Characterization of Electromyography Signals of the Forearm Muscles from Pen-Tip Coordinates, using RELS Algorithm

Ines Chihi, Afef Abdelkrim, Mohamed Benrejeb

Abstract— used in several domains (biotechnology engineering, medical diagnosis, etc.), the reconstitution of ElectroMyoGraphic signals (EMG) is the main contribution of this paper. We propose a linear mathematical structure to generate Integrated ElectroMyoGraphic signals IEMG of the forearm muscles from the coordinates of handwritten traces. The identification of this structure is based on Recursive Extended Least Square algorithm (RELS).

Index Terms— coordinates of handwritten traces, Extended Least Square algorithm, forearm muscles, Integrated ElectroMyoGraphic signals.

I. INTRODUCTION

Human handwriting motion is a biological process, considered as an important communication tool, having the same importance as the voice, the view and other human activities.

Several investigators have focused on the study of the handwriting process to propose direct and inverse handwriting models based on conventional or unconventional approaches, [1], [2], [3] and [4].

In 1962, Van Der Gon proposed a mathematical model to characterize this phenomenon [5], an electronic version is then proposed by Mc-Donald [6] to describe this biological process by a linear differential equation of second order. In1983, Yasuhara presented another system to identify and decompose a fast system of handwriting [7]. From this model Iguider proposed two approaches, one to extract control pulses [8], and the other to recognize the cursive Arabic writing [9]. Edelman and Flash elaborated, in 1987 a model based on the trajectories of the hand [10]. An approach of linear modeling is obtained from experimental data was proposed by Sano in 2003 [11].

The handwriting motion needs the coordination between the eyes, the brain, the forearm, the hand, etc. In spite the complexity of this act that includes forty three muscles, Yasuhara fixed four muscles responsible for the hand motion, [7].

Indeed, EMG records the electrical activity of muscles and generally used in variety engineering and medical applications as clinical diagnosis and controlling assistive systems for disabled (prosthetic devices), [12], [13] and [14].

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From this analysis, we proposed in [15] a mathematical model to reconstruct Arabic letters and geometric forms from integrated forearm muscular activities called IEMG signals. This model is based on Recursive Least Squares algorithm (RLS).

Given the importance of these signals, considered as a health indicators, the reconstruction of IEMG signals using the coordinates of a pen-tip moving on (x,y) plane, is the subject of this research. We propose a new mathematical model characterizing the studied process from input - output data system recorded from an experimental approach, allowing to record the movements of the pen-tip on (x,y) plane and the EMG signals. The proposed model is based on Recursive Extended Least Squares algorithm (RELS).

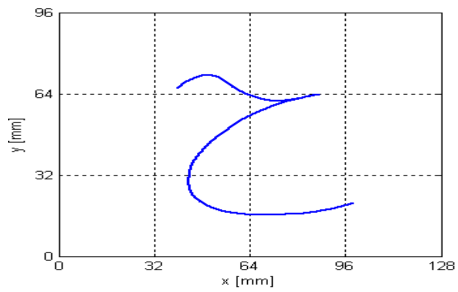
After a description of the considered experimental approach, the presentation of the identification’s technique used to characterize the studied biological process is then proposed. In the last section, a validation step of the proposed model is presented.

II. MATERIALS AND EXPERIMENTAL STUDY

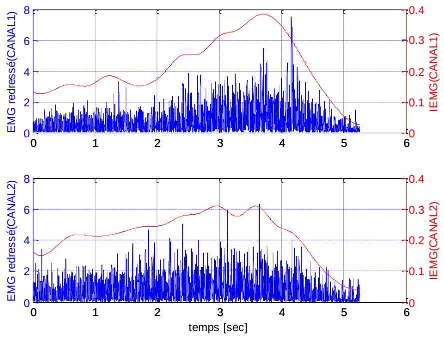
In 2003, Sano presented in [11] the relationship between the muscular activities of two forearm muscles and the pen-tip movements according to (x,y) plane. The measurements of two ElectroMyoGraphic signals, EMG1 and EMG2, during the writing process require to propose an experimental approach already taken in [11]. This study requires different writers who have written different Arabic letters and eight basic geometric forms.

In this experimental approach a measuring system allows to write some graphic traces on a digital tablet and to memorize into computer the positions of the pen-tip and ElectroMyoGraphic signals, EMG, recorded with the use of surface electrodes.

Pen-tip movements according to x and y directions, EMG1 and EMG2 recorded, for the Arabic letter “SIN”, during the handwriting process by surface electrodes are given in figure1.



(a)



(b)

Figure 1. Recorded data of the Arabic letter "SIN", [16]

(a) Form, (b) Full wave EMG signals and IEMG signals

EMG waveforms present transient phenomena and other disruptive signals resulting from various sources, such as electromagnetic phenomenon sector and noise associated with electrodes and uncertainties of measures. They can be filtered by rectifying technique to obtain new curves called Integrated EMG (IEMG), figure 1.

III. THE PROPOSED MODEL TO RECONSTRUCT IEMG SIGNALS

In this section, we propose a mathematical, linear fourth order model to reconstruct integrated electromyographic signals of two most active forearm muscles, named, IEMG1 and IEMG2. This is obtained from the pen-tip movements on the plane of a digital tablet and from the generated signals (IEMG1 and IEMG2) at delayed moments.

The model's inputs are the signals, e_1 and e_2 relative to (IEMG1 and IEMG2 signals), delayed at the instants: *k-1*, *k-2*, *k-3* and *k-4* and the coordinates, *x* and *y* at the instants: *k*, *k-1*, *k-2*, and *k-3*. The outputs are e_1 and e_2 waves at *k* instant, equations (1) and (2).

$$e_1(k) = \sum_{i=1}^{3} -\left[\hat{a}_{i1}(k)\, e_1(k-i) + \hat{b}_{i1}(k)\, e_2(k-i)\right] + \sum_{i=0}^{3}\left[\hat{c}_{i1}(k)\, x(k-i) + \hat{d}_{i1}(k)\, y(k-i)\right] \qquad (1)$$

$$e_2(k) = \sum_{i=1}^{3} -\left[\hat{a}_{i2}(k)\, e_1(k-i) + \hat{b}_{i2}(k)\, e_2(k-i)\right] + \sum_{i=0}^{3}\left[\hat{c}_{i2}(k)\, x(k-i) + \hat{d}_{i2}(k)\, y(k-i)\right] \qquad (2)$$

with :

e_1 : EMG signal of the first forearm muscle,

e_2 : EMG signal of the second forearm,

x, y : Coordinates according to *x* and *y* movements respectively,

$a_{i1}, b_{i1}, c_{i1}, d_{i1}$: Estimated parameters according to *x*,

$a_{i2}, b_{i2}, c_{i2}, d_{i2}$: Estimated parameters according to *y*,

k : Discrete time.

In this work, the Recursive Extended Least Squares (RELS) algorithm with constant forgetting factor in the particular case of linear systems is used to identify the proposed mathematical model

A. *Estimation of the proposed model's parameters*

The experimental approach requires to record inputs and outputs data, which allows to consider the studied process as a black box system. In this case, we resort to a parametric identification to define the different parameter of the considered structure, without physical signification. This experimental technique allows to avoid the long development time define in the case of theoretical model.

Several recursive and not recursive algorithms of identification are proposed in the literature, [18], [19], [20], [21], [22], [23]. The implementation of non-recursive algorithms in real time is almost impossible in the case of systems with important computing power and limited storage data capacity.

The Recursive Extended Least Squares (RELS) method is a solution of this problem. It is, also considered as an improvement of the ordinary least squares algorithm. The parameters estimated by this technique are used to describe, in an stochastic environment an Auto Regressive Moving Average with eXternal inputs structure (ARMAX). This method has the advantage of estimating both the parameters of the studied system and those of the noise, [20], [21], [22] and [23].

The Extended Recursive Least Squares algorithm, considered as an improvement of the ordinary Least Squares algorithm, estimates parameters of a studied system by ARMAX model, equation (3) and figure 2, [22] and [23].

$$A(q^{-1})\, y(k) = q^{-d} B(q^{-1})\, u(k) + C(q^{-1})\, e(k) \qquad (3)$$

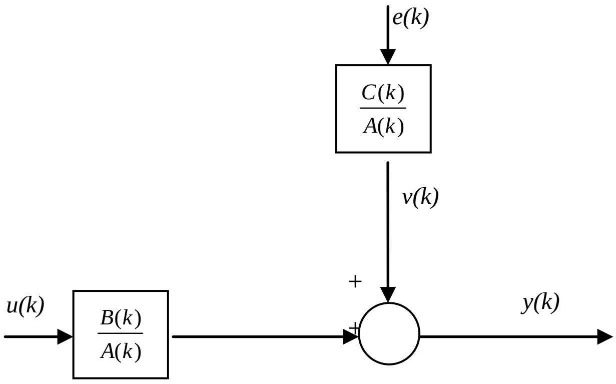


Figure 2. Structure of ARMAX model

with:

$y(k)$: system output,

$u(k)$: system input,

$v(k)$: filtered white noise,

$e(k)$: system white noise,

A, B, C : polynomials.

With

$$y(k) = \frac{B(k)}{A(k)} u(k) + \frac{C(k)}{A(k)} e(k) \qquad (4)$$

The estimated parameter's vector is given in (5).

$$\hat{\theta} = \left[\hat{a}_1 \hat{a}_2 \cdots \hat{a}_n\ \hat{b}_1 \hat{b}_2 \cdots \hat{b}_m\ \hat{c}_1 \hat{c}_2 \cdots \hat{c}_p\right] \qquad (5)$$

The matrix of observation, ψ^T (k), is expressed in relation (6).

$$\hat{\psi}^{T}(k) = \left[-y(k-1)\cdots-y(k-n)-u(k-1)\cdots \right. \\ \left. \cdots-u(k-m)-e(k-1)\cdots-e(k-p)\right] \quad (6)$$

Relations (7) and (8) define the prediction error, ε, between the system output y and the model output $\hat{y}$.

$$\varepsilon(k) = y(k) - \hat{y}(k) \quad (7)$$

$$\hat{y}(k) = \hat{\theta}^{T}(k-1)\,\psi(k) \quad (8)$$

The mathematical structure of RELS identification technique is presented by the equations (9) to (11).

$$\hat{\theta}(k) = \hat{\theta}(k-1) + P(k)\sum_{i=n+1}^{k}\Psi(i)\,\varepsilon(i) \quad (9)$$

$$P(k) = P(k-1) - \frac{P(k-1)\,\Psi(k)\,\Psi^{T}(k)\,P(k-1)}{1+\Psi^{T}(k)\,P(k-1)\,\Psi(k)} \quad (10)$$

$$\varepsilon(k) = y(k) - \hat{\theta}^{T}(k-1)\,\Psi(k) \quad (11)$$

where:

$P(k)$: adaptation matrix,

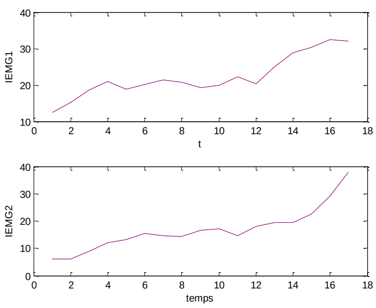
$y(k)$: actual output of the system to identify,

k : discrete time.

RELS algorithm helps to get a sequential processing of experimental data available at each time. These data are evaluated during the system evaluation [18] and [19].

Figure 3 illustrate the evolution of some model's parameters, a_{i1}, b_{i1}, c_{i1}, d_{i1} and a_{i2}, b_{i2}, c_{i2}, d_{i2}, which converge to constant values. Consequently, not time-varying parameters are considered to the proposed handwriting model.

The results of this identification technique show good agreement with the recorded signals for several king of graphic traces, figure 4.



(a)

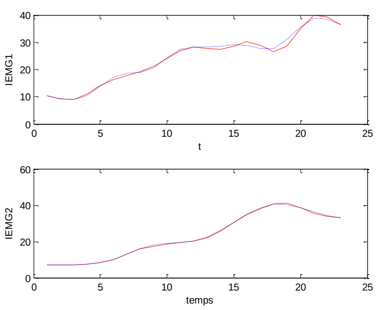
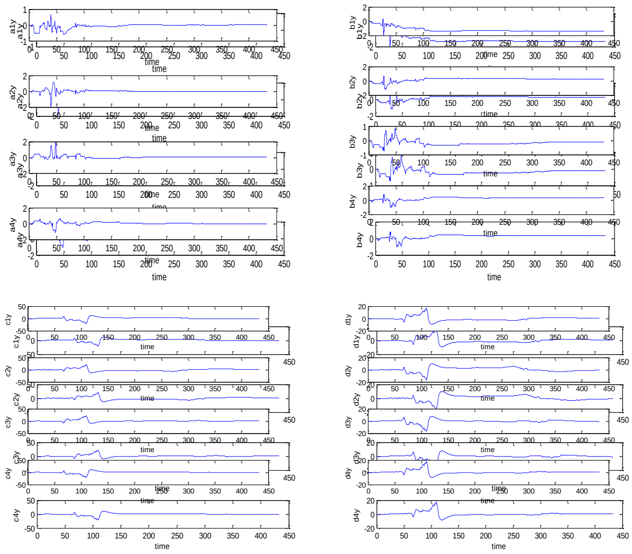


Figure 3. RELS identification's results



(b)

Figure 4. Parameter's evolutions of the Arabic letter "AYN" (a) relative to e_1 (b) relative to e_2

B. Evaluation and validation of the proposed model

The parametric estimation of the proposed model process is completed by a validation step, which contains different tests carried out to retain or reject the proposed structure.

In a first analysis, we try to valid one model allowing to reconstruct two IEMG signals relative to the same type of graphic trace, written by the same writer. For this, the parameters of a model characterizing a drawing shape are integrated with the data saved from another example of the considered trace. Figure 5 shows the result of this validation. Indeed, this figure presents an example of IEMG signals relative to the Arabic letter "AYN, obtained by applying the experimental data of one model (1) to another model (2), relative to another example of the same kind of the first graphic trace "AYN".

In a second analysis, we valid the proposed structure to generate one model characterizing two IEMG signals representing different types of traces, written by two different persons. Figure 6, presents the result of applying the experimental data of IEMG waves of the Arabic letter "AYN", produced by a second writer to the model (1) that describes the same type of letter, "AYN", produced by the first writer.

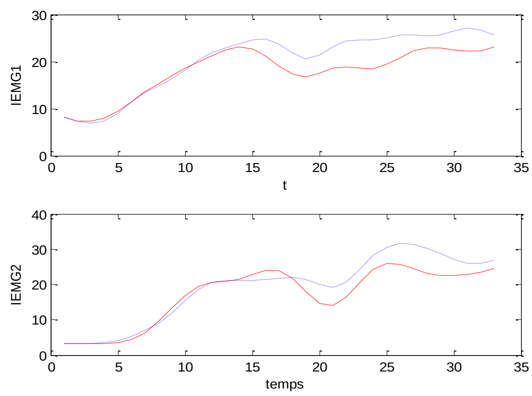


Figure 5. Validation's results in the case of the same writer

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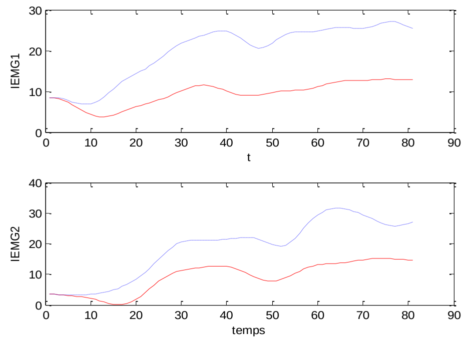

Figure 6. Validation's results in the case of the different writer

The model's responses illustrated by figures 5 and 7 show a correspondence between the answer of the proposed model and the existing data from the experimental approach. In fact, figure 5, obtained in the case of monowriter validation, presents good concordance, compared with the reconstructed trace illustrated by figure 6.

But both figures prove that a refinement should be proposed to this model in the case of IEMG signals generated by the same or different writers.

IV. CONCLUSION

This paper proposes a new linear of fourth order model, characterizing integrated electromyographic signals, using the relationship between the pen-tip movement and the muscular activities of the forearm muscles.

The Extended Recursive Least Squares identification algorithm, RELS, allows to estimate the parameters of the handwriting model.

The proposed model reconstructs IEMG signals of the forearm muscles from the positions of the pen-tip movements in x and y directions.

The different simulations already presented confirm that a remarkable concordance is shown between IEMG waves generated by the proposed model the experimental data. An error is mainly showed in the case of monowriter validation. The multiwriter validation presents an important error.

Accordingly, it would be of a great interest to continue the experimental investigations to ameliorate the model in the both cases monowriter and multiwriter.

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