A MICROPROCESSOR BASED SYSTEM FOR CONTROL OF MULTIFUNCTIONAL MYOELECTRIC HANDS

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SUMMARY

A microprocessor based system for pattern recognition control of multifunctional prostheses is described. Its features are small size and low weight which allows it to be incorporated as a module in most conventional prostheses. The power consumption is reduced through a separate power down function during stand by. The computing capacity of the control system is great enough to perform proportional control based on pattern recognition of multiple myoelectric signals. The introduction of the microprocessor based control system is believed to increase the clinical patient acceptance of multifunctional prostheses as it makes self-containment possible. Furthermore, the routines of prosthesis application will be simplified as the digital systems allow individual adjustments to be carried out through changes in the program rather than through changes of resistors as in an analog system.

INTRODUCTION

Multifunctional prosthetic hands allowing grasp, forearm rotation and wrist flexion are widely believed to be of value in rehabilitation of below-elbow amputees. Several attempts to develop multifunctional hand prostheses for clinical use have been made (8, 11, 12, 14, 16, 17). Two major obstacles have up to now impeded successful clinical use of these devices: failure to construct a reliable, light and self-contained prosthesis, and difficulties to achieve sufficiently accurate control of multiple movements.

A new approach based on pattern recognition for the control of multiple prosthesis movements was introduced by Finley & Wirta (7, 18, 19). The pattern recognition method has since then been developed and modified for control of multifunctional prosthetic hands by Herberts et al. (9). A clinical application study of a Swedish multifunctional hand prosthesis (10) shows that the pattern recognition method is an accurate and easy way of achieving control of multiple movements. Therefore, pattern recognition control seems to be the solution to the difficulties in controlling several simultaneous movements.

Systems for proportional control of myoelectric prostheses, i.e. the force and/or velocity of the movements are proportional to the RMS value of the EMG signal, are under development at several prosthetic centers. Proportional systems are necessary for accurate control of the fast prostheses now appearing on the market (6, 13). Proportional control also gives sensory feedback to the amputee, thus increasing the usefulness of the prostheses (3). However, the signal processing necessary for proportional control, especially in a multifunctional prosthesis, is more complicated than in on-off control. As pointed out by Childress (5) and confirmed by most researchers working in the field of hand prosthetics, self-containment of the prosthetic system including the power source and electronic circuitry is essential for the patient acceptance. The Swedish myoelectric pattern recognition system for on-off control (1) is based on analog electronics. The development of an analog proportional control system would make containment within the prosthesis very

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difficult to achieve. As showed by Almström et al. (4), the lack of self-containment makes the patients reject the prostheses because of problems with the cables and the suspension of the electronic circuitry. The problem of clinical rejection of the multifunctional prostheses in spite of excellent control is thus a problem partly related to the unability to achieve prosthesis self-containment. Therefore, the aspects related to the system development as well as to miniaturization are in favour of utilizing digital systems for proportional control.

This paper is a report of the first steps in the development of a microprocessor-based digital system for pattern recognition control.

PRINCIPLES OF PATTERN RECOGNITION CONTROL

In almost all cases, an amputee retains a cortical image of the lost limb. This phenomenon is known as the phantom limb perception. The amputee can imagine movements of the limb, yielding an outflow of signals to the peripheral nervous system. In response to these signals, there is activation of the remaining muscles or parts of muscles that would have been recruited for the imagined movement of the uninjured limb. When a below-elbow amputee performs - or rather attempts to perform - movements with his phantom hand, he contracts the remaining forearm stump muscles. These muscle activities can be registered as electric signals by means of a number of surface electrodes. The relative intensities - the patterns - of rectified myoelectric signals picked up are specific to the various movements imagined. Patterns recorded by six surface electrodes when the patient performs finger flexion and extension, forearm rotation (i.e. pronation and supination), and wrist flexion and extension are shown in Fig. 1. Such patterns being reproducible can be utilized for classification and identification of the phantom hand movements. This can be accomplished by means of pattern recognition techniques.

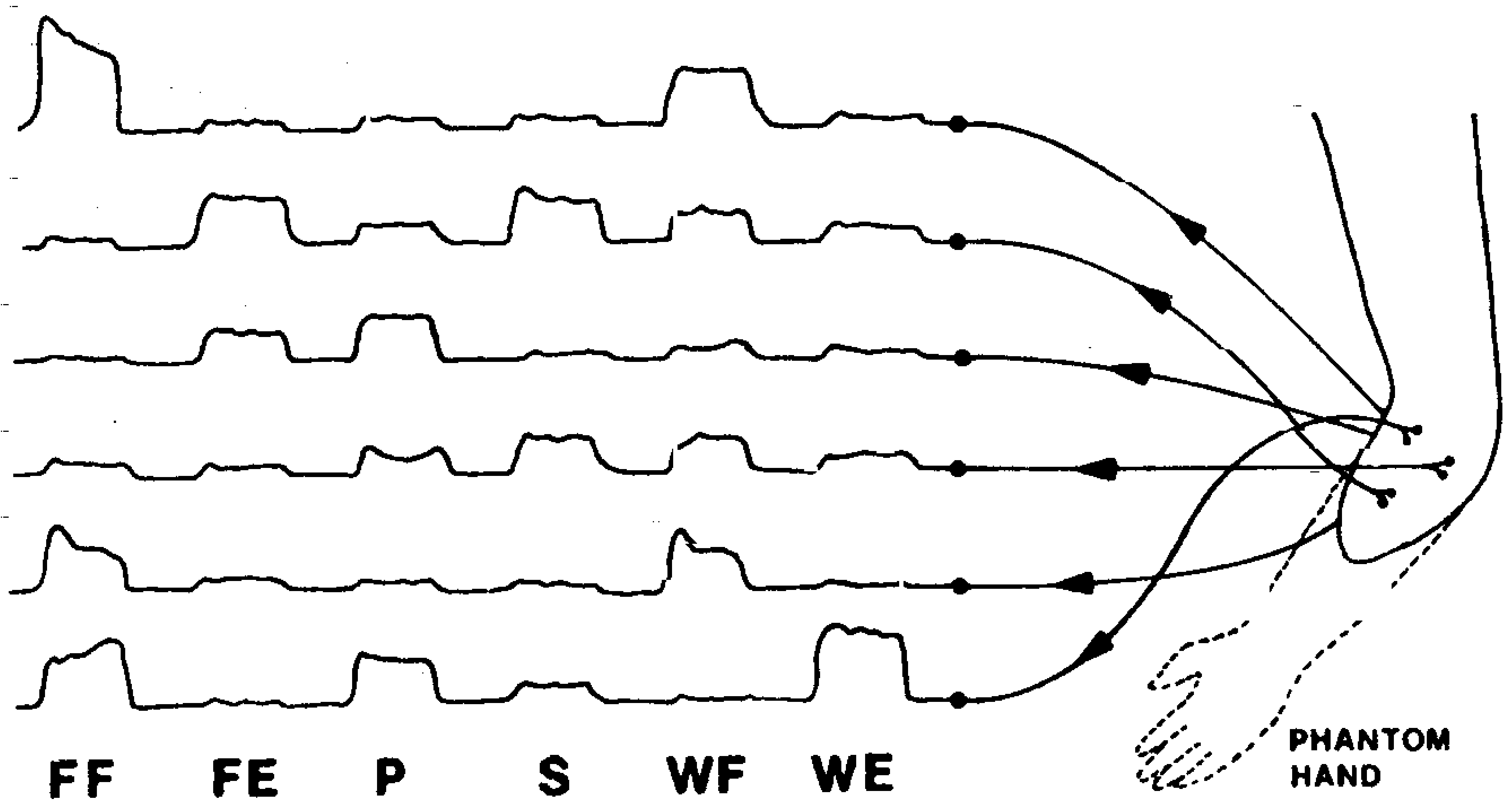

Fig. 1. Myoelectric signal patterns recorded by six surface electrodes when the patient performs finger flexion (FF), finger extension (FE), pronation (P), supination (S), wrist flexion (WF) and wrist extension (WE).

By means of a computerized linear discriminant analysis of six myoelectric signals, a set of discriminant functions can be calculated. The discriminant functions, one for each movement, can be expressed as follows:

$$f_j(X) = W_j^t X + w_{oj},$$

where

$$X^t = (x_1, \ldots, x_i, \ldots, x_6)$$

and

$$W_j^t = (w_{1j}, \ldots, w_{ij}, \ldots, w_{6j}).$$

The index j is used for movement number j, and index i is used for electrode site number i. The symbol x_i denotes the rectified myoelectric signal from electrode site i, the symbol w_{ij} denotes the corresponding weighting factor obtained by the computer analysis for movement number j. The symbol w_{oj} is a constant term.

In the classification procedure performed by the microprocessor, the function values $f_j(X)$ are examined. If $f_j(X) \geq 0$, the pattern is classified as deriving from movement number j, and if $f_j(X) < 0$, it is not classified into this class. The examination is performed independently for each movement and hence simultaneous movements are possible.

SYSTEM DESCRIPTION

The entire system consists of the following main parts (Fig. 2):

a) Active electrodes
b) A/D converter
c) Processor
d) Motor interface
e) Power control circuit

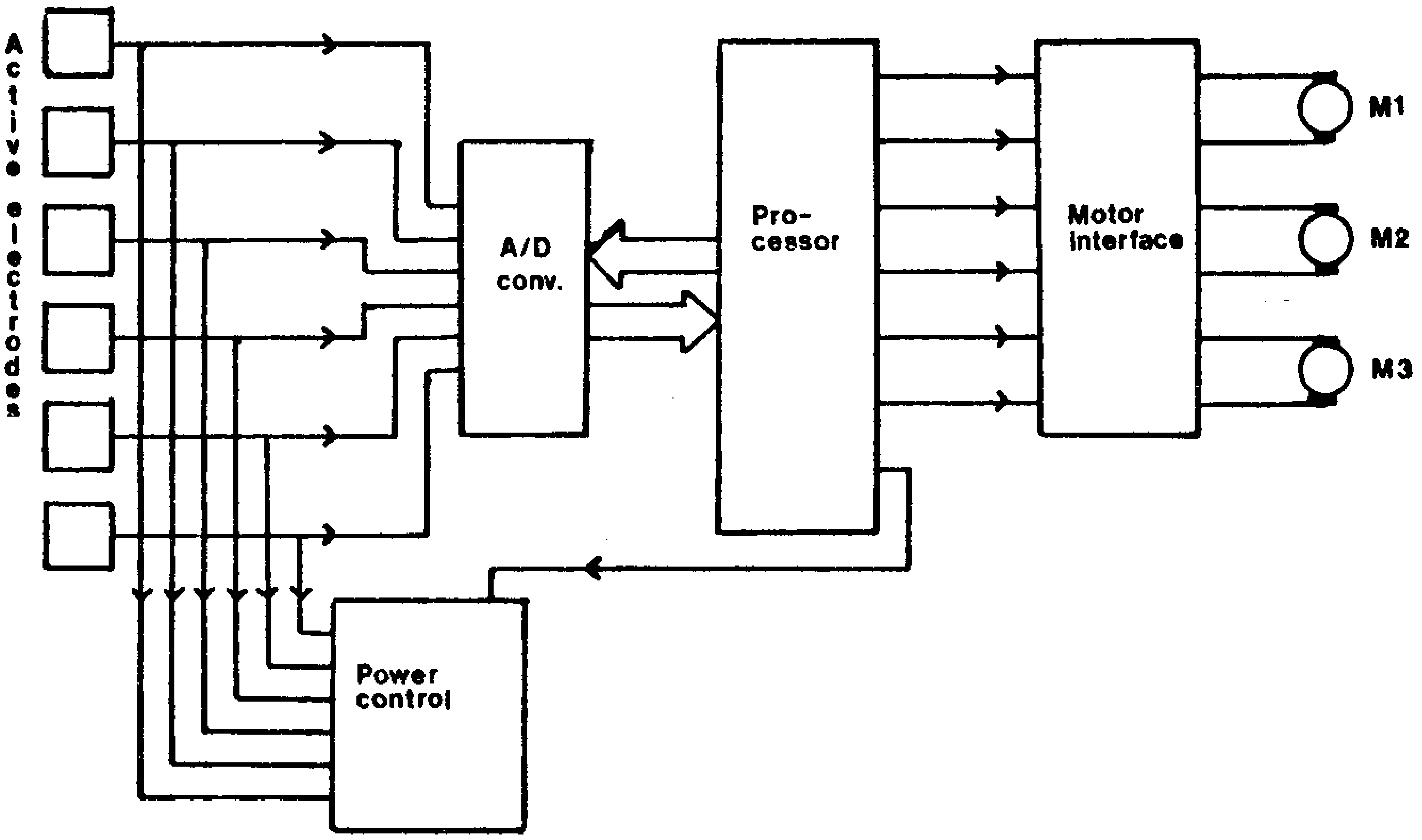

Fig. 2. Block diagram of the control system.

Active electrodes

Because of the low amplitude (50-1000 µV) of the myoelectric signals recorded on the skin, it is necessary to use active electrodes in order to reduce the influence of disturbing noise. By means of a differential amplifier and appropriate filters, effective noise suppression can be obtained.

A suitable electrode for the system has been developed previously (2). This electrode contains amplifier, band pass filter, active rectifier, and a low pass filter with a time constant of 100 ms. The output from the electrode is a DC signal approximately proportional to the RMS value of the myoelectric signal and hence to the mechanical force developed by the muscle (15). The time constant is chosen together with the sampling rate to give acceptable control accuracy and speed.

A/D converter

The amplified, rectified and low pass filtered signals from the six skin electrodes are fed into an analog multiplexer and into a following A/D converter. National ADC 0809 was chosen as A/D converter because it provides the multiplexer on the same chip. As it has a conversion time of approximately 100 µs and the signal from the electrode is low pass filtered with a time constant of 100 ms, no sample-and-hold circuit is required.

Processor

The single chip microprocessor Motorola 68701 has been chosen for implementation of the control circuit. This 8 bit processor provides 2 kbyte EPROM memory and 128 bytes scratch pad RAM on the same chip, which is adequate for this application. Totally 19 of 29 available I/O lines are used to control the A/D converter, the motor interface and the power control. An internal programmable timer serves as a real time clock for synchronization of data acquisition and motor control. The processor yields six signals for control of the motors, one for each possible prosthetic movement. By means of an extended program, these signals can be pulse-width modulated to obtain proportional control.

Motor interface

In order to control the three motors in the multifunctional prosthesis, the interface consists of three identical power circuits, see Fig. 3. The special design makes it possible to select the rotation direction of the motor depending on which input is activated. The interface requires a single voltage source and the inputs are TTL compatible.

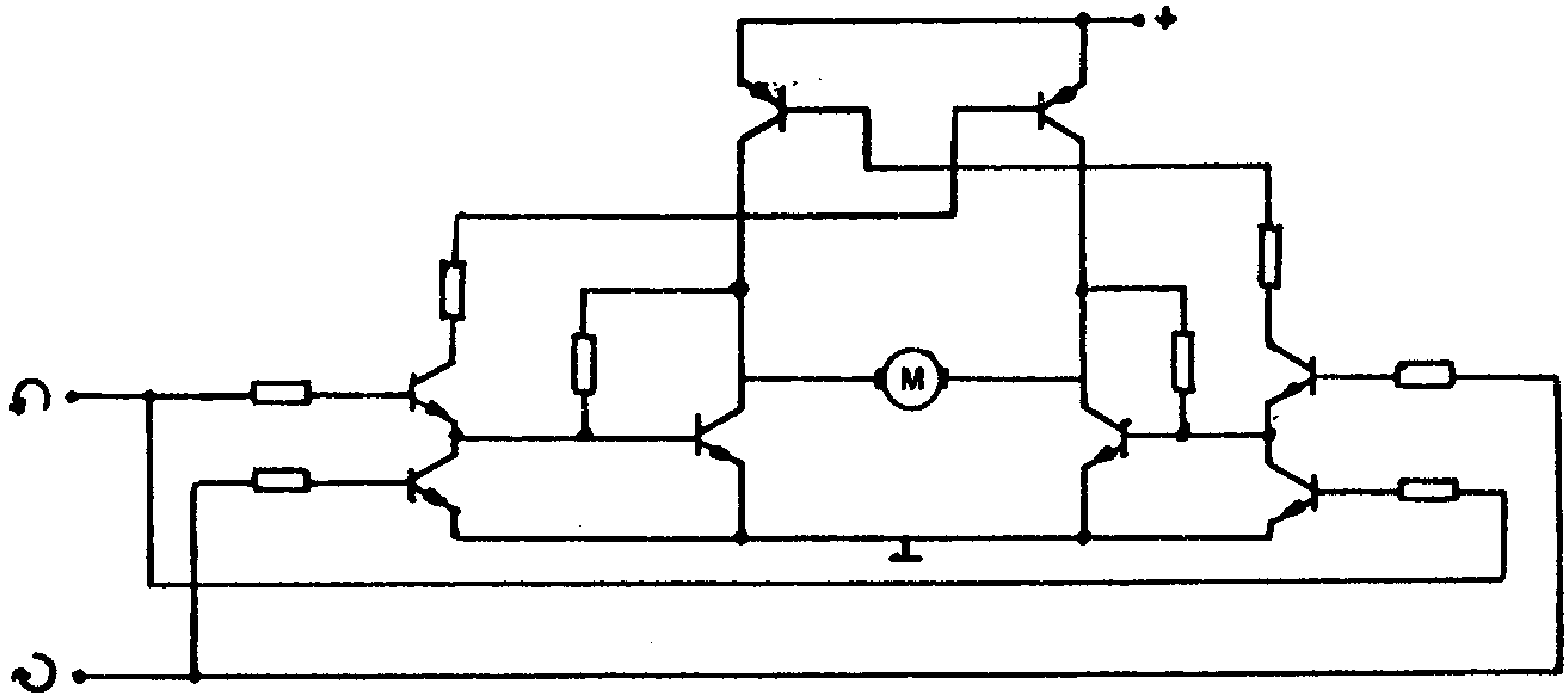

Fig. 3. Motor interface for control of a prosthetic motor. The rotation direction depends on wich input is activated.

Power control circuit

This circuit has two major functions:

a) Voltage stabilization

b) Power on-off control for the processor

The power for operation of the system is supplied from rechargeable batteries, the same as used for the prosthetic motors. Start and stop of the motors cause voltage transients, which increase in frequency with proportional control. Therefore voltage stabilization is required. To reduce the average power consumption, the processor yields a power down signal after a preprogrammed time of inactivity. This signal controls a power switch which disconnects the voltage source from the processor. The power up procedure is accomplished by a circuit sensing the myoelectric signals from the electrodes. When activity rises above an adjustable level, a power up signal is generated and the processor starts to work.

PROGRAM DEVELOPMENT

All program development has been performed on a PDP 11/40 minicomputer supported with a crossassembler for Motorola 6801/68701. For testing purposes, a special developing system has been constructed, allowing loading and running programs under terminal control.

DISCUSSION

In the development of a microprocessor based control system, suitable for prosthesis operation, the following items must be considered:

a) The physical size of the system

b) The computing capacity

c) The power consumption

Furthermore, it is essential that the program is easy to change and adapt to individual patients. For clinical acceptance it is necessary to give high priority to the physical size of the system, so that the prosthesis can be made self-contained. The computing capacity, however, must be sufficient in order to perform the control with reasonable speed.

Today many different kinds of 8 bit single chip microprocessors are available. Except the intrinsic processor, they provide program memory (ROM), data memory (RAM) and I/O ports on the same chip. The use of such a circuit will minimize the number of chips, and consequently, the physical size of the system. Since the weighting coefficients in the discriminant functions providing the pattern recognition must be individually adapted, the program memory has to be of EPROM type, which can be programmed and erased by the user. In a real time microprocessor system, sufficient computing capacity is of great importance. This is achieved by a processor with an efficient instruction set and short instruction cycle time.

We have examined and tested many types of single chip microprocessors, with reference to the special demands listed above. Four processors stood out as possible alternatives, namely Intel 8748, Mostek 3874, Zilog Z8, and Motorola 68701. All of them provide EPROM memory on the same chip (in the case of Mostek and Zilog "on top of the processor") and suitable I/O functions. The major drawback with these processors is the power consumption. This may be reduced, however, by means of a power down function during stand by. Eventually we selected Motorola 68701 on account of its efficient instruction set, which contains instructions for 8x8 bits multiplication and 16 bits addition.

From a clinical point of view, the main importance of a microprocessor based control system is that it allows prosthesis self-containment. This means that the microprocessors can be built in as a separate module in most conventional hand prostheses. For the clinical use, especially with reference to fast and efficient application routines, it is also important to emphasize that the necessary individual adjustments of the control system with digital technology are performed through changes of the microprocessor program rather than through tiresome soldering and trimming of resistors as in an analog system. Furthermore, the program of the microprocessor can be extended to perform proportional prosthesis control without adding weight or complexity to the system. These advantageous properties of the microprocessor based control system will be important contributions for an increased clinical patient acceptance of multifunctional prostheses.

REFERENCES

(1) Almström, C. (1977) Myoelectric control of multifunctional hand prostheses. Technical Report No. 79, School of Electrical Engineering, Chalmers University of Technology, Göteborg, Sweden.

(2) Almström, C. (1977) An electronic control system for a prosthetic hand with six degrees of freedom. Technical Report 1:77, Research Laboratory of Medical Electronics, Chalmers University of Technology, Göteborg, Sweden, pp. 12-16.

(3) Almström, C., Herberts, P. & Körner, L. (1980) Proportional control of prosthetic hands based on pattern recognition of multiple myoelectric signals in the forearm. Proc. of 1980 ISPO World Congress, Bologna, Italy, pp. 23-24.

(4) Almström, C., Herberts, P. & Körner, L. (1981) Experiences with Swedish multifunctional prosthetic hands controlled by pattern recognition of multiple myoelectric signals. International Orthopaedics (SICOT). To be published.

(5) Childress, D.S. (1973) Powered limb prostheses: their clinical significance. IEEE Transactions on Biomedical Engineering, BME-20, 200-207.

(6) Childress, D.S., Billock, J.N. & Thompson, R.G. (1974) A search for better limbs: Prosthetic research at Northwestern University. Bulletin of Prosthetics Research, BPR 10-22, 200.

(7) Finley, R.R. & Wirta, R.W. (1967) Myocoder-computer study of electromyographic patterns. Archives of Physical Medicine and Rehabilitation, 48, 20-24.

(8) Germans, G.H., Brekelmans, F.E.M. & Wijkmans, D.W. (1970) Some aspects of the design of an EMG-controlled artificial hand with two functions. In Advances in External Control of Human Extremities: Proceedings of the 3rd Int. Symposium on External Control of Human Extremities, ETAN, Dubrovnik, pp. 185-190.

(9) Herberts, P., Almström, C., Kadefors, R. & Lawrence, P.D. (1973) Hand prosthesis control via myoelectric patterns. Acta Orthopaedica Scandinavica, 44, 389-409.

10) Herberts, P., Almström, C. & Caine, K. (1978) Clinical application study of multifunctional prosthetic hands. J. Bone Joint Surg., 60-B, 552-560.

Hägg, G.M. & Spets, K. (1973) SVEN-Project I - Electrically controlled hand prosthesis. FOA 2 report A 2575-H5. Swedish Research Institute of National Defense, Stockholm, Sweden.

Hägg, G.M. & Öberg, K. (1978) Adaptive EMG controlled hand prosthesis for wrist disarticulated patients. In Advances in External Control of Human Extremities, ETAN, Beograde, pp. 441-450.

(13) Jacobsen, S.C. (1980) The Utah prosthetic arm. Proc. of 1980 ISPO World Congress, Bologna, Italy, p. 20.

(14) Kato, I., Yamakawa, S., Ichikawa, K. & Sano, M. (1970) Multifunctional myoelectric hand prosthesis with pressure sensory feedback. Waseda Hand 4P. In Advances in External Control of Human Extremities: Proceedings of the 3rd International Symposium on External Control of Human Extremities, ETAN, Dubrovnik, pp. 155-170.

(15) Lippold, O.C.J. (1952) The relation between integrated action potentials in a human muscle and its isometric tension. J. Physiol., 117, 492.

(16) Lymark, D. & Möhl, F. (1967) An electromechanical forearm and hand. In Advances in External Control of Human Extremities: Proceedings of the 2nd International Symposium on External Control of Human Extremities, ETAN, Dubrovnik, pp. 142-150.

(17) Rakic, M. (1975) An above elbow arm prosthesis. In Advances in External Control of Human Extremities: Proceedings of the 5th International Symposium on External Control of Human Extremities, ETAN, Dubrovnik, pp. 373-388.

(18) Taylor, D.R., Jun., & Finley, F.R. (1974) Multiple-axis prosthesis control by muscle synergies. In The Control of Upper Extremity Prostheses and Orthoses, pp. 181-189. Edited by P. Herberts, R. Kadefors, R. Magnusson & I. Petersén. Springfield: Charles C. Thomas.

(19) Wirta, R.W. & Taylor, D.R. (1970) Development of a multiple-axis myoelectrically controlled prosthetic arm. In Advances in External Control of Human Extremities: Proceedings of the 3rd International Symposium on External Control of Human Extremities, ETAN, Dubrovnik, pp. 245-254.