INTERNATIONAL SYMPOSIUM ON THE APPLICATION OF AUTOMATIC CONTROL IN PROSTHETICS DESIGN
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W E D N E S D A Y, 29 AUGUST

SESSION II (continued)
SESSION III

SESSION II - CHAIRMAN Prof. WOOMER, England

CHAIRMAN: Good morning Ladies and Gentlemen. May we continue with session II and Dr. Groth will deliver her second paper.

Dr. GROTH: This is more a question for electronic people.

(THE PAPER ENTITLED: "PRACTICAL TRANSDUCER PROBLEMS IN ELECTRO-MECHANICAL CONTROL OF ARM PROSTHESES" by John Lyman, Dr. Hilde Groth and Gershon Weltman of University of California, Los Angeles, has been already distributed).

CHAIRMAN: Thank you Dr. Groth. It has not been possible to arrange to have a complete summary of this paper this morning. This paper is open to discussion. It has been suggested to me that it would save time and probably be acceptable if questions that are asked in English are not translated into other languages, only the questions asked in Serbo-Croatian or other languages will be translated into English. Does that meet with general acceptance? Thank you. This paper is now open for discussion.

CHAIRMAN: Dr. Wiener? If you wish, the microphone is on your left.

Mr. WIENER: The word transducer has been used here and I wonder whether it has been used in a general sense of all transducers, or linear transducers.

Dr. GROTH: In the general sense because we are not quite sure upon its linearity.

Mr. WIENER: Yes, I see. Well, then I think that it must be a very relevant thing to consider the problem of transducer design both from the standpoint of analysis and the standpoint of synthesis, as applied to non-linear transducers.

Dr. GROTH: Well, yes, I go along with that, but we still have the problem of how to get it on the man, how do we get the stability.

Mr. WIENER: Yes, I know, I did not say that it was everything, but I said that it was a very important thing to do. Now, the point I wanted to make is that I think that we can actually, if we can get a record, in some sense or other, of what the person is trying to do of his idea of what his will is to do and at the same time of the actual motion made, which will actually measure his own action as a transducer of his will into action potential, then we can determine what sort of external transducer would be necessary to convert the action of that transducer into the programmed action desired. Is there any way that you can do a record, or can you imagine any way of what the man is trying to do? Could you give an indication in some way of what he is trying to do, so that he could examine himself, his own actions as a transducer of his will, into whatever comes out as electrical activity? If you could do that, you would be in a very strong position to determine what external transducers should be coupled to give the programmed motion wanted

Dr. GROTH: I do not see anything except getting into the EEG and thereis very little correlation to outward activity.

Mr. WIENER: No? What is the possibility of getting EEG and recording it on the same tape, that you record the EMG and study the outward correlation and cross correlation for the linear relations, or even going beyond to non-linear.

CHAIRMAN: Could I point out that by EEG you mean electroencephalogram that may not be obvious to everyone. If you could

forgive my interruption.

Mr. WIENER: Sure.

Dr. GROTH: Well, I know of some work that has been done along those lines, and I think that so far they have all failed to find any correlation between the EEG and some outward activity. Anything beyond fatigue or something or other.

Dr. WIENER: Is there any way of doing the following thing: Not working with the EEG but having the patient describe, as you give various clicks- let's say so to give him a timing from outside, when he wishes to move, when he is determined in other words to play a subjective record against electromyogram record and compare these. I think it can be done.

Dr. GROTH: Well, it might be interesting to try.

Mr. WIENER: Yes, I think it is well worth trying.

CHAIRMAN: Is there anyone else who wants to take part in the discussion?

Mr. WEINMAN: What kind of transducers have you actually used?

Dr. GROTH: For the EMG?

Mr.WEINMAN: No, for getting the muscle movement.

Dr. GROTH: Oh, for the muscle movement. Well, the Northwestern arm has those little mercury switches. The model and the French hand is being started by pressure on an air-filled bladder. You can get a little pump attached to it and you can adjust the pressure to the patient, since some of them like to work against fairly high pressure and others against fairly low pressure. So the pressure can be individually adjusted, but the whole thing is non-linear, and of course, since you can adjust the pressure individually you really do not know the characteristics too well at all and, furthermore, it is, well, just sliding round and adjustes in the great sweat accumulation in the circuit, and therefore it leaks after about a week or two. So it is a real

problem. Now, the Heidelberg arm comes in various diagrams, depending on the patient, I only mentioned here the word key sequential valves, where you have a six position key valve. That is the pneumatic arm. If the patient happens to have some cine-plastic canopy or some other means, they use individual valves. And that works somewhat better. But those are the only ones in existance which we have in the States just now.

Mr. WEINMAN: You did not use them?

Dr. GROTH: We did not use them at all yet and we have been thinking about that. This will entail a new fitting method, because you need a very tight fit of whatever shell you will put on the arm. You know that, leather changes in the shape of the stump, sometimes the matter can increase in bulk considerably, sometimes it sort of degenerates. So it might take quite frequent re-fitting. We would like to try some surgical methods and for the past two years we have been looking for an amputee. One of our surgeons would be quite willing to loosen little parts of a muscle and have localized bulges which than would be very easy usable for strain-gauge transducers, but we are lacking a subject.

CHAIRMAN: Thank you. Dr. Reswick.

Mr. RESWICK: I just want to mention a type of strain-gauge which I saw in the group at the University of Kentucky used for studies of anthropological nature, that is they are interested in the movements of bones relative to each other under high acceleration and so on. To make these measurements they have developed a transducer which is rather similar to a strain-gauge with many orders of magnitude of extension. It is very simple and perhaps someone may want to try it. We considered it but we did not yet. It consists merely of a rubber tube of a diameter of perhaps 1/20.000 of an inch, filled with mercury and with electrodes at each end. As the rubber tube is extended by a hundredth or more the cross sectional area decreases by approximately the same amount and the resistance of the mercury thereby decreases.

The total volume stays about the same and eventually comes under a certain amount of pressure, so that the mercury does not come apart. So it becomes essentially a very low impedance strain-gauge which may have some real use in transistor applications, where low impedance changes are more desirable. I thought for a long time that it is so simple to make an orthesis thing work. One can attach these small devices, which have relatively smart force characteristics and are easy to move across the muscles to measure the muscle strength.

CHAIRMAN: We are rather ahead of it. One of our own colleagues has been using this type of strain-gauge to put round the chest, to measure breathing, to measure the respiratory excursion. We have found it, as you say, satisfactory. An alternative filling for it is coloidal graphit.

Dr. RESWICK: Yes, that is correct.

CHAIRMAN: Does anyone else wish to take part in the discussion? Thank you. In that case I declare this session, session II closed, and session III will start immediately under the chairmanship of Dr. Rakić. Dr. Rakic has very kindly agreed that I shall continue although he will be here at my hand to correct it if I go wrong.

Now we open session III, with the paper by Dr. Reswick from the Case Institute of Technology entitled CONSCIOUS CONTROL OF PROGRAMMED MOTIONS IN ORTHOTICS AND PROSTHETICS. Dr. Reswick.

Mr. RESWICK: Mr. Chairman, Ladies and Gentlemen, in approaching this conference I want first to explain, to make sure that everyone will understand the work which I am going to talk about. This paper is in the nature of a progress report that tells about some things that have been done but mostly about things that we hope to do, and I believe that the dinstinction between these two will be fair. We hope in some years to give a rather differentkind of paper with scientific results. I think that professor Tomović and his associates are to be highly congratulated for considering this kind of conference to be held at this time. I

think that it is particularly appropriate and I am to give my own personal appreciation for very well seat and run of the Conference and such a lovely place on the Adriatic Sea.

The work which we are doing has been carried out in a Laboratory which is associated with the University and the work has been done primarily be students, supervised by faculty members. The work represents the research work of the students - advanced grades. We have an engineering Institute and our object is to involve our students in changing and worthwhile research activities while they are in school. Because we feel that at the time they are learning their theoretical and analytical skills it is important for them also to learn how to work under a disciplinary team and be given important responsibility. And so it is rather different than a Government operated institute of professional people and for this reason some of our ways of working are different. The area of rehabilitation is an important one in our work and of course the opportunity for engineering to make real contributions. It is a vitally important area which has not received, we feel, the kind of attention, scientific attention, that it deserves. This is perhaps the main reason that we as an engineering school are becoming involved in this work. It is being carried on in co-operation with a hospital and the doctors in the hospital, the Western Reserve Medical School. Well, so much for the reasons we are here. Incidentally, if you are interested in the laboratory or some of the other projects that we are doing, I have along a few copies of the progress report. I shall leave it outside with the secretary, and if someone is interested in receiving them I can easily mail them to you. (PAPER DISTRIBUTED)

CHAIRMAN: Thank you Mr. Reswick for your extremely interesting work. Dr. Reswick's paper has been published and distributed and I think that most of you have been fortunate enough to get it. We will now adjourn until 11 o'clock. The session will stop at 12 noon.

First we will have a discussion on Dr. Reswick's paper. After that we will use the opportunity of the projector here that we now have for Dr. Kinnier Wilson to show his slides because when they were shown in the first session, they were not the best. Finally Dr. Lord from Oxford will like to talk to us for a little while on the work that has been doing there.

CHAIRMAN: Dr. Reswick would like to have a word before the discussion is opened.

Mr. RESWICK: One thing I would like to say which I said I shall come back to it but I did not. The problem of maintaining a pressure feedback signal from the orthesis we propose to solve in the following way: The pressure in the cylinder used for voluntary closing, is a very close measure of the force which is being applied by the fingers. So when one obtains a signal of this pressure one knows approximately how hard one is pressing. While we have not studied this thing carefully, initial experiments lead us to believe that it is going to be difficult to use a simple pressure finger. In other words, the first thing that you might think of is to push somewhere on the head region as hard as possible with a simple pressure plunger. The trouble in fact is that as you push on your tissue you feel, but after a while you do not feel it any more and you can not obtain any sort of signal which is proportional to the pressure being applied. Our initial experiments may be of interest to you. It seems that if you produce a simple Bourdon tube, perhaps a rubber tube on winding as a piston on the back of the ear and cause the ear to deflect by an amount which is proportional to the pressure then you obtain a signal which does not deteriorate. At present time one can correlate the position of the lobe part of the ear to a pr ssure signal rather well. At least this is our first attempt.

CHAIRMAN: Thank you Dr.Reswick. Dr. Reswick's paper is now open for discussion.

Mr. LORD: Just one simple question. I am supposing that there would be no difficulty whatever in having this device of yours eventually operated by an amputee. I have particular reason to ask that. Are you sure that this can be fitted to a normal hand?

Mr. RESWICK: Eventually, after a long time.

CHAIRMAN: Dr. Bottomley.

Mr. BOTTOMLEY: May I ask Dr. Reswick what power is consumed by his pneumatic valve?

Mr. RESWICK: The torque motor draws at its maximum about 200 miliampers at about 25 volts.

Mr. WEINMAN: Two questions. Is the high pressure you are using not dangerous?

Mr. RESWICK: There are a number of elements to the safety problem in using carbon dioxide as this high pressure. The first concerns the container itself. The problem of storing carbon dioxide in liquid form at the very high pressures is not really a problem. Our country at least is completely equipped to produce carbonated leverages, and the art of handling the carbon dioxide in containers and storing it and distributing it has been made very, very safe. So the ability to load the containers and to transport them and so on is not dangerous. Now, as to the device itself. First of all it is a research device and we intend that it would be used under very careful supervision. Secondly, all the passages are very close to critical flow, purposely designed this way, so that the velocity of the gas in the passages is just about its maximum. This means that it can not run any faster. It is related to the speed of sound, and therefore if a vlave, a cable, or tube tears, the flow of gas can not be any greater than when it is normally used. Somewhat, but not a great deal. Therefore the major danger, if any, would be that the discharging jet might come close to itssue and perhaps freeze it. But we have an external set-up to warm up the gas so that it is not critical on expansion and we have no freezing. The material we are using is plastic tu-

bing which is rated at 2.000 oz./in^2. Plastic is easy to handle and we use only 500 psi in the tubing.

Mr. WEINMAN: Next question. Can this device be made so cheap that not only millionaires could use it? I mean is it only made for paralyzed millionaires?

Mr. RESWICK: It is not even meant for paralyzed millionaires. By the time we are through, at least in a specified phase of program, the device will cost at least 200.000 dollars. Obviously, it is not a clinically useful device. I think that this is an extremely important point because we do not want anyone to think that this has an immediate clinical use either in hospital or in a lofty home. The project is purely a research project. We are hoping to answer and to ask questions which are asked now and which will be of use perhaps in about ten or twenty years from now. But obviously technology and techniques are moving so fast that in about ten, fifteen or twenty years we may have information storage systems with solid state devices which will be so small, so cheap that actuators can be worn, or there may a central system in a house or in a rehabilitation centre which is broadcasting and available by radio to all of the patients. These things are not possible now but they will be in the future.

Mr. WEINMAN: The results of your work are very, very useful, but the last question is this. You spoke about the transmitter. Now, my question is this: could this transmitter also accept very low signals for modulation?

Mr. RESWICK: Yes.

Mr. WEINMAN: But could it be used also for telemetering let us say EEG signals?

Mr. RESWICK: Yes, it is being used right now to telemeter EEG signals of cats in Western Reserve University.

Mr. WEINMAN: It can not accept signals of a microvolt?

Mr. RESWICK: Yes. You see the effective noise ratio is half a micro volt so that it can handle five microvolts quite easily.

CHAIRMAN: Tahnk you Mr. Weinman. Any other questions? Yes, please, Mr. Kokotović.

Mr. KOKOTOVIC: If I understood well there are five degrees of freedom in Dr. Reswick's system and for each one of them there is an independent servo. This concerns the arm, the upper part of the arm. Has Dr. Reswick considered the possibility of applying an analogous way of thinking to the case of the hand where we have several degrees of freedom? Which and how many of these freedoms would it be necessary to take into account and should they be controlled independently applying similar ideas of programmed control? I understood that the last demonstration with fingers was in fact a willing control.

Mr. RESWICK: Well, let me first ask and answer the question I thought you were going to ask but did not, because I think it is important. The five degrees of freedom are kinematically independent and it took us a long time to find out a structure which would be kinematically independent. For, it is very important that each control system is independent and that there is no coupling between them. Otherwise you get instabilities due to inter-coupling. Now, I thought that Mr. Kokotović was going to ask about the dynamic coupling, that is when one element moves there are inertial reactions which may cause a second element to move. This then will cause a reaction which may reflect back to the first element and cause it to move. This is a very complex control problem and it is being studied by a student now. We do not know the answer yet and we hope that the problem will not be severe but the whole thing may simply go like this. Now, to answer your question, I think that the answer is certainly yes. We are anxious to attack the problem where there is a tremendeous amount to be gained for the patient even if it is costly and difficult to achieve because the C-7 patient has nothing. He can perhaps just barely feed himself if he is lucky, or perhaps he may not even do that. If we can provide the patient with a device which will give him back the ability to eat, to scratch, to shave and to smoke he will try very hard to

make it work for him. Therefore we have to study the problems of communication, of psychology, the problems of cosmetics and so on. These are the most important issues in our study. Now, as to the hand. When I think of the difficulty of designing a high performance servo-device with its feedback and its control valves and everything on the scale of the arm, where everything has to be much smaller, I consider the problem very much more difficult than just the mechanical design problem. If we had a reducing way which would cause everything to compress perhaps it would work. The angle transducer for example, the encoater which we are building is only one quarter of the size of the smallest commercially available. The problem of mounting the disks is extremely severe since they must be mounted to 50 to a 100 millionth of an inch otherwise the signals are erronious. To get the same transducer on the finger it must be again quarter of the size. In ten years it may be possible but I do not think it is now.

CHAIRMAN: Thank you very much Dr. Reswick. Any other questions?

Mr. NIGHTINGALE: First of all I would like to mention the obvious comment that has been made by dr. Weinman that although this is a very forward looking research, some of the byproducts are obviously going to be applicable on a much closer date to practical problems. One of the problems that dr. Reswick has encountered is the same as ours, i.e. the changeover from the electrical part of the control system to the pneumatic part. I personally have been disappointed in a way that, after a considerable study, dr. Reswick decided that this was necessary, that he had been using pneumetics and that he could not find electric motors. As far as I could make out it was smallness combined with speed of action. The other thing is you have gone to 500 psi and this is an interesting departure which is so much higher pressure than other people are using. This of course has probably also increased the difficulty or rather increased the amount of electrical power you need to operate the valve. Now a particular question: you have voluntary control over the finger movement or you are

post-relating voluntary control over the finger movement with feed-back to the ear of the pressure between the fingers. What happens when in your programmedmovement a resistance is encountered? Have you got the information thenwhich tells you how hard you are pressing? Can you override this danger or situation getting dangerous?

Mr. RESWICK: There is an emergency stop provided and we are not quite sure even how that should happen. Whether it should freeze everything where it is or whether it should loosen everything to fall or whether it should slow in carefully back to a neutral position, if it is at all possible. We do not have any signals built in and contemplated for interventions. The power level of the transducers of the actuators is such that it has been designed for example to support a 4-5 lb. weight at the extremity. So this gives you an idea of the kind of forces which it is capable of producing. I think that initially we shall be very careful as we begin to move people into this device, to move slowly and cautiosly and to try and avoid such happening by pre-arrangement. Incidentally, on the control valve the higher pressure does not require higher currents to activate the valve. Really, the problem comes about because of a proportional action that we require. We want the motion of the valve to be directly proportional to the applied current and at the present time the higher speeds of response to do this are obtained through a torque motor which applies an electro magnetic force to a quite heavy spring so that the deflexion of the spring is proportional to the current applied. The flow forces to the gas are not substantially greater than the deflexion take-away forces. We are concerned about leakage, of course, and at the present time the valves we build will leak a pound of CO_2 away in a few hours. To give you an idea where we stand. We hope to get around this possibly by having a solenoid valve in series which will turn the torque motor off when it is not being used to at least stop the leakage

during the normal movement. On the other hand we do not care so much about the leakage because we have the patient firmly enclosed in a room surrounded by equipment and we got lot's of carbon dioxide so this is the least of our worries.

CHAIRMAN: Now, Mr. Lord from the Disabled Living Research Centre the Nuffield Orthopaedic Centre, Oxford will speak for just a few minutes.

Mr. LORD: Ladies and Gentlemen, I am very pleased to have an opportunity to say a few words. I suppose that at this stage in the proceedings my contribution could in some ways be interpreted as being a negative one. Certainly, in the sense that whilst we are not by any means certain of answers we are only too well aware of the problems. To start with, let me tell you a little of the basic outline and aims of the establishment which I am here to represent.

(Diagram produced on blackboard).

The plan was conceived and directed by Professor of orthopaedic surgery in the University of Oxford. Team work is essential and consists of physicians, physical and occupational therapists, engineers and the appropriate nursing and administrative staff. Built as an integral unit on an open plan, accommodation is provided for ten in-patients and 1 small family at any one time, and this in addition to outpatients. Facilities for occupational therapy, physical therapy, recreation and specialized engineering services are integral. Its aims are briefly to provide the maximum possible assistance in any given set of circumstances to disabled persons, with a high emphasis on the paralyzed, and all this in direct relation to the activities of daily living, or as prof. Reswick referred to A.D.L.

The net result of all this takes many forms. In the first instance the unit provides a half-way stage, a step in between the hospitalization and/or other organization. Living-in enables us to observe more closely the personal habits and to endeavour in some ways to find and provide

a suitable answer. Finally, it has provided us with perhaps a unique opportunity of studying in great detail at first hand the problems of approximately 250 patients over approximately two years. Uses made of as many modern techniques as are available, together with additional contribution which our own staff are able to make from time to time. Emphasis is of necessity on the paralyzed type of patients, hence the engineering facilities, and we are therefore more than casually interested not only in what is available to-day but in what modern science and technology is likely to offer to us tomorrow, particularly as to the adaptability of such devices and their acceptance of them by patients. Even at this stage in the proceedings of the Symposium it is quite clear to me that there exist already a definite pattern of relationship between the projects and exhibits which we have so far seen and which have been so ably described and certain major block groups of crippling diseases.

(At this point schematic diagrams of, on the one hand, disabilities and on the other the projects were produced and inter-related by arrows).

Briefly, the major blocks appear to consist of firstly, the amputee with which block Mr.Swettenham of Roehampton is concerned. The second major block would appear to be consisting mainly of the paralytic polio and the distrophic group with their wheelchair as a common factor. In the case of the amputee blok it is quite obvious that both the motor described by Dr. Kinnier Wilson and the motor described to us by Prof. Reswick will be applicable. In relation to the second major block, it is possible that the motor described by Dr. Wilson may be used under control system which has been so well described by Dr. Nightingale and Dr. Bottomley. At the same time we have found that the use of simple ball bearing arm supporting equipment, is both practical, economical and provides a fairly high dividend in results and requires no engineers. From time to time use is made of the McKibbon muscle but only in selected cases.

The third block undoubtedly consists of the high cervical lesions which as has already been pointed out is unfortunately on the increase and in this connection the project put forward by prof. Reswick would appear to offer a practical means for using a control system. I am impressed by his paper and although he has told us that the initial cost is likely to be of a phantastic order and mindful, that all developments charges are high. And the possibility surely exist that by the time this is available costs will have become more realistic. At the same time where the need is paramount cost may at necessity have to take a second place. The fourth block in which I have put a question mark relates to the immediate problem of dealing in some affected way with the Talamid children. Together with other organizations we are concerned that solutions in some of their problems of living should be presented fairly quickly. Informally we have already had discussion with interested parties in this connection the contribution made by prof. Reswick strikes me as an equipment which could be of great importance. The control unit of Dr. Nightingale and Dr. Bottomley could well be a first step, and at the same time I regard the paper given by Dr. Hilde Groth of some importance. Obviously now that we have been presented with suggestion of alternative body sites for control systems the importance of this paper will be readily appreciated when attempting to work out schemes for dealing with children borne without either upper or lower extremities. Little has been said about the desigm of the terminal splints. In both professor Reswick and Dr. Wilson's illustrations the devices are presented as being applied to an upper extremity of fairly generous physical proportions. In actual practice this seldom occurs and one is more likely to be faced with the problem of fitting a splint to an arm which may be little thicker than a cigarette packet. Careful consideration should therefore be given in good time to suitable terminal splint design. During the Symposium I have had the opportunity of speaking informally with scientists and technologists working in this field, and in-

deed coming over from Italy an board I had a long session with Dr. Nightingale and Dr. Bottomley. They are both very conscious that in many instances there exist a fairly wide gap between the projects and their development and the patient, sometimes they do in fact wonder if, as Dr. Nightingale so ably put it "They are working under right lines." We would do well to remember why this Simposium isbeing held, our work interesting and varied though it may be, is entirely in the long run directed towards improving the lot, although less fortunately placed.

To the various questions put by dr. Nightingale, I would express the view that there exists a definite place in the general pattern for the type of control systemupon which he is working. Indeed, I hope that he will be encouraged to proceed so that in the near future we on the application may have the advantage of using this equipment.

CHAIRMAN: Thank you Mr. Lord.

END of the WEDNESDAY session, August 29, 1962.