A SINGLE SITE MYOELECTRIC CONTROL SYSTEM FOR PROSTHESES

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Summary

A control system that is suitable for use with prosthetic and orthotic system has been designed and fabricated at the Applied Physics Laboratory of the Johns Hopkins University. The closed-loop, position servo system comprises signal acquisition electrodes, signal and servo amplifiers, power control circuits, and a battery pack power supply. The control system has been used with a prosthetic hand operated by a small, self-contained electric motor. It has also been applied to a power pack concept, which transmits power to terminal devices through a flexible cable.

The control system concept, rather than the particular prostheses with which it has been used to date, is of primary interest. The major advantages of the system accrue from its utilization of only one control site. In these applications, the "rest" (terminal device closed) position corresponds to minimum (relaxed muscle) control signal voltage. The terminal device opens in direct proportion to control signal amplitude as the muscles contract. Power control circuits conserve battery power by de-energizing the servo amplifier when it is not necessary that the drive motor be powered.

This concept is believed to be applicable to a variety of prosthetic and orthotic functions and devices.

Introduction

Since myoelectric potentials were first used to control prosthetic devices, many types of systems and control mechanisms have been developed. Typically, a small, high speed DC motor is geared down to drive a mechanical linkage that, in turn, operates the moving parts of the prosthesis. For a self-contained drive mechanism to be satisfactory for a wide range of applications, including use in prostheses for amputations near the wrist, it must fit within the space envelope of the hand and must satisfy such diverse criteria as high closing force and moderately high opening and closing velocities. It must be light, silent in operation, and low in power consumption. Control of prostheses is frequently acomplished by using myoelectric signals from two or more control sites to operate the drive motor in either on/off or proportional modes of operation.

Initial studies of myoelectrically-controlled prostheses conducted at the Applied Physics Laboratory of The Johns Hopkins University were based upon the concept of operating the motor in the on/off mode. The direction and duration of motor rotation were controlled by signals from a pair of control sites. Threshold detectors were utilized to control electromechanical relays that, in turn, controlled the drive motor.

Analyses of an experimental embodiment of this concept substantiated concern about many of the practical problems that must be considered in such a design. As a result of the initial study of the two-site, open-loop system, the control concept was modified to provide operation of the prosthesis in a proportional mode using only one control site. This technique effectively eliminated difficulties with electrical cross-talk, which are some of the major problems with the two-site control system. In a later modification, a remote power pack concept was modeled. This obviated the requirement for packing the motor and system within the prosthesis. This concept also allows additional flexibility in the selection of components and in the mechanical design of the drive and control mechanisms.

This paper reports on the work conducted at the Applied Physics Laboratory and discusses results obtained from experimental hardware.

Prosthesis Control Concept

In the initial work with the two-channel, open-loop control system, difficulties with electrical cross-talk similar to those encountered by other researchers were much in evidence. On almost all of the (non-amputee) volunteer subjects examined, it was very difficult to locate control sites that provided sufficiently high-amplitude signals, correspoding to the natural flexion and extension of the fingers, and sufficiently low-amplitude cross-talk, so that inadvertent actuation occurred infrequently. On some subjects a pair of suitable control sites could not be found on the forearms. In all cases, placement and "quality" of electrical contact with the skin were critical. Changes of as little as one-fourth inch in location of the electrodes introduced problems. This control technique was deficient also because even with optimized electrode location the hand motion was unnatural and jerky and control of the hand required much concentration on the part of the subject.

In the course of this work, it became apparent that the usable dynamic range of the signal between the noise level with muscles relaxed and the maximum output with muscles contracted was typically as great as 6 : 1. It appeared that signals from one control location could be used for proportional control provided the hand mechanism could follow these signals and not expend excessive power in doing so.

The first servo-controlled terminal device fabricated at our laboratory is shown with its cover removed in Figure 1. The fingers are driven by a small DC motor. The frame casting is from an Army Prosthetics Research Laboratory-Sierra cable-operated mechanical hand with the internal mechanism and the actuated fingers and thumb removed. A 30:1 gear reduction and lead screw mechanism is utilized to operate the thumb in opposition to the fore and middle fingers in three-jaw chuck fashion. The operating fingers are made of silicone rubber cast on "skeletons" of aluminum. Because of the silicone rubber and skeletal structure, this hand is superior for picking up objects of small diameter to hands fabricated of cast plastic or formed steel. Also, the resiliency of the silicone rubber and the aluminum skeleton minimizes loss of grip resulting from structural deformation. In use, the hand would be covered with a realistic-looking cosmetic glove commercially available in the United States. The hand is relatively rugged, but will suffer damage if abused. The major weaknesses of the design appear to be the motor, with its rather severely limited brush life; the gear train, which utilizes comparatively light-duty gears; the slip clutch, which tends to change in adjustment; and the lead screw, which has a tendency to seize at extremes of its travel or if the fingers are closed firmly upon a rigid object.

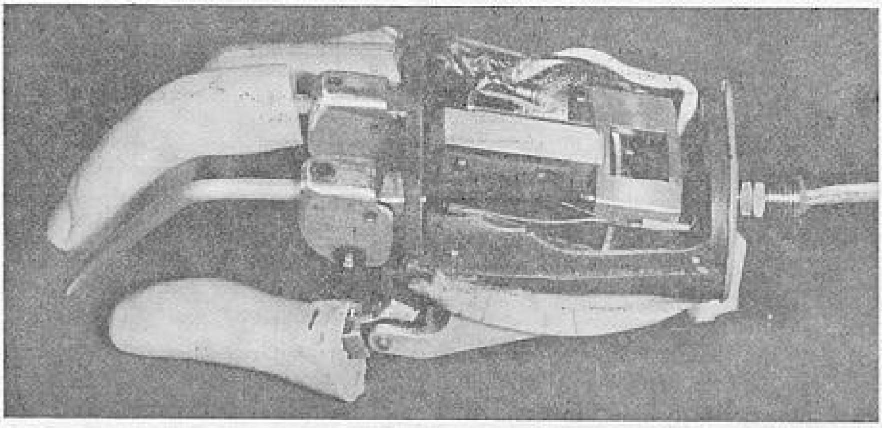

Fig. 1. Servo-controlled artificial hand

A block diagram of the control system is shown in Figure 2. The system is a closed-loop position servo that follows the amplitude-demodulated myoelectric signal. A description of the operation of the system follows.

The myoelectric signal is acquired by stainless-steel-surface electrodes that are held in intimate contact with the forearm. The signal electrodes are spaced approximately one inch apart; the ground reference is located midway between the outer electrodes. The electrodes can be placed close to the flexor or extensor muscles that control the fingers or anywhere else on the body where suitable signals exist. One commercial-grade "flat pack" integrated circuit operational amplifier is used in the preamplifier. The circuit is arranged with a differential input and has a gain of approximately 2000. The preamplifier response peaks at approximately 200 Hz. At 60 Hz, the gain is down by a factor of 12 db and is attenuated by 28 db at 4 kHz to reduce system noise. The output signal from the preamplifier is amplified by an additional stage before it is envelope-detected. Over the operating range of the system, the DC output of the detector is roughly proportional to the amplitude of the myoelectric input signal.

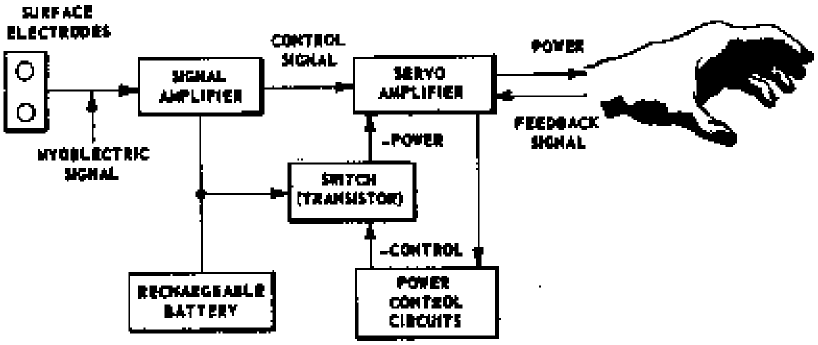

Fig. 2. Block diagram, servo-controlled prosthesis

The output of the detector is applied to the servo amplifier that controls the electric drive motor in the hand. With the muscles relaxed and with minimum control signal, the hand is in its closed position. When the muscles tense the electrodes pick up the motor, opening the hand. The hand continues to open until the voltage on the wiper of a potentiometer sensing finger position is equal to the control signal. The system drives in both directions with equal force and velocity. The hand is servo-controlled for all positions between closed and full open. Grasping force is limited during slow closure by the stall torque capability of the motor. If the motor is operating at high speed when the fingers close upon a rigid object prehensive force is limited by the slip clutch. When power is removed from the motor, the fingers are locked in position by the nonreversible lead screw mechanism.

The position servo allows the hand to be opened slowly or quickly and to any opening the amputee wishes depending upon the user. This control technique provides a simple interface between the amplitude-time characteristic of the control signal generated by the amputee and his prosthesis. The system mimics electronically the time-proven voluntary opening hook. The amputee need generate only one signal when he desires to open the hand, and when the control muscle is relaxed the hand automatically closes and maintains a grasp force without any further effort or attention on the part of the amputee. When the amputee wishes to disengage the hand, he contracts the control muscle. When the command signal exceeds the voltage that corresponds to the hand opening, the fingers open and the object is freed.

One of the limitations of a position servo for a portable system application such as a prosthetic device is that it could consume an excessive amount of battery power if it were allowed to operate continuously. To minimize power consumption, a power cutoff circuit was developed that cuts off power from the servo amplifier when the hand is closed or after the hand has grasped an object. Operation of this circuit is fully automatic and does not require additional input from the amputee. Power control circuits that operate from the servo error signal were devised. Typical operation of the power cutoff circuit is shown in the diagram of Figure 3.

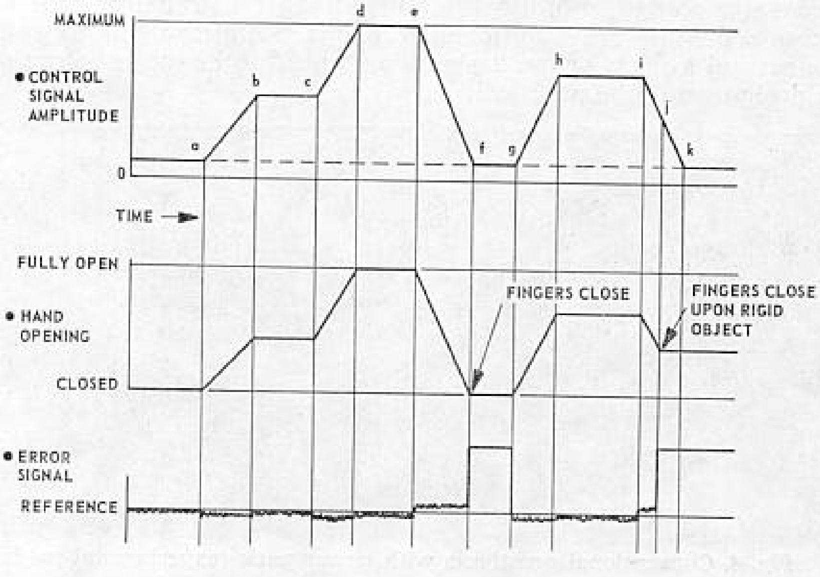

Fig. 3. Typical operating sequence (position-servo prosthesis)

Other power control techniques are also being considered. One such technique is being evaluated in conjunction with the servo error signal cutoff circuit. Power is removed from the motor when the control signal drops below a prescribed threshold as well as when an error signal is developed. The hand can be de-energized when the fingers contact an object with light force, and nonrigid objects can be grasped without being crushed. The input signal for this circuit is taken at a point preceding the final low-pass filter in the control channel, and can therefore drop faster than the servo control signal.

Mechanization of the Prosthesis

A study of techniques that could be employed to mechanize the hand so as to achieve desirable grasping force levels and acceptable opening and closing velocities pinpointed some of the more significant problems in achieving a satisfactory mechanical design for such a prosthesis. The limited volume, allowable weight, power consumption, etc., impose serious constraints upon the mechanical design and potential reliability of the actuating mechanism. Severe design trade off compromises must be made to achieve even primary system objectives. For example, the APL experimental hand shown in Figure 1 weighed 18 ounces, developed a force of approximately 5 pounds at the finger tips, and opened or closed in 0.9 second. The excessive weight, motor-gear train noise, and probably poor long-term reliability are significant problems. Significant improvements in several aspects of the design would need to be made before such a design would be practical.

Fig. 4. Conventional prosthesis with power pack (experimental model)

An example of an alternate approach to mechanization of prosthetic devices is the external power pack concept. In such a system, the driving force is developed by a mechanism that is not an integral part of the prosthesis itself. Instead, the force is transmitted to wherever it is to be used by a flexible cable or some other power transmission mechanism. A conventional above-elbow prosthesis operated by an experimental model of an external power pack is shown in Figure 4. The Bowden cable provides both hand opening and elbow function. This experimental unit can supply 21 pounds of force to the cable, and will open or close the hand in approximately 0.5 second. The power pack weighs 2.0 pounds; it seems probable that this can be reduced in later models through selection of a motor better suited to this application. The motor is a low speed, high efficiency, direct drive servo motor of a configuration used extensively in high-performance, severe-environment servo applications. A gear reduction of only 3 : 1 is used. The minimal use of gears results in a quiet system with a predicted life (without service to the motor) of 5 to 10 years. Such a unit could be worn at the waist, as shown in Figure 5, or elsewhere on the body.

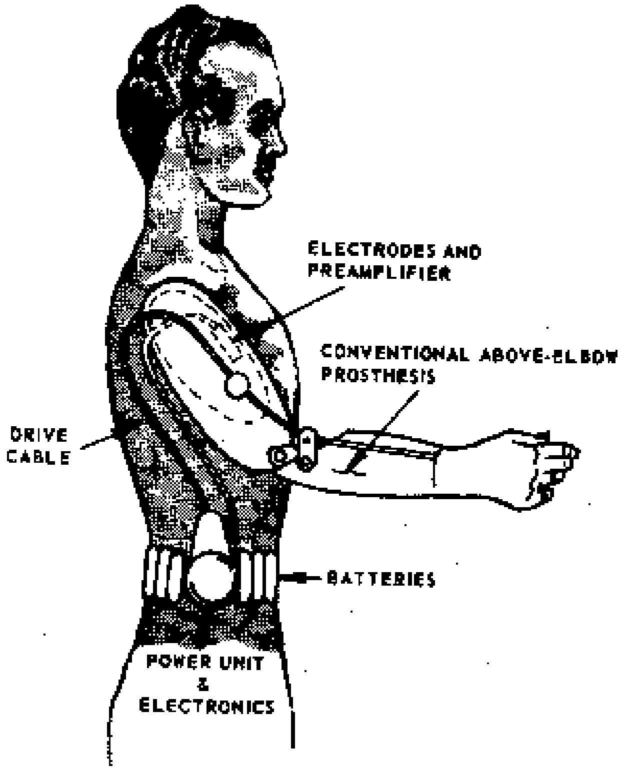

Fig. 5. Typical "power pack" system utilization

The major disadvantage of this system appears to mechanical losses in the drive cable. Heavy cables are commonly used in body-powered prostheses because they must be able to withstand the high forces that can be developed by the body. The amputee can develop forces significantly greater than those required to operate terminal devices. High losses are normal with heavy cables because they are stiffer and larger in diameter than lighter-duty cables. It seems highly probable that more efficient power transmission mechanisms (including push-pull cables) could be designed for use with this power pack.

Large motors like the one used in this power pack may provide a means of operating prosthetic devices at velocities and force levels sufficient to carry out many everyday tasks. Motors with high torque capability at low speeds minimize the need for gearing and configuration. A large motor like the DC toque motor utilized in the prosthesis alleviates some of the limitations on motor weight and configuration. A large motor like the DC torque motor utilized in the experimental power pack is not likely to fail due to prolonged stall loads.

Conclusions

A power pack used in conjunction with the servo control system described here may provide, at least in some measure, solutions to some of the problems encountered in externally-powered prosthetic devices. It could perform a variety of functions, and could be used with commercially available hands, hooks, or orthotic devices where power-assist would provide an advantage to the user. The same power pack and electronic design could be used by children as well as adults.

The mechanism designer has much more latitude when designing a power unit for a system such as this. For example, additional reliability and simplicity of the mechanical design can be achieved if a power pack weight of 25 to 30 oz. is acceptable and if the designer is not limited to small mechanisms that must fit inside the prostheses. A power mechanism of comparable weight located in a hand would be intolerable.

Additional engineering and evaluation tests are planned to further explore this remote power pack concept for control of prostheses. Clinical testing is planned at the Johns Hopkins Medical Institution to help define problem areas and practical capabilities and limitations of such a system.