Evaluation of Two-Dimensional Coding of Surface Electromyographic Signals in Dynamic Contractions Using HEVC-Intra Encoder

C. H. S. Mendonça, D. B. Gusmão, and M. V. C. Costa

Abstract

Digital signal processing has several applications in biomedical engineering and it is possible to observe the great technological progress resulting in digital devices. Electromyographic signals are an important source of information regarding biological parameters but generate a large amount of data when digitized. This work presents the evaluation of HEVC (High Efficiency Video Coding) encoder operating in intra mode applied to the compression of surface electromyographic signals (sEMG) of three different dynamic exercise protocols: (i) Increasing power and constant speed; (ii) Constant power and increasing velocity; (iii) Constant power and constant speed. Objective evaluation metrics are applied in the analysis of the results: the percentage root mean square difference (PRD%) and the compression factor (CF%). Different behaviors of the encoder were observed when different protocols were applied and with different rectangular temporal window lengths. Competitive results were obtained in comparison to the reference literature with the signals of the third protocol (iii) under a window of 8192 samples, when CF of 85, 90 and 95% was applied.

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Keywords

Electrophysiological signal compression • Surface electromyography • Dynamic muscle contractions

1 Introduction

Biomedical engineering brings many contributions to the development of information technology applied to life sciences and for the evolution of scientific knowledge within the health field. Surface electromyography (sEMG) is one of its applications in the evaluation and diagnosis of muscular pathologies that uses various techniques of electronic instrumentation that must have its signals processed, stored, and often transmitted by different medias [1].

Monitoring any kind of biosignal for a long period of time generates an enormous amount of data. In order to store or transmit this large amount of data and retrieve them, it is necessary to perform compression by efficient methods and techniques, considering that the use of biomedical signals in telemedicine requires quality and fidelity in the representation of the reconstructed message [2].

Several techniques for signal compression have been proposed in the literature and can be classified into two main classes: lossless compression and lossy compression [3]. In lossless compression, decompressed data are mathematically equal to the original data, with moderate compression rates, whereas in lossy compression a significant increase in compression rates is achieved by tolerating a limited difference between the original and the recovered data [4, 5].

Recently, in our research, we evaluated the influence of three different dynamic activities protocols on the result of the surface electromyographic signals compression algorithm using the HEVC-intra encoder. As the HEVC operating in intra mode is an image encoder, the sEMG signals were segmented and arranged as columns of a two-dimensional matrix to be encoded.

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2 Materials and Methods

The High Efficiency Video Coding (HEVC) is a standard video encoder designed for general and open use. The main objective is to improve the performance of video compression compared to others off-the-shelf encoders [6]. The intra mode of the HEVC is its form of coding in the same figure, with the purpose of verifying redundancies and eliminating them in the compression process [7]. To perform the evaluation of the HEVC-intra encoder, we used sEMG signals data bank acquired by Andrade [8]. The signals, amplified by 10 V/V and acquired at 2000 Hz, came from three different dynamic test protocols. The tests had 9 volunteers with a mean age of 24.4 ± 4.3 years, 6 male and 3 female, all young and healthy, riding a cycloergometer (to evaluate and map muscular fatigue): 1st Protocol—Initial load of 150 W, increase of 50 W each 30 s, constant speed 30 km/h; 2nd Protocol—Constant load of 70% of the final load of the first protocol, initial velocity of 30 km/h and increase of 3 km/h every 30 s; and 3rd Protocol—Constant load and speed with high intensity, applying 70% of the final load of protocols 1 and 2. In this work we use only the sEMG of the vastus medialis muscle available in Andrade's work.

The initial stage of treatment of the electromyographic signals of each of the three protocols was the pre-processing as preparation to insert in the HEVC-intra encoder. The signals were transformed from vectors (1D) to matrices (2D) so that their processing was given as an image. For the signal compression with the HEVC encoder, temporal windows were adopted with 2^k samples (k = 5 … 13); the 2D representation is achieved by putting each of these windows as rows in a matrix. As the sEMG signal is transform into a single image, the intra-prediction works more efficiently. Then the dynamic range of the images was normalized to 16 bits, i.e., a mapping of the values of the range of 0 to $[(2^{\text{bits}}) - 1]$ for this bit-depth.

The HEVC encoder was configured with Monochrome 16 Intra profile. In this profile, the encoder uses the 4:0:0 image pattern (luminance samples only), word depth equal to 16 bits, and only the intra-frames prediction. The QP (DCT quantization parameter) value was varied from 1 (higher rate and better quality) to 51 (lower rate and worse quality).

The signal length and its maximum and minimum values were transmitted to the decoder as overhead information. After the decoding, the signal is mapped to its original 1D format and dynamic range. The encoding evaluation is done comparing the original signal with the reconstructed signal in unidimensional representation. Objective evaluation criteria were used to assess the compression quality of a particular compressed archive: compression factor (CF%) and percentage root mean square difference (PRD%).

The compression factor is defined as

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

where Os is the number of bits required to store the original data and Cs is the number of bits required to store the compressed data, including the overhead information.

The percentage root mean square difference is defined as

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

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

The compression performance comparison of sEMG signal encoders is carried out by the relation CF x PRD. In general, it is verified that the higher the CF and the lower the PRD, the better the results obtained in the reconstructed image after the coding process.

3 Results and Discussion

Figures 1, 2 and 3 present the average PRD curves for each window length juxtaposed in three dimensions with the CF variation (i.e., CF x mean PRD as a function of window length). The length of the windows is given in log2 for better adjustment of the values to the figures axes.

The difference between protocols when analyzed graphically is imperceptible because there are many similarities among the graphic behaviors of the encoder for the three protocols. To clarify the differences, this data was emphasized to some points of interest (Tables 1, 2 and 3), as described below.

Tables 1, 2 and 3 present the mean value of PRD for CF in the range of 80–95%. The values are given in different temporal window lengths and in the cases explored it is possible to verify that the larger the signal window, the lower the PRD of the reconstructed signal.

The results show that the HEVC encoder has different behaviors for each protocol, also considering the size of a particular window. The lowest PRD values are mostly found for windows of length 8192 and are marked in bold in Tables 1, 2 and 3.

This probably occurs because of the shape of the contents of each sample window. In smaller windows small amounts of signals and noises are captured, however, this capture follows the windowing of bursts (action periods) and silences (rest periods), managing to correlate and identify redundancies between signals juxtaposed in ordered sequence. The uniformity of the characteristics of the signals

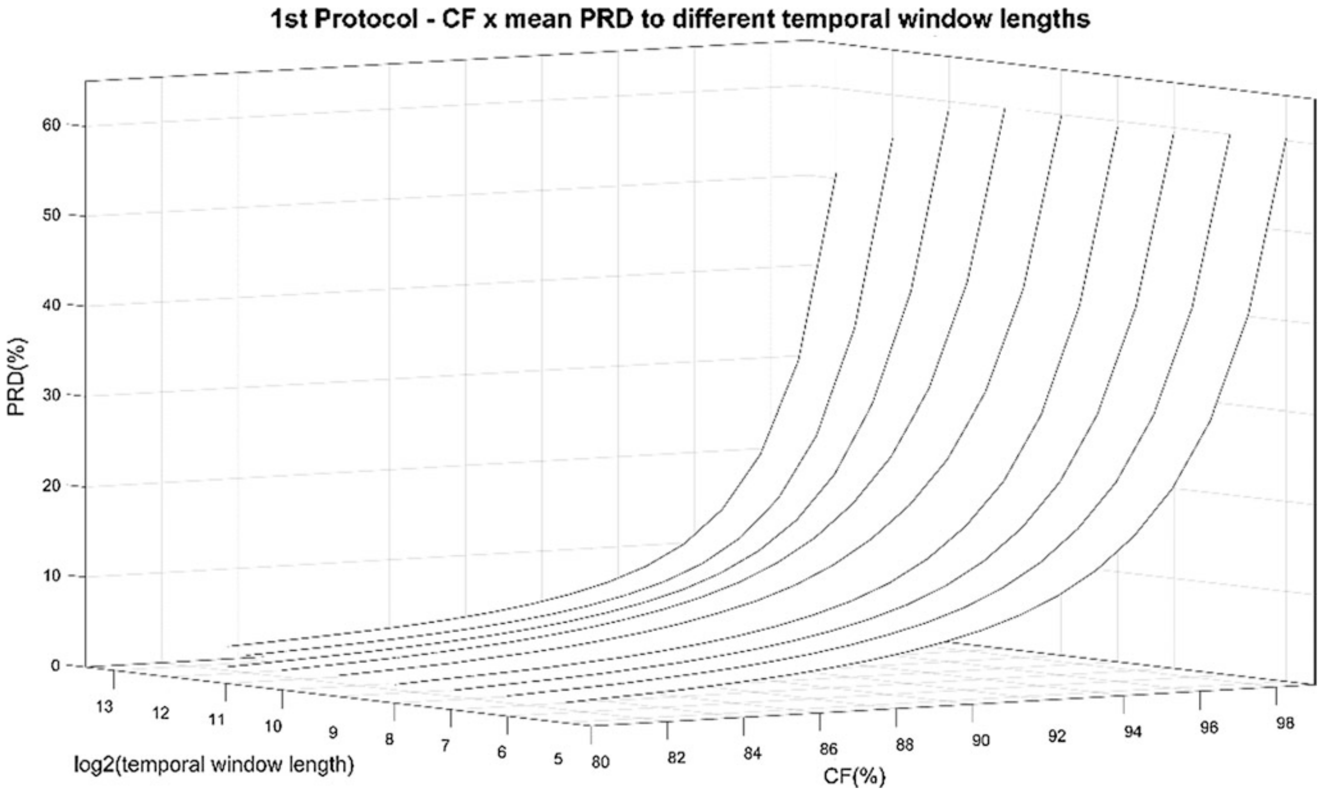

Fig. 1 PRD curves mean × CF as a function of a temporal window—protocol 1

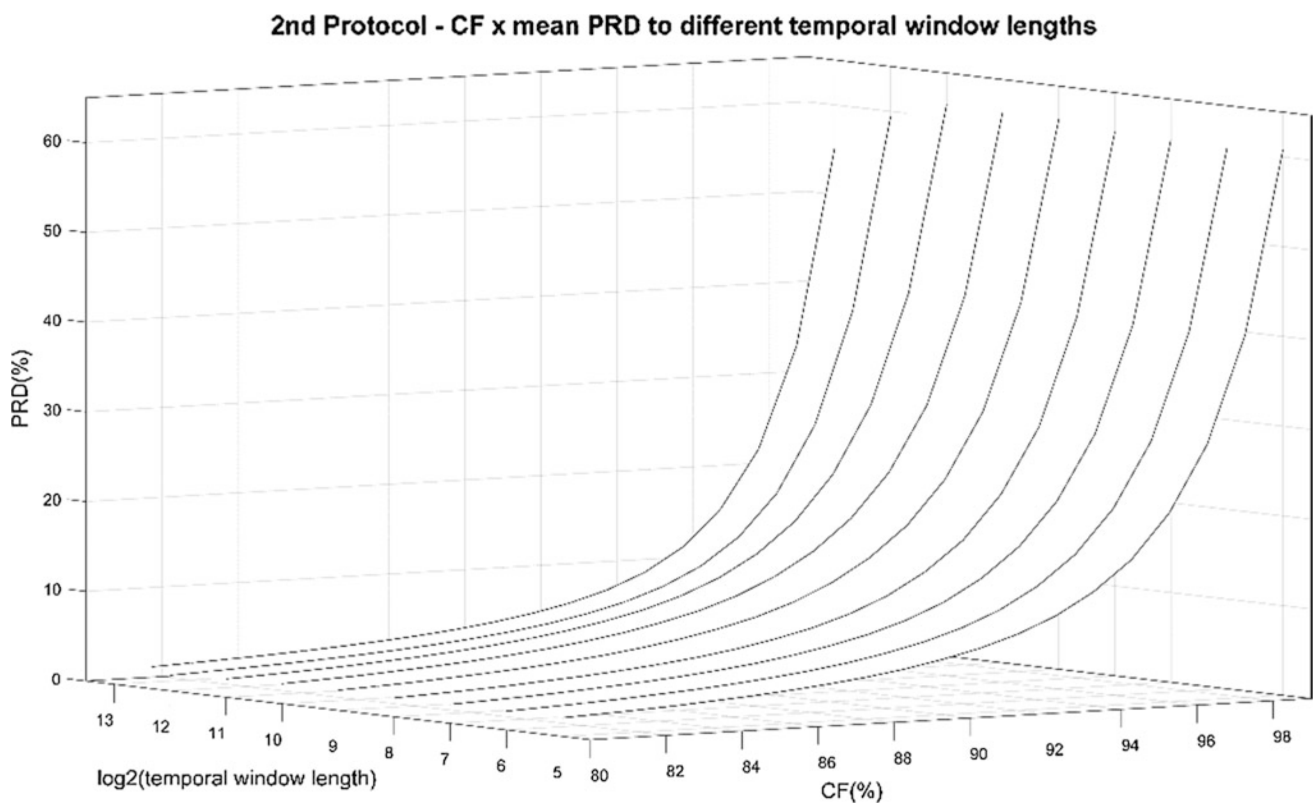

Fig. 2 PRD curves mean × CF as a function of a temporal window—protocol 2

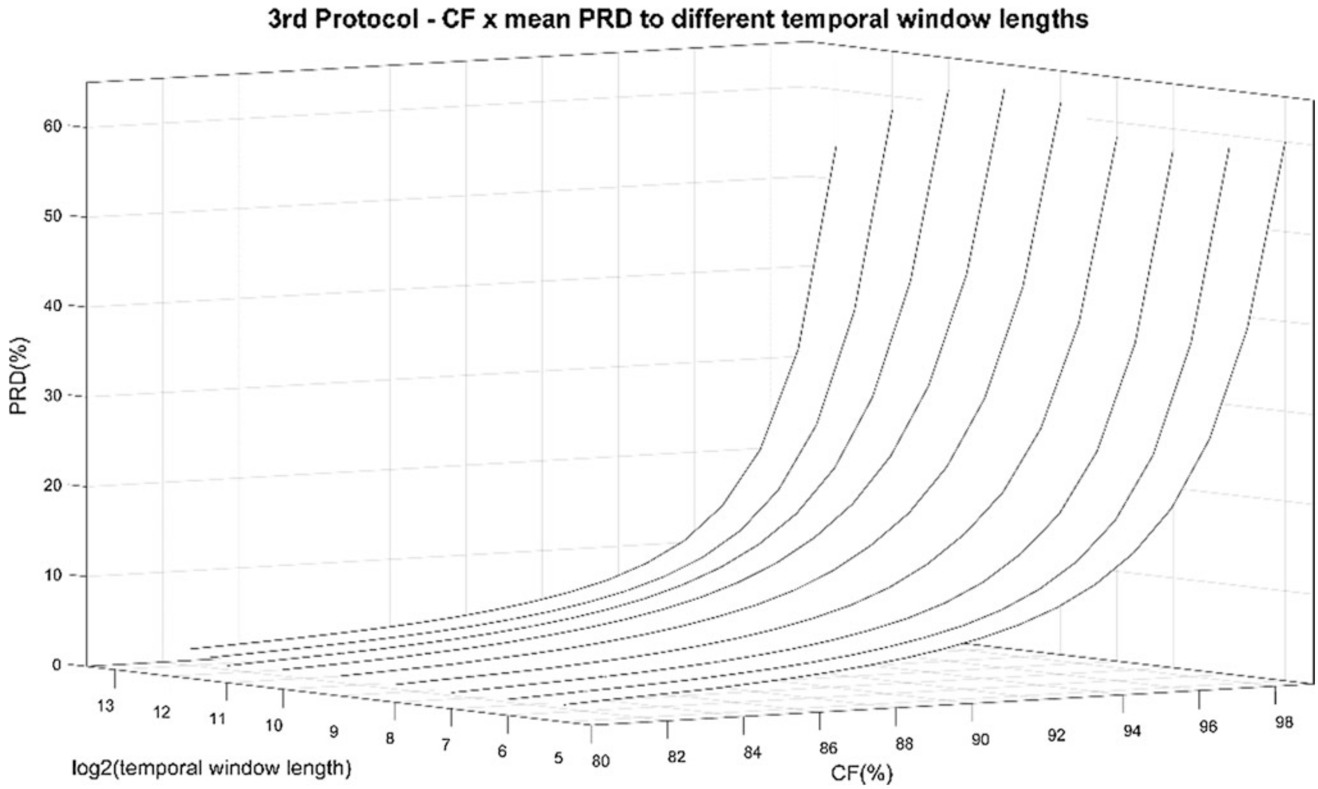

Fig. 3 PRD curves mean × CF as a function of a temporal window—protocol 3

Table 1 PRD values (%) for signals in protocol 1 (HEVC)

Temporal window	Compression factor—CF (%)			
	80	85	90	95
32 samples	2.29	3.63	6.76	17.39
64 samples	2.32	3.66	6.87	17.54
128 samples	2.20	3.52	6.55	16.85
256 samples	2.16	3.44	6.30	16.27
512 samples	2.41	3.81	7.13	18.01
1024 samples	2.27	3.62	6.79	17.53
2048 samples	**1.88**	3.09	5.66	14.83
4096 samples	–	2.66	4.75	12.21
8192 samples	–	**2.47**	**4.33**	**10.89**

Table 2 PRD values (%) for signals in protocol 2 (HEVC)

Temporal window	Compression factor—CF (%)			
	80	85	90	95
32 samples	2.15	3.47	6.38	16.48
64 samples	2.18	3.50	6.43	16.44
128 samples	2.22	3.55	6.54	16.63
256 samples	2.19	3.52	6.49	16.63
512 samples	2.34	3.78	6.97	17.56
1024 samples	2.34	3.79	7.00	17.64
2048 samples	2.15	3.46	6.41	16.63
4096 samples	1.82	2.98	5.42	14.15
8192 samples	**1.65**	**2.70**	**4.84**	**12.33**

obtained in each small window makes it possible to obtain good PRD values, regardless of when the signal is present.

For sample windows of intermediate sizes there is a mismatch of signals between each segment. The signals are composed of several intervals, where there is execution of the physical exercise (muscular request), raising the amplitude and generating the so-called burst, and moments of rest, where the signal is at its lowest amplitude level. The size of each burst is related to the time or speed of the muscular contraction performed by the volunteer; these can be longer or shorter according to the activity. This randomness between the size of the bursts and the amplitude of the acquired signals makes it difficult to achieve segmented windows with more homogeneous characteristics, and intermediate-length windows may contain truncated segments of the muscle activity and its simple juxtaposition impairs two-dimensional uniformity.

The fields not filled in Tables 1 and 3 are for the compression factors of 80%. This shows that the HEVC is an efficient compressor, because in some cases (larger

Table 3 PRD values (%) for signals in protocol 3 (HEVC)

Temporal window	Compression factor—CF (%)			
	80	85	90	95
32 samples	2.25	3.64	6.63	16.99
64 samples	2.10	3.36	6.03	15.15
128 samples	2.13	3.40	6.09	15.31
256 samples	2.36	3.71	6.72	16.96
512 samples	2.58	4.03	7.51	18.63
1024 samples	2.55	3.99	7.49	18.89
2048 samples	2.23	3.61	6.61	17.02
4096 samples	**1.97**	3.15	5.63	14.28
8192 samples	–	**2.87**	**5.00**	**12.32**

Table 4 Comparison PRD (%) for HEVC (Window of 512 samples)

	Compression factor—CF (%)			
	80	85	90	95
Protocol 1	2.41	3.81	7.13	18.01
Protocol 2	**2.34**	**3.78**	**6.97**	**17.56**
Protocol 3	2.58	4.03	7.51	18.63

Table 5 Comparison PRD (%) for HEVC (Window of 8192 samples)

	Compression factor—CF (%)			
	80	85	90	95
Protocol 1	–	**2.47**	**4.33**	**10.89**
Protocol 2	1.65	2.70	4.84	12.33
Protocol 3	–	2.87	5.00	12.32

windows) it starts compression with high rates and with a low distortion of the reconstructed signal.

Tables 4 and 5 make a comparison between the three protocols for the 512 samples and 8192 samples windows, respectively. The best results are highlighted in bold and it is verified that for different sizes of temporal sample it has a different behavior of the encoder.

With a window of 512 samples (Table 4) the encoder managed to obtain a better uniformity of the signals when the power is constant, and the speed varies. For a window of 8192 samples (Table 5) the coder was able to extract better information in the protocol where there is the variation of constant power and speed.

It is harder to the encoder to obtain areas of uniformity in the images for compression with smaller window, for instance 512 samples, requiring more bits in the compression process.

Table 5 shows that in protocol 1 HEVC encoder has the lowest PRD, in which the signals have increasing power and constant speed. This indicates that the encoder can adjust the two-dimensional matrices with better results, and it shows a decrease in performance if the temporal information is misaligned between the temporal segments juxtaposed in the two-dimensional sEMG matrix.

Table 6 Comparison of PRD performance evaluation (%) with literature

	Compression factor—CF (%)					
	70	75	80	85	90	95
Berger et al. [2]	2.44	2.70	4.41	7.52	20.10	29.96
Costa et al. [5]	–	–	4.39	5.77	9.39	–
Melo et al. [9]	–	4.71	6.25	8.91	12.60	–
Norris et al. [10]	7.75	7.93	9.06	10.02	19.98	35.71
Trabuco et al. 1D—WDAL [1]	**1.12**	**1.74**	**2.64**	3.93	6.11	12.63
Trabuco et al. 2D—RI-HEVC [1]	–	–	2.71	4.28	7.96	19.53
Trabuco et al. 2D—BD [1]	–	–	–	**2.66**	**4.39**	**10.28**
Proposal P3 J8192	–	–	–	2.87	5.00	12.32

Comparing Tables 4 and 5, it is verified that the larger the sample window, the better the quality of the compression. This shows that the encoder can better adjust redundant areas and null values facilitating the signal processing and it's clear that sample window sizes impact the behavior of the encoder according to the applied signal protocol.

Table 6 makes a comparison with the results of the most significant work in the compression area of dynamic sEMG signals. With the best results highlighted in bold, it is verified that the project proposal obtained good compression results, with the lowest PRD (%) with the protocol 3 signals and with a window of 8192 samples, to values of CF equals to when 85, 90 and 95%, with worse values only in comparison with Trabuco's et al. [1] research, which uses signals with same characteristics of this work but performs much more effective pre-processing steps.

The most recent work of the sEMG compression area in dynamic protocols found in the literature, by Trabuco et al. [1], presents better PRD results (%) for all CFs. We tested the same vastus medialis muscle signals that Trabuco et al. [1] used in their work to enable better comparisons.

It is important to note that, regardless of the reduction of signal distortion (PRD), there will always be a reduction in the quality of the reconstructed signal in relation to the original when the compression factor (CF) is increased. This means that it is difficult to obtain expressive quality signals when a high compression ratio is applied, since there is a significant loss of information that degrades the reconstructed signal.

4 Conclusion

The present work presented an evaluation of the influence of three different protocols of dynamic efforts of surface electromyographic signals on the HEVC encoder. Different temporal window cut-off lengths were applied to the signals of each protocol. Were applied two widely used criteria for evaluating the compression performance of the sEMG signals: the residual percentage difference in relation to the compression factor (PRD $\times$ CF) applied to the compressed signal.

It was possible to observe, that there is a small difference in the behavior of the coders in relation to each protocol, however, there is no discrepancy in the final result of the compression of the signals of the applied protocols. It is observed that HEVC is robust in signal coding with amplitude variation, as in the case of protocol 1, that is, it obtains good compression results with low percentage distortion (PRD%) when the sample window is large (8192 samples) and better performance with constant signals (protocol 3) with a small sampling signal (512 samples).

The objective of this research was to apply the signals from each protocol to the already recognized and widely available encoders and to evaluate the two-dimensional coding of the sEMG signals in dynamic contractions in relation to their PRD $\times$ CF curves. Comparing with the reference literature of the area, it can be said that the results presented were consistent and with competitive performances, especially in the CF range between 85, 90 and 95%. The HEVC tests presented one of the lowest PRD results in this range, even without a more elaborate preprocessing, only with the signal adjustments for its application to the 2D encoder, losing only to the most recent research in compression area.

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