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A SYSTEM FOR DIGITAL ANALYSIS OF ELECTROMYOGRAPHIC SIGNALS

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INTRODUCTION

The use of Neuromuscular Electrical Stimulation (NMES) in the rehabilitation of paraplegic and tetraplegic individuals has been under investigation [1,2]. However, in order to use this technique beyond the laboratory, there is the need of well elaborated control strategies. Among these strategies, the monitoring of myoelectric (EMG) signals seems to be very promising.

A real-time system could detect and analyse the surface myoelectric signals from the musculature of the trunk and upper limbs (under volitive control by the patient), as well as detect the body movement when the patient wants to perform a step.

A comparison between the intensity of the myoelectric signal and a reference threshold was tried, but it didn't yield good results [3]. In order to analyse the surface myoelectric signal more deeply in order to find control patterns for NMES control, a system for digital EMG signal analysis has been developed.

MATERIAL AND METHODS

The system can be divided into four parts : an analogic signal conditioner, an Analog-to-Digital converter, a microcomputer and the required software (Fig.1).

The signal conditioner consists of five blocks (Fig.2). The first one is an instrumentation amplifier with gain set at 100. The second block is a low-pass filter with f_c=500 Hz. The third block is a notch filter with cutoff frequency of 60 Hz. The fourth block is an adjustable-gain amplifier and the last block is an isolation buffer, for patient safety. The whole circuit is portable and battery-powered. The total gain can be set to 500, 1000, 2000, 5000, 10000 and 20000. The circuit can be held next to the patient and is connected to the converter, inside the microcomputer, by cables.

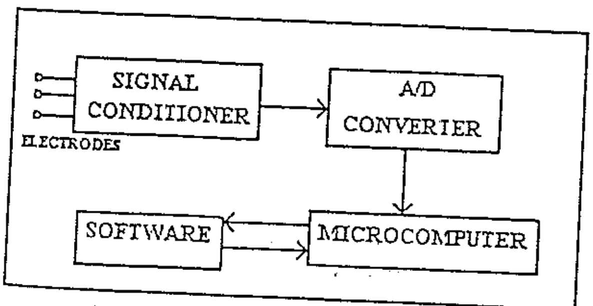

Fig.1 : System blocks

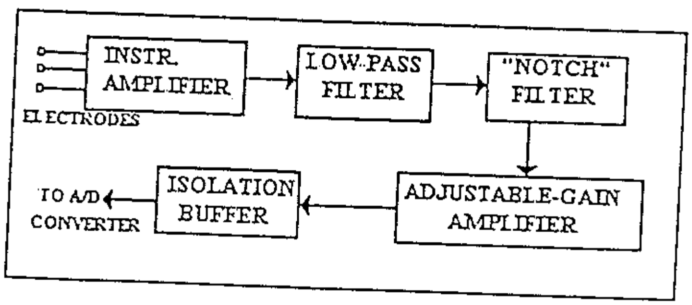

Fig.2 : Conditioner blocks

In order to execute the Analog-to Digital conversion and the data transfer to the microcomputer, a specific add-in board for PC microcomputers was used. This board is connected to a standard slot of the computer. It executes the sampling, the Analog-to Digital conversion (with resolution of 10 bits) and the data transfer via DMA automatically. The input range is from -5V to +5V and the maximum sample frequency is about 40 kHz.

The software consists of three programs. The first one controls the data acquisition and storing in magnetic disks. The user can get up to five block of acquisition, each one with up to 2 seconds of duration, with sample frequency of 1 kHz. This program, written in C language, also stores the data in floppy disks, in a compressed format.

The second program, also written in C language, controls the selection of part of the signal for data processing. It reads the signal stored in disks and shows the selected block in a 500 ms window. The user can select the start and the end of the chosen signal portion and store this portion in a file in the "binary stream" format, to be used by the next program.

The last program, written inside the MATLAB® workspace, reads the binary stream and executes digital processing. The developed program executes three algorythms : Variance of the signal, Fast Fourier Transform (FFT) and the Autoregressive Model (AR) parameters' extraction [4].

The Variance calculation uses the conventional equation (Equation 1):

$$s^2 = \frac{n\sum x^2 - (\sum x)^2}{n(n-1)} \qquad (1)$$

The Autoregressive Model coefficients' extraction is performed to get the minimal error, using a least-squares algorythm, between the real data and the model given in equation 2:

$$x_k = \sum_{i=1}^{N} a_i \, x_{k-i} \qquad (2)$$

Where N is the model order and a_i are the cofficients. Remember that the data is the sequence x_k.

RESULTS AND DISCUSSION

The system was tested with two patients. The first one is a complete paraplegic (lesion level T7) and the other is an incomplete tetraplegic (lesion level C6). The muscle analised was the brachial triceps. This muscle performs a strong contraction when the patient displaces his gravity center laterally, with the intention of performing a step, in order to keep the arm extended. Because of this feature, we can suppose that the brachial triceps contraction is synchronized with the gait rythm the individual desires.

The initial idea was to distinguish between these contractions (here called STEP, or "S") and other uncorrelated ones with the step intention (here called NOT-STEP, or "NS"). Several samples were collected for each case (just before the step and during other events, like lateral displacements of the trunk), in order to find patterns for a pattern recognition system. The figure 3 shows one of these tests.

In order to find the patterns, a neural network simulation software was used. The network used was a three layer perceptron with back-propagation learning algorythm. The input parameters for the networks were the signal variance and the order 4 AR model coefficients [5]. The network for the T7-level patient worked well (see table 1), but the network created for the other one (incomplete tetraplegic clinical case) presented errors of recognition (see table 2), maybe due to

the innervation deficiency of the muscle, that is controlled by the C6, C7 and C8 medular segments.

The tables show the type of samples (STEP or NOT-STEP), the result of the network and the fuzzy value given by the network, which can be considered a measure of the confidence degree of the result.

As it can be seen, for the T7 level patient, there are some "false negative" situations, that would not be a problem in a control system, because the patient can try the step again. The "false positive" situations can be dangerous (a step performed when the individual is not ready), but it almost doesn't happen for the first case. The second case, however, has many of these situations, being necessary more studies to find a secure pattern.

A basic pattern was found in all samples, except in some from the C6-level patient. The difference probably shows the neuromuscular deficiency of this individual.

Figure 3 : A test with a C6 lesion level patient

Table 1 - Results for the T7 lesion level patient

Sample	Type	Network output	Value
A	S	NS	0.6023
B	S	S	0.9442
C	S	S	0.9999
D	S	NS	0.5150
E	S	S	0.9994
F	S	NS	0.6249
G	S	NS	0.9795
H	NS	NS	0.9997
I	NS	NS	0.9996
J	NS	NS	0.9920
K	NS	NS	0.9762
L	NS	NS	1.0000
M	NS	S	0.7359
N	NS	NS	0.9674

Table 2 - Results for the C6 lesion level patient

Sample	Type	Network output	Value
A	S	S	0.9996
B	S	S	0.9998
C	S	S	0.9999
D	S	S	0.9982
E	S	S	0.9947
F	NS	NS	0.7527
G	NS	NS	0.9996
H	NS	S	0.9965
I	NS	S	0.9905
J	NS	S	0.9948

CONCLUSION

The system works as expected. The possibility of implementing new algorythms for signal processing inside the MATLAB® enviroment makes the system very flexible. Due to this feature, the system can be used in other research areas, as myoelectric control for upper and lower limb prostheses and orthoses, which are now under development in our Department. The pattern differences found in one of the patients shows the possibility of clinical applications of the system, i.e., the use of surface electromyography in the diagnosis of neuromuscular diseases.

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