TWO-DIMENSIONAL COMPRESSION OF SURFACE ELECTROMYOGRAPHIC SIGNALS USING COLUMN-CORRELATION SORTING AND IMAGE ENCODERS

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INTRODUCTION

Surface Electromyographic (**S-EMG**) signals are important tools in the investigation of muscular behavior [1], [2]. The **storage and/or transmission** of these signals is an issue, because the amount of data is typically large, depending on factors such as the sampling rate, quantization precision, number of channels, and number of subjects, among others.

Several different approaches have been proposed for **compression of electromyographic signals**, including DPCM [3], linear prediction and orthogonal transforms [4], embedded zero-tree wavelet (EZW) algorithm [5], [6], algebraic code excited linear prediction (ACELP) [7], discrete wavelet transform with dynamic bit allocation [8], discrete wavelet packet transform followed by an EZW-like coder [9] and the multiscale multidimensional parser algorithm [10].

We have recently proposed the use of the **JPEG2000** image encoding algorithm for compression of S-EMG signals, by segmenting the S-EMG signal and arranging the segments as columns of a 2D matrix [11].

In this work, we propose the use of a **preprocessing** step in which the columns of this matrix are **reordered** based on a measurement of their **similarity**. We compare results obtained with and without column-reordering, and also evaluate the use of an alternate image encoder, the **H.264/AVC intra** algorithm.

MATERIALS AND METHODS

SIGNAL ACQUISITION PROTOCOL: Isometric and isotonic S-EMG signals were sampled at **2 kHz** using **12-bit** quantization.

Isometric contraction 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. Signals were measured on the **biceps brachii** muscle. The signals were collected using 60% of the MVC, with a 90° angle between arm and forearm, and in standing position.

S-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. S-EMG was measured on the **vastus medialis** and **vastus lateralis** muscles, which are leg muscles with high surface electromyographic activity during the proposed exercise. The exercise was performed using 70% of maximum power and 70% of maximum speed, until exhaustion.

COMPRESSION OF S-EMG SIGNALS USING 2D ENCODERS: **Fig. 1** shows a block diagram of the proposed coding scheme. The method consists in **segmenting** each S-EMG signal into 512-sample segments, and then arranging these segments as different **columns** of a two-dimensional (2D) matrix, which can then be compressed using 2D encoders: JPEG2000 and H.264/AVC.

JPEG2000 [12]–[14] is a state-of-the-art image coding standard which uses embedded block coding with optimal truncation [14] on the subband samples of the discrete wavelet transform of the image.

The H.264/AVC encoder is the latest standard for video compression [15], [16], and provides a two-fold gain in compression efficiency compared to the MPEG-2 and H.263 algorithms [17]. The H.264/AVC intraframe encoder has been effectively used for the compression of ECG signals [18], but has not been evaluated for S-EMG compression.

The number of columns in the 2D matrix is defined by the number of **512-sample segments**. The last (incomplete) segment is zero-padded. The matrix is scaled to the **8-bit range** (0 to 255). The columns are rearranged, based on their cross-correlation coefficients.

The **JPEG2000** algorithm was evaluated with compression rates ranging from **0.03125 to 8 bits per pixel**. The **H.264/AVC** encoder was used in intraframe (still image) mode, with DCT quantization parameter values ranging from **51 to 1**.

The encoded matrix is recovered using the appropriate image decoder, and the S-EMG signal is reconstructed by rearranging the matrix columns back into a one-dimensional vector and then scaling the signal back to its original dynamic range.

PREPROCESSING BASED ON CORRELATION SORTING: In order to increase 2D-compression efficiency, we attempt to increase the correlation between adjacent columns, by rearranging the columns based on their **cross-correlation coefficients**.

The matrix of column cross-correlation coefficients (R) is computed from the covariance matrix C, as follows:

$$R(u,w) = \frac{C(u,w)}{\sqrt{C(u,u) \cdot C(w,w)}}.$$

Then, the pair of columns that present the **highest cross-correlation coefficient is placed as the first two columns** of a new matrix, and so forth. A list of column positions in annotated. This procedure is similar to that used by Filho *et al.* for reordering segments of ECG [18].

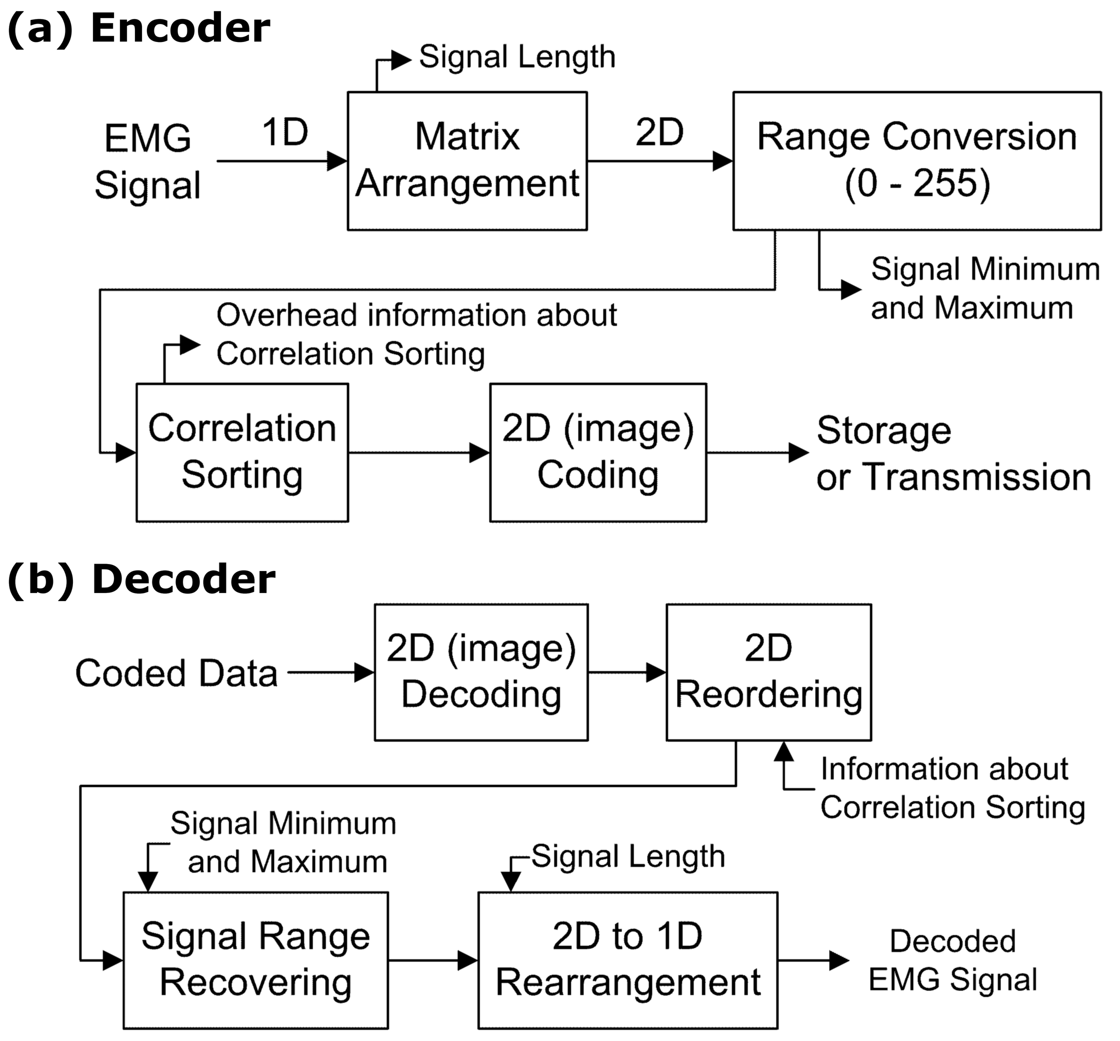

Fig. 1. Block diagram of the proposed compression algorithm.

Fig. 2 illustrates the result of applying the proposed column-correlation sorting to a S-EMG signal arranged in 2D representation.

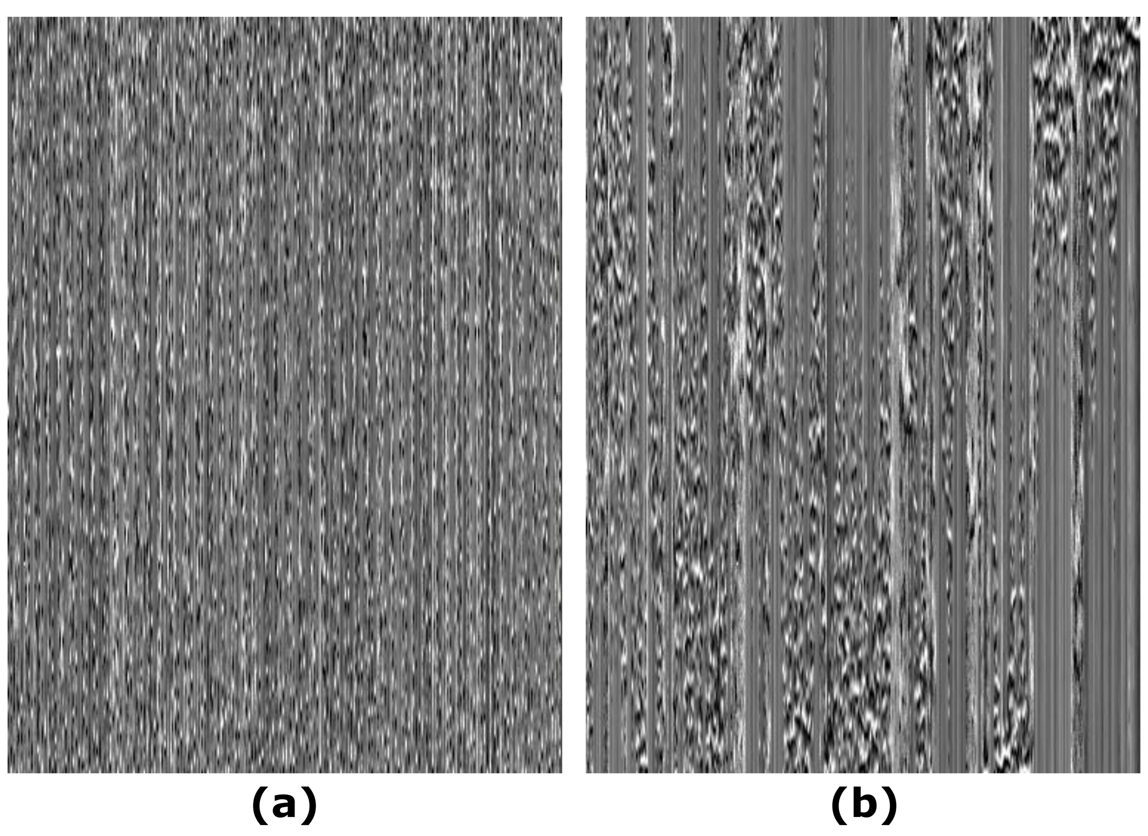

Fig. 2. S-EMG signal in 2D representation, where each column is a 512-sample segment of the signal. **(a)** original matrix. **(b)** preprocessed matrix (after correlation-based column reordering).

PERFORMANCE EVALUATION: The performance of the proposed compression algorithms was measured using two metrics: compression factor (**CF**) and percentage root mean square difference (**PRD**).

RESULTS

Table I shows mean PRD results for **isometric** contraction signals. The proposed preprocessing stage **(correlation sorting) improves the performance of the JPEG2000-based approach.** This is especially true for 90% compression, in which its performance is comparable to that achieved by Berger *et al.* The H.264/AVC-based method showed low overall performance, even with preprocessing.

Table II shows mean PRD results for **isotonic** exercise signals. **With correlation sorting, the JPEG2000-based approach is superior to all other evaluated methods for the range of evaluated compression rates**. The H.264/AVC-based method achieved better overall performance than the algorithm by Norris *et al*., especially when preprocessing is used.

Fig. 3 illustrates the compression quality for a S-EMG signal measured during isotonic muscular activity **(CF=80%): PRD = 3.82% for the JPEG2000 and PRD = 4.43% for the H.264/AVC.** Reconstruction errors are magnified by 10-fold. The reconstruction error of the JPEG2000 algorithm is noticeably **smaller** than that of the H.264/AVC algorithm. The noise pattern observed for both approaches seems visually uncorrelated with the signal.

DISCUSSION

The signal acquisition protocols used by Norris *et al.* [6] and Berger *et al.* [8] for **isometric** contractions was **very similar** to the one used in this work: 12-bit resolution, 2 kHz sampling rate, S-EMG measured on the biceps brachii muscle. However, with respect to **isotonic** exercise, this work used signals from both vastus lateralis and vastus medialis muscles, whereas those studies only used signals measured on the vastus lateralis muscle. Furthermore, since Norris *et al.* did not describe their acquisition protocol for isotonic exercise, 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**. These facts must be taken in consideration when evaluating the results presented.

Table I

MEAN PRD RESULTS (IN %) FOR ISOMETRIC CONTRACTION SIGNALS

Compression Factor	75%	80%	85%	90%
Norris *et al.* [6]	3.8	5	7.8	13
Berger *et al.* [8]	2.5	3.3	6.5	13
JPEG2000	3.58	4.60	7.05	16.69
c.s. + JPEG2000	3.50	4.48	6.92	13.44
H.264/AVC	5.51	7.03	10.01	16.68
c.s. + H.264/AVC	5.37	6.90	9.93	16.62

c.s. refers to correlation sorting preprocessing.

Table II

MEAN PRD RESULTS (IN %) FOR ISOTONIC EXERCISE SIGNALS

Compression Factor	75%	80%	85%	90%
Norris *et al.* [6]	7.85	9	9.5	20
Berger *et al.* [8]	2.6	4.4	7.25	20
JPEG2000	4.27	5.36	7.62	13.61
c.s. + JPEG2000	–	4.39	5.77	9.39
H.264/AVC	5.59	7.21	10.17	16.39
c.s. + H.264/AVC	4.13	5.16	7.12	11.30

c.s. refers to correlation sorting preprocessing.

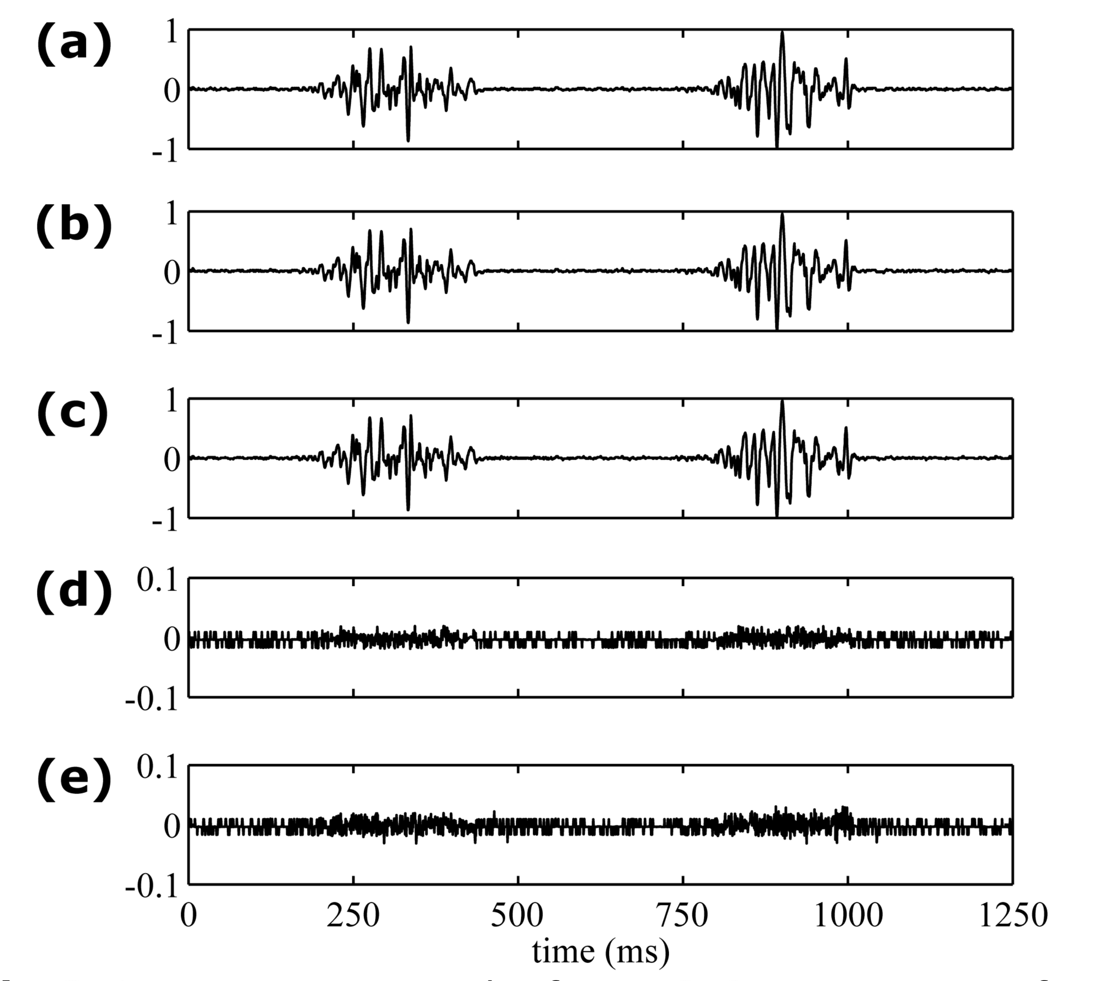

Fig. 3. Representative results for a 1250-ms segment of an isotonic signal. **(a)** Uncompressed; **(b)** *c.s.* + JPEG2000; **(c)** *c.s.* + H.264/AVC; **(d)** JPEG2000 reconstruction error; **(e)** H.264/AVC reconstruction error.

CONCLUSIONS

This work presented a method for the compression of surface electromyographic signals using off-the-shelf image compression algorithms. Two widely used image encoders were evaluated: **JPEG2000 and H.264/AVC intra**. A **preprocessing** step was proposed for increasing inter-column **correlation** and improving **2D compression** efficiency.

The proposed scheme was evaluated on surface electromyographic signals measured during both isometric and isotonic exercise. We showed that commonly available algorithms can be effectively used for compression of electromyographic signals, with a performance that is **comparable or better than that of other algorithms** proposed in the literature. We also showed that the **proposed preprocessing stage significantly improves the performance** of the proposed method.

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