

## LEARNING NEUROPROSTHESES CONTROL BY USING REMOTELY TUTORED SIMULATION AND EXPERIMENTS

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**Abstract:** Functional Electrical Stimulation is a means of producing contractions in muscles, paralysed due to central nervous system lesions, by means of electrical stimulation. The devices that provides the required stimulation pattern are termed as *neuroprostheses*. By increasing the number of specialists that are trained to implement control strategies within a neuroprosthesis an increased number of disabled people may benefit during their rehabilitation processus. The main feature of the developed system is support for the training, development, implementation and testing of user defined control algorithms with remote equipment laboratory that emulate a neuroprosthesis.

**Keywords:** Remote labs, E-learning, Functional Electrical Stimulation, Neuroprostheses.

### 1. INTRODUCTION

During any teaching processus the physical experiments are indispensable for developing skills to deal with physical processes and equipment control. The Internet provides new possibilities for universities to provide access to their laboratories for an increased number of students or interested individuals without incurring any increase in cost. During a physical experiment the learners can verify if a certain mathematical model of a process or equipment corresponds with nature and to study the limitations of such a model. Real-world problems solving and hands-on experience gain are one of the outcomes for students during practical projects. Nowadays, the tendency in higher educational programs is to move from traditional teaching methodologies to new ones, such as Problem Based Learning (PBL). The students have to face practical problems in a set up learning environment that help them to find the proper problem solution on there's own initiative on a base of the necessary theory. It has been proved that this kind of methodology increase the interest of students in the learning process (Matthew *et al.*, 1994). During the last decades, there is a trend to reduce the number of instructional laboratories and to use simulations that

replace physical experiments (Magin *et al.*, 2000, Schmid *et al.*, 2001). This is due to the fact that an increased number of users may learn and test different concepts at a low cost and also it may respond to a need to substitute the experiments that have to be carried out on humans, for example in the field of neuroprostheses.

Functional Electrical Stimulation (FES) is a means of producing contractions in muscles, paralysed due to central nervous system lesions, by means of electrical stimulation. FES-based standing in paraplegia has been achieved with relatively simple systems of surface stimulation in both laboratory and clinical settings. A closed-loop control system improves standing by reducing fatigue and increasing patient safety (Poboroniuc *et al.*, 2004). Successful clinical implementation of FES-induced standing in paraplegia requires that simplicity in all aspects be maximized. The devices that provides the required stimulation pattern are termed as *neuroprostheses*. An increased effort in terms of organizing and performing experimental tests with a neuroprosthesis, dealing with the required ethic approvals, is required from those testing a neuroprostheses as well as from a patient by himself. Much more, there is no permanent availability of a disabled person to test a

novel control strategy implemented within a neuroprostheses. Therefore, simulations and an equipment that emulate the effects of a neuroprostheses aiming to rehabilitate disabled humans are required. On the other side the new FES-based rehabilitative techniques are not used at their maximum potential and it is estimated that only a small percent of potential users are currently treating their illness by means of a FES-based rehabilitative device. Therefore there is a great interest among the physiotherapists, physicians and those performing research within the FES field to learn more about the way to adapt a neuroprostheses parameters for an individual in need. Existing FES courses (on-line references: OML site, ELECTROSTIM site) requires the presence of the participants and only a limited number of them can be accepted in a course session. A web-site that offers FES tutorials, an e-learning method to control a neuroprostheses and much more a set up environment to implement new control strategies would bring benefits for many interested specialists within the FES-based rehabilitative techniques. The idea of the set up environment that aims to teach users on dealing with challenges encountered while setting up a control strategy embedded within a neuroprosthesis is shown in figure 1.

The paper presents an e-learning application in the field of neuroprostheses that has been developed during a cooperative work within the Romanian PRIC project. The maintenance of information documenting neuroprostheses tutorials, laboratory experiments and the implementation of the Internet-based communication process make use of HTML (Hypertext Markup Language), of XML (Extended Markup Language) and of Java technology. The client software developed to support the remote experimentation on physical setups over the Internet is implemented as a series of Java Applets.

The paper is organized as follows. In the next section we explain shortly the tutorial part that support the users in earning their knowledge within the FES field and neuroprostheses control.

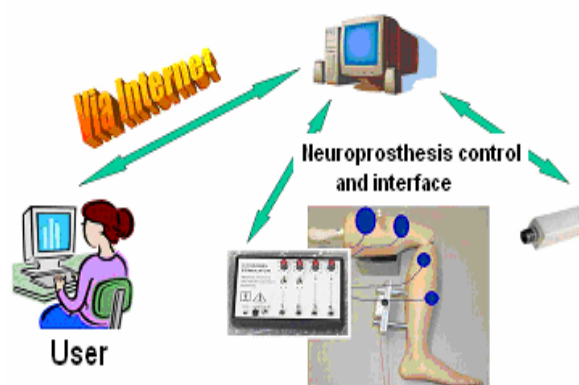


Fig. 1. E-learning set up environment for controlling a neuroprosthesis.

The following section describe the test part that has to be passed by any user prior performing any experiment or proposing any new controller that has to be embedded within a neuroprosthesis. The last session offers an idea upon the activities that have to be performed in order to test a new neuroprostheses controller on a set up environment that emulate a human individual wearing the proposed neuroprosthesis. The paper ends with concluding remarks.

## 2. TUTORIALS AND QUESTIONARY

Functional Electrical Stimulation is an important and complicated research subject in Biomedical Engineering. It address the rehabilitation field in individuals with their extremities affected by paralysis resulting from spinal cord injury (SCI), head injury, stroke (CVA) or other neurological disorders, aiming to restore function in people with disabilities. There is no doubt that touching all the aspects that concerns the FES-based rehabilitation is practically impossible. Therefore we had to focus on the idea of designing neuroprostheses aiming to restore function in disabled people.

The tutorial has to offer some general information that explains the concept of functional electrical stimulation, who may benefit from using FES-based devices, an overview on the existing devices that provide electrical stimulation and perspectives in developing neuroprostheses. Therefore we decide to organize the tutorial as follow (see figure 2):

- Functional electrical stimulation principles;
- Short review of the FES-based therapeutic techniques and patient categories that may benefit from using FES;

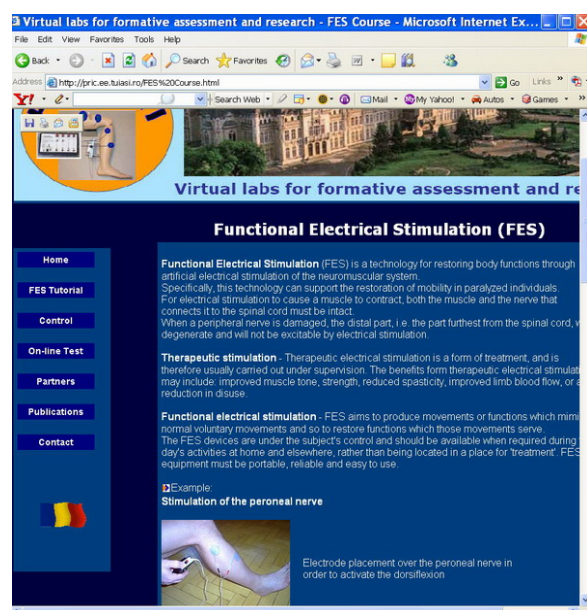


Fig. 2. The PRIC on-line tutorial for neuroprostheses control.

- Electronic stimulators;
- Sensors for FES systems;
- External control of movement by means of a neuroprosthesis: modeling of the musculoskeletal system, control methods to restore standing in paraplegia, control methods to restore walking in paraplegia.
- References;

The purpose of the tutorial is to guide the interested individuals towards the idea of controlling a neuroprosthesis. If someone become more interested in rehabilitation techniques that involves functional electrical stimulation, he/she has to start using the references and to get deeper within the chosen study subject.

Advancing towards the point of being able to propose a new control method embedded within a neuroprosthesis that correct a certain disability in people affected by paralysis isn't an easy task. Essential knowledge in the field of modeling of the musculoskeletal system, parameters of the electrical stimulation, electrodes for electrical stimulation, Matlab&Simulink programming skills and control theory are required. We have to establish a constraint for the users that aim to implement a control for a neuroprosthesis and to test it on our set up environment. They have to successfully fill a *prelab form* that poses technical questions that must be answered in order to gain permission to access the test module. This requirement has been introduced to ensure that the users have the necessary prior knowledge to benefit from the experience, and to motivate them to do preparatory work on their own. In order to perform a test via Internet, the user has to complete the following steps:

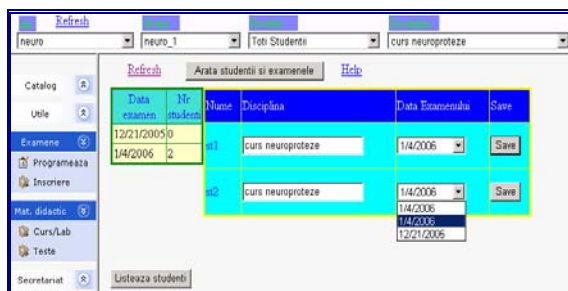


Fig. 3. Users registration panel.

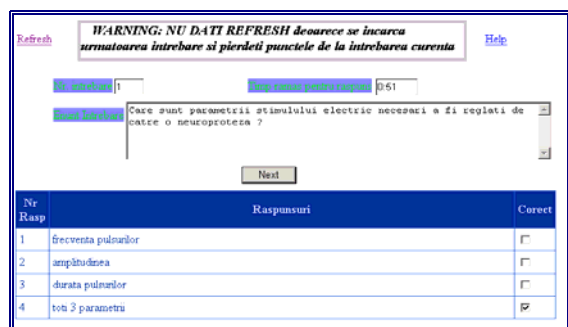


Fig.4. The panel for filling in the question answers.

In order to perform a test via Internet, the user has to complete the following steps:

- To register (see figure 3).
- To answer the questions that are shown one after another (see figure 4).

Prior to offer access to the proposed questionnaire, the owner had already filled in: enunciation, response time interval, number of earned points and a list with possible responses. If it is necessary, the owner can include an image. Once the user passes the test he/she will be able to pass towards the next step of controlling a neuroprosthesis in a set up environment. Due to security reasons, a permission has to be granted to each user and all the remote experiments have to be performed under supervision.

### 3. E-LEARNING SET UP ENVIRONMENT FOR TESTING THE NEUROPROSTHESES CONTROL

In order to convert the presence learning environment to a successful remote experience it is needed to allow users to interact at different levels. The first one is the debugging level, which permits the users to download their own code, to monitor and control a Simulink control block, and to see the simulation results. It is provided with a screen like the one shown in figure 5. They can test some control strategies that have been already proposed or to propose new control strategies. The first results obtained will be those obtained after performing a simulation.

The Simulink scheme comprises a model of the musculoskeletal system, one for parameters initialization, a control block that requires a Matlab function proposed by the end user and different blocks that allows the results and diagrams to be displayed. In order to create an interactive simulation, Easy Java Simulations (Ejs) concepts have implemented, in connection with Matlab and Simulink.

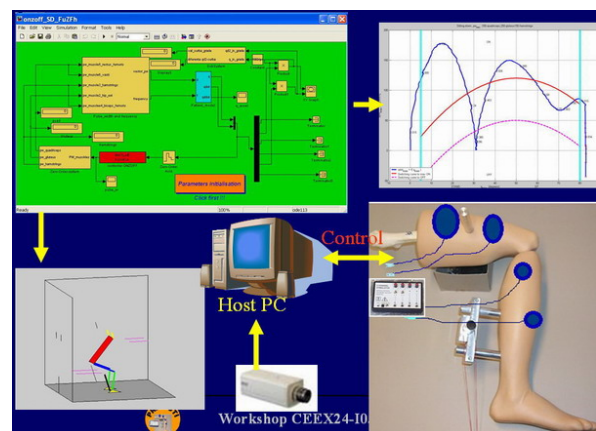


Fig. 5. Test bench for different control strategies that has to be embedded within neuroprostheses.

Easy Java Simulation is an authoring tool that has been specifically designed for the creation of interactive simulations in Java (Esquembre, 2005). Ejs offers the possibility to build interactive user-interfaces, whose properties are linked to the Matlab/Simulink model variables, an easy way to model automatic control systems and to remote control dynamic systems via Internet. Once the modeler has defined the model and the view of the interactive simulation, Ejs generates the Java source code of the simulation program, compiles the program, packs the resulting object files into a compressed file, and generates HTML pages containing the narrative and the simulation as an applet. The user can readily run the simulation and/or publish it on the Internet (Sanchez *et al.*, 2002, Petrescu *et al.*, 2006). This tool can be used on its own, generating stand-alone Java applications or applets, or in conjunction with Matlab/Simulink, using them as the internal engine that describes and solves the model. Using Ejs in conjunction with Matlab means that users of Ejs can call any Matlab function (either built-in or defined in an M-file) at any point in their models or run Simulink models.

The second level is the interaction between the users and the equipment at a physical level, such as to press a key on the keyboard, to turn on or off different switches and watch the display output. It is practically impossible that at any hour a human been with some disabilities to be connected to an equipment that is driven by a neuroprosthesis and someone to control it remotely. Ethical and practical matter will impede such approach. Therefore, our idea has been to use a robot that emulate the human lower body, and to concentrate on control strategies that aims to restore standing and walking in paraplegia. Animations will provide the user with useful information on the way that the human body may react to the proposed control strategy (see figure 6).

The developed Simulink model takes into account the idea that the targeted muscles are stimulated with electrical signals whom parameters as pulse width, intensity and frequency have to be tuned, and the musculoskeletal model of the body moves accordingly. The simulation results as joints angles, joints speeds and joints accelerations are provided to the real equipment, a Lynx6 robot, whom movements can be live visualized over Internet by means of a webcam. The same variables will be used by the Ejs created applets to provide user with human body animation. Therefore, the Matlab function that has to be created by the user accepts joints angles, joints speeds and joints accelerations as inputs. In accordance with the proposed control strategy it has to provide the electrical stimulus parameters for any of the stimulated muscles.

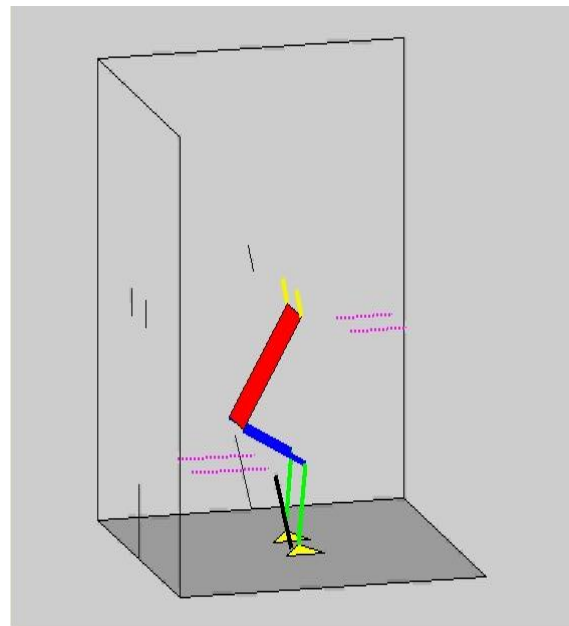


Fig. 6. The animation window in connection with the human body control in standing that is provided by a neuroprosthesis.

Besides the graphical windows that the user will be provided with, another windows will show live the results of the experiment (see figure 7). If a user get in touch with the entire process required to propose and test a control strategy that has to be embedded into neuroprostheses and provides support in standing or walking in paraplegia, it will be easy to transfer the control strategy into a real neurostimulator. Once all the ethical approvals are granted such device can be then tested on disabled people aiming to use FES to restore their lost motor functions.

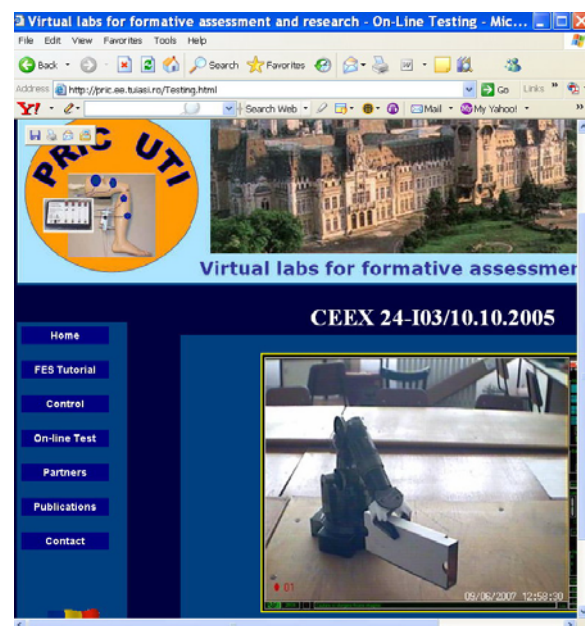


Fig. 7. The PRIC webpage and the movie that the user is provided with during an experiment.



#### 4. RESULTS AND CONCLUDING REMARKS

The proposed remote controlled application in the field of neuroprostheses aims to spread the knowledges within the field of neuroprostheses control and to bring closer the moment when such a neuroprosthesis will be easy to be used by injured people participants to a rehabilitation treatment to restore their lost motor functions.

We tested a ONZOFF controller (Poboroniuc *et al.*, 2002, see figure 8) that aim to help paraplegics in performing controlled lowering and standing exercises by means of FES. The Matlab function that is required has been created and downloaded to be available to the simulink control block. The speciality of this control strategy is that it requires only the knee joint angles and velocities and provides the stimulus parameters for the quadriceps and/or hamstrings muscles. The ONZOFF (ON-Zone-OFF) controller, works according to a second order switching curve in state space (see figure 9), with a smooth increase or decrease in pulse width (muscle stimulation) between the On and Off boundary (Zone). The results of the proposed application have been seen on graphical windows, and live over Internet (see figure 10).

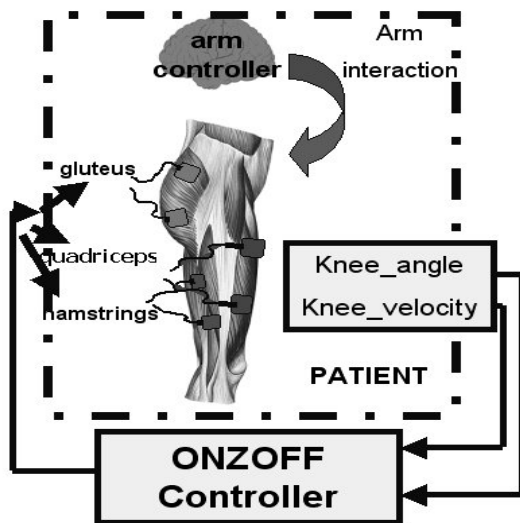


Fig. 8. The ONZOFF controller schema.

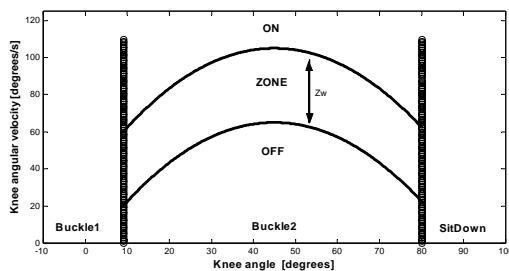


Fig. 9. The ONZOFF controller working diagram (e.g. sitting-down motion task). Adapted from Poboroniuc *et al.*, 2002.

All the components of the proposed application provided us with visual and numeric information during the experiment. There were no observable differences between the real move of the robot emulating the human body and the animations.

Before opening the application to users over Internet we have to perform some more tests that give information at which extend we have to supervise an end user in order to avoid damage to the equipment. When you are anonymous it may be tempting to test the security of the laboratory.

To resume, we proposed an e-learning application that aim to teach users on building and implementing different control strategies within a neuroprosthesis. Its associated online environment integrates remote access to experimentation facilities and Web-based simulation capabilities. A comprehensive set of necessary documents that discuss the objectives, FES theory, neurostimulators particularities, along with a questionnaire and bibliography needed to complete the experimentation, is provided. Currently, the *PRIC* project is still going on and further development aims to improve the database of the predefined controllers and to perform extensive testing.

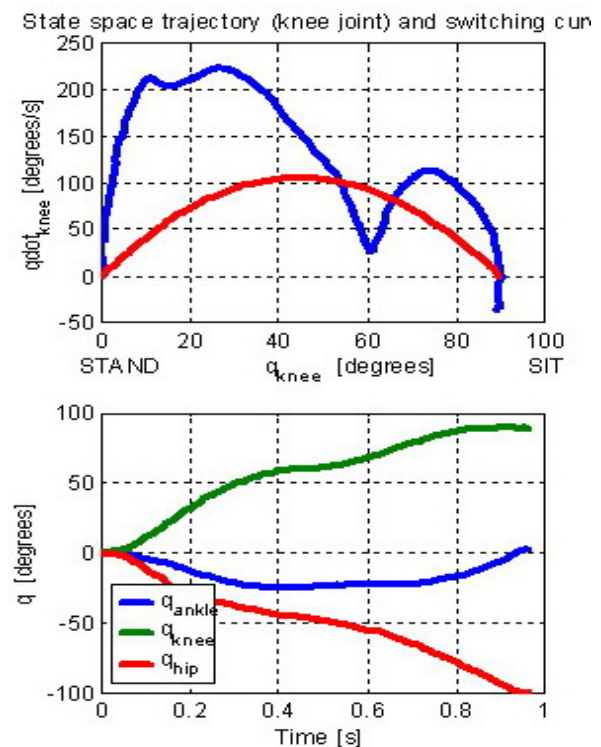


Fig.10. The simulation graphs: state space trajectory (upper graph) and joint angles over time (lower graph).

## ACKNOWLEDGEMENT

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