Virtual Platform Technologies for Evaluation of Rehabilitation Progress and for Prosthetic Control

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Abstract—**The on-line reproduction of the movements performed by a patient in virtual environments has been proposed for several applications, including the evaluation of new prosthetic control strategies, the training of prosthetic users and for new rehabilitation programs. Since the availability of the hardware and software technology necessary to implement various types of virtual environments, our laboratory has been interested in the development of a simulation environment which could be used as part of the rehabilitation treatment of lower limb amputees. Therefore, in this paper, a scaled prototype solution aimed at reproducing the movement of the lower limb during walking in a simulated environment was developed. A robotic simulation software was used and two forms of simulated limb control were tested: one used data from a hardware interface, collecting data from external inputs (sensors) and the other used electrophysiological signals. The software used was the free version of V REP and the hardware selected was the Arduino Mega. The implemented system complied with the requirements previously established and probed to be sufficiently versatile for the proposed application.**

Keywords- **Virtual Experimentation Platform, Rehabilitation.**

I. INTRODUCTION

Virtual reality is the human-machine interface technology that allows real time simulation of user environments, situations or activities and the interaction between the user and the interface is performed through one or more sensors [1]. It has been proposed, in conjunction with robotic systems, for rehabilitation of patients after stroke [2] and for training in the use of upper limb prostheses [3], among other applications. Additionally, experimental research has demonstrated that these interfaces have a positive effect in the rehabilitation process and are efficient in improving gait and balance. This has been partly attributed to the richness of sensory information provided by the simulation, the feedback given by the interface which stimulates specific neural networks, and their stimulating effect on the patient [4]. In lower limb amputees, the clinic viability of prosthetic use is challenged in part by the complex process of adaptation to the equipment, which is related to the ability of patients to incorporate the prosthesis to their body image [5]. Virtual environments could be used in these patients not only to evaluate prosthetic control, but also to facilitate the rehabilitation process and psychological adaptation, as well as an alternative tool to conventional gait analysis [6]. The technological solutions already developed are in general expensive, difficult to customize for different users and conditions, with limited scalability, with restricted user interaction with simulated environments and / or they have been restricted to upper limb simulations [7,8].

Nowadays it is possible to access the hardware and software technology needed to implement virtual environments, and provide them with user interaction in such a way that the patients could see their body projection in a real time simulation. The aim of this work was to develop a scaled prototype solution that reproduces the movement of the lower limb during walking in a simulated environment. The solution should be versatile to allow for different controlling sensors strategies and interface options so that it could be used for different research projects.

II. MATERIALS AND METHODS

A. Software selection

The following criteria were established for selecting the simulation software:

- User friendly interface and possibility of lower limb modelling.
- Possibility of controlling the components of the model from external applications or remote hardware.
- Capability of interacting with external applications, to acquire control signals for the model.
- Possibility of constructing environments with easily customizable settings for each patient or research targets.
- Ability to model interaction with virtual objects and sensors.
- Low cost.

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B. Hardware selection

The platform should be able to obtain information from a wide range of possible sensors, such as accelerometers, gyroscopes, force sensors, etc. Also, the data obtained from these sensors should be processed to obtain control signals intended to move the lower limb model. For that reason, an additional criterion for the hardware and software was compatibility with signal processing systems, for testing new prosthesis control algorithms or to develop new systems for gait analysis. In Figure 1, the scheme of proposed simulation platform is shown.

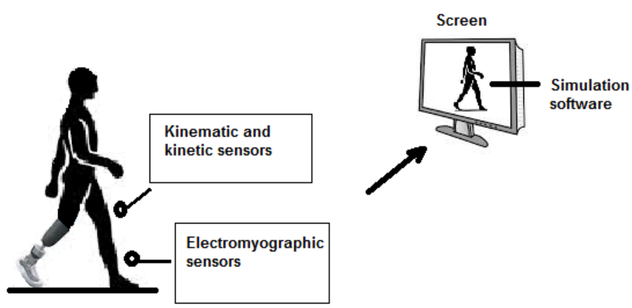

Fig.1. Scheme of the proposed simulation platform. Simulation software should be able to reproduce movements executed by the patient in the graphical environment. To accomplish that, the model should simulate human motion and each object of this environment must be controlled by information from the sensors of data acquisition on the patient.

C. Design of model

The designed model was limited only to the lower limb. It was established as a requirement the ability to independently control three joints: hip, knee and ankle. The movements of the limb segments (thigh, leg and foot) were constrained to physiological range of motion.

D. Experimentation with the platform

Two tests were designed for the experimentation with the platform and the platform was evaluated qualitatively viewing on the screen the movement that a healthy subject executed. For the first one, independent flexion and extension commands for the three joints (hip, knee and ankle) were proposed, using the information provided by the selected hardware interface. For the second one, a test electromyographic signal, obtained from the rectus femoris muscle according to SENIAM recommendations [9] and processed with Matlab, was used to command the movements mentioned above.

III. Results

A. Software selection

V-REP was selected as simulation software [10]. This software has been widely used for the simulation of robots [10, 11]. Among its features, it includes the possibility to build a lower limb model using objects from the simulation environment, which can be controlled both individually and collectively. This software allows interaction with several control modes and easily extendable means of communication within V-REP or with the outside world, which allows quick commissioning of prototypes [11]. To accomplish that, drivers in C / C + +, Python, Java, Lua, Matlab, Octave or Urbi can be written [10]. This software has also a free version (V REP EDU) which includes all the features mentioned above. In this work the free version was used.

B. Hardware interface design

For the hardware interface, an Arduino Mega 2560 was selected. This board possesses an ATmeg1280 based microcontroller. It has 54 digital input/outputs (of which 14 provide PWM output), 16 digital inputs, 4 UARTS (hardware serial ports), 16MHz crystal oscillator, USB connection, power input, ICSP connector and reset button [12]. The Arduino Mega has a number of possibilities for communication with other devices (for example computer software or other microcontrollers), including a virtual com port. It provides the advantage of fast prototyping by acquiring data from sensors, for example accelerometers giving to the system the versatility proposed as objectives for this work.

In order to test the designed interface, two potentiometers and six pushbuttons were used to emulate the information that may come from external sensors connected to this board, and were used to assess in real-time the control of the objects that formed the lower limb model.

C. Design of model

A lower limb model in V-REP was constructed, defined from the selection of objects, which were subsequently articulated and arranged on the same hierarchy tree. The basic model of the lower limb was constructed from what it is called in the software as 'pure forms' and consists of 3 joints ('hip', 'knee' and 'ankle') and 4 segments ('pelvis', 'thigh', 'leg' and 'foot'). The model is shown in Figure 2.

It was also possible to use a model provided by the software. Unlike the previous one, in this model meshes were added to the pure forms mentioned above, giving to the model a more aesthetic visual aspect, so that both models only differ in visual appearance.

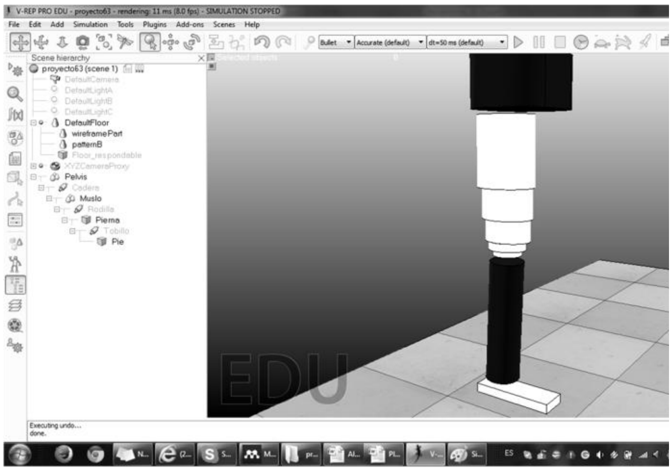

Fig.2. Schematic of a basic model of the lower limb in the simulation environment. The model is composed of 7 objects: 4 segments representing the pelvis, thigh, leg and foot and three joints for the hip, knee and ankle. The properties and movement of the objects in the environment can be controlled by external applications.

D. Experimentation with the platform

The models described in the previous section were controlled externally using two alternative methods, as mentioned in section II.D. For the first one, the flexion and extension movements for the three joints (hip, knee and ankle) were achieved. In this configuration, the input from the pushbuttons was used to manage the increase or decrease (in one degree steps) the flexion-extension of the selected joint. The potentiometer is used to flex or extend the same joint in a continuous way. In the upper panel of Figure 3 the appearance of the model provided by the VREP is shown, first with the right leg fully extended (figure on the left side of the panel) and then with the hip in neutral position and the knee in flexion (right side). Positions are reached starting from a neutral position through the commands from the pushbuttons, without appreciated delays in the synchronization of events.

In the second test, the electromyographic signal of rectus femoris was used to control the flexion-extension of the knee of the same model, but in a sitting position. In the lower panel of Figure 3 the model with the knee in full extension (left figure) and maximum flexion (right figure) is shown. The knee flexion was commanded by the control signal obtained from the external application (Matlab) without an appreciated delay in the synchronization of both software (Matlab - VREP).

IV. DISCUSSION

In this work, a prototype scaled platform was designed aimed at performing the simulation of lower limb movements. To do this, the robotic software simulation V-REP was used, because its characteristics such as flexibility and scalability, complied with the established criteria [10]. One of the future applications of this platform is the testing of new algorithms to control lower limb prosthesis. The tests performed in this study showed that it is possible to simulate certain movements of the lower limb, controlled by either signals sent from a hardware system or Matlab processed signals, in a similar way to the signals used in previously published research on upper limb [7] and lower limbs [8]. But unlike the above referenced works, the designed prototype is easily modified to test other control signals obtained from sensors of kinematic and/or kinetic variables (e.g. accelerometers) and/or from the processing of the signals. Furthermore, the possibility to control the properties and movements of the different objects that composed the model, makes it possible to reproduce the movement executed by a patient in the simulated environment, which would have a direct application in the evaluation of new rehabilitation strategies based on virtual environments [4], as well as on the study of new techniques for gait analysis [6].

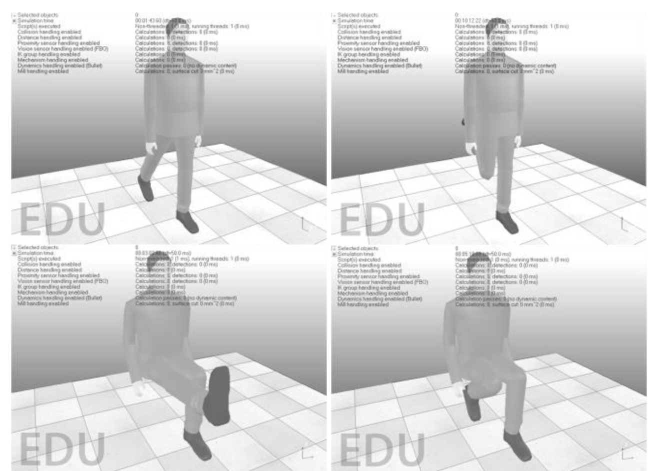

Fig.3. Schematic of a lower limb model moving in a simulation environment. As shown, it was possible to control flexion and extension of the hip, knee and ankle. These movements were externally controlled by a hardware interface built from an Arduino microcontroller board and also from control signals obtained by electromyography signal processing using an external application (Matlab).

V. CONCLUSION

The results of the experimental testing performed with this prototype were satisfactory. Specific applications for this platform will be developed in future research. Future work will include more tests with the platform for quantitative evaluation about the correct representation of movements.

Conflict of Interest

The authors declare that they have no conflict of interest.

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