CONTROL FOR ELECTRICAL NEUROMUSCULAR STIMULATOR USING FUZZY LOGIC

Trainning gait in paraplegics

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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 specifies the desired joint angle. The movement that the patient will execute can be imitated 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 of a computational system, which the movement is structuralized by means of vectors, angles and times placed of supposed form.

1 INTRODUCTION

The electrical neuromuscular stimulation is the most adjusted technique to be applied in cases of atrophied muscle due to the lack of movements caused mainly by spinal cord injury or vascular encephalic accident because it can cause development and increase of muscular strength, even in those without a voluntary contraction (Quevedo at al., 1997).

During and after the development of muscles, it is possible to make the body get used to certain movements and create a sensorial engram, so that 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. (Quevedo & Cliquet Jr., 1995), who presented an ideia of neural networks-based control, which presented the disadvantage of needing to much time for the network's training for each type of movement.

In 1998, Zagheni (Zagheni, 1998) developed a multi-channel computer controlled neuromuscular electrical stimulation system which by operating in open loop and containing 8 analog inputs that allow processing of electrical physiologic signs, consequently, served 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, are obtained as output the amplitude of the stimulatory signal to be applied on the muscle, via transcutaneous electrodes.

The in-vivo tests were applied to 4 paraplegic volunteers, controlling the knee extention and hip. During the tests two goniometers were used, controlling both knees independently or one knee and the hip, in this case being applied the same stimulation to both legs, standing the volunteer up.

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 (Dietrich, 2005). The system presented in this article could be used in steps 1 and 5.

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2 PROBLEM FORMULATION

The possibility of the spinal cord injury rehabilitation could come in a near future. Some researches are already bringing concrete results in guineas pigs, like the implantation of stem cells (Rosano et al., 1999) and cells of Schwann (Oudega et al., 2001), making a backup of the communication between the brain and the remaining portion of the body below of the part affected by the injury possible.

As for the integral rehabilitation of the disabled person, we have necessarily to pass through the 5 steps described by Dalton Dietrich (Dietrich, 2005). So, passing through the pre-training, where it 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 by which the not enough trained muscle passes through the exercising process so that it can fulfill its role. In these two stages, the use of the electrical stimulator with closed loop control is important.

Figure 1: Pacient with electrical goniometer to control knee joint

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

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 started to have the locomotion movements of posterior legs, being able to hold its body's weight (Rossignol et al., 2000).

The theory of sensorial feedback is based on the theory of the neural plasticity of the spinal cord, from which it was concluded that, among other things, the spinal cord drive the step processing complicated sensorial information of the peripheral nerves (APA, 1998). The training and the learning are fully specific, because if a cat is trained to take a step, it will take a step; if it is trained to stand still, it will do so, but it will not take a step (Rossignol et al., 2000).

The system can be applied to human beings with problems in the central nervous system (CNS) so that they can develop new abilities as it has been demonstrated by Calancie (Calancie et al.), who says that there is a central pattern generator (CPG) located in the spinal cord for the generation of the step. According to that, a person without voluntary movements, after spending intensive physiotherapy sessions walking, even lying down, kept the pattern of gait, showing that the body had learned. As a result, we can assume that after the stimulation of the patient's muscle to walk, he or she must learn to do 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 takes into consideration the angle of the joint, the applied force and the amount of fatigue beyond the amount applied stimulation (Silva & Nohama, 2000,1)(Silva & Nohama, 2000,2).

The system was initially developed in the Simulink of the Matlab (Matlab, 5.2.0). Due to its assembly, tests and alterations easinesses, besides providing one easy interaction with the logic fuzzy blocks used for the control and simulation system.

To establish the artificial gait using fuzzy logic, first, the control of the knee extension was developed 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 using Visual C++. Currently, we have upgraded that software with the fuzzy controller algorithm in two channels of input and sexteen channels of output, eight for each input. In the present moment, it allows two goniometers connected. Therefore, the knees joint and hip were chosen for tests, made stimulating and controlling the Rectus femoris, Gluteus maximus and Vastus lateralis muscles, and used Gastrocnemius to help stabilising when the volunteer stands up.

The triangular membership functions of the fuzzy system had been chosen by being the most commonly employed, being able to be adjusted later. The controller was designed with an input called angle input with 3 membership functions, another input called the difference between active angle and the desired one, with 5 membership functions and the output is the difference of stimulation with 5 membership functions (Silva & Nohama, 2000,2).

In the output of the system fuzzy we had the value to be calculated from the value currently applied to obtain a new amplitude. To become the generic system, at first model, all the values are normalized (between 0 and 1), because the majority of the parameters vary from patient to patient, thus, the data needs to be processed for the input after an output of the fuzzy system.

We did 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 there is, 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 to the muscle.

In one test a fixed angle of, more or less, 45 degrees was used as target of the member; the member was initiating the motion with an angle of more or less 85 degrees (fig. 1 and 2). That angle was chosen due the difficulty to be kept during electrical stimulation.

In figure 3, we have the amount of stimulation applied to the muscle, we can notice the compensation that the system makes due to the fatigue that the muscle is submitted to during the stimulation, also it 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 on purpose, because, during our daily activity, the movements are not totally precise, so an alteration of stimulation for small natural variations in the contraction wasn't necessary.

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

So that the movement can be more natural and can have the possibility of a bigger gamma of movements, with more easiness of configuration, it is in final phase of development be read the angles of the joints from a person with normal movements for posterior reproduction in one patient, through electrical stimulation. With this feature, the movement pattern is easier 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 the way they're supposed to. In this way, the movement is better assimilated and later reproduced through the process of the Central Pattern Generator demonstrated by Calancie (Calancie et al.) and also by already existing a previously stored engram, when the person had the normal control of its movements, helping the rehabilitation work if the cure of spinal cord injury had been discovered.

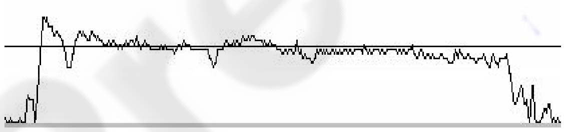

Figure 2: Leg's angle during the electrical stimulation

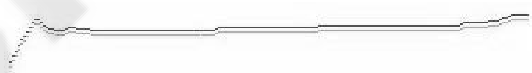

Figure 3: Amount of stimulus applied at Rectus femoris e Vastus lateralis

4 CONCLUSION

In the continuation, the number of goniometers will be expanded to be possible doing a gait at a paraplegic. It needs to make a better design of goniometers to be better adjusted to each joint.

Assembling a major number of goniometers, allows us to test more complex movements. The loop of control is already prepared and software will need small implementations making possible for the patient to execute movements like walk, ride a bicycle or go up stairs, depending only on the correct pattern of the angles to be executed. For the future, an input system to acquire the intention of the patient can be installed (Kostov et al., 1995), to make the system slave of patient volitions and not only of what is pre-determined by it. The improvement of this technique will represent a great advance in the area of functional electric stimulation for paralyzed members, making the practical application of this therapeutical feature easier.

These innovations bring a new age in the control of neuromuscular electrical stimulator, allowing a person without the voluntary control of its movements to imitate another one who have full movements. It could give him or her a much more worthy and calm life. By using techniques of implantation of electrodes, which already exist, through a surgery, apparent wires will no longer be necessary. And with the movements soften than ones gotten through the systems of control currently in use, the deficiency can be unnoticed.

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