Design of a Portable Functional Electrical System for Foot Drop Patients

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Abstract*- A portable functional electrical stimulation system has been designed using embedded systems technology. The system, which was applied to patients suffering from foot drop, uses sensors to monitor foot movement and orientation in a unique way, uses sophisticated algorithms for feedback, and drives an array of surface electrodes for stimulation. A new technique was invented based on using the twitch response of muscles to optimize the configuration of the electrode array. This reduces the setup time in the clinic. The feedback is used from the sensors and the optimum configuration of electrodes is chosen to produce correct stimulation and movement in real time. The instrument presents the patient with a ranked list of electrode combinations that are likely to be optimum, the patient can then choose a combination that is both effective and comfortable. The system can change the pattern of electrodes and also the stimulation signal during the process of stimulation. This may enable some problems associated with fatigue and skin irritation to be reduced. Trials were carried on 10 controls and 2 patients to test the instrument and study and develop the system optimization and control algorithms. These preliminary clinical trials showed that control of the stimulation during walking, based on the optimization algorithms developed in this work, gives high quality correction of foot drop. This was shown by gait assessment analysis by the physiotherapists earlier in the project. These trials prove that the concept of using the electrode array for stimulation has advantages over using a conventional 2-electrode system. The system has been designed and developed for the mentioned problem and has been tested for its efficacy.

***Index Terms*— Embedded systems technology, foot drop , functional electrical stimulation system**

I. INTRODUCTION

When the dropping of the forefoot occurs due to weakness, damage of the peroneal nerve or paralysis of the muscles in the anterior portion of the lower leg, such condition is called FOOT DROP. Though it is not a disease, it serves as a symptom for a bigger problem. Foot drop is characterized by the difficulty or the inability in moving the ankle and toes upward (dorsiflexion). Foot drop condition, can be temporary or permanent depending upon the weakness state of the muscle or paralysis. It can occur unilaterally or bilaterally. While stepping forward during walking, the knees are bent slightly so that the front of the foot can be lifted higher than usual to prevent the foot from dragging along the ground. Another cause of foot drop is the nerve damage. Multiple Sclerosis (MS) or Spinal Cord Injury (SCI) can produce partial or total paralysis. A person suffering from any one of the above conditions may not be able to move his or her body parts. Other factors that may get affected includes problems in breathing, blood circulation, bladder and bowel function. Over the last 30 years several methods and devices are invented by scientists and engineers to assist these problems. One such technique is called Functional Electrical Stimulation (FES). Any person suffering from MS or SCI can try FES as a treatment option as it can be applied to many different physical problems.

FES is a method of application of low level electrical currents to certain body parts to restore or improve its function. One example of FES system is a pacemaker. Some other types of FES may help to restore lost abilities such as standing or grasping. Also, FES may assist with some secondary problems of paralysis such as slow wound healing or poor blood circulation. In such treatments the term used is general called as Electrical Stimulation or ES. Some drawbacks of FES systems are found especially with people having complete spinal lesion, in such cases it provides benefits only when the system is operating. The benefits disappear when the system is turned OFF. So FES is an assistive device. In cases where patients suffer from incomplete spinal lesion or multiple sclerosis the usage of FES may help to recall some amount of voluntary muscle function. In such cases benefits are present even when the system is turned OFF. This is a restorative benefit of FES. FES itself does not reverse paralysis. People of any age or any level of injury can undergo this technique. This makes FES technology far more superior than many other similar techniques.

II. FES TECHNOLOGY

The main components of an FES system are the electrodes**,** the stimulator**,** and sensors or switches. When FES is being used to move muscles, current

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pulses in the electrodes cause the weakened or paralyzed muscles to contract. In other applications, currents in the electrodes may simply produce electrical currents in the tissues without moving any muscles. The stimulator controls the strength and timing of the low-level pulses that flow to the electrodes. The sensors or switches control the starting and stopping of the pulses supplied by the stimulator. The FES simulator unit is shown in figure 1 and the parts of it are explained as follows.

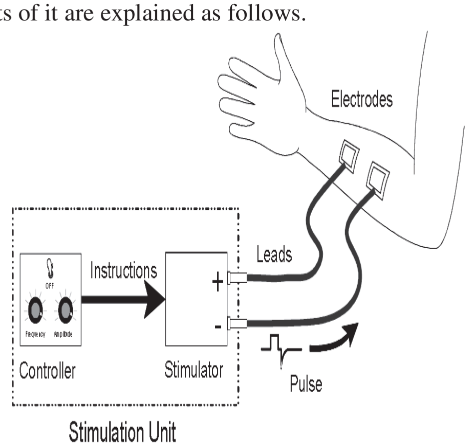

Figure 1. FES Simulator unit

A. Electrodes

Skin Surface electrodes may be attached to the skin daily. Several other types of electrodes are available that can also be implanted within the body. Skin surface electrodes are generally made of a flexible material such as rubber that has the ability to conduct electricity. Tiny electrical currents are sent through the electrode to the skin and the tissues beneath the skin. Generally surface electrodes are attached with a conductive gel while others are self adhesive. The electrodes of either type may be reusable. It is convenient to simply apply electrodes to the skin surface. Examples are plate electrodes, suction type electrodes, floating electrodes etc.

B. Leads and Stimulators

Leads are used to connect the electrodes to a stimulator. The leads are insulated wires. The electrical charge is delivered to the nerve, muscle or other tissue through the leads from the simulator. Stimulators mostly are external units. The size of a stimulator can be as small as a calculator or as large as a computer workstation. A stimulator usually has a computer controller unit built into it. Each stimulation channel sends pulses to one or more electrodes.

C. Sensors

Sensors are electronic or mechanical devices that measure some feature of the environment and send information about it back to the stimulator-controller. This information is used by the controller to adjust the stimulation. Sensors may include switches that the FES user can use to start and stop the system. Also some systems have switches that allow the user to select from a menu of choices. Certain sensors are built into shoes or braces to detect the angle at a joint or the pressure when weight transfers onto a foot. All the sensors used are man-made or artificial sensors.

III. HARDWARE MODEL

The basic hardware is divided into two parts Required Voltage Supplier and the Controller part

A. Required Voltage Supplier

The Required Voltage Supplier is shown in Figure 2 It supplies around 200 Volts to the body surface electrodes which are used to stimulate the inactive nerves. It contains the following parts

- Astable multi vibrator
- Centre tapped transformer
- Bridge rectifier

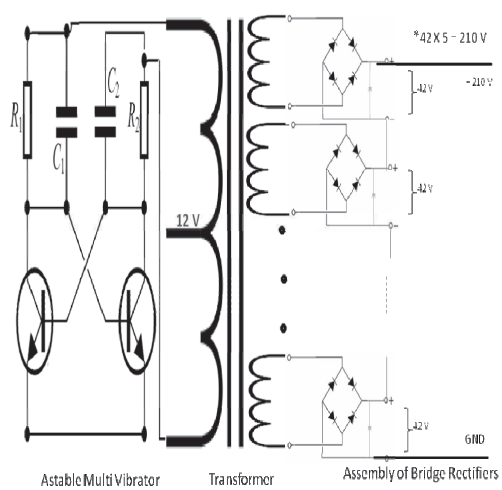

Figure 2. Required Voltage Supplier

An Astable Multivibrator is also known as a FREE-RUNNING MULTIVIBRATOR. When the time is ON it alternates between two different output voltage levels

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hence it is also called free-running. The output remains at each voltage level for a definite time period. The output of the astable multivibrator is a continuous square or rectangular waveforms. There is no input for an Astable Multivibrator but has two outputs.

A Centre tapped transformer is a transformer with a tap in the middle of the secondary winding, usually used as a grounded neutral connection, intended to provide an option for the secondary side to use the full available voltage output or just half of it according to need.

A diode bridge is an arrangement of four diodes in a bridge configuration. For either polarity of the input it provides the same polarity of output. A diode bridge is commonly called as a bridge rectifier when used for conversion of an alternating current (AC) input into direct current (DC) output. A bridge rectifier provides full-wave rectification from a two-wire AC input. This results in lower cost and weight as compared to a rectifier with a 3-wire input from atransformer with a center-tapped secondary winding.

B. The Controller

The major components in this half of the hardware are

- Micro controller
- Opto isolator
- IGBT
- Sensor

If the first part helps in giving high voltage to the body surface, this part helps in regulating that potential in such a way that, it doesn't cause any kind of damage to the body. Here, the 210 V potential is always supplied to the positive electrode, but the negative electrode is grounded based on the regulation of the micro controller. Whenever a high pulse is supplied from the MC to the opto isolator, 12 V is given to the IGBTs. When the IGBTs are given a 12 V potential, they ground the negative electrode and thus 210 V is supplied to the body surface. This helps in activating the inactive nerves. Here the major problem is, if this high potential is supplied for a long time of 5-10 secs continuously to the body, it may affect the particular nerves. For this reason, we use a MC to control in such a way that the duration of the applied potential does not become greater than 2-3 mill seconds. The pulse width starts initially at 0.05 ms and is incremented in terms of 0.05 till the foot position reaches the required height. Figure 3 shows the parts of controller.

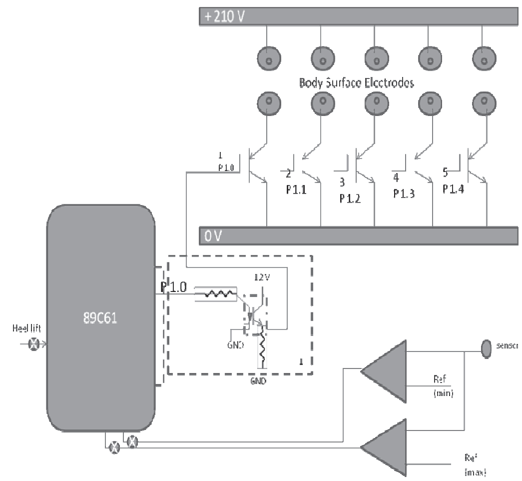

Figure 3. The Controller

During testing the hardware for accurate results, the presence of leakage currents was detected. To reduce these leakage currents, the following circuit was used in place of electrodes. Instead of attaching electrodes directly to 210V, we use the following design, which will help in eliminating unnecessary leakage currents.

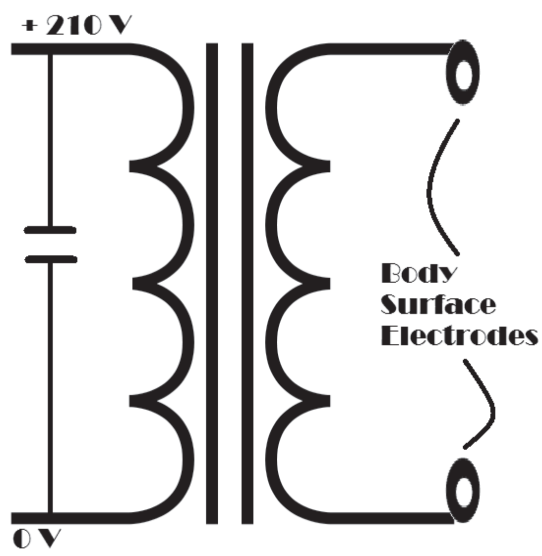

Figure 4. Solution for leakage currents

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IV. CONCLUSION

The benefits of FES begin with improved walking:

- Provide close to natural movement while walking
- Increase speed and improve steadiness while walking
- Increase social participation
- Re-educates the muscles to function without the need of the system
- Prevents loss of muscle
- The range of motion in the ankle and foot is maintained or increased
- Increase in local blood flow

V. REFERENCES

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