A METHOD OF EMG DECOMPOSITION BASED ON FUZZY LOGIC

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Abstract - **A new method for decomposing the EMG signal into their constituent motor unit action potentials (MUAPs) is presented. We propose a specific iterative algorithm with a classification method using fuzzy logic techniques. A statistical analysis of Inter-pulses Interval (IPI) and amplitude detected MUAPs is realised before its classification step. The algorithm was evaluated on simulated surface EMG signals (SEMG) before its application to real SEMG. On simulated signals, the rate of successfully classified MUAP was 88.4%. On real Laplacien SEMG, the algorithm identified correctly 21 MUAP trains (MUAPTs) on the 29 MUAPTs identified by an expert. The efficiency of the decomposition on Surface EMG makes the method very attractive for non invasive investigations.**

Keywords – Decomposition, Fuzzy logic, motor unit, MUAPT, EMG signal

INTRODUCTION

Electromyographic examination aims at analysing the electrical activity of the active muscles. It produces valuable electrophysiological information for the assessment of neuromuscular disorders. EMG signals are composed of MUAP generated by the activated motor units. The motor unit is the smallest functional entity of the muscle that can be voluntarily activated. It consists of a group of muscle fibres all innervated from the same motor nerve. The MUAP shape reflects the structural and functional organisation of the motor unit [1]. With increasing muscle force, EMG becomes interferential due to the increase in the number of activated MUAPs recruited at increasing firing rates, making it difficult for the neurophysiologist to distinguish individual MUAP waveforms. The detection of the modification of the motor unit characteristics requires to identify the MUAPs composing the EMG signal. Therefore the production of EMG decomposition algorithms is an important issue in EMG processing.

Many automatic EMG analysis systems have been developed during the last twenty years [2] [3] . Most of them are based on sequential decomposition techniques. Usually the proposed algorithms consist of the two following stages : segmentation and classification. In the first stage, the EMG signal is cut into segments of possible MUAP waveforms. In the second stage the detected MUAPs will be sorted into different groups based on the similarities between MUAPs.

In our study, we have developed an iterative decomposition algorithm with a classification method based on fuzzy logic techniques. Each iteration may lead to the identification of a MUAPT. Our algorithm was successfully applied in the decomposition of SEMG signals from normal subjects. SEMG decomposition may be of greatest interest for non-invasive clinical applications.

METHODOLOGY

Our decomposition algorithm consists of the three main following stages : detection, statistical analysis, classification. Figure 1 illustrates the system flowchart.

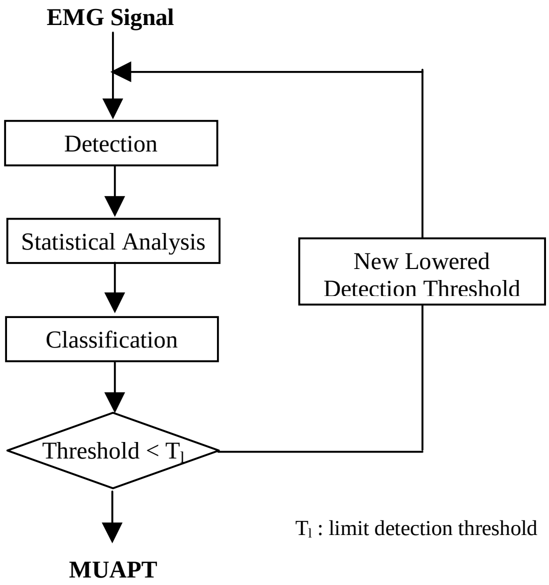

Fig. 1. : flowchart of the EMG decomposition algorithm

Detection

The MUAP detection is based on an amplitude detection scheme, where the threshold value is set at each iteration. For a given iteration, the threshold is determined by lowering its precedent value. This principle allows the detection of a reduced number of MUAPs, thus facilitating the identification of a MUAPT.

Statistical Analysis

In this stage, the distribution function of the IPI and the amplitude of the detected MUAPs are computed. After a linear interpolation of the distribution functions, the smooth numeric derivatives are calculated. The IPI and the amplitude which correspond to the maximum of their respective derivative distribution functions are then determined. These values are noted IPIref and Aref. The MUAP waveform, noted Fref, is searched for the signal by using IPIref and Aref. Those three values IPIref, Aref and Fref constitute the classification parameters set for the iteration in progress.

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Classification

At this stage the set of the detected MUAPs and the classification parameters provided by the two precedent stages are available. The classification process based on fuzzy logic techniques may identify one MUAPT.
The five following steps describe the fuzzy logic system used :

- Input / output fuzzy variables definition

The first input of the classification system is the linguistic variable : "relative deviation in terms of IPI" (noted ΔIPI)

$$\Delta IPI = \left| IPI_{obs} - IPI_{ref} \right| / IPI_{ref}$$

It represents the membership degree of the observed MUAP to the class in relation to its temporal position in the signal. It is qualified by three fuzzy trapezoid intervals on [0 ; +∞[.

The second input is the linguistic variable : "relative deviation in terms of amplitude" (denoted ΔA).

$$\Delta A = \left| A_{obs} - A_{ref} \right| / A_{ref}$$

It represents the membership degree of the observed MUAP to the class in relation to its amplitude. It is qualified by three fuzzy trapezoid intervals on [0 ; +∞[.

The third input is the linguistic variable "Correlation" (noted C). It represents the membership degree of the observed MUAP to the class in relation to its shape. It is qualified by three fuzzy trapezoid intervals on [0 ; 1].

The outputs of the system are two linguistic variables. The former informs us on the **S**atisfaction **D**egree for the observed MUAP to **B**elong to the class. The latter informs us on the **S**atisfaction **D**egree for the observed MUAP to be **R**ejected. The two variables are respectively noted SDB and SDR.

- Fuzzy partition qualifying the input variables

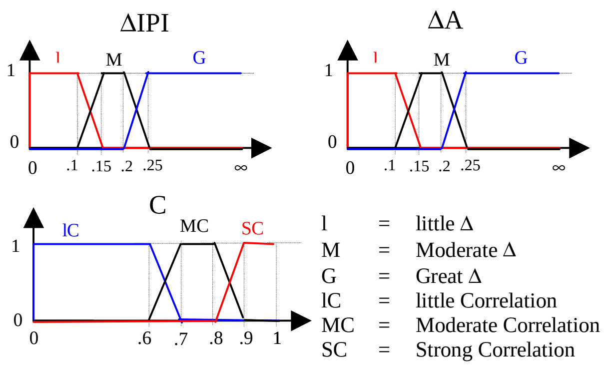

Figure 2 : Membership function of the three input variables

The border values of the trapezoidal fuzzy intervals (fig. 2) have been determined according to bibliography study [1] [2] [4].

- Setting up fuzzy rules

The decision table defines a system of 27 fuzzy rules. The strategy to build the decision table is defined by the following principle : the lower ΔIPI and ΔA are and the higher C is, the more acceptable the observed MUAP is.

		C	**ΔIPI**		
			l	M	G
ΔA	G	lC	**R**	**R**	**R**
		MC	**R**	**R**	**R**
		SC	**A**	**R**	**R**
	M	lC	**R**	**R**	**R**
		MC	**A**	**A**	**R**
		SC	**A**	**A**	**R**
	l	lC	**A**	**R**	**R**
		MC	**A**	**A**	**R**
		SC	**A**	**A**	**R**

Table 1 : decision table representing the rules

Each rule can be linguistically written as follows :
IF ΔIPI is Great **AND** ΔA is Great **AND** C is little **THEN** Reject the observed MUAP

IF ΔIPI is little **AND** ΔA is Moderate **AND** C is Strong **THEN** Accept the observed MUAP

- Fuzzy logic operators choice

We have kept the Zadeh primary operators [5] for the modelisation of conjunction and disjunction : respectively the MIN and the MAX operators. We have used Sugeno's method [6] for the modelisation of inference scheme. Its first step consists of regrouping by an OR on the premises, all the rules having the same conclusion.

- Method to get the final conclusion

The partial conclusions are represented by the value of the two variables SDB and SDR. The final conclusion is determined by taking into account those two values and the following principle : The higher SDB is AND the lower SDR is, the more acceptable the observed MUAP is.

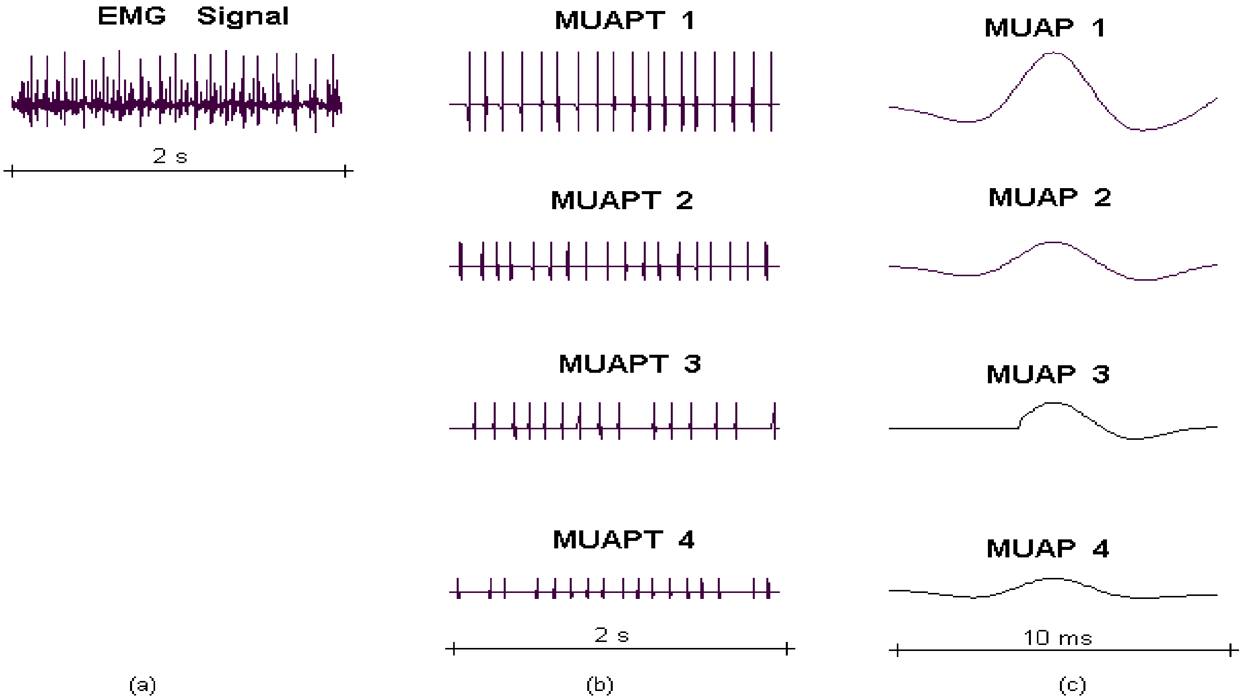

Figure 3 : Decomposition of a real SEMG recorded on *biceps brachii* with Laplacian electrode.
(**a**) A 2-second duration of raw SEMG signal. (**b**) Motor Unit Action Potential Trains that compose the SEMG signal in (a).
(**c**) MUAP shape retained for the classification stage

RESULTS

The decomposition algorithm was validated on a set of synthetic signals generated using the simulation software developed by Duchêne and Hogrel [7]. The results reported in a conference paper [8] show a performance of 88.3% of correctly classified MUAPs.

This algorithm was then applied to real SEMG which were detected by positioning a Laplacian electrode on the *biceps brachii*. The healthy subjects performed isometric low-intensity contraction. EMG signals were analogue bandpass filtered at 2 – 1000 Hz, and sampled at 10kHz.

Figure 7 represents the decomposition results of one SEMG. The algorithm correctly identifies 4 MUAPTs out of 4 present in the signal.

On a set of 18 decomposed signals, lasting 3 seconds, 21 MUAPTs were correctly identified out of 29 present in the signals.

DISCUSSION AND CONCLUSION

When decomposing a real EMG, the number of MUAP classes, the number of MUAPs per class, their firing rate and the MUAP waveform are unknown. The problem gets even more difficult because of MUAP waveform variability, jitter of single fibre potentials, and MUAP superposition. Fuzzy logic techniques are well adapted to the processing of imprecise information. Our classification parameters are those usually used by many decomposition algorithms. The originality of our classification method resides in the combination of those parameters. The acceptance of a MUAP in a class takes into account simultaneously the three criteria : IPI, amplitude and shape.

Our new technique has been successfully applied to the decomposition of SEMG signals recorded from healthy subjects. The algorithm has to be tested on signals recorded from subjects suffering from neuro-muscular disorders.

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