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Electronic Nerve Stimulation Device for Drop Foot People

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Abstract*: Drop foot syndrome is a general term for difficulty in raising the rear of the foot from the ground, a common problem that can lead to falls, trips, and accidents in human life. It is normally a neuromuscular disorder that causes peroneal neuropathy between the fibula and the neck. In other words, the cause of drop foot is the lack of contact between the peroneal nerve and the central nervous system which enables the dorsiflexion of the foot. The person is unable to lift the foot or the toes upward. Foot drop correction is usually accomplished by electrical stimulation of the common peroneal nerve by transmitting a sequence of pulses at a given amplitude, length and frequency. The proposed work is to develop a product to help people those who are affected by drop foot syndrome. The proposed method uses force sensor to identify the proper positioning of the foot, based on the output microcontroller will provide the signal to the driver circuit to operate the stimulator. The proposed work offers low-power, low-cost, battery powered, high-performance, and portable electronic stimulator for drop foot correction. The proposed stimulator is wireless and has been developed using sensors instead of eliminating cables from the device to the stimulator unit using the radio frequency transmitter/receiver pair. Hence it may heplful for the person affected by drop foot syndrome and make it has compact and portable one.

***Keywords* : Drop foot syndrome, Drop foot correction, Microcontroller, Peroneal nerve stimulation.**

I. INTRODUCTION

Foot drop is a walking abnormality where forefoot drop is caused by weakness, irritation or harm to the common fibular nerve, including the sciatic nerve, or muscle paralysis in the reduced leg anterior part. Usually, it is a symptom of a bigger issue, not an illness in itself. Foot drop is defined by a failure to raise the ankles or lift the foot from the knee or impaired capacity. Depending on the extent of muscle weakness or paralysis, foot drop may be temporary or permanent and may happen in one or both feet. The raised leg is bent at the knee to avoid the foot from dragging along the floor while walking.

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Foot drop alone or muscle or spinal cord trauma, abnormal anatomy, atoxins, or disease can cause nerve damage. Toxins include compounds of organophosphate that were used in warfare as pesticides and as chemical agents. The poison can result in further bodily harm such as a neurodegenerative disorder called delayed polyneuropathy caused by organophosphorus. This disease leads the motor and sensory neural pathways to lose their function. In this situation, owing to neurological dysfunction, footfall may be the consequence of paralysis, Spinal Cord Injury (SCI), Multiple Sclerosis (MS), head injury, stroke, Cerebral palsy and several nerve damage.

It can also happen as a consequence of surgery to repl ace the hip or reconstruction of the kneeligament. Figure 1.1 shows the drop foot syndrome.

Figure 1.1 Drop Foot Syndrome

II. LITERATURE SURVEY

Liberson et al [2] initially referred to a functional electronic device as functional electrotherapy. He made the first real effort to provide electronic stimulation as an aid to recover function in a person with a disability. Liberson designed a portable FES device for the treatment of foot drop by stimulating the peroneal nerve of hemiplegic patients with drop foot during gait, they have developed the electronic device which is capable of generating pulses and applied to the damaged nerves externally.

Broderick et al [12] developed a typical application in which external electrodes are placed above the peroneal nerve, energized by an electronic device. While walling the heel switch triggered stimulation, pulse applied to the anterior tibialis muscle to contract through the swing phase of the gait cycle, hence it helps the patient to prevent passed out it to the ground and helps to lift the foot.

Hart et al [11] developed a new design which is a simple but innovative stimulator that started a new area of patient recovery that is known as an FES system. The development of electrical stimulators produces stimulation by implantable electrodes and transcutaneous, cutaneous electrodes. This model is used in subjects with head trauma, MS and stroke to allow spastic hand opening and correct irregular pattern of walking.

Broderick et al [12] developed a Percutaneous FES which is more efficient than external FES, but it may require medically qualified personnel to place it. Percutaneous FES is also prone to infection, and long-term preservation of it is difficult. Implanted FES is based on a small surgery to permanently place the electrodes under the skin. The actual stimulation device can also be implanted under the skin in some applications. Though this is suitable for long-term use, qualified medical personnel is required to implant the device because it is belongs to percutaneous type FES. Pierce et al [7] proposed the comparison of percutaneous and external stimulators for the duration of gait in a person with hemiplegic cerebral palsy. The author absorbed in study that an increase in dorsiflexion with percutaneous stimulators wa s greater.

Seifart et al [13] concluded that the external FES is the preferred mode of stimulation for medical treatment. A trial includes hemiparetic, outpatient and 32 chronic patients with one foot drop each. They either received rehabilitation sessions for physiotherapy or FES. In conclusion, patients in the electronic stimulation group walked with the common peroneal stimulators significantly faster, more efficiently and more efficiently than patients in the physiotherapy group. Ho et al [10] analysed the effects of external FES on the gastrocnemius-soleus complex, and proposed that FES is effective in increasing momentum during the gait cycle push-off phase, but it has drawback of decreasing rigidity.

Postans et al [8] conducted an experiment on the effect of FES on the gait for spastic cerebral palsy. There were major medical changes for three of the eight children. Stein et al [16] did a study in the therapeutic and orthotic effects of a drop-foot electronic stimulator on the gait output of subjects with chronic non-progressive (stroke) and progressive (MS) disorders were contrasted. From this analysis, both had an orthotic benefit from FES but the therapeutic effect in progressive conditions stopped for a shorter period. Kottink et al [6] conducted a systematic investigator study to enhance the gait process during peroneal nerve stimulation in stroke patients with foot drop. The researchers proposed that FES has a strong orthotic effect on walking speed.

III. CONCEPTUAL BACKGROUND

In the existing method there are three components in ES systems they are control, an electrical stimulator and electrodes that connect the ES to the nervous system. There are various ways to configure ES devices. Figure 3.1 shows the overview of the ES device and configuration.

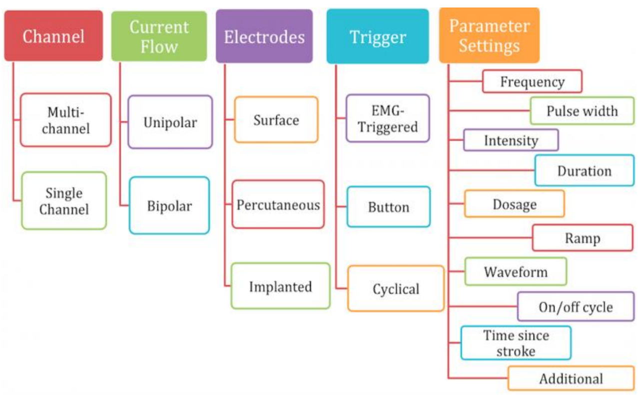

Figure 3.1 shows the overview of the ES device and configuration.

A. Electrodes

ES is applied via electrodes that produce the electrical field via either surface or percutaneous electrodes.ES can be supplied via single or multichannel devices. Multichannel devices can be used to mimic a physical action such as reaching or grasping by targeting several muscles, while a single-channel tool is used for less complex movements such as shoulder subluxation rectification. While single-channel systems are primarily used for simple movements, they may be more portable, making them more practical for home use.

Surface electrodes are most often placed directly over the nerves on the body. In addition to stimulating the muscle, it is also possible to use surface electrodes to induce a reflex action. When using surface electrodes, ES parameters can differ depending on factors such as electrode content, location, and surface area. These are non-invasive and relatively inexpensive and are ideal for use across a wide range of environments and by clinicians and clients, encouraging self-management and autonomy.Percutaneous electrodes penetrate the muscle through the skin via hypodermic needles or can be fully implanted by receiving stimulation from an external unit. By being able to target deep muscles, they can overcome the difficulties faced in surface electrodes and are stated to be less painful as they use lower currents. Price and practicality considerations, however, need to be taken into account.Following the SSAF guidelines, this guide focuses on surface-mounted electrodes as they are affordable and most widely used, which is why it is best suited to this target audience training tool as it addresses the devices that they are most likely to find in practice.

B. Unipolar vs Bipolar

Two electrodes are needed to generate a current flow, but in configuration, these may be unipolar or bipolar. Unipolar is when, because of their sizes, one electrode is more active than another. Typically, the active electrode is smaller and placed close to the nerve to be stimulated by placing the indifferent electrode over less excitable tissue like fascia. There are several active electrodes in multi-channel configurations, but only one indifferent electrode is required. All bipolar electrodes are the same size indicating that the current will be identical at each site.Both active and indifferent electrodes are placed near the stimulated nerve, and there is an indifferent electrode for each activity in multi-channel configurations. Bipolar systems allow more muscle targeting.

C. Cyclical, button & EMG-triggered

In the existing method, the timing of electrical stimulation is regulated through a key, cyclic or EMG-triggered device. The button method is an ES manual type which allows the user to trigger the stimulus by clicking a switch. Cyclical means that the timing and sequence are predetermined by selecting a suitable program on the device, which is sometimes referred to only at NMES. Instead, the device activated by the EMG uses sensors built into the active electrode to assess when voluntary muscle contraction is above a predetermined threshold which activates the ES.It was suggested that this approach promotes greater involvement of users in encouraging neuroplastic improvements and leads to better outcomes. Usually, to distinguish from cyclical, this is called EMG-triggered ES.

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Cyclic or predetermined programs are considered open-loop systems that rely on the user to turn on / off while EMG-triggered is classified as closed-loop systems as the on / off timing of the EMG trigger is determined. Figure 3.2 shows open and closed loop ES systems.

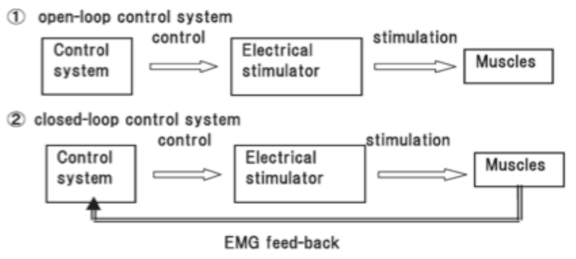

Figure 3.2 open and closed ES systems

IV. PROPOSED METHOD

In this research work, a microcontroller-based wireless FES system is designed to induce electrical pulses on the paralyzed muscles to restore muscle contraction so that FES can improve the performance of the patient's gait as well as overcome cable complexity and foot sensors wire discomfort with wireless system design. Bluetooth software can monitor and control this entire system.The block diagram of proposed system is shown in figure 4.1.

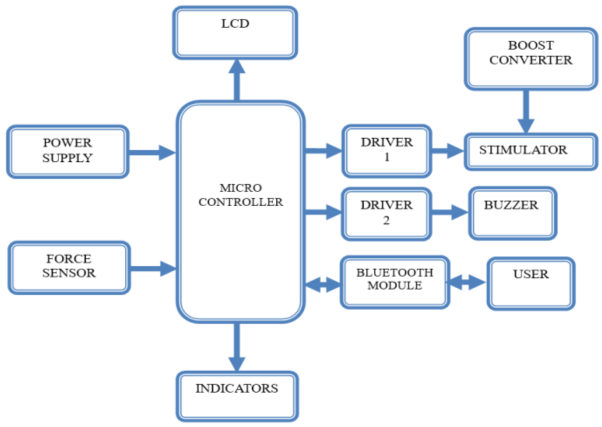

Figure 4.1 Proposed method

In the proposed system, The FES design consist of a microcontrollers, force sensing sensors, electrodes, and wireless system. The force sensitive resistors are placed inside the patient's shoe (insole) which is transmitter side of the wireless communication unit. When patient 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'sfoot strikes to the ground stimulation is stopped by microcontroller.

The circuit diagram of the proposed system consists of FSR type sensorsto detect the force as well as to make the design simple and economical. The two FSR are connected analog input pin AN0 and AN1 of the PIC microcontroller 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 AN0 and AN1 of controller so current converted into the digital signals. The digital signals makes the stimulator to operate through relay which is connected to RD0 and RD1 of the PIC microcontroller. The RD2 pin of the PIC microcontroller is connected to the buzzer which sounds if the foot is not placed properly. The PORTB of the PIC microcontroller is connected to the LCD which shows the output of the distance between the foot and the sensor. The circuit diagram of the stimulator consist of several components as shown in Figure 4.2.

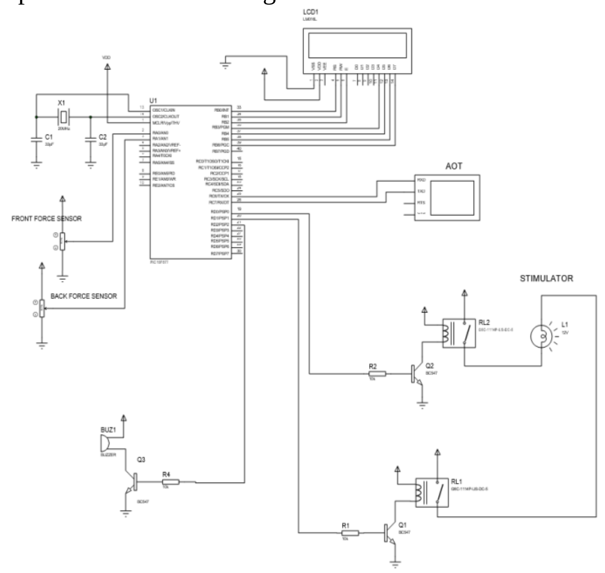

Figure 4.2 Circuit Diagram of the Proposed System

The FES algorithm is based on 4 states which are 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. The operational states of FES is shown in Figure 4.3.

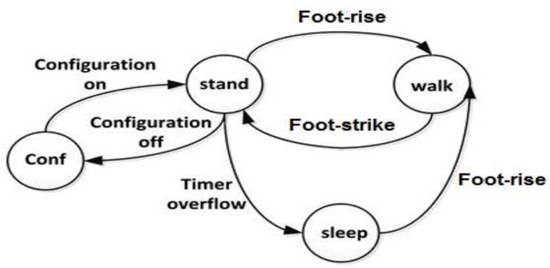

Figure 4.3 Operational states of FES

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

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

Sleep: While in the Stand state inactivity of FSR or pre-specified duration has occurred system reached to sleep state. In this state, the system gets self-protection to minimize energy expenditure so that the microcontroller is virtually shut down and the system operates with a 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 system, so it enables the FES device to be re-configured without the use of setting the power switch. The operational structure of the software is described in the following figure using Program Description Language. The simulation algorithm practically composes the base of the program. The Figure 4.4 shows the FES software in Program Description Language.

```
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 4.4 The FES software in Program Description Language

When there is no activity on a pre-specified period or in other words force is applied on any FSR during the Stand state, during the time the processor is enforced to sleep mode. When the foot-rise is detected by the processor, the system automatically exits from the Sleep mode than the program turns to the Walk state. The required user parameters 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. The end of the configuration begins with the running mode. The program runs continuously. The Foot Switches(FSR) are checked by the 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.

V. HARDWARE AND EXPERIMENTAL RESULTS

The hardware setup consists of force sensor, stimulator circuit and Bluetooth module. It consists of voltage regulator 7805 which converts input voltage to 5V supply, since the operating voltage of sensor and microcontroller is 5V and the output is given to force sensor and microcontroller .The signals of the sensor are of analog form. It is then converted to digital using analog to digital converter. The digitalized values are displayed on the LCD display. The stimulator circuit is supplied with 3V rechargeable battery. The Fig 5.1 shows the complete hardware setup of nerve stimulation device.

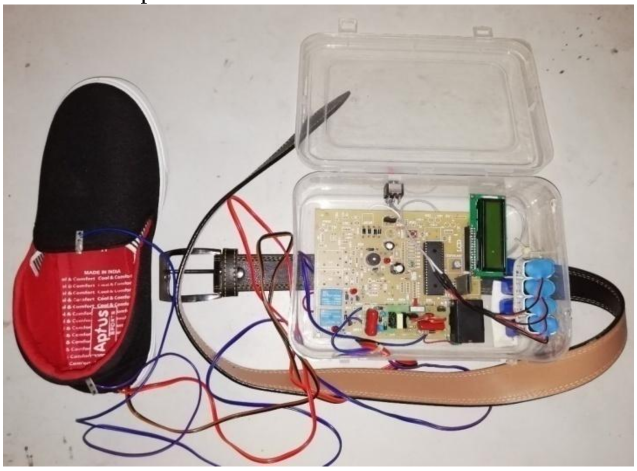

Fig 5.1 Complete Hardware Setup of Nerve Stimulation Device

In the proposed work, the output from the sensor is transmitted through PIC microcontroller to the LCD display. The stimulator circuit works based on value displayed on LCD. If the back side of the foot does not touch the sensor the LCD displays 0000 and abnormal. If the back side of the foot touch the sensor the LCD displays the value of force and normal. Similarly this happens in rear part of the foot. Abnormal and normal Back Foot Reading is shown in Figure 5.2 and 5.3.

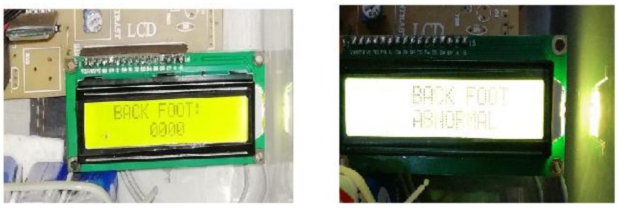

Fig 5.2 Abnormal Back Foot Reading

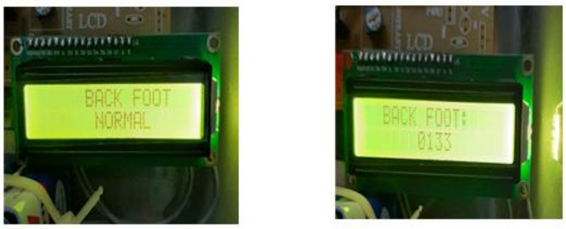

Fig 5.3 Normal Back Foot Reading

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VI. CONCLUSION

This project proposed the nerve stimulation device for drop-foot people to make their walk simple and increase their walking ability. The proposed system uses a radio frequency transmitter and receiver to reduce the number of cables and to make a compact device. Due to the special design, the stimulator power consumption is very low.

The processor turns off the device while the patient is waiting in the foot-strike position and the system enters the low-current sleep mode with almost no current consumption. The FES wakes up automatically once an action has been detected and activation begins again with the detection of the foot-rise, thus increasing patient involvement. The standard microcontroller development systems and electrical equipment were used during the design process as well as standard wireless components that are easily found on the market so the overall system cost is very low. The FES system developed is functional and programmable. So, that the functions of the written program can be enhanced. Through the minimum amount of spark, the foot is corrected and their walking ability is increased. The LCD Display shows the status of the foot position. This system sends information through the Bluetooth module to the person wearing a device. Thus the system is a stand-alone device with no external support and it makes life easy for drop foot people.

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