described as follows:

The system enters the configuration stage if the MODE key is pressed while the power is applied (or system is Reset). During the configuration mode the FREQUENCY and the PULSE WIDTH can be set as desired by pressing the SET key. During the configuration phase the following frequency, pulse-width, and profiles can be selected by the user. Pressing the SET key moves through the options. Pressing the MODE key moves from the Frequency selection menu to the PULSE-WIDTH selection menu and then to the PROFILE selection menu.

Frequencies that can be selected:

5Hz, 10Hz, 20Hz, 30Hz, 50Hz, 100Hz, 200Hz

Pulse-width that can be selected:

50us, 100us, 200us, 300us, 400us, 500us, 600us, 700us, 800us, 900us, 1000us

Profiles that can be selected:

Profile 1, 2, 3, 4, 5

This version of the program is based on using a PIC16F887 microcontroller which is supported by the wireless communication unit and 2 foot sensor, with 2 electrodes, placed on the peroneal nerve of the patient.

******/

```
// Declare the variables used in the program
unsigned char TMR0Value;
unsigned char Rising_Ramp;
unsigned char Falling_Ramp;
unsigned char Extension_Time;
unsigned char Fixed_Time;
unsigned char TMR1HValue;
unsigned char TMR1LValue;
unsigned char frequency;
unsigned char pw_high;
unsigned char pw_low;
unsigned int pulse_width;
unsigned int temp_pulse_width;
unsigned int TMR1Value;
unsigned long Period;
float TimerValue;
// Define the various symbols used in the program
#define MODE PORTB.RB0
#define SET  PORTB.RB1
#define MOSFET PORTC.RC0
#define Foot_Switch PORTC.RC1
#define Heel_Rise 1
#define Heel_Strike 0
#define Enable_Stimulation INTCON.GIE = 1
#define Disable_Stimulation INTCON.GIE = 0
// LCD module connections
sbit LCD_RS at RD2_bit;
sbit LCD_EN at RD3_bit;
sbit LCD_D4 at RD4_bit;
sbit LCD_D5 at RD5_bit;
sbit LCD_D6 at RD6_bit;
sbit LCD_D7 at RD7_bit;
// LCD pin directions
```

```
sbit LCD_RS_Direction at TRISD2_bit;
sbit LCD_EN_Direction at TRISD3_bit;
sbit LCD_D4_Direction at TRISD4_bit;
sbit LCD_D5_Direction at TRISD5_bit;
sbit LCD_D6_Direction at TRISD6_bit;
sbit LCD_D7_Direction at TRISD7_bit;
// End LCD module connections

*****/      TIMER INTERRUPTS service routine (ISR)
```

Both TMR0 and TMR1 timer interrupts are serviced here TMR0 is used to generate the PULSE-WIDTH, and TMR1 is used to generate the required frequency of the waveform. The following PDL describes how the waveforms are generated by the two timers (Here, PIN is the output of the microcontroller that drives the MOSFET):

```
Set PIN ON
Load TMR0 with Pulse-width
Load TMR1 with Period
Start TMR0
Start TMR1
Enable TMR0, TMR1 interrupts
  Wait for interrupts
TMR0 ISR:
  Toggle PIN
  Return from interrupt
TMR1 ISR:
   Toggle PIN
   Reload TMR0
   Reload TMR1
   Enable TMR0 interrupts
   Enable TMR1 interrupts
   Return from interrupt
/*****
```

```
void interrupt(void)
{
// Check if TMR1 interrupt
  if(PIR1.TMR1IF == 1)
  {
    MOSFET = ~MOSFET;              // Toggle output
    TMR0 = TMR0Value;              // Reload TMR0
    OPTION_REG = 0x03;
    TMR1H = TMR1HValue;            // Reload TMR1 High
    TMR1L = TMR1LValue;            // Reload TMR1 Low
    T1CON = 0x31;
    INTCON.T0IF = 0;               // Clear TMR0 interrupt flag
    PIR1.TMR1IF = 0;               // Clear TMR1 interrupt flag
    INTCON.T0IE = 1;
  }
  else if(INTCON.T0IF == 1)        // TMR0 interrupt
  {
    MOSFET = ~MOSFET;              // Toggle output
    INTCON.T0IF = 0;               // Clear flags
    INTCON.T0IE = 0;
  }
}

/*****
        This function sets the PROFILE parameters
There are 5 profile parameters that can be selected by the user. Profiles change the starting
(heel off) and ending (heel strike) conditions. These 5 profile parameters are selected
during the configuration phase and they are:
 Rising_Ramp:    Specifies the time that the initial pulse should be extended
 Falling_Ramp:   Specifies the time that the ending pulse should be extended
 Extension_Time: Total extension time after heel strike
 Fixed_Time:     Total fixed time that the pulse is applied
```

```
*****/
void Set_Profile_Parameters(unsigned char P)
{
  switch(P)
  {
    case 1:
           Rising_Ramp = 0;
           Falling_Ramp = 0;
           Extension_Time = 0;
           Fixed_Time = 6;
           break;
      case 2:
           Rising_Ramp = 2;
           Falling_Ramp = 2;
           Extension_Time = 1;
           Fixed_Time = 6;
           break;
     case 3:
           Rising_Ramp = 2;
           Falling_Ramp = 3;
           Extension_Time = 1;
           Fixed_Time = 6;
           break;
      case 4:
           Rising_Ramp = 3;
           Falling_Ramp = 3;
           Extension_Time = 2;
           Fixed_Time = 8;
           break;
        case 5:
           Rising_Ramp = 4;
           Falling_Ramp = 3;
           Extension_Time = 1;
```

```
        Fixed_Time = 6;
        break;
      }
}

//  This function generates the required timer values for both TMR0 and TMR1

void Generate_Timer_Values()
{



/******
       Calculate the values to be used to load into TMR0 and TMR1

TMR0 is used for Pulse-Width generation and TMR1 for FREQUENCY generation.
The clock frequency is 11.0592MHZ which corresponds to a period of:
0.0904x4 = 0.361 microseconds. The formula to calculate the timing for both
TMR0 and TMR1 are as follows:

  TMR0 to be used to generate PULSE WIDTH between 50us and 1000us.
     TMR0 = 256 - Time in us/(0.361*Prescaler) and with a Prescaler of 16
     TMR0 = 256 - Time in us /5.776
  TMR1 to be used to generate FREQUENCY between 5Hz and 200Hz, or the Period
  of the waveform will be between 200,000us (5Hz) and 5000us (200Hz).
     TMR1 = 65536 - Time in us/(0.361*8)
  or  TMR1 = 65536 - Time in us/2.888

This procedure calculates the values to be loaded into TMR0 and TMR1 as
follows:

Calculate the Period of the waveform from the required frequency
Calculate the value to be loaded into TMR0 and store in variable TMR0Value
Calculate the value to be loaded into high and low bytes of TMR1 and store in
```

```
  TMR1HValue and TMR1LValue respectively
Configure TMR0 with a Prescaler of 16
Configure TMR1 with a Prescaler of 8
Configure TMR0 OPTION_REG
Configure TMR1 T1CON register
Configure INTCON for interrupts
******/
   Period = 1000000 / frequency;                  // in microseconds
//
   TimerValue = 256.0 - pulse_width / 5.776;
   TMR0Value = (unsigned char)TimerValue;          // TMR0 value

   TimerValue = 65536.0 - Period / 2.888;
   TMR1Value = (unsigned int)TimerValue;
   TMR1HValue = TMR1Value / 256;                   // TMR1 HIGH value
   TMR1LValue = TMR1Value - 256*TMR1HValue;        // TMR1 LOW value
// Configure TMR0 as Prescaler=16, PSA=0 T0CS=0
// Clear TMR0 interrupt flag (T0IF) and enable TMR0 interrupts (T0IE)
   OPTION_REG = 0x03;
   INTCON.T0IF = 0;
   INTCON.T0IE = 1;
   TMR0 = TMR0Value;
   MOSFET = 1;                                     // Set output ON
// Now Configure TMR1 for the FREQUENCY
// Configure for Prescaler =8

   TMR1H = TMR1HValue;
   TMR1L = TMR1LValue;
   PIR1.TMR1IF = 0;
   PIE1.TMR1IE = 1;
   T1CON = 0x31;
   INTCON.PEIE = 1;
}
```

// Copy const to ram string. This function is used to save space in the RAM memory where //the text to be displayed on the LCD is stored in the program memory and is then transferred
//to the RAM memory just before being displayed on the LCD

```
char * CopyConst2Ram(char * dest, const char * src){
  char * d ;
  d = dest;
  for(;*dest++ = *src++;);
  return d;
}
// This function reduces the Pulse Width by 30% and then loads TMR0 with the correct value. //A reduced pulse width is used during heel rise and heel strike
void Apply_Reduced_PulseWidth()
{
   temp_pulse_width = pulse_width - 0.3*pulse_width;     // 30% less
   TimerValue = 256.0 - temp_pulse_width / 5.776;
   TMR0Value = (unsigned char)TimerValue;
   TMR0 = TMR0Value;
}
// This function applies the selected Pulse Width and then loads TMR0 with
void Apply_Normal_PulseWidth()
{
   TimerValue = 256 - pulse_width / 5.776;
   TMR0Value = (unsigned char)TimerValue;
   TMR0 = TMR0Value;
}
```

```
/******
 START OF MAIN PROGRAM

This is the beginning of the main program. The operations performed here areas follows:

Declare local variables used in the main program
Configure I/O ports
Initialise LCD
Display a STARTUP message on the LCD

IF Configuration (MODE is pressed during a RESET) THEN
      Configure Frequency
      Configure Pulse-Width
     Configure Profile
ELSE
       Display the working Frequency, Pulse-Width and Profile on LCD
       IF Foot Switch is enabled (heel off) THEN
       Start stimulation
       IF Foot Switch is disabled (heel strike) THEN
       Stop stimulation
   ENDIF
   ENDIF
  Check if Configuration is required and enter Configuration mode
ENDIF

*****/
void main()
{


// Declare local variables


   unsigned char Profile;
   volatile char msg[17];
   unsigned char Txt[7];
//
// Declare text to be displayed on the LCD
//
   const code char Head1[]="Near East Univ";
```

```
   const code char Head2[]="    FOOTAID";
   const code char Running[]="Running...      ";
   const code char Stopped[]="Stopped...      ";
   const code char Ready[]="Ready...        ";
   const code char Frequencytxt[]="FREQUENCY";
   const code char Pwidth[]="PULSE WIDTH";
   const code char Profiletxt[]="PROFILE         ";
   const code char Blanktxt[]="                ";

// Configure I/O
   ANSELH = 0;
   ANSEL = 0;
   TRISB = 3;                // RB0 and RB1 are inputs
   TRISC = 2;                // RC0 = Output, RC1 = Input (Foot Switch)
   MOSFET = 0;
   WPUB = 0;
// Initialise LCD
   LCD_Init();
   LCD_Cmd(_LCD_CLEAR);
// Send a startup message
    Lcd_Out(1,1,CopyConst2Ram(msg, Head1));
    Lcd_Out(2,1,CopyConst2Ram(msg, Head2));
    Delay_Ms(2000);

// Check if configuration required
    if(MODE == 0)
    {
      Lcd_Out(1,1,CopyConst2Ram(msg, Ready));
      goto Run;                           // No configuration
    }
// Configuration is required. The user can select the required Frequency,Pulse Width, and
//the Profile here. Press MODE switch to move between the modes. At the end of Profile
//selection, press MODE switch to jump to the RUN mode.
```

```
// THE EEPROM memory stores the selected variables as follows:
// EEPROM(0): Frequency
// EEPROM(1) and EEPROM(2): Pulse Width
// EEPROM(2): Profile
Start_Of_Configuration:
    while(MODE == 1);
    Lcd_Cmd(_LCD_CLEAR);
    Lcd_Out(1,1,CopyConst2Ram(msg, Frequencytxt));
    frequency = EEPROM_Read(0);
    if(frequency < 5 || frequency > 200)
    {
      frequency = 5;
      EEPROM_Write(0, frequency);
    }
    ByteToStr(frequency, Txt);
    Lcd_Out(2, 1, Txt);
// First configure the FREQUENCY
    while(1)
    {
      if(SET == 1)
      {
        Delay_Ms(100);
        while(SET == 1);
        switch(frequency)
        {
          case 5:
               frequency = 10;
               break;
          case 10:
               frequency = 20;
               break;
          case 20:
               frequency = 30;
```

```
        break;
    case 30:
        frequency = 50;
        break;
    case 50:
        frequency = 100;
        break;
    case 100:
        frequency = 150;
        break;
    case 150:
        frequency = 200;
        break;
    case 200:
        frequency = 5;
        break;
    }
    EEPROM_Write(0, frequency);
    ByteToStr(frequency, Txt);
    Lcd_Out(2,1,CopyConst2Ram(msg, Blanktxt));
    Lcd_Out(2, 1, Txt);
    Delay_Ms(100);
   }
// Now configure the Pulse Width
    else if(MODE == 1)
    {
      Delay_Ms(100);
      while(MODE == 1);
      Lcd_Out(1,1,CopyConst2Ram(msg, Pwidth));
      pulse_width = 256*EEPROM_Read(1) + EEPROM_Read(2);
      if(pulse_width < 50 || pulse_width > 1000)
      {
        pulse_width = 50;
```

```
  EEPROM_Write(1, 0);
  Delay_Ms(20);
  EEPROM_Write(2, 50);
}
IntToStr(pulse_width, Txt);
Lcd_Out(2, 1, Txt);
while(1)
{
   if(SET == 1)
   {
     Delay_Ms(100);
     while(SET == 1);
     switch (pulse_width)
     {
       case 50:
             pulse_width = 100;
             break;
       case 100:
             pulse_width = 200;
             break;
       case 200:
             pulse_width = 300;
             break;
       case 300:
             pulse_width = 400;
             break;
       case 400:
             pulse_width = 500;
             break;
       case 500:
             pulse_width = 600;
             break;
       case 600:
```

```
            pulse_width = 700;
            break;
        case 700:
            pulse_width = 800;
            break;
        case 800:
            pulse_width = 900;
            break;
        case 900:
            pulse_width = 1000;
            break;
        case 1000:
            pulse_width = 50;
            break;
      }
      pw_high = pulse_width / 256;
      pw_low = pulse_width - 256*pw_high;
      EEPROM_Write(1, pw_high);
      Delay_Ms(20);
      EEPROM_Write(2, pw_low);
      IntToStr(pulse_width, Txt);
      Lcd_Out(2,1,CopyConst2Ram(msg, Blanktxt));
      Lcd_Out(2, 1, Txt);
      Delay_Ms(100);
    }
// Now configure the Profile
    else if(MODE == 1)
    {
      Delay_Ms(100);
      while(MODE == 1);
      Lcd_Out(1,1,CopyConst2Ram(msg, Profiletxt));
      Profile = EEPROM_Read(3);
      if(Profile < 1 || Profile > 5)
```

```
{
  Profile = 1;
  EEPROM_Write(3, Profile);
}
ByteToStr(Profile, Txt);
Lcd_Out(2,1,CopyConst2Ram(msg, Blanktxt));
Lcd_Out(2, 1, Txt);
while(1)
{
  if(SET == 1)
  {
    Delay_Ms(100);
    while(SET == 1);
    switch(Profile)
    {
      case 1:
            Profile = 2;
            break;
      case 2:
            Profile = 3;
            break;
      case 3:
            Profile = 4;
            break;
      case 4:
           Profile = 5;
           break;
      case 5:
            Profile = 1;
            break;
      }
      EEPROM_Write(3, Profile);
      ByteToStr(Profile, Txt);
```

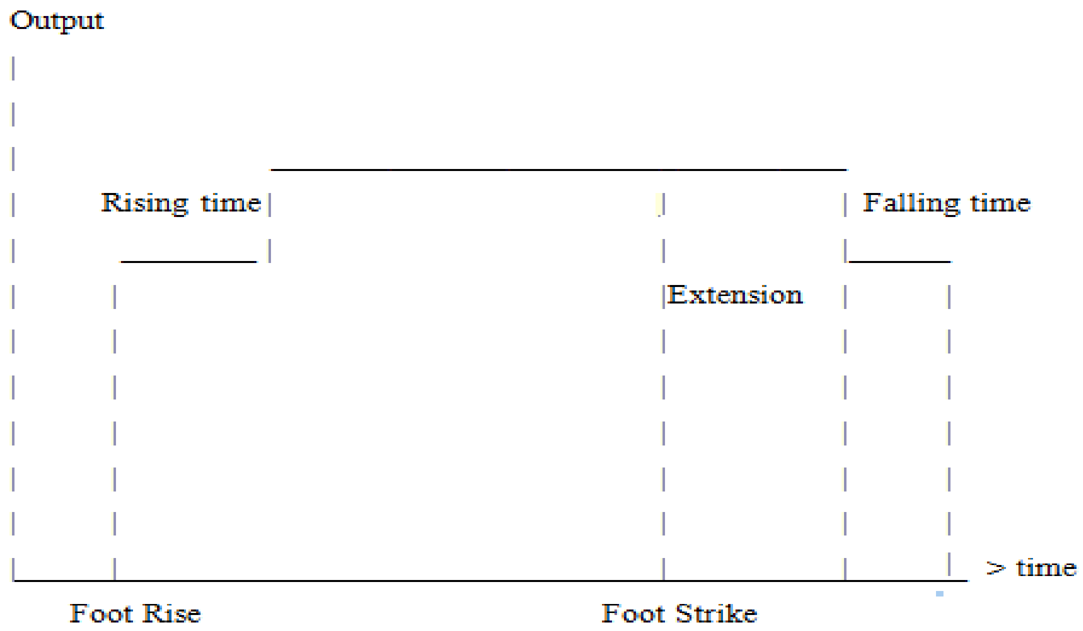
```
                Lcd_Out(2,1,CopyConst2Ram(msg, Blanktxt));
                Lcd_Out(2, 1, Txt);
                Delay_Ms(100);
               }
               else if(MODE == 1)
               {
                while(MODE == 1);
                Lcd_Out(1,1,CopyConst2Ram(msg, Ready));
                goto Run;
               }
               }

               }
         }
     }
   }
```

// End of configuration. Beginning of RUNNING mode. The program runs here //continuously.The Foot Switch is checked. If the patient lifts his/her heel then stimulation //starts with eight selected frequency, ten pulse-width and four profile. The stimulation //stops after the heel strike where the patient presses on his/her feet.

```
Run:
  frequency = EEPROM_Read(0);
  pulse_width = (unsigned int)(256*EEPROM_Read(1) + EEPROM_Read(2));
  Lcd_Out(2, 1, "F=");                 // Display F=
  ByteToStr(frequency, Txt);
  Lcd_Out_Cp(Ltrim(Txt));
  Lcd_Out_Cp(" W=");                    // Display W=
  IntToStr(pulse_width, Txt);
  Lcd_Out_Cp(Ltrim(Txt));
  Profile = EEPROM_Read(3);
  Lcd_Out_CP(" P=");                   // Dislay P=
  ByteToStr(Profile, Txt);
```

```
  Lcd_Out_Cp(Ltrim(Txt));
  Set_Profile_Parameters(Profile);
// Generate required timer values and enable timer interrupts
  Generate_Timer_Values();
// Endless Running loop waiting for interrupts. Goto configuration routine if MODE is
//pressed.The Foot Sensor(FSR) data is received and then the algorithm is applied to
//stimulate the nerve. Interrupts are enabled and disabled to start and stop the stimulation.
//Adjust the Pulse width during Rising_Ramp and Falling_Ramp by 10% Check if Foot
//Sensor is enabled and if so enable stimulation with the chosen PROFILE parameters. The
//Foot Sensor output comes from the receiver unit is:
// No load: 1(5volts),      With Load: 0(0volts)
// Heel_Rise = 1(5volts),   Heel_Strike = 0(0volts)
// FOR TESTING Enable_Stimulation;
//          while(1);
/*****
```

The algorithm applied during the stimulation of the foot is described by the following PDL and in thefigure below:



```
 DO FOREVER
    IF Heel Rise THEN
      Reduce pulse width by 30%
      Enable stimulation
      Wait for Rising_Ramp time
      Apply selected pulse width
      Wait while Heel Rise
 AT THIS POINT HEEL STRIKE OCCURS:
      Wait for Extension time
      Reduce pulse width by 30%
      Wait for Falling_Ramp time
      Disable stimulation
    ENDIF
    IF MODE switch is pressed THEN
      Disable stimulation
      Goto configuration mode
    ENDIF
  ENDDO
*****/
     while(1)
     {
       if(Foot_Switch == Heel_Rise)
       {
         Apply_Reduced_PulseWidth();           // Load TMR0 with reduced PW
         Enable_Stimulation;
         Lcd_Out(1,1,CopyConst2Ram(msg, Running));
         Vdelay_Ms(Rising_Ramp*1000);

         Apply_Normal_PulseWidth();            // Load TMR0 with normal PW
         while(Foot_Switch == Heel_Rise);      // Wait until feet Strike
         Vdelay_Ms(Extension_Time*1000);        // Wait for Extension time
         Apply_Reduced_PulseWidth();           // Load TMR0 with reduced PW
         Vdelay_Ms(Falling_Ramp*1000);
```

```
            Disable_Stimulation;
            Lcd_Out(1,1,CopyConst2Ram(msg, Stopped));
        }
//Check if MODE switch is pressed and if so stop stimulation and jump to Configuration
//menu. This is only checked after the patient's foot is back to normal. i.e. Not walking, but
//steppin on.

        if(MODE == 1)
        {
            Disable_Stimulation;
            MOSFET = 0;
            Lcd_Out(1,1,CopyConst2Ram(msg, Stopped));
            Delay_Ms(2000);
            goto Start_Of_Configuration;            // Jump to Configuration
        }
    }
}
// END OF THE PROGRAM
```

APPENDIX B

Wireless Communication Unit Program Codes For Receiver & Transmitter Parts

<u>Trasmitter;</u>

```
/******

Arduino FIO Sender

*****/

int ledPin = 11;      // selection the pin for the LED,

int sensPin = A0;    // selection of the  (FSR)sensors pin as an input

int voltage = 0; // variable to store the brightness and voltage of the LED when foot strikes
to the ground

int sensorValue = 0;  // variables to store incoming value from the sensor

int lastValue = 0;

int volt=0;// Variable to store the last value of the(FSR) sensor voltage

void setup()

{

  // declare the ledPin as an OUTPUT:

  pinMode(ledPin, OUTPUT);

  Serial.begin(9600); // Begin serial output

}

void loop() {

  // read the value from the sensor (FSR):

  int sensVal = analogRead(sensPin);

   if( abs(sensVal - lastValue) > 5){

     Serial.println(sensVal);

     lastValue = sensVal;

     volt=analogRead(sensPin)*3.3/1024;
```

```
  Serial.print(volt); Serial.println("volt");
 }


  // Maping the full range of the 1024 analog pin input value to the possible ranges of the
LED 0-255
{
  voltage = map(sensVal, 0, 1023, 0, 255);
 analogWrite(ledPin, voltage); // write the value to the LED
 Serial.print(voltage); Serial.println("voltage");
   delay(500);
//slow down output for reading
 }
}
// END OF THE PROGRAM
```

Receiver;

```
/*****
 Arduino Uno Receiver
 *****/
char inString[6];
int inByte = -1;
int lastValue = 0;
int stringPos = 0;

int voltpin=10;
void setup()
 {
  pinMode(11, OUTPUT);
  Serial.begin(9600);
}
void loop() {
   inByte = Serial.read();
  //if there is any numerical serial available, store that
  if((inByte >= '0') && (inByte <= '9')){
    inString[stringPos] = inByte;
    stringPos ++;
  }
  if(inByte == '\r'){
    int voltage = atoi(inString); //convert string to int
    //incoming will be a range of 0-1023, we need 0-255
     Serial.print(voltage,DEC); Serial.println("sens");
    int  volt= voltage*5/225;
    Serial.print(volt,DEC); Serial.println(" volts");
{
```

```
 if (volt>4) analogWrite(voltpin,0);   // set the Pin11- off (0Volts)
 else
 {
if (volt<3) analogWrite(voltpin,255);   // set the Pin11 -on(5Volts)
  }
   //clear the values from inString
   for (int c = 0; c < stringPos; c++){
     inString[c] = 0;
   }
   stringPos = 0;
 }
}
}
// END OF THE PROGRAM
```