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CONTROL SYSTEM FOR A MULTI-FUNCTION PROSTHETIC HAND*

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Abstract

A modular system was developed for controling a five-finger hand with individually activated fingers. The desire is to permit the amputee to try out different classical and advanced control schemes before he chooses a prosthetic for his one use. The system is destined for use in rehabilition centers where patients would be given a prosthetic hand that is individually taylored to their needs and ability to control by assembling modular mechanical and modular electronic components. The simplest control permits one of three preselected types of grip (pinch, hook, or key). By changing modular circuit cards we can have the two-grip Belgrade system or some new three-grip systems. The control systems only require one control signal and offer automatic features to unburden the user of the device from direct control.

Introduction

After explaining the difference between on-off and proportional control to hand surgons, prosthetists, and patients alike only with some difficulty, and having it forgotten the next day, a recent experience was quite convincing as to the value of practical demonstrations. In a test setup where both on-off and proportional control of a prosthetic hand by means of a sholder mounted potentiometer could be compared, a hand surgon replied that though he still could not find much difference between the proportional and on-off systems, still being able to make small or large movements with either, he greatly preferred the proportional system!

With the task at hand of designing a simple to operate, multifunction control system for the five-fingered Télemécanique hand, we kept in mind the value of practical demonstrations. Primarily at the urging of Professor P. Rabischong a modular

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system of control was designed that permitted both single- and multiple-function operation to be compared as well as the standard variations: on-off vs. proportional, EMG vs. potentiometric, and one vs. two sites of control.

Télemécanique Hand

The Télemécanique hand (Figure 1) is a completely modular design with five identical electric motors powering the four fingers and thumb. Each of the motor-finger units is independantly removeable and replaceable. The four finger units are identical except for the little finger which has shorter joint segments. After each motor and worm reductor stage there is a unidirectional coupling that passes the full torque of the motor to the finger in closing, but permits the force of a spring to do the opening. In this way, once the hand is closed on an object, a very large force is required to open the fingers, back driving the worm gear, but when the fingers are open a very small external force can close them. The fingers while closing with an active force of 5 Newtons resist an opening force ten times greater (50 N) and close with an external force one-tenth as large (0.5 N).

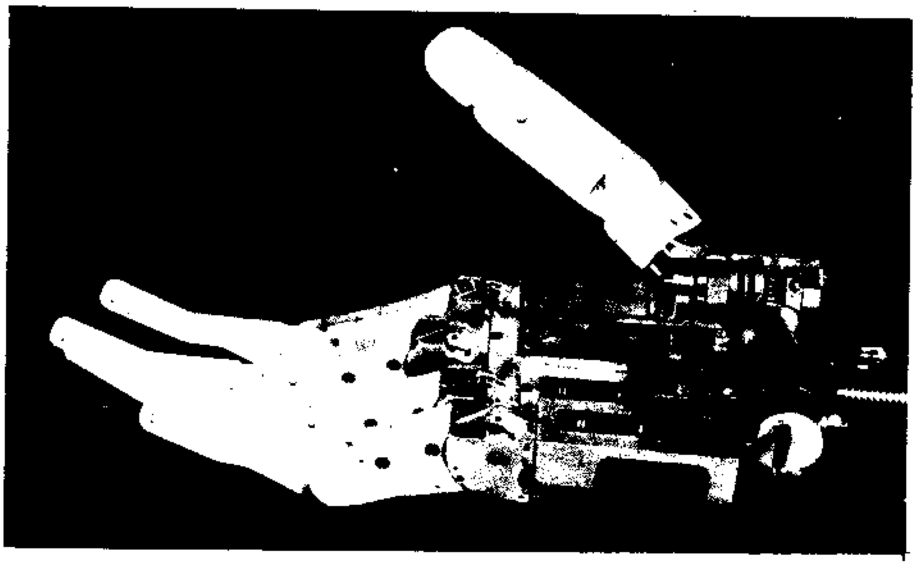


Fig. 1 Télemécanique Hand Prothesis

The operation of the thumb is different from the fingers in that it has two motions, a rotation and a flexion. when the inward rotation toward the palm is stopped, either by the mechanical stop or by meeting an object, a clutch is mechanically engaged and the thumb flexes and curls to meet the palm of the empty hand or the object.

With these modular components many different hand combinations are possible. The prosthetist may make a hand using one or two modular powered fingers and a fixed thumb or,alternatively, fixed fingers ond a powered thumb. Control of such single function gripping systems poses mo problem for the control system, but what intrigued us was the possibility of using both powered thumb and the first two fingers to obtain a multiple gripping system.

Modular Control System

The control of such a multifunction hand poses a difficult problem for the amputee. For example, using straightforward proportional control of the three motors, three independent control sites would be needed. With standard EMG control of each of the three fingers we would need six sites, three for opening and three for closing. Obviously too cumbersome to control. What is actually desired in a useful system is a way to control the desired grips that requires only one or two control sites.

Because of the comparative evalulation to be carried out with the different control systems, effort was made to make the new multi-grip control system modular rather than minature. To achieve this goal the structure was divided into four functions, with one circuit card per function. The different functions chosen, shown as blocks in Figure 2, are implemented as seperate printed circuit building blocks that plug into a chassis. By standardising the signal levels in the circuits it is possible to provide interchangable function cards that work with all the other cards. With a dozen seperate function cards it is possible to realize hundreds of combinations that a rehabilitation center may wish to implement for custom fitting a wide variety of patients.

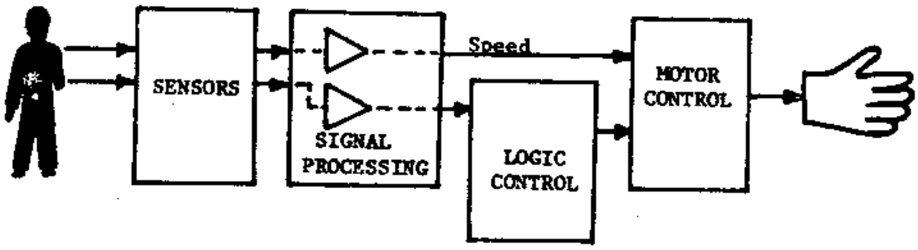


Fig. 2 Breakdown by function of the control system

The building blocks listed in Table 1 are largely conventional and well known to readers except for a few that deserve special attention. "One-site amplitude control" uses the amplitude of the control signal to operate the hand. For example, a large

Table 1. Control Building Blockes Desired

Function	Building Blocks Desired
Sensors	Potentiometric (body mounted) EMG Muscle volume
Signal Processing	2-site (agnoist-antagonist) 1-site amplitude control 1-site sequence control
Logic Control	Single function • Triangular pinch • hook • Termino-lateral Two function • Belgrade Hand (pinch, hook) Three function (all single functions) • Code & Speed • Self-sequencing • Code Control
Motor Control	Same circuit common to all other blocks

amplitude causes opening of the hand and a small amplitude causes closing. The three-level amplitude control described by Klasson /1/ may be more valuable because it permits intermediate rest positions of the hand with the small amplitude(or relaxed) position. The "one-site sequence control" is the same as used in the Belgrage hand prothesis /2/. The motor control system has a common speed input that controls the speed of all three motors and seperate open and close logic commands for each motor. A new approach to EMG processing and the approach to multifunctional control are described seperately below.

EMG Proportional Control

It is possible to obtain a proportional, direct voltage for controlling the speed of a motor from the EMG by rectifying, filtering, and intergrating the myoelectric signal. Because of the noisy characteristic of the EMG, however, it is desireable to use an integrating filter with a long time constant to obtain a smoothe, well filtered signal. This type of filter has the disadvantage of introducing a signigicant delay between the stop of the musclear activity and the stop of the motor.

In our laboratory we have made use of a simple electronic device which reduces the stopping delay to 0.1 second. The block diagram of the processing system shown in Figure 3 is basically similar to other EMG control systems as the system of Lozac'h /3/ The sens of rotation and speed of a moter are smoothely controlled by the voluntary contraction of two muscles, usually an agonist and atagonist. Electrical activity of each muscle is detected by a pair of external silver electrodes and amplified by a classic differential amplifier. An Absolute value circuit doubles the frequency of the signal, increasing the sensitivity of the system, and facilitates the filtering. The pulse former which follows is a monostable vibrator giving standard pulses of 1 ms. duration for each EMG pulse.

The main difference between this processing and the conventional processing are the rectifier-filters F_1 and F_2 following the monostables of Figure 3 (shown in detail in Figure 4) which reduce the time delay in stopping the motor. The filter has a discharge time constant (RC) of 2 seconds providing good smoothing of the musclear contraction signals. The gate voltage of the FET is kept positive during this time, but when the musclear activity ceases, the gate voltage falls to zero 0.1 sec. later, quickly discharging capacitor C through resistor r.

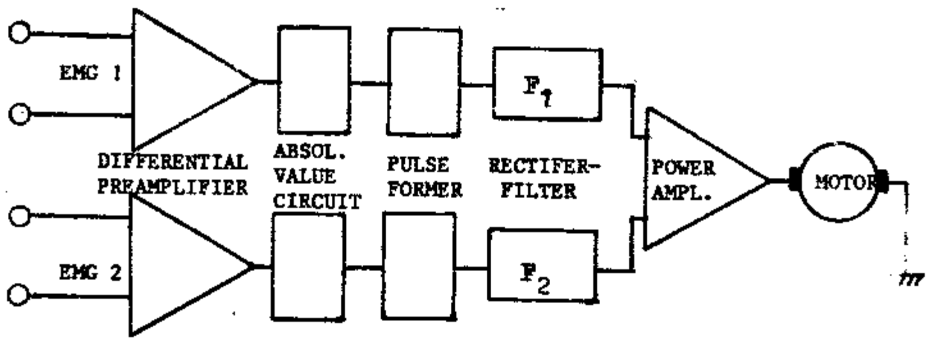


Fig.3 Block diagram of EMG proportional control

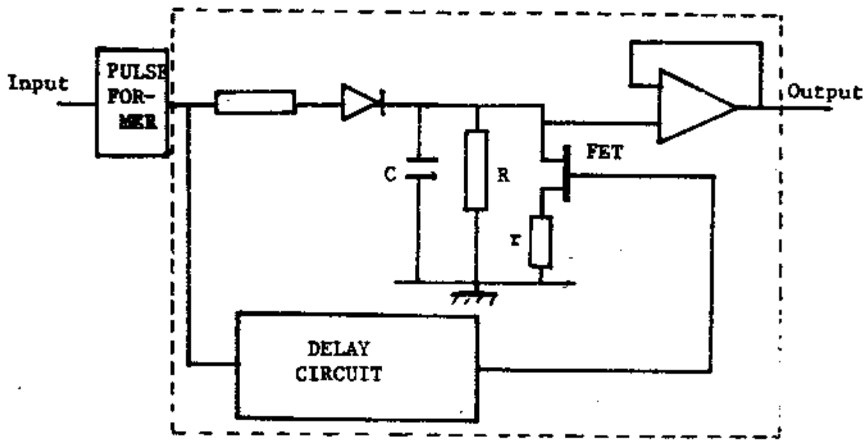


Fig.4 Schematic diagram of the rectifier-filter

The time coarse of the rectifier-filters F_1 and F_2 is shown in Figure 5. As the frequency of the input signal (upper trace of Figure 5) is increased slowly to 150 Hz and quickly dropped to zero, the response of the two filters (lower traces) follow proportionally the frequency of the input and drops to zero quickly after the signal ceases.

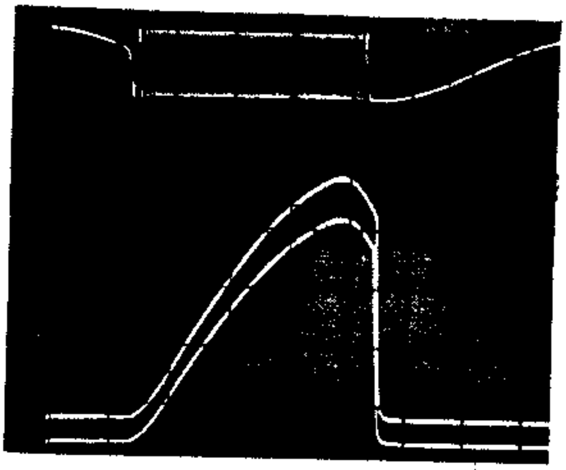
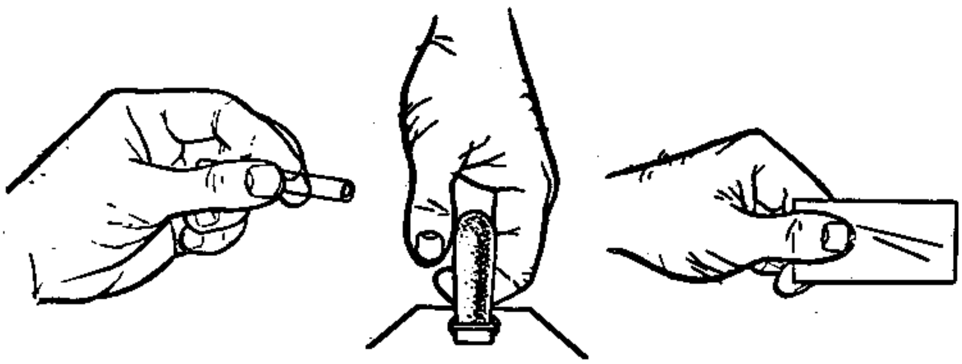


Fig. 5 Response of the EMG detector circuit

Multiple Function Control Systems

Of the many grips possible with the five fingered télemécanique hand we have chosen the three shown in Figure 6 as the most usefull. All three grips use the index and middle fingers and thumb.The problem is to control these three motors of the hand to obtain proportional control of the three selected types of grips. Three approaches to this problem are being implemented for comparison. They are based on the control system described by Sword and Hill /5/ that uses one proportional and one binary (or code



Triangular Hook Terimmo-Lateral

Fig. 6 The three grips used as defined by Schlesinger /4/

selector) control site to control a 7-df arm orthosis. The block diagram is shown in Figure 7a. In addition two other systems have been built for comparison. First is the self-sequencing control system of Figure 7b which is similar to the two-function Belgrade hand system /6/ except that the closing of the hook grasp is terminated with the thumb to obtain the termino-lateral grasp.

With self-sequencing control the state of the hand (the position of the fingers and thumb) is used to regulate the motor directions to obtain a series of three grips. The state of the thumb and fingers is determined by individual microswitches which sense the opening of the three fingers. Closing of the fingers is sensed by the motor currents which mount when the fingers close. With this information a simple system of digital logic causes

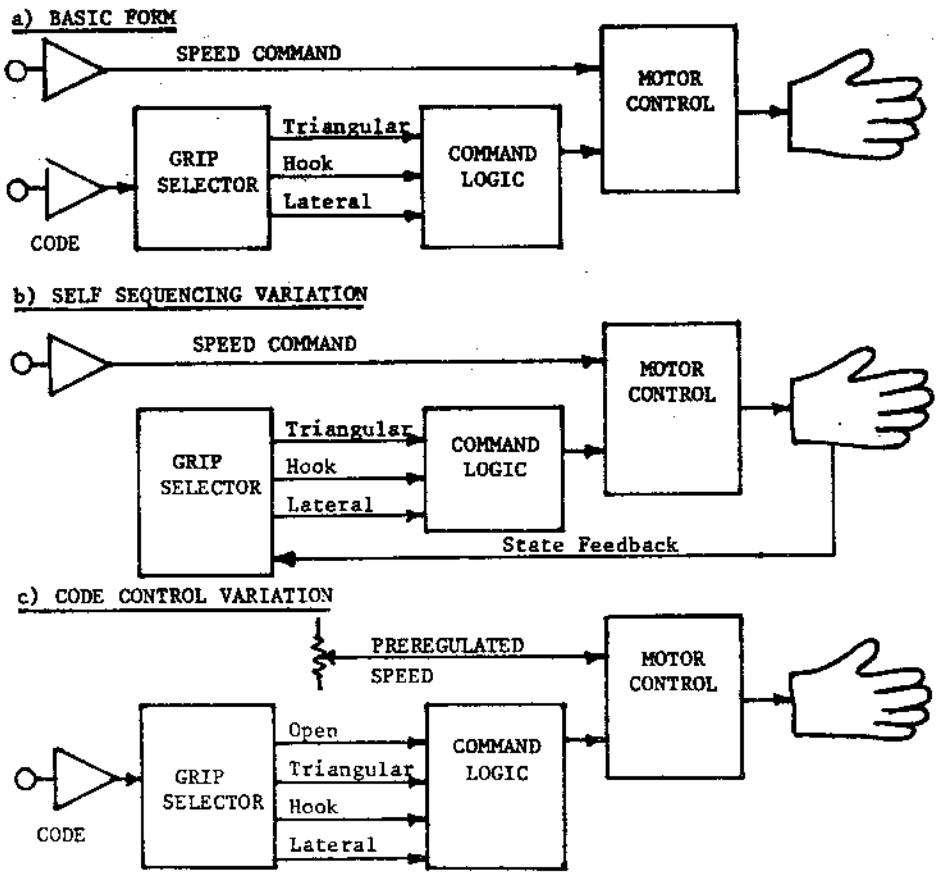


Fig. 7 Three types of multifunction control systems

the following sequence of motion:

1) Starting with the closed <u>triangular</u> pinch, the fingers first open, the thumb remaining fixed.
2) When the fingers are full open, the thumb lifts.
3) When the thumb is completely open, the fingers close (<u>hook</u>).
4) When the fingers are completely closed, the thumb closes (<u>termino-lateral</u>).

A control signal of the opposite polarity reverses the sequence.

In the code control variation of the system shown in Figure 7c, the speed is preregulated and the type of grip is determined by a code signal. Allthough different types of code signals have been proposed using both amplitude (hi-low), duration (short-long) or location (two seperate body operated switches) the mode of code control used here utilizes tactile feedback. When a body switch, for example, is closed, a series of bursts of vibration are presented on a tactile stimulator. If the person releases the switch after the first burst, the hand opens; if the switch is released after the second, third or forth vibration, the hand closes with the triangular, hook, or termino-lateral grasp respectively.

Getting back to the basic form of binary-proportional control which uses both the mode selector and proportional sites as shown in Figure 7a, one site with feedback specifies the mode of griping and the other site controls the opening and closing ot the hand. If it is not desireable to provide active control of the mode selector by a body switch, an external push-button switch mounted on the hand itself may be used to select the different grips.

<u>Summary</u>

During the design of the multiprehension control system, the goal of a simple to use control system was kept in mind. The amputee must not be burdened with many control sites and hard to exercise control, but must be provided with a system compatable with his lost member. In controlling our arms or hands we think in terms of directions and distances. For example, we may want to move our arm up and to continue the motion until we contact an object. Similarly with our hand, we may simply want to drop something, no matter how we are holding it. To do this with an artificial hand we must not burden the patient with a large number of control sites and the job of thinking which to operate simultaneously (like the three motors of a prosthetic hand). Instead we must convey the idea of function to the automatic control system. One attempted effort to convey this function with code signals is described in this paper. The authors hope to carry out an evalulation program to compare the three types of multifunctional hand control systems with conventional single-function control using both normal and amputees as subjects in a following study.

Refrences

/1/ B. Klasson, "Three-way Valves for Biomechanical proportional Three-state Control," in P. Herberts, et.al.(ed): The Control of Upper-Extremity Prosthesis and Orthoses, Springfield, Thomas, 1974, p107.

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/4/ G. Schlesinger, "Der Mechanische Aufbau der Künstlichen Glieder," Part II of Ersatzgleider und Arbeitshilfen, Springer, Berlin, 1919.

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/6/ Z. Stojiljković, "Control of the Multifunctional Hand Prothesis," M.Sc. Thesis, Center for Multidiciplinary Studies, University of Belgrade, 1971.

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