Software and Hardware for Locomotory Disabled Patients Assisted Training and Prosthetic Solutions Choosing

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Abstract: - Designing intelligent prostheses for the taken off limbs, controlled by myoelectric signals, implies specific issues. To optimally solve such problems, we’ve devised a software solution set which eases identification stage for every patient's specific case, his training in order to refine the biosignals’ control and optimal choice of the adequate prosthesis solutions. Case identification implies searching for the maximum number of available biosignals on the snag and choosing the appropriate such signals based on their natural emplacement, amplitude and inter-correlation. The training involves the patient's awareness in learning how to control such 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 solutions, both because of delays and prosthesis mismatching elimination and because of the patient's involvement in picking up the appropriate solution.

Key-Words: Intelligent Prosthesis, Amputee Patients Training, Prosthetic Solutions Choosing, Virtual Environment, Software Assisted Training, Prosthesis Modelling, Biosignals.

1 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 obviously 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”.

2 Problems' exposition
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.

3 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.

3.1 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 acqisationed 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.

3.2 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.

3.2.1 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.

### 3.2.2 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. 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.

![Fig.2 Utilized hardware equipment](image)

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.

### 3.3 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.

#### 3.3.1 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%.

#### 3.3.2 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.

On the screen a colored disk is displayed. Its color and diameter vary proportional to the envelope amplitude of the EMG signal sampled in the studied points (Fig. 3). At the right side the maximum and minimum values of the EMG envelope 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, through a virtual vu-meter indicating the current percentage.

![Fig.3 Biosignals representation for bio-feedback](image)

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.

#### 3.3.3 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. Although 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.

### 3.3.4 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 (a) Coordinate system convention color](image)

(a) (b)

**Fig. 4** (a) Coordinate system convention color  
(b) Bone representation

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. 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.

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. 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).

The next figure contains a hand representation, with 3 different axes for each bone end.

![Fig. 5. Hand and associated 3D axes systems](image)

The skeleton position data is stored in an XML file. In this representation, each bone has a node with a parent bone and other nodes with a set of child bones. An amputated limb is represented by replace a full bone with a rest of bone having length equal with the real rest of the bone. In next figure are shown two kind of amputation.

![Fig. 6. (a) Full humanoid, (b),(c) Humanoid with amputations](image)

(a) (b) (c)

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.

![Fig. 7. (a) Amputated limb, (b) Prosthesis adaptor, (c) Prostesis](image)

(a) (b) (c)
4 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 8 presents a few snapshots taken during the tests.

![Fig.8 Control of the virtual prosthesis with biosignals sampled from the upper part of the limb: a) hand, b) foot](image)

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.

5 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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References: