ON THE HUMAN CONTROL OF "CRITICAL" TASKS IN PROSTHETIC AND ORTHOTIC EQUIPMENT

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Introduction

Studies in prosthetics and orthotics in the past have been concentrating on two basic approaches: first, to operate a device completely by direct human control, and second, to make the tasks automatic with the human control relegated to a higher level [1]. There are obviously problems with both approaches. Direct human control of complicated equipment, such as a hand and arm prosthesis, is difficult because of the number of degrees of freedom which must be controlled. If one muscle of the man were "connected" to each degree of freedom, the man could conceivably, in time, be able to train himself to operate such a device successfully. However, this is a complex way of solving the problem from a user's standpoint. Even with this scheme, it may be necessary to have a small computer make the proper coordinate transformations, etc., necessary to resolve the control axis into something which can be humanly controlled. Thus some automation is required.

On the other side of the spectrum is a completely automatic device in which the human has to decide only simple functions such as mode of operation; on, off, etc. The problem with this solution is one of adaptability. That is, to pick up an egg would require different forces than to pick up a cigarette; to hold a suitcase would be different than holding a candy bar, etc.

It is the purpose of this paper to show a way in which the advantages of both approaches can be attained with one device. The basic prosthesis considered will be effectively an automatic device in which the "sensitive" requirements are reassigned to direct control by man. The idea is to use direct control only when necessary. In most operations this mode may be locked out. Direct man control will be done by an element of the man with similar sensitivity as the element being replaced. Thus in a hand prosthesis when sensitive control is required, perhaps a foot could be used to provide the direct control.

Finally, the purpose is to show the increased usefulness and adaptability of prostheses and orthoses so designed. This is provided by a mechanical hand model operated by the foot.

The basic concept involved is one of defining the tasks requiring sensitive direct control. Such tasks as mentioned above require a prosthesis to be adaptive dependent upon the situation. In the case of a hand prosthesis such tasks require the same basic operation. The only significant difference is the pressure required to hold an object. The selection of the proper pressure is essential. Thus the operation of holding an object with a hand prosthesis can be considered a "critical task".

It is interesting to note that one human control element, such as the foot in the above example, can be used for many different critical tasks if they are spaced sequentially in time. This is the most general application of this concept. Thus, if a prosthetic arm-hand system, for example, has the requirement to hold objects, to transfer objects from place to place, to maintain precise positions, etc., each critical function can be controlled in turn by the same foot. The only necessary requirement is a selector mechanism which allows the switching of these functions.

In order to allow this switching, it is obvious that locking mechanisms are required to maintain a desired force or position. For example, consider a prosthetic hand-arm system which is required to 1) pick up a cigarette and hold it, 2) to transfer it precisely to the patient's mouth and maintain this position, 3) to return to an ash tray and release the cigarette, and 4) to return the arm to a rest position. To perform all these functions, a single foot operated transmission element can be used. It can be used first for force or pressure control to pick up the cigarette, then a force lock must be used to hold the cigarette. Next the transmission element can be used for final position vector control for the arm, i. e., the magnitude of the closing velocity vector to the patient's mouth. Once the desired location is reached this function must again be locked in position. (Note vector directional control can be an automatic system as proposed by others [2]. Next, for returning the arm to the ash tray the same velocity vector control can be used but in a negative sense. Finally, to return the arm to a rest position, the element can be used for velocity control. Actually this final function can be completely automatic since no "critical tasks" are involved.

Discussion

The method suggested here for the solution of this problem is the concept of hydraulic transmission. A hydraulic transmitting system consists of a transmitter or pick up, a transmission line or tube, and a receiver or reproducer. Both force and position can be transmitted, dependent upon the system design (transmitter versus receiver sizes, etc.). Schematic of such a system is shown in Figure 1.

The objective is to transmit the force or motion of a human controller to the prosthetic device. This fluid coupling provides a simple means of transmitting forces or positions. That is, for a force transmission system, the transmitter may be large compared with the receiver. On the other hand, for a position transmission, the transmitter and receiver may be comparable in size. Each system must be designed specifically for a task.

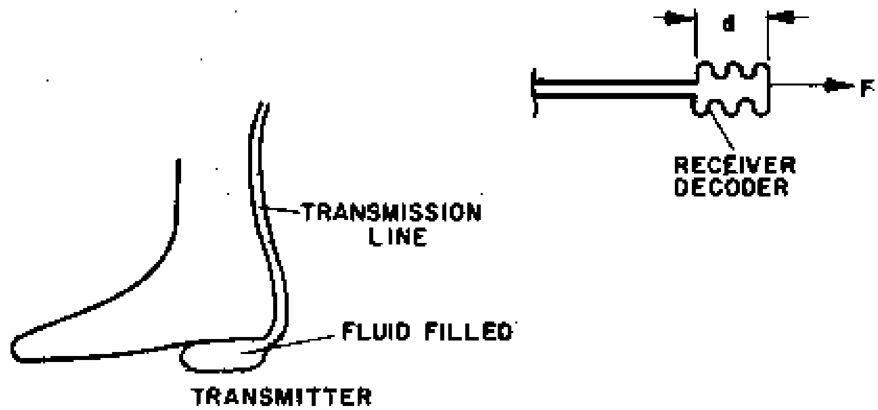

Fig. 1. Hydraulic transmission system

In general, it is not desirable to force the human element to maintain control continually. At least two problems arise if the human is required for continuous control: first, he cannot be used for other functions, and second, he must concentrate on the use of the device continuously. Thus, to alleviate these problems and to provide the capability of using the same human element for other control purposes, a hydraulic lock can be introduced. Such a lock maintains pressure or position of the receiver regardless of the transmitter's behaviour. A possible lock mechanism is shown in Figure 2.

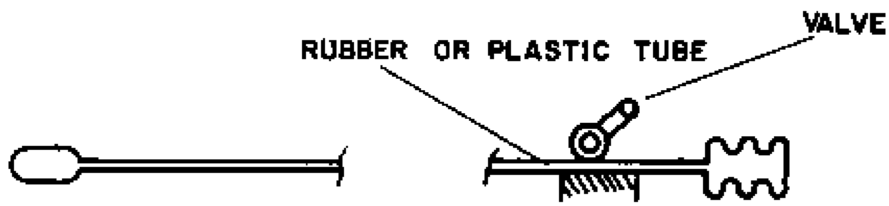

Fig. 2. Hydraulic transmission system with lock

A slight change in receiver pressure or position can exist at the receiver when operating such a lock; however, if the transmission line or tube were small, then this change can be kept quite small.

These locks allow much system flexibility, since the transmitter section is completely independent of the receiver, when the lock is "on." Thus, it is possible to have many functions for a single transmitter. The circuit of such a device looks like one given in Figure 3.

Thus, by the selection of valves, the various receivers can be operated. Of course, it is also possible to operate all receivers at the same time, and in certain cases this may be desirable. In general, single operation seems to be the most applicable.

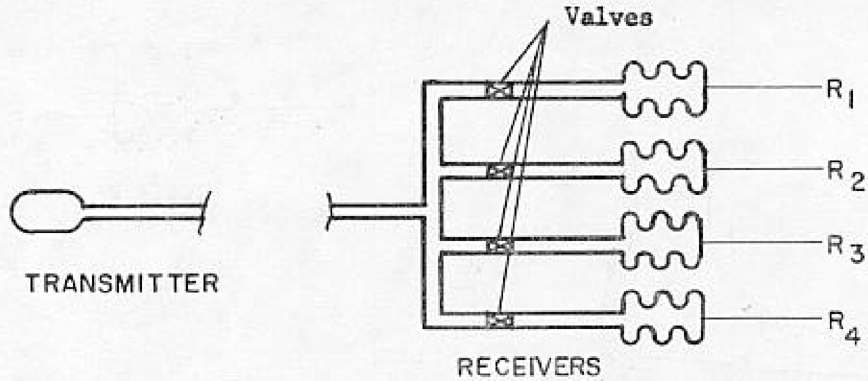

Fig. 3. Multiple duty hydraulic transmission system

The design of a hand-arm prosthesis using this concept is shown in schematic form in Figure 4.

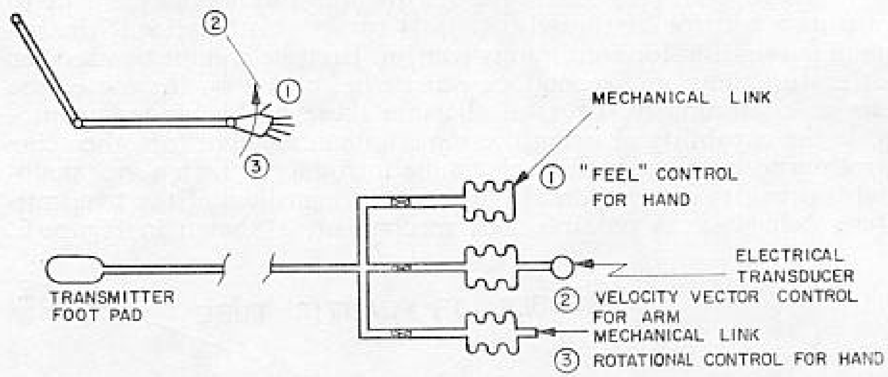

Fig. 4. Hydraulic transmission system for an arm-hand prosthesis

The first function provides purely force control to a hand. The second provides velocity control where velocity is a function of the force applied by the controller much as an accelerator pedal. The problems of coordination of joints and angles must be solved by a computer in order to achieve the desired path. The transducer merely provides an electrical signal proportional to the force applied. The computer then determines the velocity vector. The third function is a positional control for the rotation of the hand. This function must rely on visual feedback to provide a judgement of the desired versus commanded angle. These three functions differ completely with respect to the type of control. The man must adapt himself to the task desired, but man has this capability. The objective is to make the various tasks simple enough so that he can conceivably control the device. Further, it is to make a device which can utilize man's continuous control and adaptive nature.

This hydraulic transmission concept is not meant to be the sole source of control for prosthetic equipment. The tasks which are non-critical are well suited for conventional automatic control.

The construction of a Hydraulic Transmission Device.

A model of a prosthetic hand has been constructed using the concept of hydraulic transmission for the actuation of the fingers. A schematic of the device using hydraulic bellows is shown in Fig. 5. A two millimeter tube connects this receiver bellows to a transmitter. This model uses another bellows for the transmitter. The final model would use a bladder which could easily fit into a man's shoe.

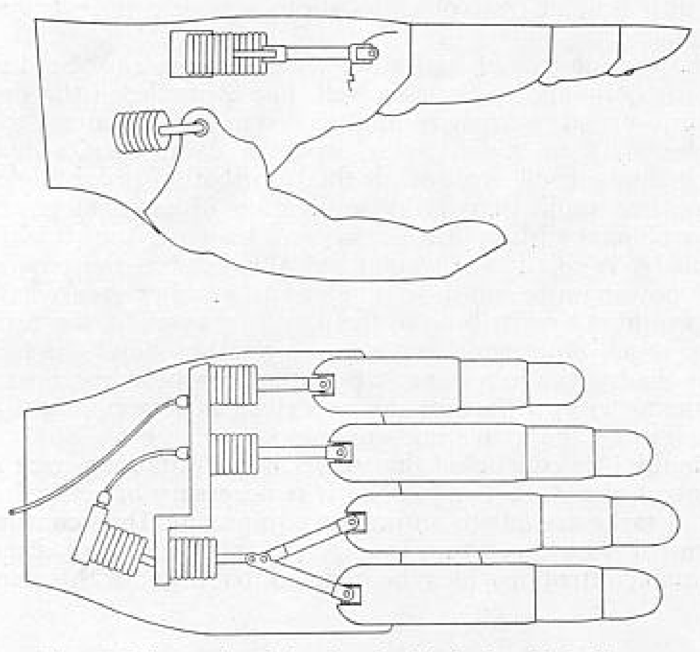

Fig. 5. Schematic of the hand with hydraulic bellows

The present model is intended only as a demonstration of a concept. It is definitely not in its final production from. This model replaces all the mechanisms now in the present model with four bellows. These are connected to the fingers. The thumb actuator is connected to the main supply through an orifice. Thus two actions are possible with this hand. For slow application of pressure, the hand will close to a pinch. For fast application of pressure, the hand will close to a clinch or fist. The orifice provides a delay on the thumb which allows this dual action.

An estimated weight for the hand is 350 grams. This is considerably lighter than a hand constructed with an electrical motor. It also has the capability of faster action, sensitive control due to its direct human connection, and the capability of locking a predetermined force. This model has very light return springs so that the sensitivity of the transmitter to receiver system can be preserved.

Conclusion

This paper shows the usefulness of the concept of hydraulic transmission in the direct control of devices in which "critical" tasks requiring careful human control are necessary.

The concept is applicable to remote manipulators, as well as prosthetic equipment. It can also be used, in an augmented form, to transmit human control to locations where proper transducers can be placed.

The mechanism of hydraulic transmission can be used for other prosthetic applications as well. For example, in the design of lower limb prostheses where angles need to be maintained, the desired angles may be given by a program cam; then a hydraulic coupling can be used to transmit the cam motion to leg angles.

Another application is in application of external power. One of the problems with artifical arms and hands is the weight of the mechanisms. A significant weight has always been the power units. If these power units could be removed to another area where their weight would not contribute to the prosthesis weight, the prosthesis could be much improved from a user's point-of-view. The idea is to use only the hydraulic receiver where the prosthesis requires power. The transmitter can then be power driven at a non-weight critical area such as on the man's body or torso.

Finally it is concluded that this scheme puts man back into direct control of a device only when it is necessary or critical; boring or menial tasks are left to automatic equipment. Thus continual human control is not necessary in general. This concept of discrete direct human control provides the main contribution of this paper.

REFERENCES

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2. Gavrilović, M. M., Marić, M. R., "An Approach to the Organization of the Artificial Arm Control", *3rd International Symposium on External Control of Human Extremities*, Dubrovnik, 1969.