INVERSE PROBLEM IN THE SURFACE EMG : A FEASIBILITY STUDY

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Abstract : **The aim of this work is the development of a localisation algorithm of the bioelectric sources using surface electromyographic (SEMG). In this paper, a feasibility study is presented : we simulate the resolution of the SEMG inverse problem. First, we developed a program modelling the SEMG signal of the biceps brachii. To resolve the inverse problem, the localisation algorithm uses an estimation procedure. We minimise the difference between calculated potential and observed potential by successive iterations. The procedure is applied successively to the defined zones of the geometrical arm cross-section. The program locates accurately an active motor unit in a given zone, regardless of time and distance.**

Keywords : Localisation algorithm, Motor unit estimation, Gradient method.

I. INTRODUCTION

In the case of neuromuscular diseases, the motor unit can exhibit some notable modifications to its characteristics. Until now these alterations are detected by more or less invasive electromyographic (EMG) techniques, the motor unit action potentials (MUAPs) being usually detected by intramuscular EMG [1]. The surface electromyography, which is a non-invasive technique, would appear to be another method if information about the bioelectric sources which have resulted in the SEMG can be obtained (inverse problem resolution).

The powerful tools of modelling and numerical methods for solving the EEG and ECG inverse problem [2] do not seem to be used in SEMG inverse yet. The few works which treat of source localisation in SEMG are often based on experimental techniques combined with invasive methods [3, 4]. The present study introduces a numerical technique for solving the SEMG inverse problem. This new approach is based on a modelling of the direct problem, and on a resolution algorithm by iterative method.

II. METHODS

A. SEMG signal modelling

1) Measurement configuration modelling. A geometrical cross section of the arm containing the studied muscle is modelised (figure 1). The multi-electrode recording system is composed of 16 electrodes regularly distributed on the upper arm half cross section with an interelectrode distance of 11mm. This system leads to a transversal recording system suitable for our problematics.

2) SEMG signal simulation. The one second simulated signals are sampled at 40 kHz. The experimental assumptions suppose a weak isometric contraction. The synthetic signals are based on the single fibre action potential (SFAP) using a mathematical model proposed by [5]. The analytical function of that single fibre action potential is given by :

$$V(t,r) = V_2(r) - b_i(r)t^2 e^{-t^2/\sigma_i(r)}$$

where

$$\begin{cases} \text{t = time, r = electrode to fibre distance,} \\ V_2(\text{r}) = 2^{\text{nd}} \text{ phase magnitude, } b_i(\text{r}) \text{ and } \sigma_i(\text{r}) = \text{shape coef.} \end{cases}$$

The motor unit action potential is calculated by the summation of the SFAPs of the fibres which constitute the motor unit. In order to generate motor unit action potential trains (MUAPTs), the firing rate is evaluated from the MUAPs duration. The firing rate ranges from 7 to 33Hz. The MUAPTs result from the convolution between the Dirac comb and MUAPs. The EMG recorded on each electrode is the summation of the MUAPTs.

B. Localisation of the most probable zone containing emission points : inverse problem

Our methodology is a simple adaptation of methods commonly used for solving bioelectrics inverse problem [2].

1) *Mathematic model describing electrical activity*. As the inverse parameters which we intend to estimate are the electrode-source distances and the positions of the sources within the arm cross section, we have chosen a simple direct mathematical model as following :

$$V(d,t) = k(t)/d^{a(t)} \quad (1)$$

V(d,t) = amplitude function of MUAP, a(t) and k(t) = middle parameters, d = euclidean distance between the electrode position (x_e,y_e) and the active source (x_s,y_s) in the recording system plane.

If we consider the potentials received by all electrodes at a given time, and if we suppose a little variation of a and b coefficients from an electrode to another, we obtain the following system :

$$\begin{cases} Y_1 = a.X_1 + b \\ \vdots \\ Y_N = a.X_N + b \end{cases}$$

N is the number of the electrode of the recording system.

In this equation system, there appears a redundancy of information which is explored for the resolution.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Inverse Problem in The Surface EMG: A Feasibility Study	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Univ. de Compiegne UMR CNRS 6600 60203 Compiegne France	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
3

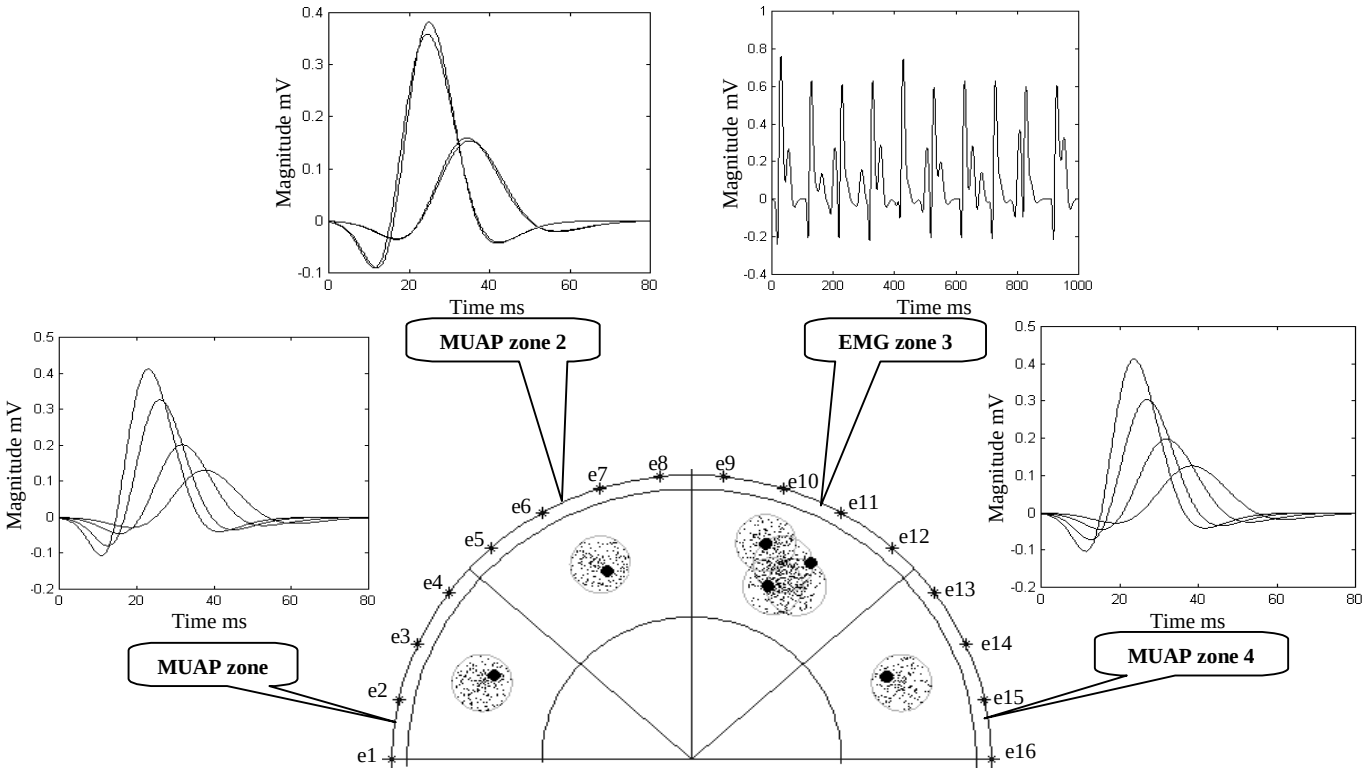

Figure 1 : Localisation of emission sources in a muscular cross section.

The multi-electrode recording system composed of 16 electrodes ($e_{i,*}$) regularly distributed on the upper half of the arm cross section containing the studied muscle is represented. The (•) marks in zone 1, zone 2, zone 4 represent the average of the coordinates of the sources detected by the program from MUAPs. In zone 3, one can observe a scattering of micro active regions which were detected on weakly superimposed SEMGs.

2) *Gradient method*.

Since there is not unique solution to a given system, we look for a solution by using an optimisation method : The gradient method. This method facilitates the minimisation of a cost function :

$$C = \sum_{i=1}^{N} (Y_{i,\text{calculated}} - Y_{i,\text{observed}})^2 = \sum_{i=1}^{N} (a.X_i + b - Y_{i,\text{observed}})^2$$

$Y_{i,\text{ calculated}} = \log(V_{i,\text{ calculated}})$, $Y_{i,\text{ observed}} = \log(V_{i,\text{observed}})$, $V_{i,\text{ calculated}}$ et $V_{i,\text{observed}}$ are the squares of the calculated and observed amplitude on the i^{th} electrode at the t instant.

The explicit expression is :

$$C = \sum_{i=1}^{N} (a.\log(\sqrt{(x_{ei} - x_s)^2 + (y_{ei} - y_s)^2}) + b - Y_{i,\text{observed}})^2$$

The gradient method is based on the following iterative principle : $u(k+1) = u(k) - \rho \nabla C(\text{u(k)})$

Where u = (a,b,x_s,y_s) a vector, ∇C = gradient, ρ = the step and k = iteration number.

The values of a, b, x_s and y_s are obtained when the minimum cost is reached.

3) *Algorithm description*. The algorithm based on the method previously described computes the coordinates of a source at a given time by minimising the difference between calculated potential and observed potential. The algorithm can be described by the four following steps :

Step 1 : Cross section zoning . The program determines four detection zones as indicated in figure 1. Therefore, the algorithm can locate one active region at most per zone and per instant.

Step 2 : Initialisation of the iterative loop. The values of a_{init} and b_{init} are determined from the maximum amplitude of potential for two given distances. In order to determine $x_{init,}$ and $y_{init,}$ the initial position of the source, the program seeks the electrode which gives the highest potential magnitude.

Step 3 : Threshold value and stop criteria. Very low values of the potential tend to make the algorithm diverge. Therefore, the program determines a threshold under which the localisation procedure is not started. Stop criteria are defined zone per zone. The stop criterion is reached when the difference between the calculated amplitude and the observed amplitude is less than 10%.

Step 4 : Regionalization and display. The program runs along the successive instants of the signal and the localisation procedure starts only when all the previous conditions are fulfilled. The results are displayed on the screen and stored in a file.

III. RESULTS AND DISCUSSION

Some synthetic signals generated by our program are shown in figure 1. Three groups of MUAPs (zone 1, zone2, zone 4) and a SEMG (zone 3) are illustrated. According to the nature of this study (feasibility of the inverse problem in SEMG), the modelisation was made with a few simplifying hypotheses in mind to facilitate the implementation of the localisation algorithm. This modelisation is nevertheless inspired by previous works [6], and the shapes of the synthetic MUAPs are similar to those encountered in the literature [7]. A model built with more fundamental physiological parameters such as conduction velocity, fibre diameter, and the anisotropy of

the middle, will be needed for the next stages of this research.

The signals, which we simulated, allowed us to have a bank of signals available for testing the algorithm of the inverse problem. The analytical function used to simulate those signals does not intervene in the inverse problem resolution.

The localisation algorithm was first tested on a simple case, one active motor unit per zone. The result is shown in figure 1 (zone 1, zone 2, zone 4). The average of the coordinates of the sources detected by the program was calculated. It was found that the resulting average point was always near the centre of the motor unit. The second group of tests was carried out on weakly superimposed SEMGs : a set of micro active regions was detected (figure 1 zone 3). These micro regions scattered on the muscular zone are difficult to interpret by our present algorithm.

In order to reconstruct the potential distribution within a muscle, one would wish to invert one of the mathematical formulation which makes it possible to approach a SEMG signal. However, because of the ill-posed nature of the problem, such an inversion is impossible without introducing a lot of errors in the solution. Techniques of optimisation, therefore, are used to minimize the effect of the error and to reconstruct a solution that is physiologically meaningful. The algorithm proposed in this paper is based on this theory.

IV. CONCLUSION

For this feasibility study, the localisation algorithm implemented was tested on MUAPs and SEMGs generated by the simulation program. The localisation program locates accurately a motor unit active in a given zone, regardless of time and distance. This first approach shows that a better localisation of the sources directly from a SEMG requires a signal pre-processing : its decomposition into its constituent action potential trains. When several motor units are active, the present program shows an evolution of the emission zones. An evolutive topological image of active MUs is thus obtained. The study of this image could make the observation of the spatial organisation of MUs possible in cases of neuromuscular diseases.

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