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Personalized Support System for The Patients with Forearm Amputations

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Abstract. This paper presents a system for assisting patients with amputated hands. Using this system, they can define and implement custom motion algorithms of mobile elements of the artificial hand they use. The system includes a virtual environment simulation, configuration and personalized assistance, a virtual reality glove and hardware components for signal processing. The patient who has one amputated hand, can load in the virtual environment, using a special glove (virtual reality glove) positioned on the healthy hand, simple or even complex sets of movements which are realized by the natural movements of the healthy hand. These sets of movements are loaded in the virtual environment of personalized assistance which then generates, through transformations and extrapolations, motion algorithms "in the mirror" for the virtual prosthesis (from the virtual environment) and then, they are loaded into the patient's artificial hand. Thus, the system enables forearm prosthesis users to define complex custom motions they need to conduct different specific activities that they are supposed to realize, in which they need the help of the artificial hand.

1. Introduction

The spectacular technological development in the last years has led to the marketing of a wide area of forearm prostheses. The increasing interest received internationally by the intelligent prosthesis domain results in recent years from the exponential growth in the number of research projects, doctoral theses and last but not least, the commercial achievements (artificial hands controlled neural or myoelectrical, and software packages for simulation and testing). Although the artificial hands domain has realized a fast progress over the past 10 years, an intelligent artificial hand, to be able to perform under direct neural control of the patient similar movements of a healthy hand, has not yet been fully realized.

At the end of 2011, the World Health Organization estimated that there were about 11.2 million people worldwide with hands partially or fully amputated registered in the organizations of persons with disabilities [1]. This huge number (and its rapid increase) is due to the high number of accidents which lead to this kind of amputations but also to the growing range of malignant and diabetes diseases occurring in the population. Each of these persons faces great difficulties both in finding a job in order to fully reintegrate in the society, but also in carrying out daily personal hygiene, nutrition, etc., being permanently dependent on financial support from their family and from the state.

Despite the performance offered by the most sophisticated hand prostheses on the market, their high purchase price makes them inaccessible to the vast majority of patients. Official statistics also show that over 90% of patients suffering amputations of the hands have a modest financial condition – this makes the vast majority of patients be "sentenced" for life to not being able to reintegrate in the society. In these circumstances, it is not surprising that the purchased prostheses are the cheapest ones, which unfortunately bring to patients almost no help.

Statistics in recent years indicate that the number of people worldwide who suffer hand amputations is increasing, which indicates the need to find affordable solutions for the patients. In this context, it is significant in a dramatically way that so far, in Romania, only five of the more than 55 000 patients were able to buy a myoelectric artificial hand at prices that started from 20 000 Euro / prosthesis. Regarding artificial hands with neural command, that are better compared to the myoelectric ones, none of the romanian patients has so far purchased this kind of artificial hand mounted directly on the stump. This is due both to their high price and the mounting surgery, that cannot yet be realized in Romania.

2. Description of the main features that artificial hands offer on the market

For patients with amputated hands, there are three types of prostheses: prostheses without intelligent functions, prostheses with myoelectric commands and prostheses with neuronal control. Of these, the protheses with myoelectric action have the best price / performance ratio, but in fact the price is too high for the vast majority of patients. However, these protheses offer patients a very small number of functions. To acquire new skills with these artificial hands, patients usually take special courses [6] to compensate in a larger extent the partial or total loss of a hand, but nevertheless, the set of movements that they can make with a classical artificial hand is very poor compared to the movements made by a healthy hand.

The main limitation of the existing artificial hands is related to the reduced set of movements they can do. These movements are different than movements made by a healthy natural hand, often being heavy and segmented. The set of movements that a patient can make with an artificial hand is poor, limited and predetermined by the manufacturer and it's not offering patients the possibility to make custom sets of movements or even completely new movements that the manufacturer haven't designed.

The system presented in this research aims to overcome this drawback and offers the patient significant features in order to realize new movements with the artificial hand, that are necessary for him in different activities he needs to perform at work or in his personal activities.

3. Personalized support system

The block diagram of the assistance system is shown in Fig. 1. It includes both hardware components (virtual reality glove, wiring termination and processing elements) and software components (virtual environment for setup and testing). The patient is connected to the system using the forearm prosthesis mounted on the amputated hand and the virtual reality glove that is mounted on the healthy hand.

4. Virtual environment for setup and testing

The software environment was presented in more detail in paper [5]. In the following, only its main features and advantages are briefly mentioned. The virtual environment allows the user to generate, configure and modify various work environments that will be used for testing the prostheses and their control programs.

In this virtual environment can be created and configured one or more virtual prostheses with different architectures and coupling modes depending on the handicap of the persons that will use them in the rehabilitation program. The features of this software environment are:

1. testing the patient's ability to consciously control biosignals by the aid of the realized prototype and choosing a full potential subset (in terms of usage) in the command of the artificial hand;
2. the implementation of the virtual hand in order to allow the patient to improve control over it in a safe environment;
3. the patient will use the acquisition module and the software application connected to it in order to command sequences of predefined movements of the virtual hand.
4. testing of biosignals and motor control acquisition modules integration through software application. The aim is the simultaneous transmission of patient commands both to the real and virtual prosthesis for best correlating the proper skills obtained by the patient with the artificial hand (using the virtual hand).
5. the determination of the deficiencies in using the artificial hand (movements which are not fully realized) and their correction using appropriate combinations of biosignals the patient can control accurately.
6. the adjusting of artificial hand movements through direct learning. Poor posture of the prosthesis is corrected by mechanical repositioning of actioning elements and recording new values over the old ones in the actioning module.

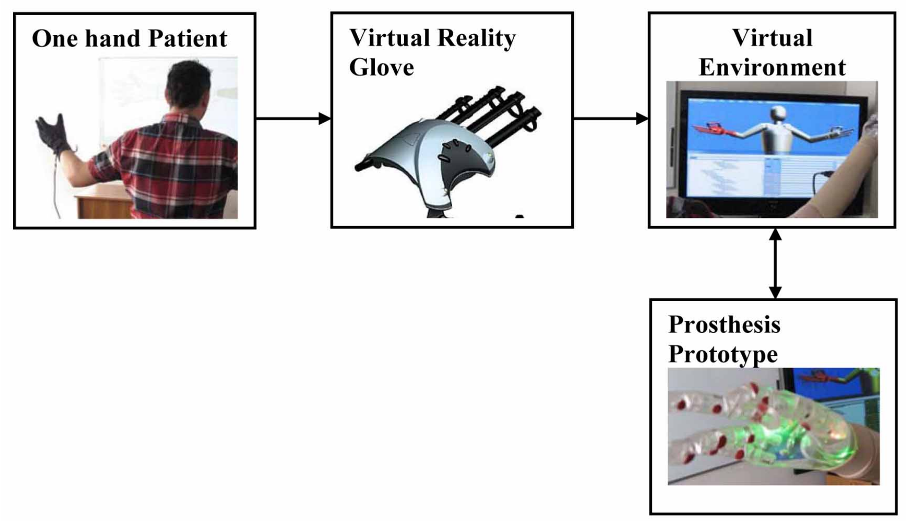

Fig. 1. The block diagram of the assistance system.

5. Loading motion algorithms in the virtual environment

With the help of the virtual environment, the researchers described and tested different motion algorithms of the virtual prosthesis elements for distinct classes of actions: gripping, clamping, rotating, etc. In a first step, these algorithms were described by movement equations, but due to the high complexity of these operations, at a later stage, the load of motion algorithms was chosen by using some gloves for virtual reality (*P5 Glove and DG5 VHAND*). The glove connected to the virtual environment allows the user to perform any movement with the healthy hand, all these movements being duplicated in the virtual environment by virtual hands and then these algorithms are stored in a dedicated database. The main advantage of using the virtual reality glove is that motion algorithms are transferred in the virtual environment and directly stored in the algorithms library, without involving intermediate and quite difficult steps necessary for describing the motion equations of all components in the virtual environment. The glove's driver sends to the virtual environment data referring to each joint position. Storing these complex positions (grips) allows the operator to set in the virtual environment motion algorithms, and to save them in motion algorithms library. In the virtual scene, the updates are made with a frequency of 60fps with the command and control module which allows, by using data provided by the glove's handler, to realize in real time (that is syncronous with the glove) the shift of the virtual environment's elements from one position to another for complex movements and great speed.

The connection gloves–virtual environment has made possible various experiments and studies on motion algorithms needed for different motion sequences. These experiments allowed the study and the decomposition in elementary movements of a wide area of movement sequences of the artificial hand, which were very useful to determine the optimal number of engine components, their arrangement and the power required to realize each sequence of movements to be implemented within the prosthesis. After loading and testing motion algorithms in the virtual environment, they were ranked according to performance and stored in the data libraries of the virtual prosthesis. In the virtual environment, researchers could study and decompose a variety of movement sequences made by the virtual hand, which helped to estimate the number of engine elements required for a prosthesis to perform these movements.

6. Patient's personalized recovery program

The strategy behind the personalized recovery program for patients who have suffered amputation of arm or forearm, aimed to connect them to a virtual environment that could help them use an intelligent mechanical prosthesis. The connection of patients to the virtual environment is realized by the prothesis (which is positioned on the stump) and a glove positioned on the healthy hand. Healthy hand is duplicated in the virtual environment by a virtual hand and the amputated arm with the mechanical prosthesis are duplicated in the virtual environment by a virtual prosthesis.During the rehabilitation program, the operator that assists the patient can choose from the motion algorithms libraries of the virtual environment different motion algorithms both for *the virtual hand* and *the virtual prothesis*.

Information provided by the position sensors of the artificial hand are processed in accordance with the predetermined algorithms libraries and they are implemented in the virtual prosthesis model. Then, a series of new orders is developed in the virtual environment for calculating new parameters of the virtual prosthesis and for the choice of new motion equations. These are sent to the virtual prosthesis to allow the validation of movement models in the virtual environment. At the end of each step of the simulation, the new configuration is implemented in the virtual prosthesis and compared with the desired parameters.

During the recovery program assisted by the virtual environment, the operator that assists the patient can choose different motion algorithms both for the virtual hand and the virtual prosthesis. Control algorithms of the artificial prosthesis and of the real artificial hand are correlated with the synchronization algorithm which is able to display the virtual prosthesis model, through the virtual environment. Figure 2 illustrates the method of patient's connection to the virtual environment.

Fig. 2. The patient's connection to the virtual environment.

7. Defining the patient's own motion algorithms and their storage in the artificial hand

In the rehabilitation program, the patient firstly realizes with the healthy hand (which is connected to the virtual environment through a glove) the main movement categories, and then they are stored in the virtual environment as motion algorithms. These motion algorithms are stored in the virtual environment to model the virtual hand, and their mirror images are stored for usage with the virtual prosthesis. Rehabilitation program requires the patient to make synchronous movements with the both hands in short sessions, during a few minutes, through healthy items (shoulders, and elbows) and afterwards contracting at the same time healthy hand muscles and stump muscles. Thus, the patient will realize synchronous and simultaneous movements with the both hands, the amputated one and the healthy one. Movements of each element, both from the healthy hand and the amputated hand, will be duplicated in the virtual environment as similar movements made by the virtual hand and the virtual prosthesis. All these movements are viewed by the patient on the monitors within the rehabilitation center, which display different perspectives of the virtual environment.

In the early phase of training, the patient will not be able to move the prosthesis because of the difficulty in distinctly contracting the stump muscles. The program includes additional features to boost confidence that when the patient seeks to contract simultaneously the same muscle groups of the healthy hand and of the stump, virtual prosthesis will move because of the signals coming from the virtual environment. The patient will gradually start to believe he will manage to succeed over the first few weeks, firstly seeing on the screen the movement of the virtual hand and of the virtual prosthesis. Support staff will assist each time depending on the situation and the level achieved in the rehabilitation program for the correct movement of the prosthetic components. The patient will gradually become able to command the engine components of the prosthesis.

The patient is assisted both by specialists and by the virtual environment and he gets real-time visual and audio feedback which allows him to learn to use the myoelectric prosthetis. Thus, the patient directly visualizes in the virtual environment firstly the use of the virtual prosthetis and then it would be easier for him to command the artificial hand. Movements are controlled / verified by the data read from the sensors placed on the artificial hand and are based on information read from myosensors.

Figure 3 shows a new set of movements defined using the virtual environment and the virtual reality glove.

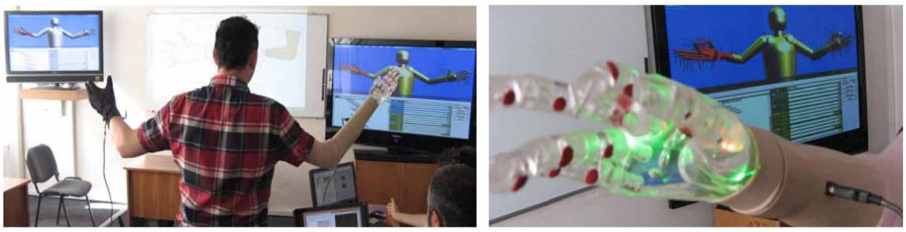

Fig. 3. Loading a new set of movements defined using the virtual environment and the virtual reality glove.

8. Experimental tests and measurements made with the prosthesis

Because of the method of connection and control with the VR glove's help, the virtual hand can realize (in the software environment) movements in real time and synchronous with those made by the patient's healthy hand. Motion algorithms obtained this way and tested in the virtual environment are then transferred to the patient's mechanical prosthesis. A mechanical prosthesis has certain limitations due to fixed dimensions that must be in accordance with the specificity of each patient but also to the number of engine components, layout and their performance. In the experiments, the designed experimental prosthesis allowed testing distinct classes of motion algorithms.

Then, on the mechanical structure were implemented a minimum number of engine components. This mechanical prosthesis was then connected to the virtual environment and then various experiments were made in order to make the prosthesis realize the main classes of movements: gripping, rotating, twisting, etc. These experiments led to finding the optimal position of the prosthetis engine components and their performance. The figure below illustrates the implementation in the mechanical prosthesis of a motion algorithm, which is followed by its storage in the data libraries of the virtual environment.

Fig. 4. The load of a custom motion algorithm in the artificial hand.

The stored custom motion algorithms of the prosthesis were then ranked according to performance. Then it was possible to study a wide area of motion sequences made by a prosthesis, which allowed the optimal choice of the number of engine elements required for a prosthesis to perform these movements. The connection glove - prosthesis allowed the patients to define custom complex movements (*which are implemented on none of the existing types of prostheses on the market [7]*) and then to upload them in the artificial hand.

9. Conclusions

The personalized assistance system is a very useful tool for patients who underwent amputation surgery and want to purchase a prosthesis. These patients can learn with the system's help to effectively use a prosthesis and to improve the control over it. The system allows simultaneous transmission of patient's commands both to the virtual and real prosthesis to correlate as well as possible the skills obtained by the patient with the artificial hand (using the virtual hand).

The system also allows extending the artificial hand's functionality by adding compound movements adapted to the modality of using the prosthesis already obtained by the patient (subcommands to be implemented in the action module). The patient may also adjust the artificial hand movements through direct learning, poor posture of the prosthesis being corrected by mechanical repositioning of action elements and recording new values over the old values in the action module.

Using this system, the patient is assisted by the virtual environment and receives visual feedback in real time, which allows him to learn to use the artificial hand more quickly and efficiently. Thus, the patient directly visualizes (in the virtual environment) the use of the virtual prosthesis and then proceeds to artificial hand's use, which has been already properly configured the use of the artificial hand. The artificial hand's movements are checked by comparing data read from the position sensors with the information read from the myosensors.

In the experiments that were conducted, a mechanical structure with a minimum number of engine elements was connected to the virtual environment and the main classes of movements (charged through the connection glove-prosthesis) were tested. The experiments led to finding the optimal position of the engine components of the prosthesis and their performance.

The personalized support system for the patients with forearm amputations prove itself to be a valuable tool also for researches and for users, opening many possibilities for further developments for all types of protheses.

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