Control for Electrical Neuromuscular Stimulator Using Fuzzy Logic

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Abstract: - This article presents a personal computer-based control system for an electrical stimulator using fuzzy logic. The input signal comes from a goniometer and the output is the stimulation level to be applied in the muscle of the patient. By this way, that control system is made for the therapist that just specify the desired joint's angle. The movement that the patient will execute can be mimicked from a person with normal movements, storing his or her joint's angles during the execution of some task, and later reproducing it in the person without the voluntary movements. Such movements will be more proper of a human than a planned execution by a computational system, which the movement is structuralized by means of vectors, angles and times placed of supposed form.

Key-Words: - Electrical stimulation, fuzzy logic, closed loop, electrical goniometers, spinal cord injury, artificial gait.

1 Introduction

The electrical neuromuscular stimulation is the most adjusted technique for application in cases of atrophied muscle due the lack of movements caused mainly for spinal cord injury or vascular encephalic accident because it can causes development and increasing of the muscular strength, even in those without a voluntary contraction [1].

During and after the development of muscles, it is possible to make the body get used to certain movements and create a sensorial engram, to lately it comes to execute such movements in an intuitive way, without the necessity of electrical stimulation.

A closed loop electrical stimulation system using goniometers as input is described by Quevedo and Cliquet Jr [2] whose presented an ideia of neural networks-based control, therefore it presented the disadvantage of needing to much time for the network's training for each type of movement.

In 1998, Zagheni [3] developed a multi-channel computer controlled neuromuscular electrical stimulation system, operating in open loop, containing 8 analog inputs that allow processing of electrical physiologic signs and, consequently, serving as feedback inputs and, thus, to control the stimulation parameters automatically.

This article presents a new strategy of control applied to Zagheni's stimulator, based in fuzzy logic, aiming to improve the control of the stimulation and to facilitate its use in the engram's development. This control system was developed with the objective of monitoring the position of the stimulated member. Using as input, the signals from electrical goniometer coupled in the joints under control and the target position, is obtained as output the amplitude of the stimulatory signal to be applied on the muscle, via transcutaneous electrodes.

The *in-vivo* tests are being initiated, and for such tests, the patient is a 39 years paraplegic volunteer with a T4 injury caused by a firearm's projectile, 18 years ago.

According to W. Dalton Dietrich, Scientific Director of the The Miami Project to Cure Paralysis, at the University of Miami School of Medicine, there are 5 steps for the cure to spinal cord injury: 1 - patient selection and pretraining; 2 - surgical intervetions and neuroprotection; 3 - tranplantation / regeneration; 4 - overcoming barriers to regeneration and 5 - rehabilitation [4]. The system presented in this article could be used in steps 1 and 5.

2 Problem Formulation

The possibility of the spinal cord injury rehabilitation could come in a next future. Some research are already bringing concrete results in guineas pigs, like the implantation of embryonic cells [5] and cells of Schwann [6], making possible a backup of the communication between the brain and the remaining portion of the body below of the part affected part for the injury.

As for the integral rehabilitation of the disable person, we have necessarily to pass for the 5 described steps by Dalton Dietrich [4]. So, passing through the pre-training, where is needed to fortify the muscle and to verify the possibility of muscles and bones to support the body. Also after that possible regeneration of the spinal cord, we go through a rehabilitation process of the not enough trained muscle passes for the exercitation process so that it can fulfill with its paper. In these two stages the use of the electrical stimulador with closed loop control is important.

The feedback signal of the system is gotten from one goniometer measuring the joint's angle of the inferior limb under control (fig. 1). The computer has stored the path that the joint must execute. As from these two information, the system controls the amplitude of the stimulation so that the limb stays in the desired position in a instant of time determined by the operator of the system. The control system works for objectives. The therapist specifies the movement that the member must execute, specifying the angle desired for each moment.

Fig. 1: Pacient with electrical goniometer

The training for development of sensorial feedback was applied in cats for the retrain of the march. A full spinal cord injury was provoked at the level T13, the locomotion capacity returned gradually and in 1 to 3 weeks the cat came back to have the locomotion movements of posterior legs supporting itself body's weight [7].

The theory of sensorial feedback is based on the theory of the neural plasticity of the espinal cord, on which was concluded that, among other things, the espinal cord drive the step processing complicated sensorial information of the peripheral nerves [8]. The training and the learning are fully specific, because if a cat is trained to give a step, it will give a step; if he will be trained to be in foot, it will be in foot, but it will not give to a step [7].

The system can be applied to a human being with problems in the central nervous system (CNS) so that it can develop new abilities as was demonstrated by Calancie [9] who says that exist a central pattern generator (CPG) located in the spinal cord for the generation of the step. According that, a person without the voluntary movements, after a heavy session of physiotherapy, walking, when he was lain down, the pattern of gait continued, showing that the body had learned. As resulting of this, we can assume that after the stimulation of the patient's muscle to walk he or she must learn to make this alone.

3 Problem Solution

So that the system could be tested before its in-vivo application, a muscle simulator was developed. It gave some evaluation of the response for a real stimulation. The simulator lead in account the angle of the joint, the applied force and the amount of fatigue, beyond the amount applied stimulation [10][11].

The system was initially developed in the Simulink of the Matlab [12] due its assembly easinesses, tests and alterations, besides providing one easy interaction with the logic fuzzy blocks used for the control and system of simulation.

To establish the artificial gait using fuzzy logic, first, was developed the control of the knee extension with the patient sat, attempting an effective control of quadriceps muscles contraction and, thereby, control the movement of the member.

The Zagheni's software for the electrical stimulator was developed Visual C++. Actualy, we have upgraded that software with the fuzzy controller algorithm, initially in only one channel of input. In the present moment, it allow just one goniometer connected. Therefore, the knee's joint was chosen for tests, maded stimulating the Rectus femoris muscle and, to test the simultaneous stimulation, two muscles - Rectus femoris and the Vastus lateralis - had been used.

The control system operate in a manner that, to know the necessary amplitude to reach the target, the system goes magnifying or diminishing the amplitude of the stimulators signals until the member arrives at the desired position, or that it reaches the defined

thresholds of stimulation for that muscular group in that individual.

The triangular membership functions of the fuzzy system had been chose by being the more commonly employed, being able to be justified later. The controller was designed with an input called angle input with 3 membership functions, another input called with 5 membership functions and the output is the difference of stimulation with 5 membership functions [11].

In the output of the system fuzzy we had how much the stimulation will be magnified or diminished of the value currently applied. To become the generic system, all the values are normalized (between 0 and 1), because the majority of the parameters vary of patient for patient, thus, the data need to be processed for the input after an output of the fuzzy system.

We are starting the phase of tests in-vivo to verify the necessity for adjustments in membership functions. In the in-vivo application we feel the necessity to establish a minimum value of stimulation, because exists in each muscle of each patient, a sensibility threshold, a contraction threshold value (when the muscle starts to contract) and a maximum value of stimulation. Above that maximum value, there is the risk to cause damage in the muscle.

In the first tests was used as target of the member a fixed angle of, more or less, 45 degrees; the member was initiating the motion with an angle of more or less 85 degrees (fig. 1 and 2).

In figure 3 we have the amount of stimulation applied to the muscle, we can perceive the compensation that the system makes due to fatigue that the muscle is submitted during the stimulation, also is important to place that during these tests, at any moment the stimulation arrived in the maximum defined for that muscle, in that patient. It had a small variation above and below the objective angle that was left proposital, because, during our daily activity, the movements are not totally precise, not being necessary an alteration of stimulation for small natural variations in the contraction.

The noise present in the input signal will be filtered in the future.

So that the movement can be more natural and that it has the possibility of a bigger gamma of movements with more easiness of configuration is in final phase of development the reading of the angles of the joints of a person with the normal movements for the posterior reproduction in one patient, through the electrical stimulation. With this feature, the movement pattern is easiest to be constructed than that one through the planning of computational systems, where related movements are structured by means of vectors, on which angles and times are placed in supposed form. In this way, the movement is better assimilated and later reproduced through the process of the Central Pattern Generator demonstrated by Calancie [9] and also by already existing a engram previously stored, of the time where the person had the normal control of its movements.

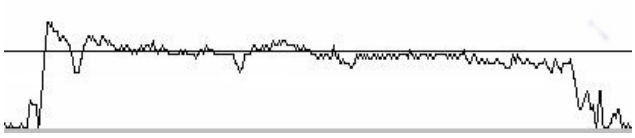

Fig. 2: Leg's angle during the electrical stimulation.

Fig. 3: Amount of stimulus applied at Rectus femoris e Vastus lateralis.

4 Conclusion

In the continuation, will be made tests in more voluntary, we already have more 5 paraplegics that are making the empowerment of the muscle with electrical stimulation to be able in applying of the control, thus getting a contraction accomplishes for the movement of the member.

After all, will be assembled a major number of goniometers, allowing to test more complex movements. The loop of control is already prepared and software will need small implementations making possible for the patient execute movements like walk, to ride a bicycle or to go up stairs, depending only on the correct pattern of the angles to be executed. For the future [13] can be installed an input system to acquire the intention of the patient, making the system slave of patient volitions and not only what is pre-determined by the system. The improvement of this technique will represent a great advance in the area of the functional electric stimulation for paralyzed members, becoming easier the practical application of this therapeutical feature. These innovations bring a new age in the control of neuromuscular electrical stimulator, allowing that a person without the voluntary control of its movements can imitate one another having full movements. It could give to he or she much more worthy and calm life. Techniques of implantation of electrodes exist, where through a surgery they will not be more necessary apparent wires, and with the movements softest of the one than the gotten ones

through the systems of control currently in use, it can be made with that the deficiency can also pass unobserved.

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