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CONSTRUCTION PRINCIPLES OF MULTIFUNCTIONAL UPPER EXTREMITY PROSTHESES BIOELECTRIC CONTROL SYSTEM

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Abstract

The main trends of development of bioelectric upper extremity prosthesis elaboration in the last few years are determined by the necessity to raise control reliability and to increase the number of performed functions. As the functionality of the bioelectric prostheses raises, the number of controlled degrees of freedom increases and it poses a problem of working out of the control methods, which ensure prosthesis movements without tiresome concentration of an invalid´s attention on the control process.

The number of muscles, serving as a signal source in the system "man-prosthesis" which may be controlled by an invalid, is limited in virtue of the certain reasons (level of amputataion, depth of position). With the application of different signal coding methods the control of multifunctional prosthesis may be organized with the lower number of muscles serving as a source of signal than the number of necessary controlled movements, under the condition of sequential movement control.

In our multifunctional prosthesis sequential control system, simultaneous activity of controlled muscles is used as the signal of switching from one type of movement to another.

The system permits to execute proportional (smooth) control of several prosthesis movements. Thus, smooth control of clench-unchlench and rotation of an artificial hand is possible with our forearm prosthesis.

The results of experimental employment of prosthetic forearm appliances, supplied with the elaborated control system, have proven positive.

Introduction

The main trends of development of bioelectric upper extremitiy prosthesis elaboration in the last few years are determined by the necessity to raise control reliability and to increase the number of performed functions. As the functionality of the bioelectric prostheses raises, the number of controlled degrees of freedom increases and it poses a problem of working out of the control methods, which ensure prosthesis movements without tiresome concentration of an invalid´s attention on the control process. It shouldn´t be fogotten, also, that the prosthesis functionability improvement due to the increase in the number of actively controlled degrees of freedom per se doesn´t yet improve its ergonomic index, because functional efficiency, with all other things being equal, depends mainly upon the inner organization of the technical section of the control system and upon the organization of its cooperation with an invalid-operator, i.e. an algorithm, and also upon the possibilities of an invalid as a control member.

It becomes obvious that when elaborating optimum control system one should try to attain, on the one hand, the normalization of the prosthesis reproduced movements and, on the other hand, should not exceed admissible level of psychophysiological strain of an invalid in the process of control.

The analysis of the existing methods of the multifunctional upper extremity prostheses control permits to classify them into the four groups. These groups are:

- multichannel system;
- switching bioelectric systems;
- program-controlled systems;
- recognizing control systems;

The analysis of multichannel control system employment (1,2,3) demonstrated that independent rather efficient control of separate movements is achieved for the number of movements not in excess of four. Simultaneous control of even three movements in multiple combinations demands rather prolonged training and excessive attention strain. This is the main reason of relative - ly infrequent employment of such control method in the last few years.

Employment of programmed control potentialities may serve as a way to decrease the number of parameters at will controlled by an invalid with the aid of such control organization when volitional bioelectric control is combined with the elements of automatized one (4). Possibilities of such systems, however, are limited by the number of programs, contained in a memory unit. Therefore a control method of such kind turns out to be the most efficient with manipulators, serving as human arms when carrying out simple frequently reiterated operations.

In view of the difficulties, related with the limited possibilities of a man-operator to work out the whole complex of commands which are necessary to control multifunctional prostheses, bioelectric control systems are intensively developed in the last few years, which employ methods of getting information on the movement from an operator without working it out in detail by the higher levels of the central nervous system. Systems of the type include devices which identify the type of performed movement on the basis of bioelectrical signal combinations from several muscles and produce controlcommands for corresponding prosthesis drives (5,6,7). As a whole, these control systems, beyond all doubts, have considerable promise, but the necessity of complicated pretreatment by means of microprocessors and an overall complexity of these appliances prevent their wide application in multifunctional prostheses at the present time.

The number of muscles, serving as a signal source in the system "man-prosthesis" which may be controlled by an invalid, is limited in virtue of the certain reasons (level of amputation, depth of position).With the application of different signal coding methods the control of multifunctional prosthesis may be organized with the lower number of muscles serving as a source of signals than the number of necessary controlled movements, under the condition of sequential movement control. When sequential action systems are used, the number of actuating mechanisms exceeds the number of control system channels and execution of necessary movement becomes possible after connection of the corresponding actuating mechanism to the control system only. With this aim in view system should be supplied with a logic commuation unit, controlled by the special commutation signal-commands. When considering the sequential action prosthesis control systems, available in the practical prosthetics, it may be noted that at the present moment there exists the great eanough number of various switching methods, studied with the help of prosthesis models and dummies and officially approved, which differ from the functional point of view (8,9,10).

Switching method selection should comply with the following physiologic requirements, made on the switching systems:

1. Switching process shouldn´t require considerable physical or mental efforts on the side of an invalid so as not to cause fatigue in case of actions with multiple switching.
2. Necessity of training to send switching signal should be minimized.

3. Switching signal should be easily differentiated by an invalid from control signal.
4. An invalid should dispose of highly reliable information as to which actuating mechanism to control system is connected to at the givenmoment.

Our own physiologic study of the prerequisites to construct sequential action control system with switching demonstrated that one of the simplest combination code versionssatisfying enumerated demands is the simultaneous activity of the controlling muscles.
Functional diagram of our multifunctional prosthesis sequential control system, in which simultaneous activity of controlling muscles is used as the signal of switching from one type of motion to another, is shown in Fig.I.

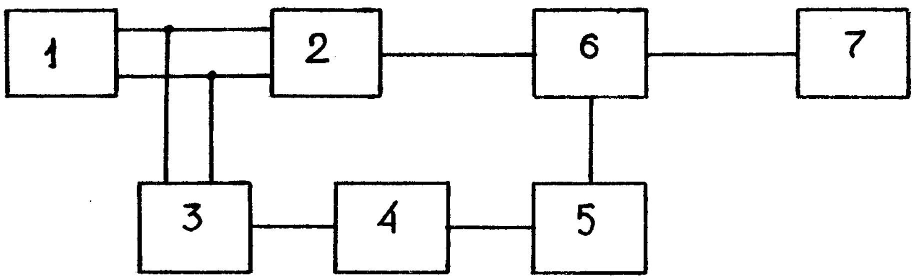

Fig.I. Functional diagram of multifunctional upper extremity prosthesis bioelectric proportional control system. I-control signal tapping unit; 2- signal amplifier-converter assembly; 3.-impuls signal forming block; 4.-logic switching device; 5.-access unit:; 6.-commutation unit; 7.-actuating mechanism assembly.

The system permits to execute proportional (smooth) control of several prosthesis movements. Thus, smooth control of clench-unclench and rotation of an artificial hand is possible with our forearm prosthesis.

The system comprises: control signal tapping unit I, assembly 2 for amplification and conversion of this signal into pulses, frequency and duration of which is proportional to input signal amplitude; impuls signal forming block 3, essential to control a logic switching device ; a logic switching device 4, which permits either writing down or carrying out a command; access unit 5, in which a signal, according to the logic switching device 4 command is sent to the corresponding device; commutation unit 6, connecting, according to the command, necessary actuating element from the assembly 7.

A number of invalids were fitted with the experimental forearm prosthetic appliances, supplied with the elaborated control system. In an effort to value prosthetics efficiency a procedure was applied, where prosthetics efficiency was determined as a quantitative index describing functional result of making prostehtic appliances,i.e. estimation of an invalid´s ability to carry out a subject action of predetermined quality with the help of a prosthesis was taken as a basis. Quality, in this case, is determined by the period of time, spent by an invalid to carry out the specific test. Quality index of a separate test execution may be defined as:

$$K= \frac{t_h}{t_{inv}}, \text{ where}$$

t_h- time interval, which is spent by a healthy man to execute the task

t_{inv} - time interval, which is spent to carry out the same task with an extremity prosthesis.

Then the functional result of prosthetics (F), determined from the comlex of the tests, is defined as:

$$F = \frac{\sum_{i=1}^{n} K_i}{n}, \quad \text{where}$$

n- number of tests.

The obtained index of the functional result of prosthetics with the experimental prosthesis models, supplied with the elaborated control system, defined according to the described procedure, is higher than the respective index of the mass bioelectric prostheses, that demonstrates advantages of the eleborated system over the available ones, in which sequential control principle is used.

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