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THE TREMOR COHERENCE ANALYZER (TCA): A PORTABLE TOOL TO ASSESS INSTANTANEOUS INTER-MUSCLE COUPLING IN TREMOR

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ABSTRACT

This paper proposes a novel system for pathological tremor study and diagnosis. The system described called TCA (Tremor Coherence Analyzer) is based on a electronic device developed for wireless monitoring of physiological variables. The device uses Bluetooth technology to communicate. The proposed technique for pathological tremor analysis uses surface EMG signals. The EMG sensors are located on forearm muscles to measure muscular activity due to pathological tremor. The coherence function between these signals is calculated. The application of the coherence function allows to determine linear dependencies between two signals.

Keywords: TCA, Coherence function, Pathological tremor, EMG sensors.

1. INTRODUCTION

The analysis of the temporal correlation between tremor of different muscles of the same limb or from different limbs using coherence spectral methods is relevant for both daily neurological practice and scientific purposes. For instance:

1. Parkinson's disease (PD) tremor is coupled within but less between limbs. In PD, a mental task increases the coherence between muscles of the same limb, whereas a finger-to-nose test decreases the coherence [1].
2. When both cranial muscles and limb muscles show high coherence values, a supra-spinal mechanism can be suspected.
3. Compensatory mechanisms during movement can be estimated.
4. Effects of drugs on the oscillatory behavior of the nervous system/musculoskeletal system can be investigated.
5. Analysis of episodes of bilateral high-frequency synchronous discharges can lead to a better understanding of tremor genesis.

Coherence values higher than 0.6 are usually considered as high. In some disorders, values between 0.9 and 1 are reached.

There are many medical telemetry devices commercially available to acquire electromyography signals like MyoMonitor (EMG Systems), MT8 Telemetry system (MIE Medical Research Ltd.), or the MESPEC 4000 Telemetry (MEGA Electronics). Tools for monitoring signals during daily life have been also developed. For example Keijsers [2] proposes accelerometers for online monitoring of dyskinesia. Another device is the TREMORanalyser, which is a portable long-term EMG recorder, but it is not wireless. This device is oriented to general diagnosis of pathological tremor. It can calculate by a PC software the mean tremor occurrence, frequency and tremor frequency distribution and interaction pattern between antagonistic muscles (phase value for documenting the antagonistic behavior).

The aim of the TCA project is to build a portable tool to assess instantaneously inter-muscular coherence, but this portable tool will be also a potential wireless system for monitoring physiological signals.

2. SYSTEM CONCEPT

The proposed system is a portable wireless electronic device that consists in three components (see figure 1). The first component is the Master Unit. The Master Unit is located on the upper limb and it collects the data from EMG sensors. The surface EMG sensors are located over the flexor and/or extensor muscles. The Master Unit processes the acquired data and shows relevant information in a LCD display. It can also transmit the data to the Base Unit. The Base Unit is a software platform that analyzes and presents the data to the clinician. The last component of the system is the Slave Unit. It is located on the other upper limb and it acquires the signal from a surface EMG sensor located over the contralateral muscle. It transmits the acquired data to the Master Unit on demand. The software platform can plot and store received data for a latter analysis. It also has a configuration tool to set up the sampling frequency of the acquisition system and the ADC channels to be used. These

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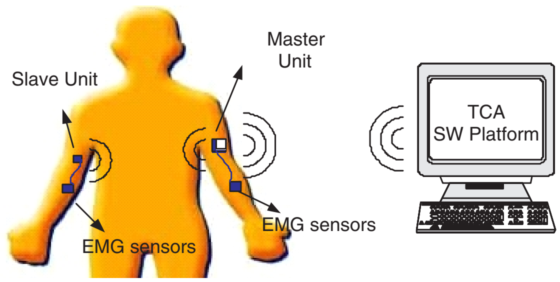

Fig. 1. System concept. In the figure, we can note the three components of the TCA system. They connect each other using a Bluetooth wireless link.

configuration parameters are transmitted to the Master Unit and if it is necessary, the Master Unit will send these parameters to the Slave Unit.

The system uses Bluetooth technology to communicate the different units. The Bluetooth wireless technology is an open specification for short-range wireless communications between electronic devices. The Bluetooth technology uses the ISM band (2.4GHz). Even though, the technology considers medical applications, just a few medical devices use this technology for signal monitoring (LIFESYNC, Wireless ECG Monitoring, GMP Wireless Medicine Inc.). The system uses a Bluetooth Module (Bluegiga Wrap Thor) in each unit. Medical Telemetric devices avoid problems with cables. A wireless network could be established using this technology. This is very important if we consider that the aim of TCA project is to develop a general tool for wireless monitoring of physiological signals.

The Master Unit is a an electronic board with a microcontroller (Atmega128, Atmel Inc.), a LCD display (8 columns x 2 lines, character display) and a Bluetooth module. The size of the board is 55x38 mm. The Bluetooth module is mounted on a secondary board, whose size is 43x32mm. There are 8 ADC channels for sensors. One of them is shared with the battery level meter. The resolution of each channel is up to 10 bits [3]. The Slave Unit uses like the Master but without the LCD display. The Base Unit needs a Bluetooth module to establish a wireless link with the Master Unit. The system is powered by Lithium Ion batteries (CGA-7/102F, 3.7 V, 900 mAh, Matsushita Ind. Corp.). Some medical equipments use NiCad batteries but Lithium Ion ones have a better power density. The disadvantage of this technology is that standard sizes are not available.

3. PATHOLOGICAL TREMOR COHERENCE

The analysis of time series acquired from different sensors has been used for a long time in order to find some hidden periodicities. Specifically, EEG and EMG signal were widely used in neurophysiology. The application of cross-correlation analysis to human EMG recording demonstrated that motor unit synchronization may occur in healthy subjects during isometric contractions [4][5]. Cross-correlation histogram computed from pairs of spike trains and various time domain measures derived from it have been used as the basis for inferring the parameters of underlying post-synaptic potentials as well as the patterns of neuronal connections [6]. Some frequency domain techniques have been also used to study dependencies between signals and to determine the signal path in the central nervous system [7]. Nowadays, thanks to new technologies and calculation capacity more frequency domain techniques are used like power spectral estimations and the coherence function. One advantage of frequency domain parameters is that confidence limits for parameter estimations can be easily obtained and they are often independent of the data characteristics.

Electromyography (EMG) is the study of muscle function through the analysis of electrical signals evoked during muscular contractions. For this work surface EMG sensors placed over the arm flexor/extensor muscles have been used. The TCA project has developed the system described which uses these signals to calculate the coherence function between forearm muscles in order to establish common motor units in pathological tremor.

We are going to focus the frequency analysis on the 3-6 Hz band and the double frequency band (6-12 Hz). This band corresponds to the Parkinson's disease resting tremor.

4. ANALYTIC METHODS

Used sensor signals are in the time domain, they are consecutive and equidistant samples of the surface EMG signals located over flexor/extensors forearm muscles. We assumed, for the analysis, that the data series are wide-sense stationary [8]. However, once we implemented the system this was checked in order to avoid inconsistencies.

4.1. Coherence

The coherence function between two wide-sense stationary random process x and y is equal to the cross power spectrum divided by the square root of the product of the two auto power spectra. This function can be imaginary and complex. Coherence is formally defined by

$$\gamma_{xy}(f) = \frac{G_{xy}}{\sqrt{G_{xx}(f)G_{yy}(f)}} \qquad (1)$$

where f denotes the considered frequency and G_{xy}, the complex cross power spectrum stated by

$$G_{xy}(f) = \int_{-\infty}^{+\infty} R_{xy}(\tau)e^{j2\pi f\tau}d\tau, \qquad (2)$$

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and is the Fourier transform of the cross correlation function.

$$R_{xy}(\tau) = E[x(t)y(t+\tau)]. \tag{3}$$

The x and y (EMG signals) are real and $E[]$ denotes the mathematical expectation. The coherence is a normalized cross-spectral density function; in particular, the normalization constrains (1) so that magnitude-squared coherence (MSC) defined by

$$C_{xy}(f) = |\gamma_{xy}(f)|^2 \tag{4}$$

lies in the range

$$0 \le C_{xy}(f) \le 1 \tag{5}$$

for all frequencies.

4.2. Confidence limits

Confidence limits for the coherence function has been widely discussed [9][10]. The procedure to get the confidence limits involves two steps: firstly the development of an expression for variance of the coherence and then the construction of confidence limits for a desired level of significance, in this paper equal to 95 %. An appropriate variance transform has been developed which leads to the expression

$$var\{\tanh^{-1}|C_{xy}(f)|\} = \frac{1}{2L}. \tag{6}$$

Considering independence of signals, $|R_{xy}(f)|^2 = 0$, therefore (6) is invalid. To evaluate de confidence limits in these cases, the incomplete Beta function is used with parameters 1 and $(L-1)$ [11][12]. Thus, the constant value

$$1 - (0.05)^{\frac{1}{L-1}} \tag{7}$$

is plotted (see figure 2) in coherence graphics as an estimate of the 95% confidence limit. This is possible considering independence of signals.

The coherence function has been used in many areas such as system identification, signal path modelling, measurement of signal to noise ratio (SNR) and determination of time delay.

5. METHODOLOGY

The first development was implemented in order to start the validation process and project purpose. The first prototype does not include the Slave Unit. Both EMG signals were acquired with the Master Unit. First trials with the system were done using Motion Lab Systems EMG sensors. Figure 3 shows the Control Unit. The sampling frequency was 512 Hz and the resolution was of 8 bits. A PC software was developed for online monitoring during trials. For these first trials, the LCD display was not used. The acquired signals are shown in figure 4.

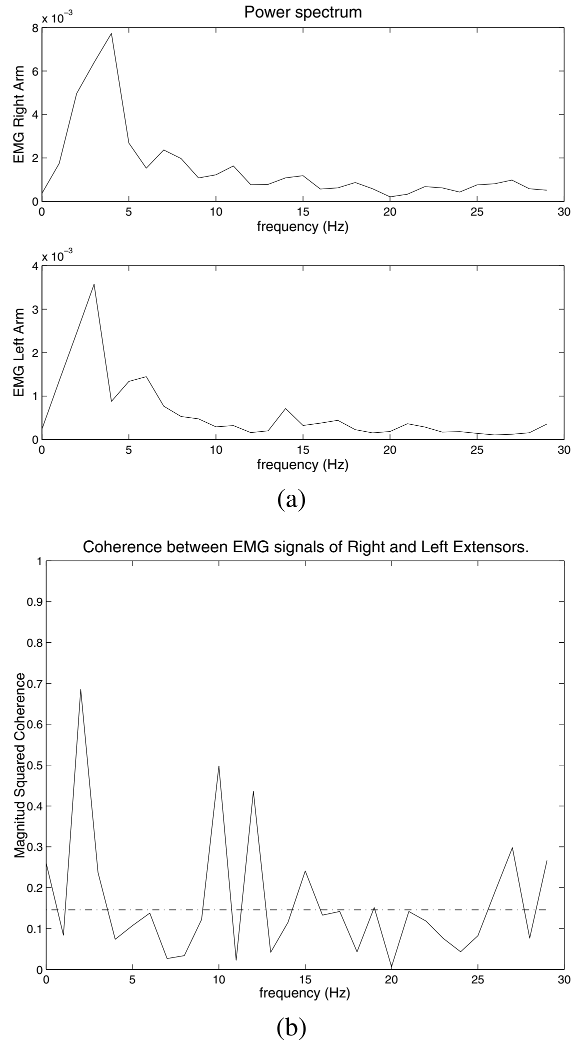

Fig. 2. (a)Power spectral of EMG signals located on the forearms of a patient with tremor. The power is concentrated around de 3-5Hz band and (b) the coherence function between signals. The dashed line represents 95% confidence limit in case of independence.

6. CONCLUSIONS

The system developed is still subject to a validation. However, in this paper we showed a system concept for a tool which will help diagnose pathological tremor. The concept was presented as a first step in the development of a wireless system for monitoring physiological variables. The Bluetooth technology enlarges this field due to its capabilities for establish a wireless network. Thus, the field of medical devices for monitoring patient during daily life is growing quickly. Under this concept, many medical devices are appearing lately.

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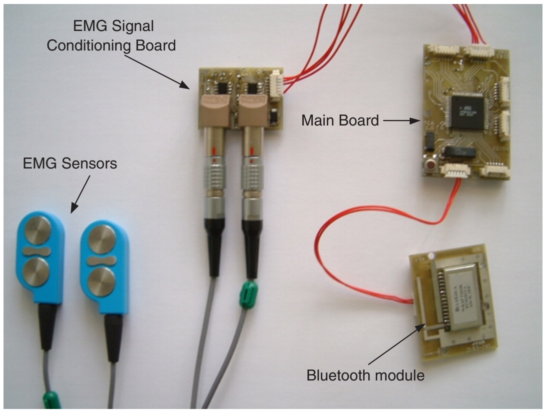

Fig. 3. Components of the prototype system used for first trials.

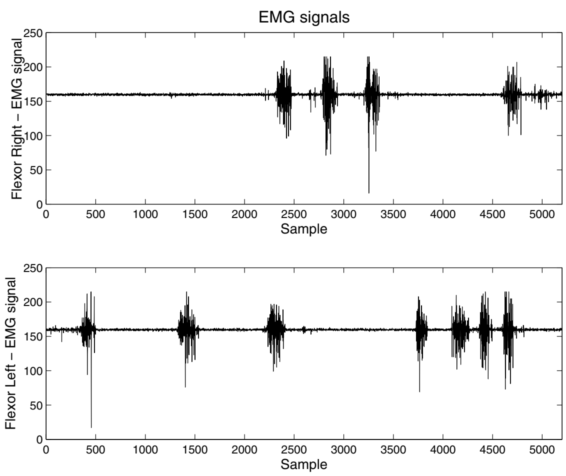

Fig. 4. Acquired EMG signals with TCA prototype system. 512 Hz sampling frequency was used.

7. FUTURE WORK

Next steps in the TCA project include the validation of the acquired signals analysis tools and the study of other types of sensors for physiological monitoring. Validation with patients is also scheduled in the project as a next step. Finally the whole concept of the system will be implemented.

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