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DETECTION AND ALERT OF MUSCLE FATIGUE CONSIDERING SURFACE ELECTROMYOGRAPHY CHAOTIC MODEL

Victoria S. Herrera[1], *Jesus Franklin Andrade Romero*[2], *Mauricio Amestegui Moreno*[3]

[1]Universidade Federal do ABC, Santo André - SP, Brasil,vitoria.herrera@ufabc.edu.br
[2]Universidade Federal do ABC, Santo André - SP, Brasil, jesus.romero@ufabc.edu.br
[3]Ingeniería Electrónica, Universidad Mayor de San Andrés, La Paz, Bolivia, mauricioamestegui@gmail.com

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The present work proposes a detection algorithm for muscle fatigue in paraplegic patients undergoing electrotherapy sessions by means of surface electromyographic (SEMG) signal processing. Electromyogram (EMG) signals studies are based on either the analysis of their stochastic temporal characteristics in the time domain, or the power spectrum characteristics in the frequency domain based on Fourier Transform (FT) and Wavelet Transform (WT). Some researches have been focused on characterization and feature extraction of EMG signals in order to identified the type of movement of a muscle [3]. Another studies use neural network to identify characteristics of movement in order to realize prosthetics control [4]. Other ones had projected signals generators based on time series in order to study EMG signal [5]. As [1] and [2] characterized the EMG signal as chaotic, this paper propose to develop a chaotic signal generator, that emulates SEMG signals of a paraplegic patient based on real signals showed in [1]. This chaotic generator will be used to extract characteristics of muscle fatigue, of paraplegic patients, during electrotherapy sessions. These signal characteristics are used to determine the fatigue thresholds that alert when electric stimulation should be stopped.

Chaotic signal generator has been based on the chaotic model of logistic map (see apendix), which has been modified according to the characteristics of the Surface Electromyogram (SEMG) signal of a paraplegic patient shown in [1]. For this purpose Matlab®7.1 was used. In order to perform the signal generator, time segment of the logistic map was modified in order to obtain characteristics of SEMG signal. Following, the most important considerations taken into account to develope the Chaotic Generator are listed.

- The only variables to consider are "r" and x_0 (system complexity and initial condition respectively).
- A constant value of "r" is used, because complexity does not vary in the suggested model.
- "r" must be greater than 3.89, considering that there is a non chaotic region near form this value, and less than 4 because the system is not observable from this value. The value r = 3.99 is chosen for all calculations.
- Initial condition values can vary from 0 to 1.
- Varying initial condition values, SEMG signals of different paraplegic patients or the same patient at different sessions are obtained .
- Time segment of logistic map was divided in three parts to perform the signal generator. Realizing arithmetic operations in each one from a scale factor.

Equations (1), (2) and (3) presents the chaotic model of the SEMG signal generator based on the nodified logistic map:

$$x_{i+1} = rx_i(1 - x_i) + f_{s1} \quad (1)$$
$$for 1 < i < \frac{n}{6}$$
$$x_{i+1} = rx_i(1 - x_i) + f_{s1} \quad (2)$$
$$for \frac{n}{6} < i < \frac{n}{4}$$
$$x_{i+1} = rx_i(1 - x_i) + f_{s1} \quad (3)$$
$$for \frac{n}{6} < i < n$$

The model based data shows that signals obtained from the signal generator could be classified as chaotic through the following criterias:

- Sensitivity to little variations in initial conditions.
- Strange attractor.
- Correlation dimension.

The second part of this work consists in realize and identify a method based on pattern recognition technique and the Continuous Wavelet Transform (CWT). This tools are applied to the chaotic model in order to extract signal features as in [12]. Figure 1 shows the CWT results applied to Chaotic Signal Generator by using a Daubechies4 (db4) as Mother Wavelet. As patient becomes fatigued it could be

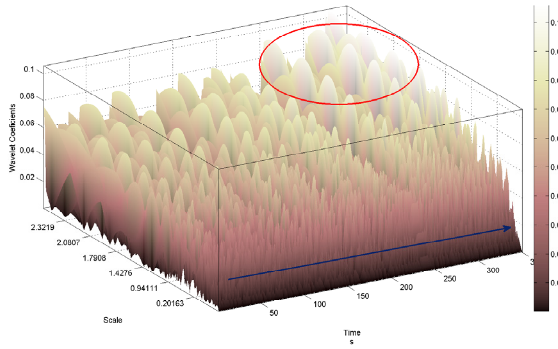

Figure 1 – Wavelet Transform of SEMG resulting of the Chaotic Signal Generator

observed that the wavelet coefficients values grow over time on high scales (low frequencies) as highlighted with a red circle in Fig.1. This feature could be quantified through Total Wavelet Entropy (TWE) observed during electrical stimulation. Numerical results obtained from the TWE, defined in [9], show that SEMG signal energy grows over time i.e. as the patient becomes fatigued. This data can raise the threshold of fatigue that will alert when electrical stimulation should be stopped. Later, an algorithm design of detection and alert of fatigue is proposed in this work, this consists of four steps:

A. Data acquisition.

B. Calculation of the CWT (each 25 sec).

C. Calculation of the TWE (of wavelet coefficients each interval).

D. Calculation of growth percentage of TWE in 25 sec intervals (in relation to the first 25 sec).

The main contribution of this work is the pattern recognition procedure proposed by means of CWT. This tool has permitted to indentify a direct relationship between fatigue increment and wavelet energy increment at low frequencies. This characteristic was quantified by means of TWE. Numerical results have permitted to obtain thresholds of fatigue. It is suggested stopping stimulation before patient allows Maximum fatigue. Implementation of the algorithm will be important because it prevents the muscle achieve maximum fatigue during electrotherapy and gives an adequate information about when electrical stimulation should be stopped. As a future work, the algorithm would be implemented on a Digital Signal Processor.

APENDIX

Logistic map equation. $x_n = rx_n(1 - x_n)$

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