INTERNATIONAL SYMPOSIUM ON THE APPLICATION OF AUTOMATIC CONTROL IN PROSTHETICS DESIGN
Opatija, August 27 - September 1, 1962

Dr. Rajko TOMOVIĆ, Professor
Electrical Engineering Faculty
and Research Adviser at the
Institute "Mihajlo Pupin"
B e o g r a d

AUTOMATIC CONTROL AND PROSTHETICS

Introduction

It is characteristic of prosthesis design that it depended for a long time merely on practical improvements. New materials and lighter equipment were introduced but basically new principles were lacking. The purpose of this report is to review some new trends in prosthesis design and thus to stimulate discussion about their potential values for the patients. Most of the recent advances in prosthetics are concerned with the application of automatic control and electronics in one or other form. The idea of bringing closer automatic control, electronics and prosthetics may become very promising for all these fields and it deserves our full attention. For this reason the Symposium in Opatija has been planned to bring together specialists of various training and to provide them with ample time for exchange of opinions.

Before proceeding further it should be noticed that the term prosthesis has a very wide meaning referring to artificial parts of human body as a whole. Evidently, the whole subject cannot be dealt with at this meeting. Since a narrower subject has had to be selected, the problem of human extremities has been chosen. In this field much effort has been put recently to obtain a basically improved prosthesis. Thus, whenever, the word prosthesis occurs in the text it should be interpreted in the above sense. This fact however, does not exclude that some principles mentioned in the paper may not have wider implications in prosthetics.

The Role of Automatic Control

It is clear that functioning of human extremities can be considered as a control problem. From the viewpoint of automatic control our extremities are a specific kind of actuators controled by conscious and reflex channels. Such an analogy with servomechanisms has little meaning unless the specific differences of the biological and conventional servoactuators are fully understood. Let us therefore observe specific features of human extremities control:

- Human extremities represent a very complex kinematic system while engineering actuators have relatively few degrees of freedom (linear and/or rotational movements).

- The many degrees of freedom of our extremities require control signal sources of high information content. This fact is important and we shall concentrate mainly on this problem in our further discussion.

- The control signals used are of two distinct origins: one set consists of conscious control signals, whereas the second governs the reflex loops. These signals are of sensory origin.

Each of the above features deserves special attention. Attempts have been made to incorporate them, at least in a most rudimentary way in different prostheses. For instance, research in the exploitation of conscious, i.e. bioelectrical signals for prosthesis control is carried out in many centers. Advances in this field will allow the patient to put the control signal sources under his willing command. In addition digital information processing devices with all their possibilities to store and process input data are also under test. Some results of such a project will be presented at this Symposium.

Generally speaking, a perfect prosthesis should incorporate all the above-mentioned features. However, at this stage of technology a more sophisticated prosthesis design hits the barrier of cost and compactness very soon. For this reason, individual research centers usually pay more attention to one or the other aspect of prosthesis control and all available models in practical use are still far from the performances of their biological counterparts. Taking this fact into account, I shall point out the specific philosophy of prosthesis improvements as developed in Yugoslavia.

Information Theory Approach

An interesting problem in the theoretical study of prosthesis is to establish some general mathematical principles which could serve as a guide for improving the design procedures. For instance, in the design of optimal and adaptive control systems, various optimization criteria, such as mean square error and others, are taken as a starting point. In our attempt to find an analogous scheme for prosthesis control, we have come to conclusion that the information theory can serve as a basis for a unified design criterion in the evaluation of prosthesis. To be specific, let us observe the grasping action of the human hand or walking process. One way to design the adequate prosthetic device would be to use conscious signal sources for all phases of the hand action and all degrees of freedom. Evidently such a solution would put a heavy burden on the patient. However, in order to obtain the natural functions of the lost limbs, the information to control and coordinate various movements must be at our disposal.

The above seemingly paradoxical situation, can be solved in another way without affecting the artificial limb performance. Having in mind that the control signals are of concious and sensory origin, the prosthesis control can be organized in such a way that reduces the information content of conscious signals to minimum. In an ideal case, it should consist of sets of on-off commands, while all additional information should be derived from lower levels.

After such a principle, which seems adequate, is established, the question arises how to incorporate it in the practical device. Consequently, in our investigation we have put much more stress on the role of information provided by the skin. This includes in the first place the information coming from the sense of touch, and temperature in the second. It is also easy to imagine artificial hands with sensory elements which are not found in biological systems such as, for instance, radioactive signal sources, etc.

Having thus obtained a new and rich signal source one can use it for the initiation and control of reflex actions. In fact, all or part of the information provided by sensory elements must not go to the central or conscious control place for processing, but should be directly used for servomotor control. Such loops are called local feedback loops and their existence greatly reduced the information content of conscious signal sources without affecting the artificial hand performance.

In addition to the sensory elements and local feedback loops, we have also used positive feedback connections, delay and simple logical elements in order to obtain flexibility of the artificial hand, but without unduly increasing the information content of conscious signals provided by the patient. The artificial hand we are designing now will have following unique features:

- Handling of objects of arbitrary shape
- Controled hand pressure
- Automatic locking of the hand in the desired position.

All above functions, however, are performed by using only one on-off conscious signal on the part of patient. In other words, the central control source has to provide only one piece of information, and the rest will come from the sensory elements. To avoid confusion, we have been referring to the grasping of the object itself and not to the control signals needed to bring the arm in the required position. This is a different process including a visual feedback. Since all necessary details concerning this process will be given by other authors, there is no need to repeat them here. The main purpose of this paper was to point out the role of a simple and general theoretical criteria in the design of our hand.

Conclusion

At this stage of development of science and technology, conditions have been created where a prosthesis with basically improved performances is feasible. The best way to achieve this aim is to give the problem of control signal sources full consideration. In our opinion it is not wise to rely only on conscious signals in the prosthesis design. In the existing prostheses with muscular power, while attempts are made today to use bio-electrical pulses. But in any case this source of control signals soon sets a limit on the available prosthesis functions. In the future work much more attention should be paid to the control signals coming from other sources, such as the sense of touch. Thus, the increase of available prosthesis actions does not necessarily mean a direct increase of the information content of conscious signals. The automatic control theory with all its recent advances is of great use in solving the above problem.

In addition to the above conclusion another fact must be pointed out. The modern prosthetics is in a great need of unifying theoretical approaches which should bring out clearly the common aspects of seemingly separate problems. Such a solid scientific foundation of prosthetics is equally important as the advances in hardware improvement. Efforts in this direction are essential for faster development of basically improved prosthesis. In order to prove this thesis, let us quote some examples. By comparing the design of prosthesis and remotely controled handling equipment from the viewpoint of reducing the centrally (consciously) produced information, one can see that both fields have many points in common. A remotely controlled manipulator with sensitive hand surfaces can greatly reduce the channel capacity by linking it to the central control place. Another problem is to use a local feedback and artificial skin for leg prostheses. In short, mathematical foundation of prosthetics, in addition to its engineering and medical aspects, is another important task laying ahead of us.
