Hardware & Software Package for Locomotory Disabled Patients Training

P.L. Milea, G. Stefan, M. Moga, A. Barbilian, S. Mitulescu, E. Cernat, O.Oltu, C. Moldovan, S. Pompilian

***Abstract*—** The design of an intelligent prosthesis involves a lot of issues that have to be solved for achieving good results. The modeling, implementation and accommodation phases for the active intelligent prosthesis is obviously a complex approach, involving both manufacturers' and patient's high implication. To support this approach we've projected and implemented a package of software solutions and hardware interfaces which eases the case identification and training stage for every patient. The package use requires some phases, described inside the paper, including: an analysis phase of the snag and its neighborhood, picking up all the useful controlling biosignals for the prosthesis and running bioelectrical tests to identify the minimum set of independent biosignals. These phases conclude with the training stage, which is done to verify the patient's ability to use and control all the prosthesis functions. This training involves the patient's awareness in learning how to control his own biosignals by means of their visual correlation to the movements of an already attached virtual prosthesis. Based on data offered by the identification and training phases, one can choose a prosthesis solution among those available, best suited to the patient's case and abilities, along with his financial availability, required by one choice or another. Considerable time and money savings can be achieved by using this set of software and hardware solutions, both because of delays and prosthesis mismatching elimination and because of the patient's involvement in picking up of the appropriate solution. The training must be finished before purchasing an intelligent prosthesis, which is costliness. The proposed methodology, the hardware and software package components we made and the tests we have run are detailed inside the paper.

***Keywords*—** Intelligent Prosthesis, Prosthesis Modelling, Biosignals, Disabled Patients Training, Prosthetic Solutions Choosing, Virtual Environment, Software Asisted Training.

I. Introduction

THE design of an intelligent prosthesis, be it leg or hand based, involves a lot of issues that have to be solved if good results must be achieved [1].

We have to focus our efforts on the prosthesis' quality (hardware and software points of view) and patient's availability to use such prosthesis.

The modeling, implementation and accommodation phases for intelligent prosthesis is a complex approach, involving both manufacturers' and patient's high implications [2].

A uniquely patient's accommodation process has to be followed for every intelligent prosthesis, by means of proper initial setting-up and/or subsequent "learning".

II. Locomotory Disabled Patients Issues

The use of biosignals requires either an analysis phase of the snag and its neighborhood (if we talk about the best case) or a complex analysis for determining as many possibilities as we can for picking up useful controlling biosignals for the prosthesis.

Usually, the patient follows a series of bioelectrical tests that is going to identify the minimum necessary biosignals used in prosthesis' further control [3].

Firstly, we have to deal with the biosignals' inter-correlation. Its effects materialize as simultaneous movements for multiple joints, even if this is not what we needed.

Secondly, if inter-correlation issues are solved, throughout successive testing, what follows is to verify the patients' ability to voluntarily control the distinct chosen signals.

A related issue here can be seen for some patients that show difficulties in controlling muscle groups thus advancing slowly or nothing at all [4].

A third issue is due to the fact that the chosen biosignals are frequently intended for other muscle groups than those that should accomplish the desired acts. That is why the prosthesis actuation parts must be, if possible, allocated to such biosignals that naturally command the desired movements [5]. The actuation parts that cannot be bounded up to the proper biosignals, simply because they are non-existent, require the patient's testing in order to determine his ability to control them based on other biosignals (obviously if such biosignals exist).

This approach requires adequate training and generally is time consuming [2]. Besides, for some situations the results are unsatisfactory and this leads to patient's disability in fully using the acquired prosthesis' resources.

It is therefore desirable that such testing can be accomplished before purchasing an intelligent prosthesis, since it is costliness.

III. The Proposed Solutions

For this purpose, within our researches we've focused upon the software aided trainings, the decisions behind the biosignals' choice and upon the prosthesis solutions that are the most adequate for every patient. Nevertheless, we have always had in mind all the necessary trainings needed for the proper assimilation and utilization of the intelligent prosthesis.

For this purpose we have designed a work methodology and we have done hardware and software components which allow the connection of the patient or of the researcher with the software implemented virtual limbs.

The proposed methodology, the hardware and software package components which are made by us are detailed in the following.

A. Proposed Methodology

From this point of view, in order to properly choose a prosthesis solution and properly assist the patient in his training, we've divided the entire process into several major steps:

- clinical analysis of the amputation and determination of the distinct number of commands needed for the future prosthesis' base functions implementation;
- the determination of a maximal biosignals set that can be acquisitioned from within the snag's proximity areas that have realistic usability in controlling the future prosthesis;
- software evaluation of these acquired biosignals in order to help us in identifying all the possible correlations among them, eventually being able to choose all but the redundant signals;
- using our own software developed kit in testing the patient's ability in voluntarily controlling the chosen biosignals, eventually being able to choose the signals that express the maximum availability in driving the ideal prosthesis's actuation parts;
- proper identification of the features that the future prosthesis will bring up, compared to the patients' expectations, all in relation to his financial potential;
- appropriate choice of the adequate prosthesis according to the patients' requirements (demands) and possibilities (both financial and in terms of biosignals). The lack of controlling capabilities can be somehow balanced out by the financial ones, by choosing those prosthesis that offer additional intelligent features;
- patient's previous training, based on the software application, in order to do a realistic prevision of his accommodation chances for a given prosthesis;
- ordering of the desired prosthesis if the previous training was successful;
- patient's training in order to use the purchased prosthesis using a software-based virtual environment, by means of the patient's biosignals inter-connection with a virtual limb exposing analogous features as the ordered prosthesis;
- prosthesis' mechanical configuration based on the clinical characteristics of the patient (e.g. snag's anatomic shape, paired limb's dimensions, patient's weight);
- attachment of the patient to the physical prosthesis he acquired and do the necessary adjustments for optimal patient's accommodation to it;
- offer periodically checking and technical maintenance.

B. Hardware solutions

The designed hardware components package implements the EMG signals acquisition and process functions. The result is send to the PC through an USB interface.

C. Data amplification and acquisition module

This module acquires signals from electrodes, amplifies them and implements the preprocessing functions. The output of this module is a digitized signal, containing EMG signals' data.

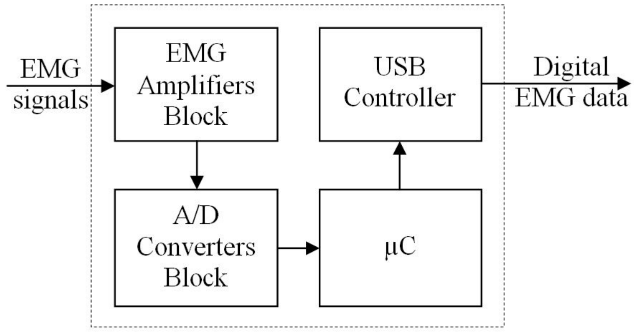


Fig.1 Patient-PC Interface Diagram

The patient EMG signals (maximum 10 cannels) are acquired by using one use electrodes. These signals are amplified by the EMG amplification block. The digital converted signals are next processed, time multiplexed and sent by µC, through an USB cable, to a parallel processing system and then to the PC.

D. Parallel data processing block

The parallel processing system is implemented in a developer platform type RPS-3000 and performs simultaneously the extraction of the EMG signal envelope from all channels and also allows the direct control of an adequate prosthesis, for research studies.

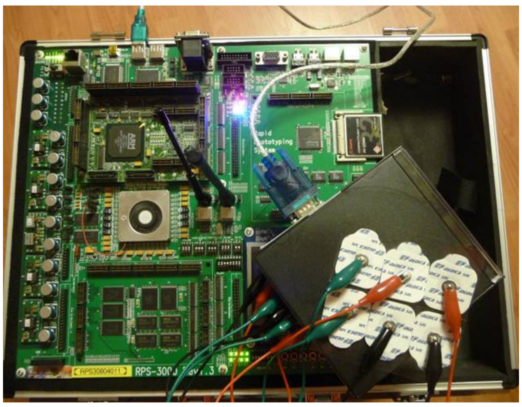


Fig.2 Utilized hardware equipment

From the developer platform, the control information for the virtual "muscles" is transmitted to the computer where it is processed by the "Virtual Pacient" software. The hardware interface, the developer platform and a usual set of electrodes are presented in the figure below.

The developer platform RPS-3000 can be dismissed if there is no need to directly control a experimental prosthesis and if the simultaneous processing of 10 signals can be executed by the computer.

E. Utilized software solutions

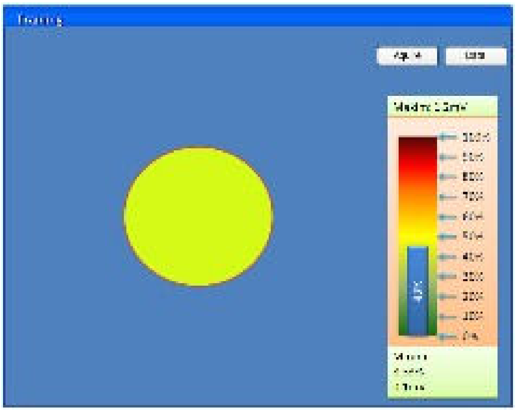
In this sub-section we briefly present the utility of the realized software applications and we detail the implementation of the application “Virtual Prosthesis”, which is much more complex.

F. Analysis of biosignals

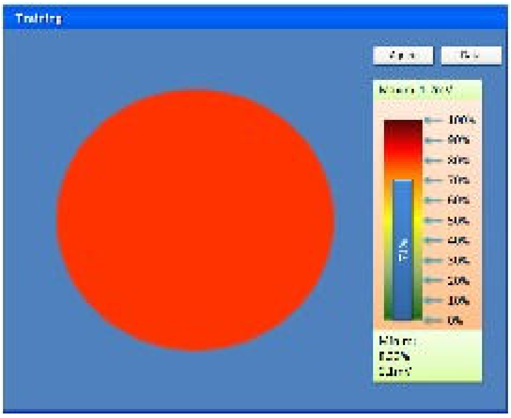
The preliminary choice of independent biosignals was done applying the correlation function to the samples of each pair of two signals, in order to identify the eventual similarities between them. We considered a good intercorrelation to be less than 10% and a acceptable one less than 25%

G. Pacient pre-training

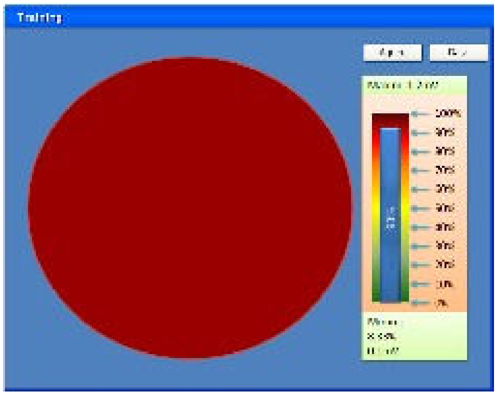
This operation is carried out using the same basic hardware and software components and the sampled biosignals are visually translated in an easy to interpret graphical form, thus allowing the pacient to use bio-feedback.



(a)



(b)



(c)

Fig.3 Biosignals representation for bio-feedback in three cases: (a) Low signal level (b) Medium signal level (c) High signal level

On the screen a colored disk is displayed. Its color and diameter vary proportional to the envelope amplitude of the EMG signal samp[led in the studied points (Fig. 3). At the right side the maximum and minimum values of the EMG anvelope from the current session are shown, as well as the ratio between them, as percentage. Also the current value of the envelope amplitude is displayed, througha virtual vu-meter indicating the current percentage.

In this stage the amplitude variations willfully generated by the patient are tested, for each biosignal separately. We considered eligible those biosignals that have a resting-value less than 15% of the maximum value generated by the pacient.

During the pre-training those biosignals will be evaluated and kept, which fit the necessary control limits, or, if so, those for which the patient shows significant progress.

H. Training with virtual prosthesis

The software application for simulation of a prosthesis allows the training of the pacient during the time-span until a intelligent prosthesis is received.

In this stage the usefull biosignals of the pacient will be connected to the dedicated hardware interface, thus connecting the patient to the virtual limb implemented in software.

The software gives to the researcher or to the patient the possibility to associate his own particular biosignals to the joints, with the agreement of the doctor or researcher, if he has enough EMG signals.

From the signals chosen in the pre-training stage, tests can be made in order to select the most suitable ones for control of different segments. Allthough specialists can estimate quite accurately how the signals are best associated to virtual actuators, the patients control capability presents a high variability and better results can be obtained if the patient can choose during the training stage. This possibility arises especially after a accommodation period of the patient with the virtual prosthesis.

I. Virtual Prosthesis Application Design

Virtual prosthesis application includes a graphic 3D module used for skeleton and humanoid representation. To reduce the quantity of information graphical represented without functionality regression the coordinate system associate to each bone is represented in a different color, like in figure below.

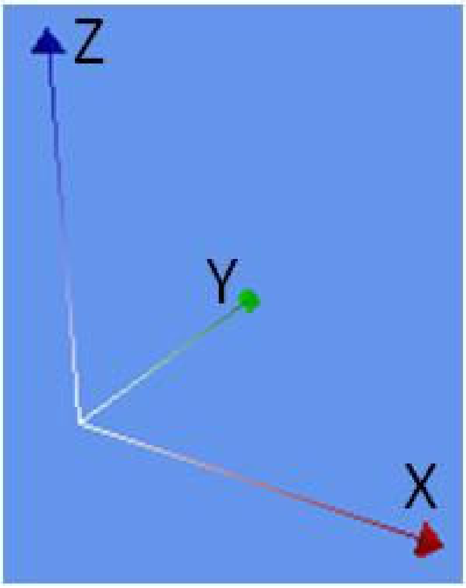


Fig. 4 Coordinate system convention color

The software contains:

- a graphic 3D engine;
- an interactive system between the user and the graphic elements;
- a module for virtual prosthesis parameters administration;
- a module synchronizing the graphic scene components according to each new value of the prosthesis parameters;
- a set of functions for environment settings and design.

The software simulator for human body parts is an interactive open base for prosthesis design.

The 3D engine graphically shows a virtual prosthesis. We adopt two solutions for the engine:

- a powerful engine under DIRECTX [4, 5] creating a high quality scene;
- a less powerful engine, using VRML [1], enabling online tests.

The engine works under a WEB browser and it is accessible over the internet.

The software offer posibbilties to design and simulation of a prosthesis control system and a movement system in accordance with all the facilities of the prosthesis and with the patient's assets.

The designed system comprises:

- a virtual environment. It allows generating, configuring and modifying different work environments for the testing of the prosthesis;
- a module allowing virtual prosthesis description. The users can create different prosthetic architectures according to the patient's disability.
- a module allowing real prosthesis specifications. The module is necessary because the virtual prosthesis must have a behavior identical to the behavior of a real prosthesis, under the same simulated conditions (on different external stimulations). The virtual environment allows the connection to an external hardware which reads a set of virtual sensors corresponding to real sensors.
- a command module sending signals to a set of devices used in the movements of a real prosthesis, as a response to different kinds of external stimuli. The module works in real time and performs a continuous monitoring of the parameter states.
- a module implementing the control logic, usually by means of a software specification.
- a module for synchronizing and coordinating the evolution of the environment components.

Each bone is graphically represented starting from its parent bone coordinate system. The bone definition includes length, and rotations with specified rotation angles around X, Y and Z axes of parent bone (Fig. 5.).

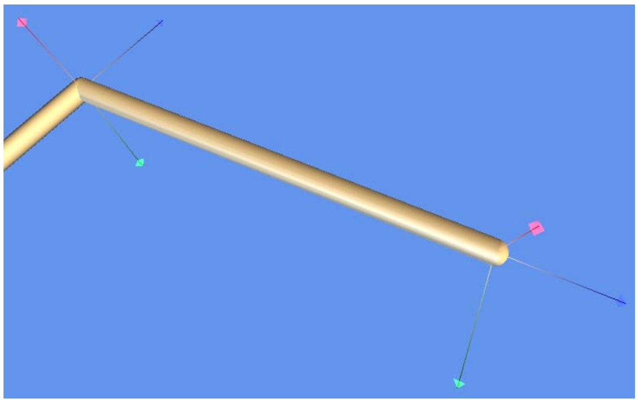


Fig. 5. Bone representation

Each bone can be a human bone or an equivalent "bone" used in prosthesis design. It has specific properties like: length, start geometry and end geometry. The rotation angles are limited between a minimal value and a maximal value. Also, the limits are used to compute output values.

The association between a degree of freedom and a sensor value is representing by using a value differed by -1 in field "Sensor". The sensor value can be used directly (as is) or inversely (0 becomes 1 and 1 becomes 0).

All these settings are grouped in the "Bone editor" control window (Fig. 6.). First option is a control used for bone name. Each bone has length, start geometry and end geometry. Each of these consists in two radiuses (one for X-axis and one for Y-axis).

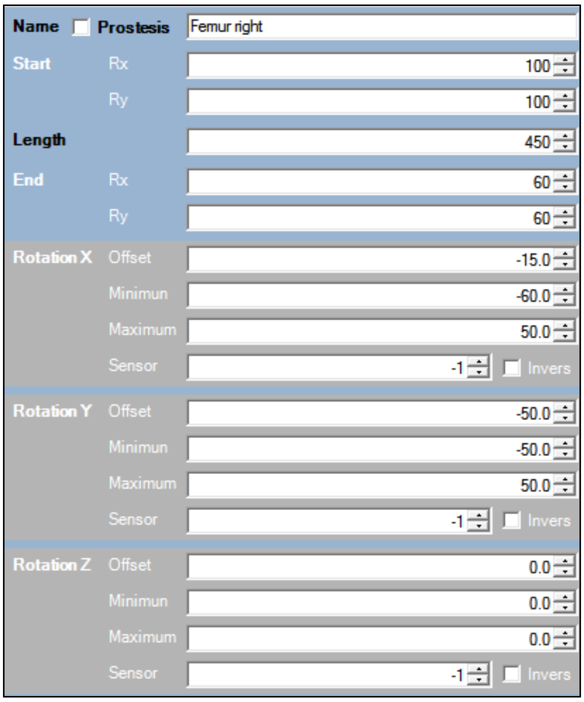


Fig.6. Bone definition window

A virtual articulation is defined as a pair of connected bones, and a limb consists in a set of articulations and bones, each one having its own coordinates systems, at both sides. The result is represented in Fig. 7.

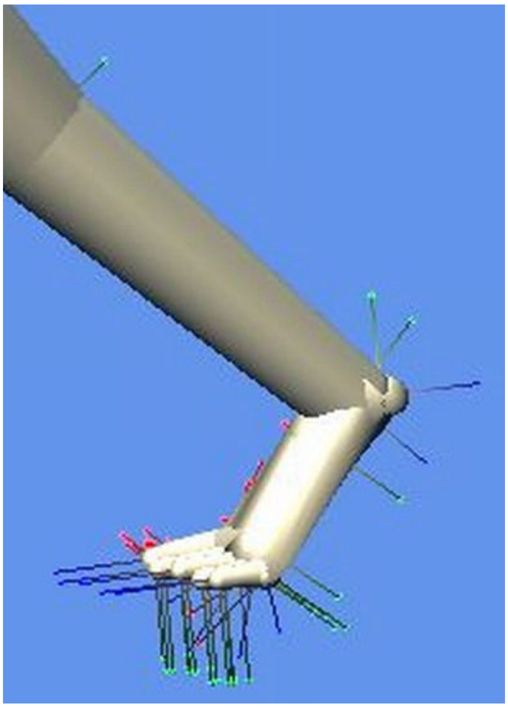


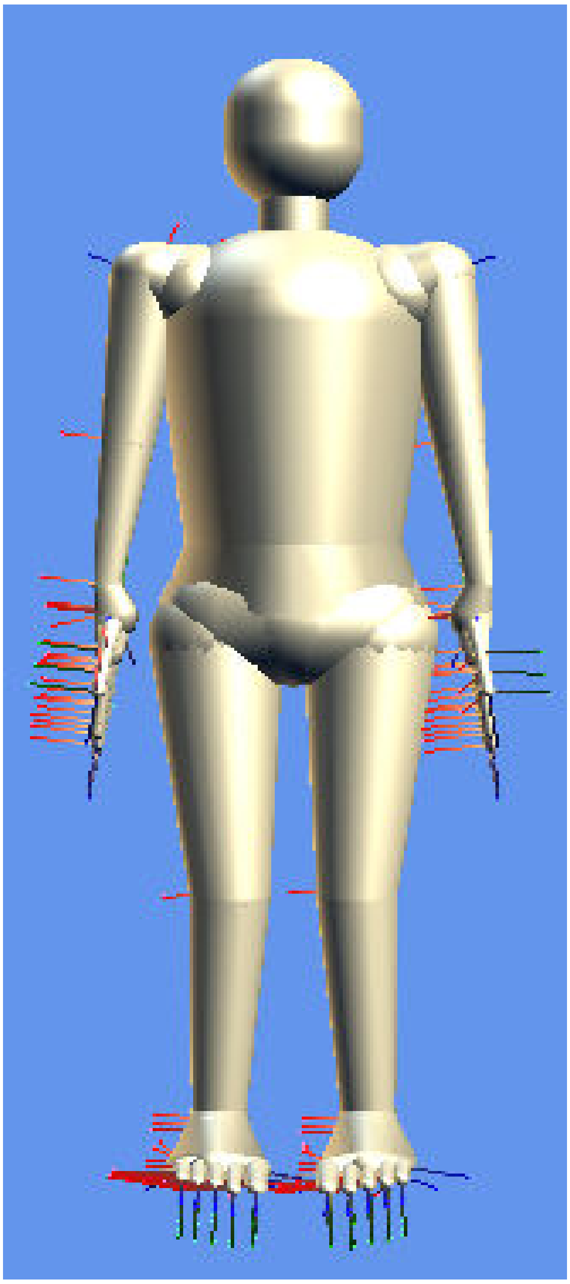
Fig. 7. Virtual leg and associated 3D axes systems

This approach has major advantage that the definition granularity is enough to create a correct skeleton for each patient, even if there are some asymmetries or bone deformation.

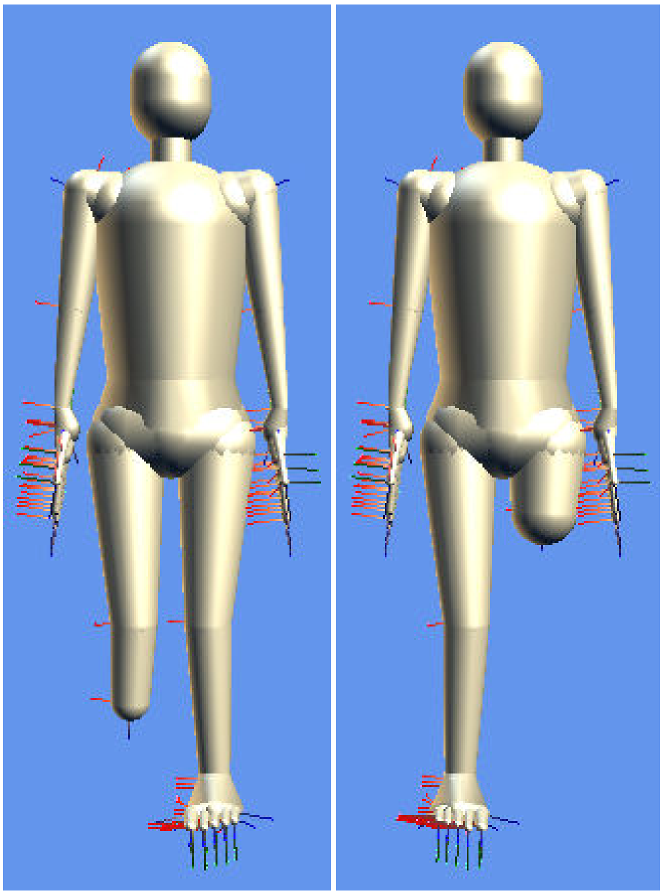
The application allows a very good skeleton representation. The start and end bone geometry are very useful because the final representation respect the human proportion.

The entire skeleton that can be easily adapted to particular situation.

Our efforts concerns hands and legs representation, but we define all the body. A full representation gives us and to the patient a global image of the future body (after prosthesis mount), like in Fig. 8.

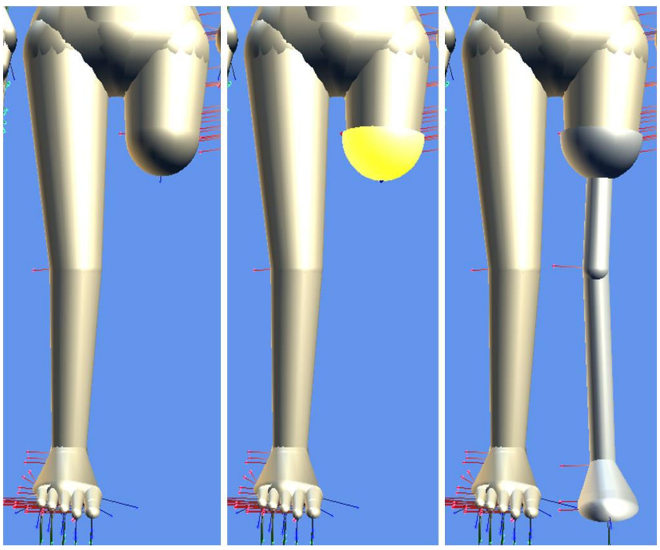


(a)

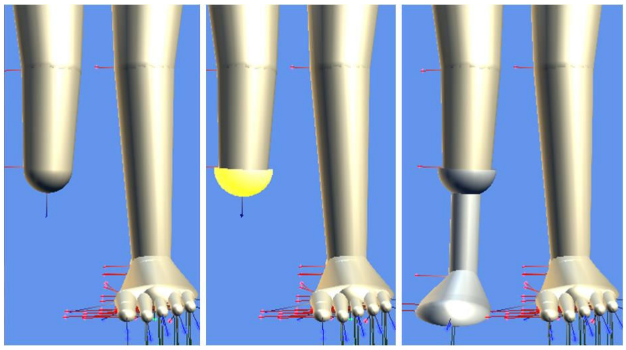


(b) (c)
Fig.8. (a) Full humanoid, (b),(c) Humanoid with amputations

The virtual prosthesis contains, like the real ones, a body adapter and a set of artificial “bones” used to complete the missing part of limb. Some examples are shown in Fig. 9., for upper and lower aputiations.



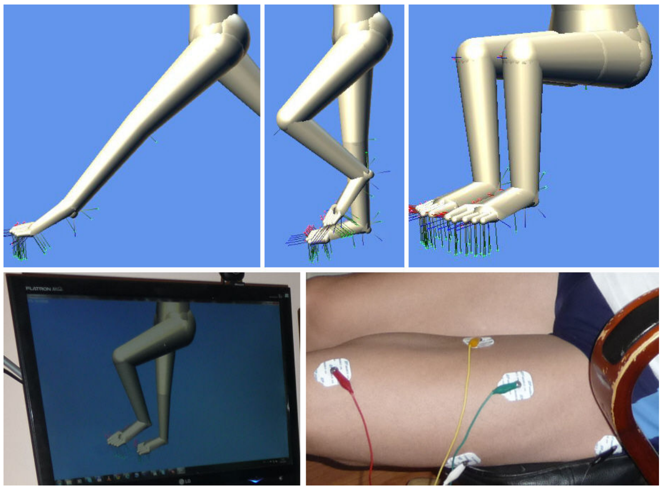
(a) (b) (c)
Fig. 9. (a) Amputated thigh, (b) Prosthesis adaptor, (c) Prostesis



(c) (d) (e)
Fig. 9. (c) Amputated leg, (d) Prosthesis adaptor, (e) Prostesis

IV. TESTS AND EVALUATION

During this stage we tested the control of the virtual limbs with EMG signals sampled from the forearm and the thigh. Figure 10 presents a few snapshots taken during the tests.



(a)

b)
Fig.10 Control of the virtual prosthesis with biosignals sampled from the upper part of the limb:
a) foot tests, b) prosthesis testing

The results confirm the expectations and validate the design and implementation of the system.

The persons who tested the system, although not amputees, accommodated with the system in 3-4 training sessions (pre-training) and managed to control the virtual limbs with a reasonable precision after a few more sessions.

V. CONCLUSION

A set of hardware and software tools for evaluating and training of locomotory disabled patients was designed and implemented.

This system was realized, in order to choose the most adequate prosthesis and for accommodating with all its facilities, during the waiting phase until the receiving of the prosthesis.

The systems' hardware components acquires signals from electrodes, amplifies them and implements the preprocessing and parallel processing functions, to make them suitable for software control.

From the developer platform, the control information for the virtual "muscles" is transmitted to the computer where it is processed by the "Virtual Pacient" software.

The implemented software package is able to:

- evaluate the correlation function between the samples of each pair of two signals, in order to identify and keep only the independent biosignals;
- visually translate the sampled biosignals in an easy to interpret graphical form, in order to provide patients' training by use bio-feedback methods.
- modelate the human limbs with all bones and articulations, as "virtual limbs" or "virtual prostheses", in order to simulate the real prostheses for patients training or research purposes;
- interconnect the patients' signals with the virtual limbs and prosthesis and move them at patients' will.

The performed tests confirmed the expectations and validate the design and implementation of the system.

We evaluated that by using this set of software solutions, considerable economic and time savings can be achieved, due to elimination of the waiting-times and to miss-adaptations to the ordered prosthesis, and also due to direct implication of the patient in prosthetic solution choosing.

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Petru Lucian Milea is scientific researcher at Politehnica University of Bucharest, Romania. He obtained a Ph.D degree in Electronics and Telecommunications Engineering at Politehnica University of Bucharest, Romania, in 2010. His main field of study is focused on hardware and software control systems for various applications.

He started his work in scientific research in 1995, at the Electronics Research Institute in Bucharest, Romania, in the field of medical electronics. From 1997 he started to work at the Electronics Technology and Reliability Department of Politehnica University of Bucharest, Romania. Meanwhile he also worked, for two years, at The National Institute for Research and Development in Microtechnologies. His current job is at Politehnica University of Bucharest, Electronics, Telecommunications and Information Technology Faculty, Electronics Technology and Reliability Department, Bucharest, Romania, Iuliu Maniu Bvd. 1-3. He is also the Manager of Solaris Consult S.R.L. Bucharest – an IT consultancy and research company. His current and previous research interests include hardware and software control systems, medical electronics, renewable energy, artificial intelligence, information technology.

Gheorghe Stefan is Professor at Politehnica University of Bucharest, Romania. His main field of study is focused on hardware and software aspects of parallel computing.

He worked mainly at Politehnica University of Bucharest, Romania. Also worked for many years at Brasov University, St. Mary's College of Maryland, USA. His current job is at Politehnica University of Bucharest, Electronics, Telecommunications and Information Technology Faculty, Department of Electronic Devices, Circuits and Apparatuses, Bucharest, Romania, Iuliu Maniu Bvd. 1-3. His current and previous research interests include Parallel Computation and I/O Systems, The Supra-Linear Condition for Parallel Computation, The Algorithmic Complexity & Digital Circuits, 0-State Universal Turing Machine, The Connex Project, Lisp Machine, Functional Information, Loops & Recursive Functions, Loops & Formal languages, Loop Based Taxonomy for Digital Systems, Virtual Multi-Processors.

Marius Moga is medical doctor at Central Emergency Military Hospital Bucharest. He is also Ph.D student at Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. His main field of activity and research is focused on orthopedic surgery and prosthetic appliances.

His current job is at Central Emergency Military Hospital, Bucharest, Romania, Str. Mircea Vulcanescu, nr. 88, Sector 1.

Adrian Barbilian is Professor at Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. He also is medical doctor and Head of the Orthopedic Clinic.at Central Emergency Military Hospital Bucharest. His main field of activity and research is focused on orthopedic surgery and prosthetic appliances.

His current job is at Carol Davila University of Medicine and Pharmacy, Bucharest, Romania, Bd. Eroilor Sanitari 8, Sector 1.

Stefan Mitulescu is medical doctor at Central Emergency Military Hospital, Bucharest, Romania. His main field of activity and research is focused on orthopedic surgery and prosthetic appliances.

His current job is at Central Emergency Military Hospital, Bucharest, Romania, Str. Mircea Vulcanescu, nr. 88, Sector 1.

Valeriu Codreanu is medical doctor at Central Emergency Military Hospital, Bucharest, Romania. His main field of activity and research is focused on orthopedic surgery and prosthetic appliances.

His current job is at Central Emergency Military Hospital, Bucharest, Romania, Str. Mircea Vulcanescu, nr. 88, Sector 1.

Eduard Cernat is medical doctor at Central Emergency Military Hospital, Bucharest, Romania. His main field of activity and research is focused on orthopedic surgery and prosthetic appliances.

His current job is at Central Emergency Military Hospital, Bucharest, Romania, Str. Mircea Vulcanescu, nr. 88, Sector 1.

Orest Oltu is Lecturer at Politehnica University of Bucharest, Romania. His main field of study is focused on software managenent of power consumption in embeded systems, and, also, in hardware aspects of parallel computation.

He worked mainly at Politehnica University of Bucharest, Romania. Also worked for many years at Newgate Design and VirtualMetrix. His current job is at Politehnica University of Bucharest, Electronics, Telecommunications and Information Technology Faculty, Department of Electronics Technology and Reliability, Bucharest, Romania, Iuliu Maniu Bvd. 1-3. His current and previous research interests include Parallel Computation and I/O Systems, Digital Systems, Virtual Multi-Processors. At VirtualMetrics, he works now to develop performance and power management solutions for embedded applications emphasizing lower energy consumption, higher efficiency and performance isolation for applications sharing one or more processors.

Carmen Moldovan is scientific researcher at Romanian Academy Research Institute for Artificial Intelligence. His main field of study is focused on intelligent sensors for various applications.

His current job is at Romanian Academy Research Institute for Artificial Intelligence, Bucharest, Romania, Calea 13 Septembrie 13, Academy House.

Serban Pompilian is scientific researcher at Politehnica University of Bucharest, Romania. His main field of study is focused on software solutions for simulation of natural phenomena.