artificial hand,
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Andrzej WOŁCZOWSKI, Marek KURZYŃSKI, Piotr ZAPŁOTNY[1]

CONCEPT OF A SYSTEM FOR TRAINING OF BIOPROSTHETIC HAND CONTROL IN ONE SIDE HANDLESS HUMANS USING VIRTUAL REALITY AND VISUAL AND SENSORY BIOFEEDBACK

In the paper the concept of a training system is presented which can help to stimulate sensory-motor cortex centers in order to develop their ability for efficient use of bioprosthesis. The basis of the training system is a virtual reality with a virtual hand, that the trained patient can move and concurrently observe the movement on the screen (visual feedback) and whose contact with virtual objects the patient may feel as a touch (sensory feedback). The construction of the virtual hand consists of physical elements, connected by joints, a graphical object representing the structure of the hand and the bones enable its deformation. The control procedure of virtual hand is realized through recognition of intention of hand motion on the basis of EMG signals coming from the stump muscles. The recognition algorithm is constructed using the learning set, i.e the set of pairs containing the class of hand fingers movement and accompanying myopotentials segments, which are acquired from the muscles of healthy hand.

1. INTRODUCTION

Loss of hand significantly reduces the activity of human life. The hand transplantations are still in a medical experiment rather than the clinical practice, mainly due to the necessity of immune-suppression (permanent, to the end of patient's life).

An alternative is “cyborgization” of patients with limb loss. So far as the design of prosthetic legs is considered, the burden of the problem lies in the field of mechanics, in the case of prosthetic arms, especially hands, the basic problem lies in controlling their movement so as to enable dexterous grasping of objects (tailored to objects property) and manipulating them [2].

This control, at the decision level, boils down essentially to recognize the intention of hand motion (the class of deliberate grasp or manipulation) on the basis of biosignals coming from the patient body .

The control of bioprosthetic hand is usually based on the myoelectric signals [2,12,13,14]. Normally, that kind of signals accompanies the muscles activity of a healthy hand, but after the hand amputation they remain (in greatest part) still available – along with the forearm muscles left in the stump. In the simplest case these signals can be detected (in a non-invasive way) on the surface of the skin using electrodes located above the examined muscles. That kind of measurement is called the surface electromyography (sEMG).

Surface EMG signal obtained in such a way is the sum of electrical phenomena taking place in the cells of the working muscles. Its form depends on the level of excitement and the spatial localization of the muscles, and that is how it identifies the type of the performed movement. This relation is the basis of the bio-prosthesis decision control. The patient tenses the muscles of the stump according to a prosthesis movement intention. The information about the type of muscles activity included in the EMG signals can be identified through adequate analysis (classification) of the signal.

To restore the lost efficiency of motion back at a satisfactory level, the bioprosthesis should adapt the way of grasping to the type of grasped object. Such ability (called dexterity) is determined by two factors [14]:

- the mechanical construction (the shape, dimensions, number of degrees of freedom),
- the ability to control various actions (by action we understand the defined fragment of grasping/ manipulating motion – e.g. finger flexion in a joint).

[1] Wroclaw University of Technology, Faculty of Electronics.

A large repertoire of motion actions demands a large number of recognized classes of EMG signals. Furthermore, since the signal acquisition (especially when performed in a non-invasive way) is accompanied by numerous disturbances, the reliable recognizing of the signals is a difficult problem. Reliability of EMG signal recognition (and thus the correctness of taking decisions by the system) is here the key issue as the prosthesis cannot perform any action inconsistent with human intention.

Unfortunately, in the brain of persons who have never had a hand or do not have it very long, there is a lack of sensory-motor center, which could control the relevant muscles of the forearm stump (responsible for moving the fingers in a healthy hand). This means that such persons are unable to produce adequate EMG signals, which could control the bio-prosthesis. There are cases of people who after re-implantation of the hand, could not move it, even though anatomically the body was fully connect with the new hand [1,6,7,8,9,10].

To solve this problem, a proper training should be carried out, which stimulates appropriate sensory-motor centers in the cortex, in order to develop their ability to use of the bioprosthesis.

In this paper we present a method of such stimulation, using training in the virtual world, as well as based on the method a concept of Training System for sensory-motor centers in the cerebral cortex of man.

2. THE IDEA OF TRAINING SYSTEM

The basis for a concept of Training System is a virtual hand, that the training patient can move and concurrently observe the movement on the screen (visual feedback) and whose contact with virtual objects the patient may feel as a touch (sensory feedback).

The monitor shows the virtual hand facing away from the patient into the virtual world, what results in training patient the impression that it is an extension of his own limbs. The hand is controlled by EMG signals collected from the stump of the patient arm. During training, the patient tends to perform movements in line with movements preset by the therapist.

An association of intended movement with a view of performed movement gives visual feedback that stimulates the sensory-motor centers in the cortex, in order to develop their capacity for efficient use of bioprosthesis.

A similar goal has a touch feeling feedback. In the moment when the virtual hand touches a virtual object, the Training System generates an electrical signal, which irritates the appropriate nerve endings on the stump of the amputated hand, and stimulates (in a slightly different way than the image) the same sensory-motor centers in the cortex [6,9,10].

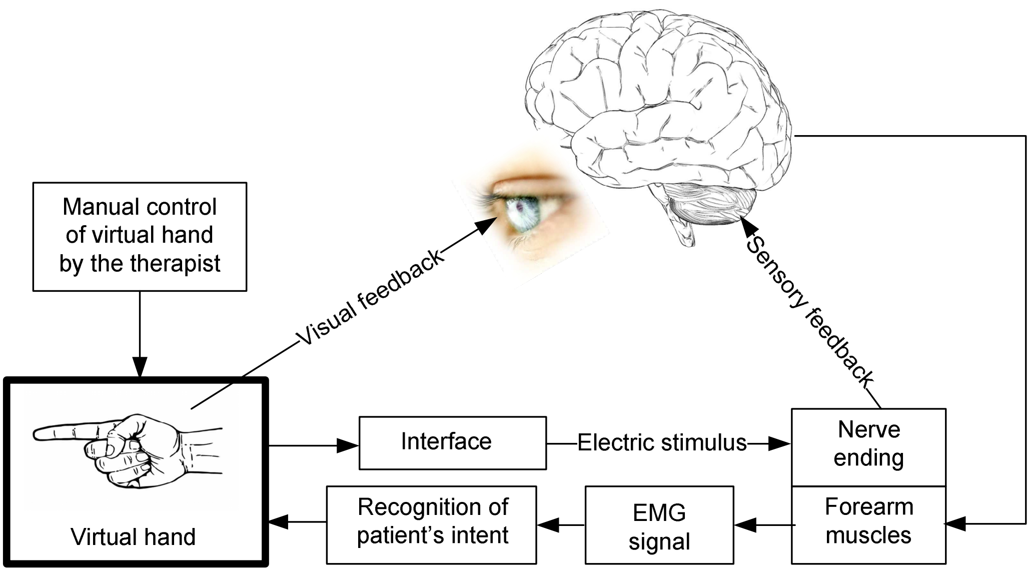


Fig. 1. The schema of Training System.

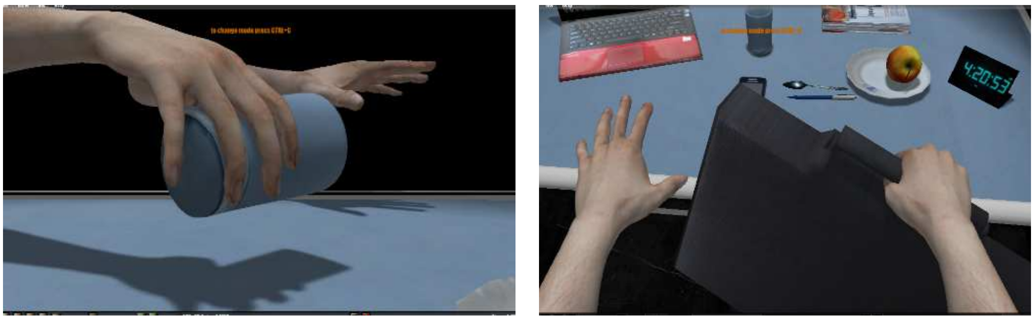
The Training System includes five major elements:

- the system generating 3D virtual world in which the patient sees the phantom limb and the items need for the training (e.g. a table, and lying on it objects chosen by the therapist),
- the generator controlling the demonstration of movements selected by the therapist,
- the system recognizing (through the measurement and classification of EMG signals from the stump of an amputated hand), the type of motion that in fact, the patient would perform (if he had healthy hand) trying to perform a movement specified by the therapist,
- the touch feeling feedback system, that receives, from the virtual world, an information about the contact of hand fingers with grasped objects, and passes it to the nervous system of training patient,
- learning system, transmitting to the muscles of the stump an information about activity of the muscle of a healthy limb when it performs the same movement that tries to perform a virtual hand.

Training procedure is as follows:

- first the system performs itself by virtual hand a movement specified by the therapist and the patient was watching him,
- then the patient performs with his good hand the movement observed, and the system (by measuring the EMG or MMG signals) records the activity of it's muscles; Then the patient tries to perform the same movement using this time a virtual hand, and the system records the resulting EMG signals, and illustrates the motion which would execute the patient's hand in the real world,
- after performing the movement the system compares the EMG signals from both hands and gives the patient advice (or suggests the therapist) how to modify the activity of the stump muscles.

Fig. 2. Virtual world – a view of patient picture provided video camera and supplemented with the missing fragments of hand and forearm.



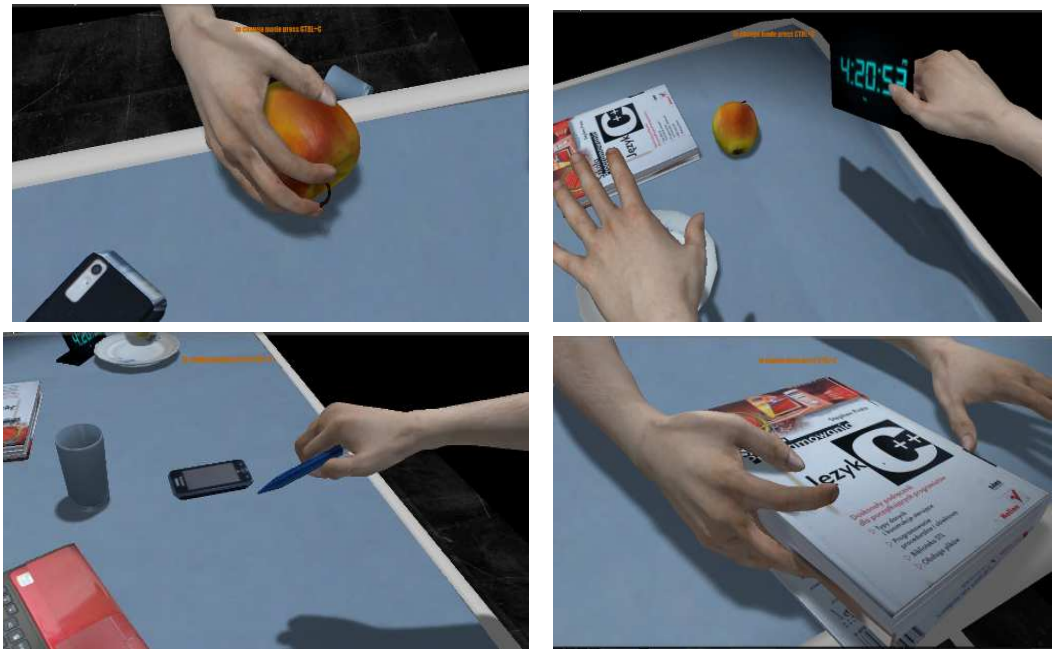


Fig. 3. Trained grasps.

3. VIRTUAL HAND AND SENSORY BIOFEEDBACK

The skeleton of virtual world was realized based on two C++ libraries, commonly called 'engines', (specialized pieces of code that relieve the user from performing alone a complex computing operations).

- Irrlicht library responsible for a layer of graphics (the graphics engine), and
- Bullet library managing physical layer (the physical engine).

Computational algorithms, contained in the Bullet library, allow to construct a kinematic chain which realistically maps real object properties, such as the mass (inertia), and perform functions, such as collision detection (and its strength) of the virtual object with the rest items of the scene, even taking into account (to some extent) the friction.

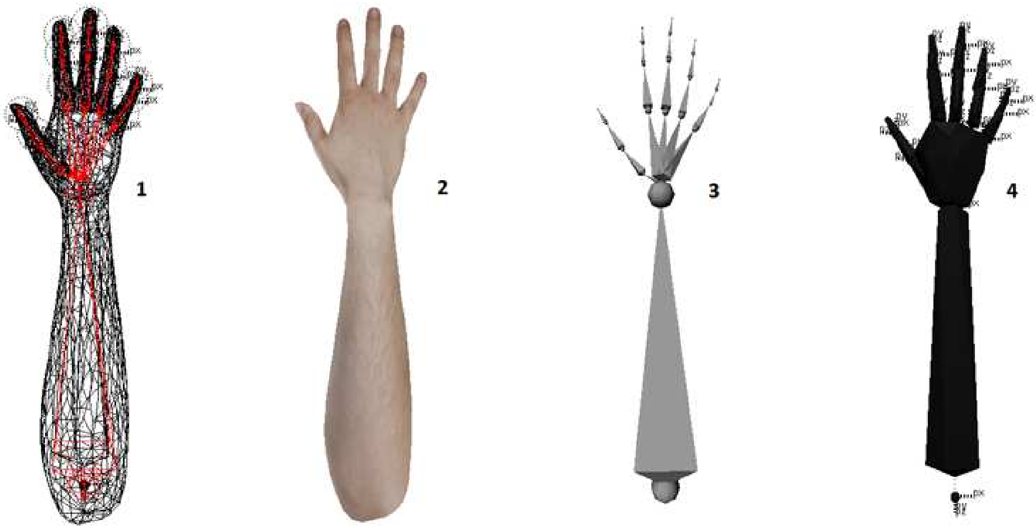


Fig. 4. Tiering in the engine. 1) location of component layers in the limb (2, 3 and 4), 2) graphical model, 3) bones of graphical model, 4) physical model.

The construction of the virtual hand with fig. 4, consists of three elements:

- physical elements, connected by joints (called Constraints in the engine),
- a graphical object representing the structure of the hand, and
- the graphic object bones enable its deformation.

The physical model was created based on the skeleton of the human hand, ignoring the complex structure of the metacarpal and fully mapping the location of the fingers. A graphic model was subordinated to the physical model, creating a structure known as 'ragdoll'. Each physical bone got a graphic bone or a group of bones (bones/armatures), corresponding to a group of vertices of a graphic model, in we can deform the part of graphic object (for example, mapping the behavior of stretched skin).

Location of the virtual limb on the scene is determined by the vision system that tracks the location of the patient stump. Position of the stump is calculated on the basis of information about the location of colored markers mounted on a stump. Movement of the limb can also be done automatically, using the generator supervising the movement demonstration.

Using stereovision system allows to determine the translation in XYZ axes, thereby allowing any manipulation of a virtual limb in 3D space. The use of an additional marker in a different color placed in the upper part of the arm allows extra to fix the rotation.

In the virtual world position of the limb is determined by translating the root element called an anchor, or by giving a rotation of particular joint, which allows simulation of different grasps. Change the location of the anchor determines the series of operations performed by the engine - among others, change the position of other elements of the kinematic chain, the calculation of the forces and accelerations of these elements, and so on.

In the application, two modes are available:

- where the user is fully located in the virtual world (it is possible to design large-scale maps, and thus build a complete 3d game),
- where the image of the limb is positioned in the area indicated by markers placed on the user stamp (allowing to complement the stump of a missing hand).

In both modes the user can practice their skills in the interaction with the visible elements of the scene.

The application enables two-way communication with the user through the RS232 serial ports, USB or Bluetooth (plus the obvious devices like keyboard or mouse). This allows to set the virtual hand posture by the system recognizing the EMG signals from the trained limb stump, and to send to user the information about events in the virtual world - about the touch of the object and about the force of the touch. The measurement of these values is realized by the physical engine and relies mainly on checking the mutual relationship of vertices or envelope (bounding boxes), of the conflicting objects - at the moment of such occurrence, to the user is sent a feedback information.

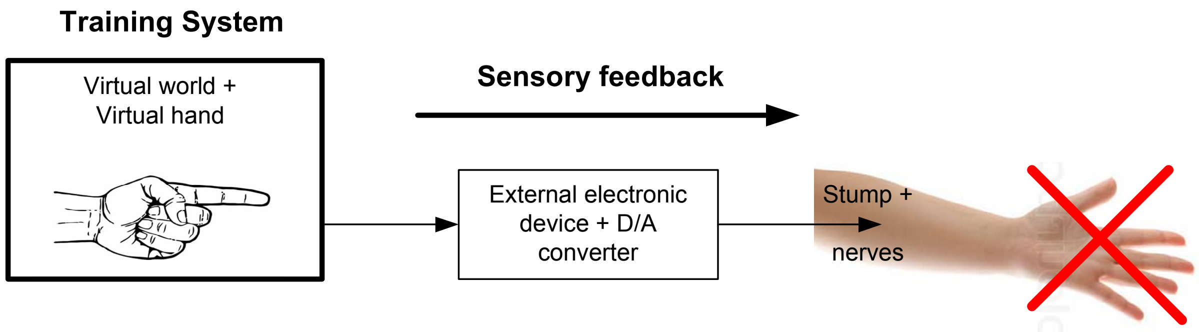


Fig. 5. Sensory feedback.

The list of vectors responsible for the forces acting in the kinematic chain and induced by contact with other virtual objects, can be passed to subsystem performing a conversion of these information onto the sensory information - that allows the user to call the impression of feeling in the limb. The subsystem is an external electronic device, containing a D/A converter, converting the information from virtual world on the form of analog electrical waveform, which by means of micro-electrodes are delivered to the stump nerves, and then by orthodromic way goes to the appropriate sensory-motor centers in the cerebral cortex.

For the purpose of determining the patient's intent recognition algorithm and – in consequence – for the control of virtual hand, we will apply the learning set i.e. the set modelling the relation between the hand fingers movement and accompanying myopotentials. Unfortunately, it is not possible to observe hand fingers posture for the stump of the hand, what means that we cannot directly use the EMG signals registered on the forearm of the stump as learning objects.
In the process of acquisition of the learning set we propose to use the healthy hand. Although this concept leads to the different sources of empirical knowledge and objects to be recognized, we can suppose that biomechanism of movement of the left and the right hand in the same person is identical. The measurement system for acquisition of learning and recognized objects is presented in Fig. 6.

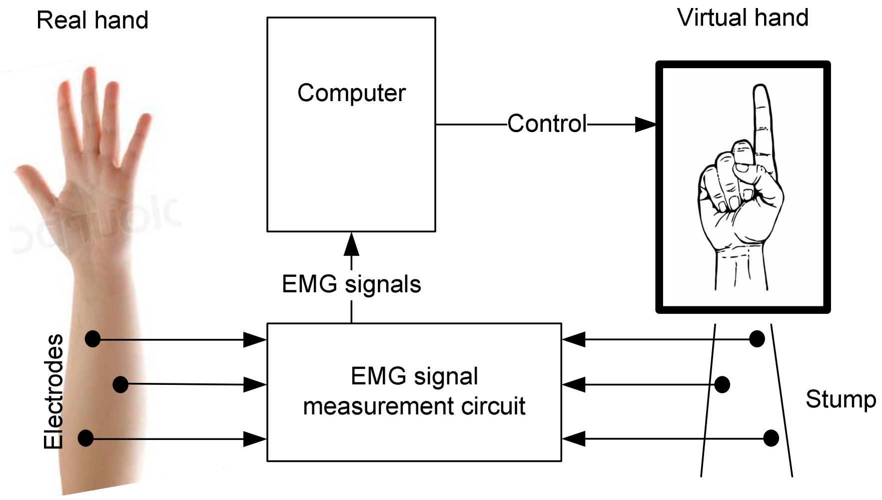


Fig. 6. The block diagram of the measurement system for identifying the relation between the hand movement and EMG signal taken from the muscles of forearm and stump.

Although as a classifier construction different methodological paradigms can be used, we suggest to use artificial neural networks or multiclassifier systems, which have proved to be an effective approach in the problem of EMG signal recognition [4,5,11,12,15].

4. CONCLUSIONS

Presented concept of the training system for the bioprosthetic hand control in one side handless humans has preliminary character. The particular components of the proposed system are demonstrating the different level of development. The virtual world and virtual hand as a sophisticated tool for generating visual and sensory stimuli are on the final stage of computer implementation. The remaining important components, especially recognition module and sensory feedback require both theoretical analyses and experimental investigations.

As it seems, the proposed computer system should be an effective tool, which will considerably shorten the time needed for efficient operating dexterous bioprosthetic hand.

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