Design and Implementation of Accurate Foot drop Prosthesis System

Abbas FadhalHumadi, LubanHamdyHameed, ZainabMajidNahy, Middel Technical University/ College of Electrical and Electronic Engineering Techniques.Baghdad-Iraq.

E-Mail: ahumadi@yahoo.com,drabbas1962@gmail.com.Luban_alqudsi@yahoo.com, zainabmajid@gamail.com.

Abstract:

In present study, an accurate foot drop prosthesis device is presented. The design of the proposed system depends on electrical stimulation generated by electronic stimulator within specific requirements. This train of pulses that delivered to the targeted group of muscles innervate by pearonal nerve, using adhesive surface electrodes, has effective voltage amplitude, duration and frequency to stimulate these muscles to lift the dropped foot of the ground effectively during the swing phase of the gait cycle. The operation begins when the patient start to walk, so starting of the swing phase will be sensed using pressure sensor located under the heel of the patient's dropped foot. In this case, the electronic stimulator will be activated by the pressure sensor to start sending the stimuli that activate the muscles to lift the dropped foot causing the gate to be balanced and normal. Results shows that the output wave form of the stimulator is biphasic type pulse wave of net charge close to zero, with maximum voltage amplitude of 90V, frequency of 62Hz, and duration of 600ms.The current delivered to the muscles will be dependent on the tissue impedance and the voltage assigned for stimulation. This output pulses will be comfortable to the patient and cause accurate effective stimulation to the targeted group of muscles, leads to cancel the effect of dropped foot.

Key words: Foot drop, Prosthesis System, Foot, Muscle.

تصميم وتنفيذ معينة سقوط القدم الدقيقة

م.د. عباس فضال حمادي, م.م. لبان حمدي حميد, م.م. زينب ماجد ناهي.

الجامعة التقنية الوسطى. كلية التقنيات الهندسية الكهربائية والالكترونية/قسم هندسة تقنيات الأجهزة الطبية.

الملخص

يردفيهذهالورقة، تقديمجهازمعينة سقوط القدم الدقيقة.
تصميمالنظامالمقترحيعتمدعلىالتحفيز الكهربائيالتيتمإنشاؤهبواسطةمحفز الكترونيضمن متطلباتمحددة. هذه النبضاتالتيجهزتإلىالمجموعةالمستهدفةمنالعضلاتو المحفزةبعصبالساق (Pearonal Nerve)، وذلك باستخدامأقطابالسطحاللاصقة، تكونذات
موجةجهدفعالومدةوتواترلتحفيز هذهالعضلاتبرفعالقدمالمنخفضةعنالأرضبشكلفعالًأثناءمراحلدورةالمشي. حيثتبدأمرحلة دورةالمشي من خلالاستخدامجهاز استشعار الضغطالموجودتحتكعبالقدمالمنخفضةللمريض. فيحالة رفع القدم عن الارضسيتمتفعيلالدائرةالإلكترونيةبجهاز استشعار الضغطلبدءإرسالالمحفزات
الكهربائيةالتيتنشطالعضلاتلرفعالقدمالمنخفضةوبذلكتكون الخطواتمتوازنةوطبيعية. وقد
بينتالنتائج،شكلموجةالإخراجللمحفز الالكترونيبشكل موجة نبضيةثنائيةالطورذاتصافي شحنةقريبةمنالصفر،معأقصى سعةجهدتصل الى 90فولت،وبتردد مقداره 62 هرتز،ومدة 600ملي ثانية. هذا التيار
الخارجإلىالعضلاتسوفيعتمدعلىمقاومةالأنسجةو الجهدالمخصصللتحفيز.
هذهالنبضاتالخارجةسوفتكونمريحةللمريضوتسببالتحفيز الفعالو الدقيقإلىالمجموعةالمستهدفةمنالعضلات،ويؤديإلىإلغاءأثرسقوط القدم عند السير علىالأقدام.

الكلمات المفتاحية: سقوط القدم, نظام تحفيز , قدم, عضلة

Introduction

The problem of dropped foot can be defined as the foot drag on the ground during the gait cycle especially within the swing phase and the ankle is not properly flexed. This problem commonly observed after many health problems especially, stroke, injuries of spinal cord, and some central nervous system (CNS) disorders [1]. The foot drop described as inability to lift foot which leads to tripping or steppage gait, so the patient left their knee high during swing phase to prevent tripping over the hanging down foot and then at the beginning of the stance phase, the foot slaps the floor. The foot drop caused many changes to the patient gait which leads to decrease the safety and efficiency of the gate, mobility limitation, and unstable gait leads to increasing risks of falls during walking, balance problems and impaired mobility, so walking becomes harder [2, 3]. Foot drop treated traditionally by using ankle foot orthosis (AFO), which is typicallya polyethylene brace that wraps under the foot and behind the calf to prevent the foot from dragging on theground. AFOs are characterized by simplicity and low priced, so it has good popularity,but also have a number of significant drawbacks and limitations; therefore, researchers have developedanther ways to treat foot drop, so functional electrical stimulation (FES) have been developed [2,4]. FES is defined in general as an artificial electrical stimulation of a muscle that has lacked of neural control, to provide muscle control to produce movement as normal movement and to restore functions lost after the impairment of nervous system. In this method, a train of short electric pulses are used to stimulate the motor neurons of the impaired organ to perform the contraction of targeted muscle. All kind of organs that has skeletal muscles with impairment could be make use of FES, so typical applications of FES system include treatment of the problem of dropped foot by stimulating common peroneal nerve to make contraction of the ankle dorsiflexors, enabling lower-limb paraplegics to stand or sit, and recover the function of hand in the paralyzed upper limb [5,6]. FES devices used basically three types of electrodes to stimulate the motor neurons which are, surface electrode , needle, or implantedelectrodes [3]. FES can provide many benefits that AFO's can't provide or poorly provide it, like active muscle contraction, enhance the strength of muscle, muscle tone reduced, energy efficiently uses of muscles of the lower limb, helps with motor relearning. FES may be used to greatly enhance gait function for patients that survive stroke, who clinically fit the requirements and have the motivation to do ambulatory training with the device [7]. The first FES system used for treating foot drop was introduced by Liberson and others researchers, in which they used external stimulator activated by sensor that detects the start of the swing phase of the impaired leg of the stroke patient, to stimulate the common peroneal nerve using external electrodes to flex the ankle of the patient and make the foot lift from the ground during the swing phase [8]. Another approach presented by Cameron, The WalkAideFES System that stimulate the leg transcutaneously by stimulate the peroneal nerve using a cuff that placed blow the knee of the patient, it contains a tilt sensors, accelerometer and inclinometers to calculate the speed and position of the leg and used these information to activate the pulse generator to trigger the peroneal nerve in order to prevent foot from dropping [2]. The most recent approach for treatment of foot drop introduced by Shimada and other researchers. There method represented by using acceleration sensor placed on the thigh of the targeted leg to detect the swing phase depending on the acceleration speed of the targeted leg, using neural network technology, to stimulate the peroneal nerve and correct the position of the foot during the swing phase [9]. In this paper, an efficient FES system will be presented to easily and efficiently treat the foot drop of stroke patient. The main components of the proposed system are shown in Figure 1.

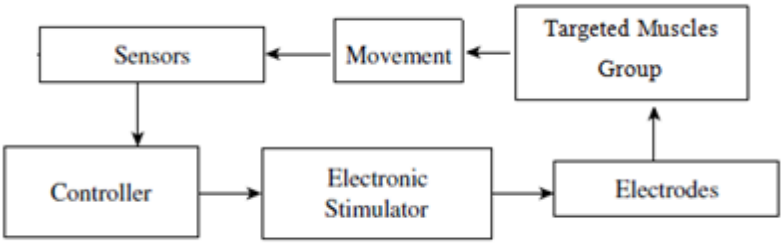

Figure 1. Main components of the proposed system

In which efficient and accurate stimulator will activated by a switch act as a sensor, this switch will be fitted under the dropped foot to work as a pressure sensor, it will tell the controller to activate the stimulator when the dropped foot has lifted from the ground, the stimulation will be conducted through surface electrode, which it is more easily accepted by patients, because it is noninvasive and no need for surgery to fit it on the target group of muscles.

System Design

The duration of the stimulus pulses, amplitude, output impedance of the generator, and impedance of electrodes, determine the electrical charge that will delivered to targeted muscles. These parameters are varies widely depending on the type of the stimulation, type of electrodes, its placement, its surface area, and the factor of safety used. In general, stimulation can be achieved using amplitude of asurface stimulation electrodeis less than 150V, and between 10 to 150 mA. The frequency of the stimulation is less than 100 Hz, and thepulse width is less than 1ms. these devices can work as a voltage regulated or current regulated device[6, 10,11]. The proposed stimulator electronic circuit is shown in figure (2) which is working as a voltage regulated stimulator, so the amount of voltage that make the best stimulation can be set by the patient manually once at the first time to use the device to reach the best results, and this will depend on the patient tissue impedance that specify the amount of current to be delivered to the muscle group.

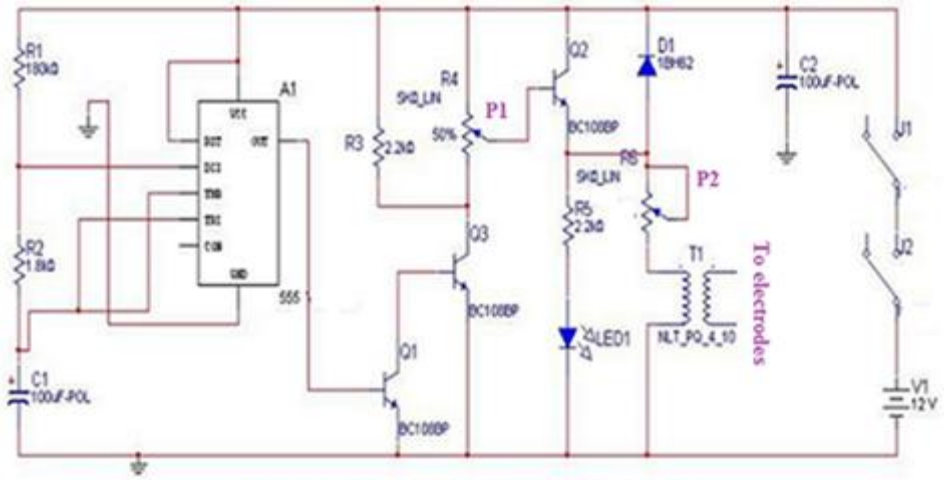

Figure 2. Stimulator proposed electronic circuit.

In the proposed design, the 555 IC will be the heart of the stimulator, in which by using suitable values for R1, R2 and C1, it will oscillate at a frequency of 62 Hz [12, 13]. These square waves with low frequency has low voltage amplitude, so it needed to be amplified to be suitable for triggering the targeted muscle group to be contracted, so the first stage of amplification will be done using PNP power transistors Q1 and Q3, this amplification factor will be adjusted used variable resistance (P2) to control the amplitude of the output pulse to be suitable for muscle stimulation. The diode that connected with emitter of Q2 and collector will protect the power transistor Q2 from inductive reactance that may lead to destroy it. The final stage of amplification will be done by using a step up transformer, so it will give the final amplification of the low frequency pulse generated by the 555 oscillator to be fitted with the requirements of muscle stimulation, the transformer will export a pulses of about 90 V maximum to the electrodes.These electrodes will be external type adhesive electrodes, which are easy to fit on the targeted muscle group; can be replaced at any time and low cost, so it is user friendly electrodes.The stimulator will be activated using switch J1, which it is a pressure sensor fitted under the heel of the dropped foot. It will sense the placement of the dropped foot on the ground during the stance phase, so when the patient lift his dropped foot at the start of the swing phase, the sensor will sense lose of pressure and activate the stimulator to stimulate the contraction of muscles to lift the dropped foot via the electrodes. The other switch is the ON/OFF switch.The power source used is a small 12 V Heavy duty type battery, to easily provide the system with the required power for a long time without increasing largely the weight of the device, and can be replaced anytime easily. The proposed system is shown in figure (3), (4) and (5).

Figure 3. The proposed system components

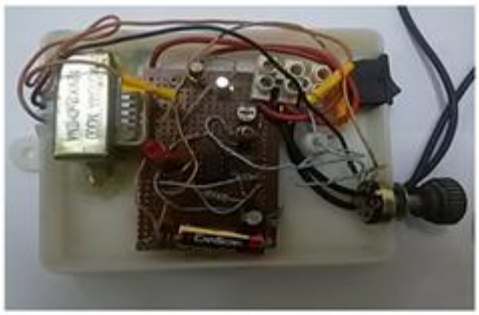

Figure 4. The implemented electronic circuit

Figure 5. The proposed system placement.

Results:

After testing the implemented system using the oscilloscope, the electrical pulses that should reached to the patient shows good values represented by 90V maximum voltage, 62 Hz , 600ms pulse width, and the will be depended on the tissue impedance of the user. These values are accepted values as they are within the range that make the stimulation occurs according to [6].

The figures 6 and 7 show the output waveform, pulses of the designed stimulator.

The wave form shows a biphasic type wave form, each pulse part is approximately the same in duration and magnitude to the other opposite polarity part, this will produce no or very small net charge in the body, which is considered more comfortable for stimulation when using surface electrode.

In the other hand, the train of pulses produced by the stimulator shows very accurate pulses produced with time regarding amplitude, frequency and duration. This will lead to active, accurate and constant with time stimulation.

Figure 5. Output waveform of the stimulator.

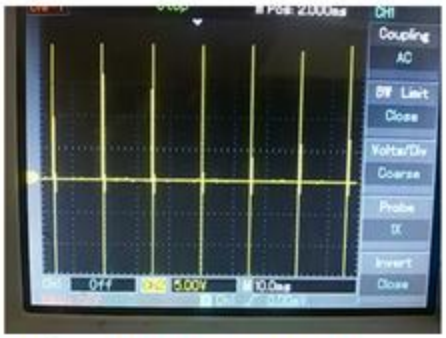

Figure 6. Output pulses of the stimulator.

Conclusions

This research presented accurate foot drop prosthesis device, in which the output pulses are biphasic type leads to comfortable and accurate stimulation of the group of muscles responsible of lift the foot of the ground for foot drop patients. The simple and low cost components of the proposed system shows results suitable for daily uses by those patients easily, by fitted the electrodes externally on the targeted group of muscle, without the need for implanted electrodes. This user friendly design needs only to regulate the output voltage for one time only at the first time to use it, and then the same setting will be used for longtime, so it will decrease the time needed for training to the minimum limits.

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