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Compression of Electromyographic Signals Using Image Compression Techniques

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***Abstract*—Despite the growing interest in the transmission and storage of electromyographic signals for long periods of time, few studies have addressed the compression of such signals. In this article we present an algorithm for compression of electromyographic signals based on the JPEG2000 coding system. Although the JPEG2000 codec was originally designed for compression of still images, we show that it can also be used to compress EMG signals for both isotonic and isometric contractions. For EMG signals acquired during isometric contractions, the proposed algorithm provided compression factors ranging from 75 to 90%, with an average PRD ranging from 3.75% to 13.7%. For isotonic EMG signals, the algorithm provided compression factors ranging from 75 to 90%, with an average PRD ranging from 3.4% to 7%. The compression results using the JPEG2000 algorithm were compared to those using other algorithms based on the wavelet transform.**

I. INTRODUCTION

ELECTROMYOGRAPHIC (EMG) signals are very important tools for the study of muscle behavior [1], [2]. The storage and/or transmission of these signals is an issue, because the amount of data is typically large, depending on sampling rate, precision per sample, number of channels, and number of subjects, among other factors.

Several techniques have been proposed for compression of biomedical signals such as the electrocardiogram (ECG) [3]–[5] and the electroencephalogram (EEG) [6]. However, few methods have been proposed for compression of electromyographic signals.

Norris and Lovely [7] investigated the compression of electromyographic signals using ADPCM (Adaptive Differential Pulse Code Modulation). Guerrero and Maihes [8] compared different compression methods based on linear prediction and orthogonal transforms. They showed that methods based on the wavelet transform outperform other compression methods. The use of the Embedded Zero-Tree Wavelet (EZW) algorithm has also been proposed for compression of electromyographic signals [9], [10]. More recently, Berger *et al.* [11] proposed an algorithm for compression of electromyographic signals using the wavelet transform and a scheme for dynamic bit allocation of the coefficients using a Kohonen layer. In a recent work, Brechet *et al.* [12] adopted the Discrete Wavelet Packet Transform (DWPT) decomposition with optimization of the mother wavelet and of the basis of wavelet packets, followed by an EZW-like coder. The use of speech coding methods has also been reported in literature [8], [13]. Carotti *et al.* [13] proposed a scheme for compression of simulated and real EMG signals with ACELP (Algebraic Code Excited Linear Prediction) and the results were evaluated with several spectral and statistics measurements.

This work presents the results of a method for compression of electromyographic signals based on the JPEG2000 algorithm. Although the JPEG2000 has been effectively used for the compression of ECG signals in previous works [14], [15], this coder has not yet been tested for the compression of EMG signals measured during isometric and isotonic contractions.

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II. MATERIALS AND METHODS

A. Signal Acquisition Protocols

In order to evaluate the performance of the JPEG2000 standard in the compression of electromyographic signals, we acquired data during isometric and isotonic contractions.

Isometric contractions

Isometric contractions EMG signals were obtained from 4 male healthy volunteers with 28.3 ± 9.5 years of age, 1.75 ± 0.04 m height, and 70.5 ± 6.6 kg weight. These signals were measured on the biceps brachii muscle. In the beginning of the protocol, the maximum voluntary contraction (MVC) was determined for each subject. The signals were collected during 60% MVC contraction, with an angle of 90° between the arm and the forearm, and with the subject standing. The protocol was repeated 5 times with each volunteer, with a 48-hour interval between experiments. One of the volunteers was absent during one of the sessions. Therefore, a total of

19 EMG signals was acquired.

Isotonic contractions

EMG during isotonic activities (cycling) were obtained from 9 healthy volunteers (6 men, 3 women), with 24.4 ± 4.3 years of age. All subjects presented normal body mass index.

The EMG was measured in the vastus medialis and vastus lateralis muscles, which are leg muscles with high surface electromyographic activity during the proposed exercise. Before positioning of the electrodes, the distances between the lateral external portion (LEP) of the patella and the head of the femur (HF) were measured, as well as the distance between the internal lateral portion (ILP) and the head of the femur (HF) of the right thigh. After tricotomy, the skin was cleaned and abraded with alcohol. One active electrode was used for the vastus lateralis muscle, placed at 1/5 of the distance between the LEP and the HF (measured from the knee). Another active electrode was used for the vastus medialis muscle, at 1/4 of the distance between the ILP and the HF (also measured from the knee).

A commercial electromyograph (Delsys, Bagnoli-2, Boston, USA) was used for signal acquisition. This equipment uses active electrodes with a pre-amplification of 10 V/V and a bandpass from 20 Hz to 450 Hz. The signals were amplified with a total gain of 1000 V/V, and sampled at 2 KHz using a 12-bit DAQ system (National Instruments, PCI 6024E, Austin, TX, USA). LabView (National Instruments, Austin, TX, USA) was used for signal acquisition, and Matlab 6.5 (Mathworks, Inc., South Natick, MA, USA) was used for signal processing.

The exercise was performed using 70% of the maximum power and 70% of the maximum speed, until exhaustion. This was preceded by a warm-up period with a maximum duration of 4 minutes. This protocol was programmed into the instrumentation of the ergometric bicycle (Ergo-Fit, Ergo Cycle 167, Pirmasens, Germany). Signal acquisition was not performed during warm-up.

A total of 18 EMG signals was acquired (9 volunteers, 2 electrodes).

B. *Signal Compression of EMG Signals Using JPEG2000*

Figure 1 shows a block diagram of the proposed coding scheme.

The method consists in segmenting each EMG signal into 512-sample segments, and then arranging these segments as different columns of a two-dimensional matrix, which can then be compressed using the JPEG2000 algorithm [16]–[20]. The JPEG2000 is a state-of-the-art image coding standard which uses the EBCOT (Embedded Block Coding with Optimal Truncation) algorithm [17] on the subband samples of the discrete wavelet transform of the image.

In the two-dimensional matrix, the number of columns is defined by the number of complete 512-sample segments. The last (incomplete) segment typically represents a post-exercise period. Thus, it does not contain critical information, and is simply discarded.

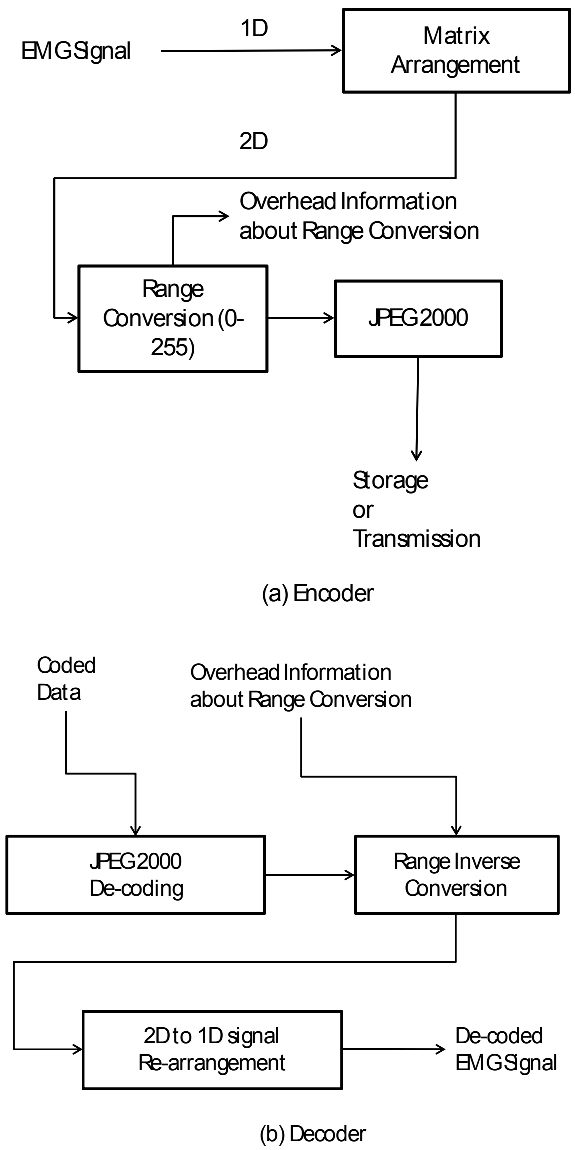

Fig. 1. Block diagram of the proposed compression algorithm.

The 2D matrix is scaled to the 8-bit range (0 to 255), and then coded using the JPEG2000 algorithm at rates ranging from 0.03125 to 8 bits per pixel. The scaling parameters (signal maximum and minimum) are also stored.

The encoded data is then reconstructed using the JPEG2000 decoder, and the EMG signal is recovered by rearranging the matrix's columns back into a one-dimensional vector, and scaling the signal back into its original dynamic range.

III. Results

The compression quality was evaluated by comparing the reconstructed signal to the original signal. The performance of the compression algorithm was measured by two objective criteria: the compression factor (CF) and the square root of the percentage root mean difference (PRD). These two criteria are the most commonly used by the scientific community to evaluate the compression of EMG signals. The compression factor is defined as:

$$CF(\%) = \frac{Os - Cs}{Os} \cdot 100 \ , \quad (1)$$

where Os is the number of bits required for storing the original data and Cs is the number of bits required for storing the compressed data.

The PRD is defined as:

$$PRD(\%) = \sqrt{\frac{\sum_{n=0}^{N-1} \left(x[n] - \hat{x}[n] \right)^2}{\sum_{n=0}^{N-1} x^2[n]}} \cdot 100 \ , \quad (2)$$

where x is the original signal, $\hat{x}$ is the reconstructed signal, and N is the number of samples in the signal.

Figure 2 shows the measured PRD as a function of CF, for all the 19 isometric EMG signals, as well as the average result. The results show that the quality decreases when the compression factor is increased. Increasing the compression factor above 85% causes significant deterioration of the decoded signal.

Figure 3 shows the result for the compression of EMG signal acquired during isotonic activities. A similar pattern was observed, with compression factors above 90% causing more significant signal deterioration.

Figure 4 illustrates the visual quality of the reconstructed signal. The central 2000 samples of the original, reconstructed, and error signals are shown.

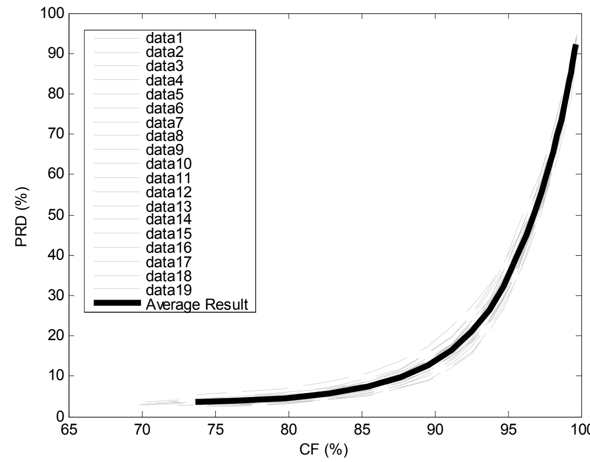

Fig. 2. CF vs. PRD for the electromyographic signals measured during isometric contractions.

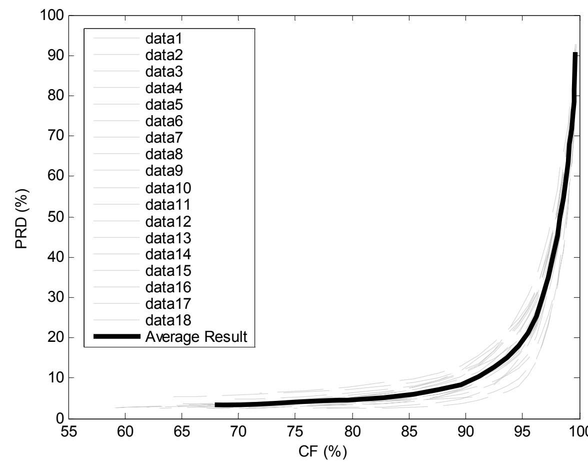

Fig. 3. CF vs. PRD for the compression of signals measured during isotonic activities.

IV. Discussion

Table I shows a comparison between the results obtained using the proposed algorithm with the isometric contraction signals, compared to the results obtained by Norris *et al.* [10] and Berger *et al.* [11]. Compared to the EZW-based algorithm used in [10], the JPEG2000 provided slightly better reconstruction quality (lower PRD) for compression factors values of 85% or lower. This difference, however, was not statistically significant. Compared to the compression method proposed in [11], JPEG2000 showed moderately inferior overall performance.

Table II presents a similar comparison, but for isotonic EMG signals. The results obtained with the JPEG2000 are significantly better than the ones obtained by Norris *et al.* When compared to the algorithm proposed by Berger *et al.*, JPEG2000 also provides superior results for compression factors higher values of 80% or higher.

Norris *et al.* [10] and Berger *et al.* [11] used protocols very similar to the ones used in this work. A surface EMG, with 12-bit resolution and 2 kHz sampling rate was also used in those studies. Moreover, those studies also used isometric signals acquired at the biceps brachii muscle.

TABLE I
Comparison Between the results obtained by the proposed algorithm and results from literature, for the compression of EMG signals measured during isometric contractions

CF(%)	Norris *et al.* – PRD (%)	Berger *et al.* – PRD (%)	JPEG2000 – PRD (%)
75	3.8	2.5	3.75
80	5	3.3	4.7
85	7.8	6.5	7.2
90	13	13	13.7

TABLE II
Comparison Between the results obtained by the proposed algorithm and results from literature, for the compression of EMG signals measured during isotonic muscular activities

CF(%)	Norris *et al.* – PRD (%)	Berger *et al.* – PRD (%)	JPEG2000 – PRD (%)
75	7.85	2.6	3.4
80	9	4.4	4.1
85	9.5	7.25	5.2
90	20	20	7.0

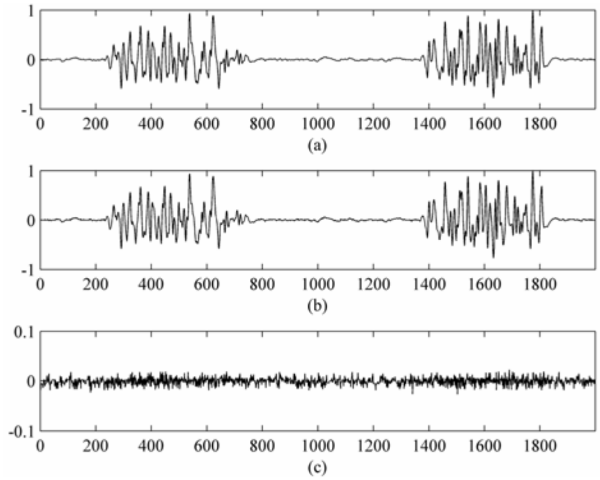

Fig. 4. Representative result for an isotonic muscular activity signal. (a) Original EMG signal. (b) Reconstructed EMG signal after 75% compression. (c) Reconstruction error. Note that the magnitude of (c) is scaled up by 10-fold.

With respect to the isotonic signals, however, those studies used only signals acquired in the vastus lateralis muscle, whereas signals from both vastus lateralis and vastus medialis muscles were used in this work. Thus, caution must be used when comparing these results. Furthermore, the protocol for signal acquisition used by Norris *et al.* was not described in [10]. Therefore, it is possible that the contraction level was different from the one used in this work, which could result in a set of signals with different characteristics.

V. Conclusion

This article presented a methodology for the compression of surface electromyographic signals using an algorithm for compression of digital images that is widely used, the JPEG2000. The compression scheme was evaluated on 19 electromyographic signals measured during isometric contractions, and 18 signals acquired during isotonic activities. The results showed that this coding scheme yield compression factors between 75% and 90%, with PRD's ranging from 3.75% and 13.7%, for isometric electromyographic signals, and PRD's ranging from 3.4% to 7% for isotonic electromyographic signals.

Even though the JPEG2000 was developed for the compression of digital images, this work has shown that this commonly available algorithm can be effectively used for the compression of electromyographic signals, with a performance that is compatible to that of other algorithms presented in the literature.

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