EVALUATION OF DISTORTION OF ECG SIGNALS AFTER COMPRESSION

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Abstract: Evaluation of compression quality is essential part of data compression. No unified approach exists in this area and comparison of different algorithms is very difficult. The paper deals with 13 common efficiency and quality evaluation methods. Two compression algorithms are tested – improved single cycle fractal based algorithm and wavelet based SPIHT algorithm. All the quality evaluation methods have the same trend for both compression algorithms. For proper evaluation of compressed ECG signal quality, it is recommended to combine various evaluation algorithms.

Keywords: ECG, electrocardiogram, compression, distortion, quality evaluation, signal

1. INTRODUCTION

Quality evaluation is very important in compression of biosignals, especially electrocardiogram (ECG). The aim of ECG signal compression is reducing data size while preserving the diagnostic information. Some compression algorithms use quality evaluation as a control of compression. There are many different algorithms for compression evaluation. They can be divided in two big groups – compression effectiveness and compression quality algorithms. The compression quality algorithms are further divided in subjective (evaluation by cardiologist) and objective groups. Objective methods consist of those with diagnostic information and without diagnostic information. Objective methods can be global (one number for whole signal) and local (value for every beat). Local methods need QRS detector for segmentation of every beat.

In articles and conference papers, the use of evaluation methods is not unified. This fact makes the comparison between different algorithms difficult. Percentage root mean square difference (PRD) is the most common method, which belongs to the group of objective algorithms without diagnostic information. Moreover, some authors use PRD (without normalization) and some PRDN (with normalization). Normalization means subtraction of DC component before compression and quality evaluation or subtraction of DC component in PRDN equation. PRD is usually smaller than PRDN, which means, that the compressed signal (algorithm) evaluated by PRD seems better than the signal (algorithm) evaluated by PRDN. It can be misleading.

2. METHODS

2.1. COMPRESSION ALGORITHMS

In this work, two different algorithms for ECG signal compression are used – fractal based single cycle algorithm and wavelet based SPIHT (Set Partitioning in Hierarchical Trees) algorithm [1]. The fractal based single cycle algorithm is based on that, which was published on EEICT 2015 [2]. It was further improved by block division, Burrows-Wheeler transform and smoothing (for smooth blocks connection). Both algorithms are tested on 5 randomly selected signals from CSE database. We used first lead of orthogonal XYZ leads – W001, W036, W063, W099 and W122. The length of the signals is 10 s, sampling frequency 500 Hz and bit resolution 16 bits per sample.

2.2. EVALUATION ALGORITHMS

In this work, we used four different approaches for compression evaluation.

Evaluation of compression in terms of data size: This group involves especially compression ratio (CR), compression factor (CF) and average value length (avL) [3]. Each of these parameters can be calculated from another. Many authors use CR in their articles, but they often mean CF (according to the definition and equations in [3]). For this reason, using of avL is clear and it is used in this work (Eq. 1).

$$avL = \frac{size\ of\ the\ output\ stream}{original\ signal\ length}, [bps] \quad (1)$$

Global objective evaluation without diagnostic information: This group consists of normalized percentage root mean square difference (PRDN) [3], cross correlation coefficient (CC) [4], mean square error (MSE) [4], normalized mean square error (NMSE) [4], root mean square error (RMS) [3], [4], signal to noise ratio (SNR) [4] and standard error (Std_Err) [4].

Global wavelet based methods with diagnostic information: In this group belong wavelet-based weighted PRD (WWPRD) [5], wavelet-energy based weighted PRD (WEWPRD) [6], wavelet energy based diagnostic distortion (WEDD) [4] and multiscale entropy-based weighted PRD (MSEWPRD) [7], which has two variants: relative mean wavelet subband energy (RMWSE) and relative wavelet subband energy (RWSE). These advanced methods are based on wavelet transform and weights. Distortion and weights are calculated for every scale. Final result (one number) is calculated as a weighted average of distortions in every scale. The algorithms differ in weights estimation.

Method based on delineation: This method needs delineation algorithm. In this work, we used delineation algorithm ECG SEEKER [8]. ECG signal is delineated; the output of the algorithm are positions of points of interest (QRS, QRSonset, QRSoffset, T, Toffset, P, Ponset and Poffset). Both original and compressed signals are delineated. Then the similarity is computed as shown in Eq. 2:

$$similarity = 100 - 100 \cdot \sum_{n=1}^{N} \frac{|PoI0(n) - PoI(n)|}{PoI0(n)}, [\%] \quad (2)$$

where *PoI* means points of interest, *N* is the length of every type of PoI vector (e.g. Ponset). When the compressed signal is distorted, the delineation algorithm can find less or more PoI of some type than in original signal (PoI0). Then the similarity should be adjusted; redundant PoI are deleted and penalization is used for this purpose as shown in Eq. 3.

$$similarity = similarity - (\frac{K}{N0} * 100), [\%] \quad (3)$$

where *K* is the difference between the length of PoI0 and PoI of one type (number of deleted PoI), *N0* is the length of PoI of one type in original signal.

Five signals were compressed by two above-mentioned algorithms and then evaluated by all mentioned evaluation algorithms. Then the mean value of all indexes were calculated and pictured.

3. RESULTS

Mean values of global objective indexes without diagnostic information are shown in Figure 1 and Figure 2. Figure 1 shows the trend of PRDN, CC, MSE, NMSE, RMS, SNR and STD_ERR in dependence of avL for improved single cycle fractal based algorithm. Figure 2 shows the same indexes for wavelet based SPIHT algorithm. From these figures is obvious, that the trend of all the indexes is the same for both methods. RMS is very similar to STD_ERR, that is why only one of these indexes can be used. CC and NMSE have very low sensitivity – their values change very little with avL (their trends are almost constant). The highest sensitivity has MSE, which decreases exponentially with increasing avL (decreasing compression efficiency). From the figures follows, that both compression algorithms are comparable (the wavelet based SPIHT algorithm causes distortion comparable with fractal based method according to CC, NMSE and PRDN, a little bit lower distortion according to RMS, SNR and STD_ERR and lower distortion according to MSE).

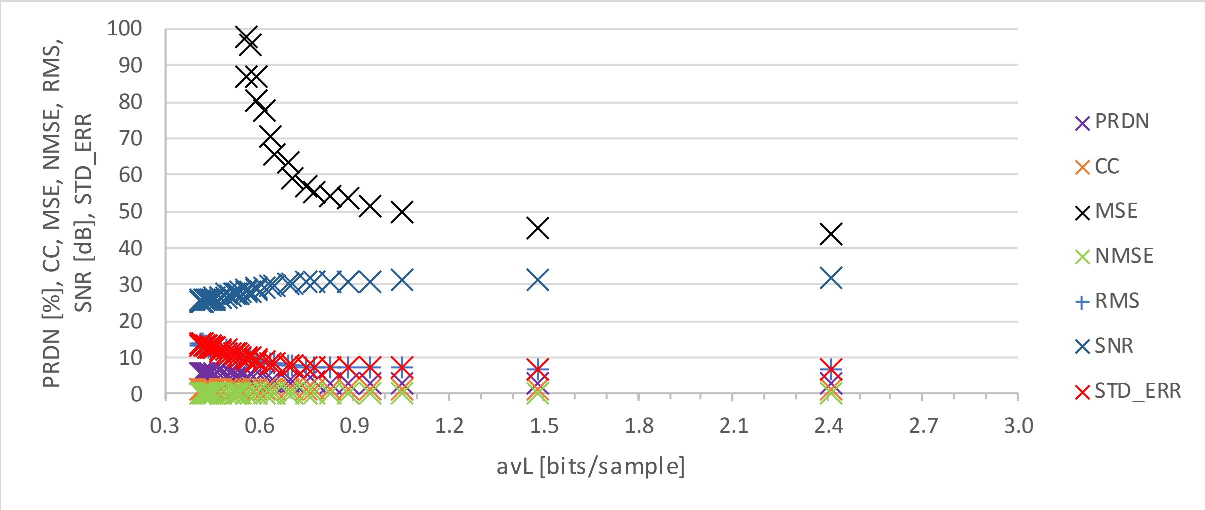

Figure 1: Trend of PRDN, CC, MSE, NMSE, RMS, SNR and STD_ERR in dependence of avL for improved single cycle fractal based algorithm.

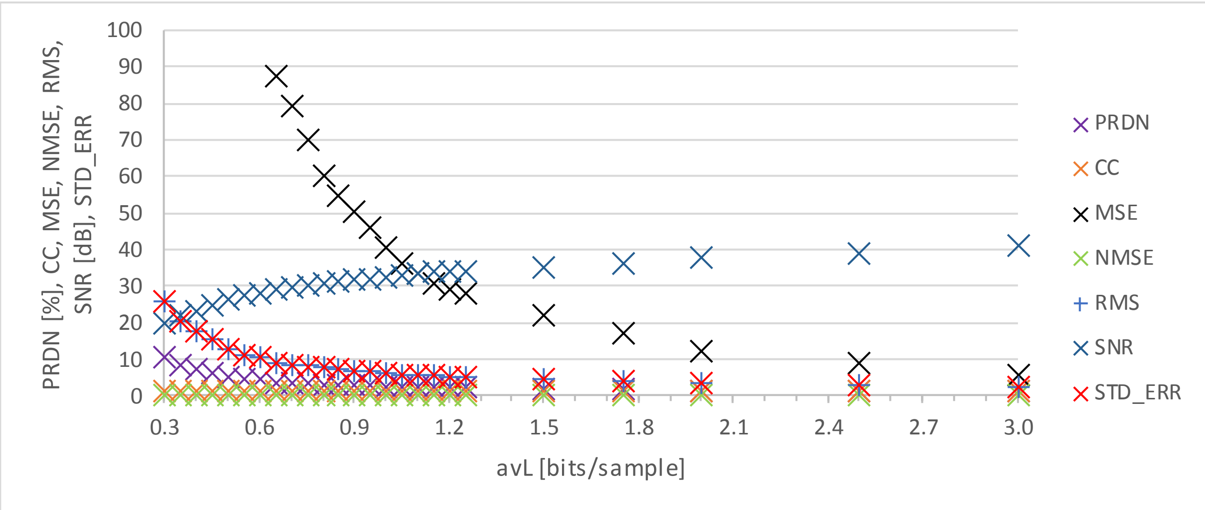

Figure 2: Trend of PRDN, CC, MSE, NMSE, RMS, SNR and STD_ERR in dependence of avL for wavelet based SPIHT algorithm.

Figures 3 and 4 show the trend of mean values of global wavelet based indexes with diagnostic information in dependence of avL for both compression algorithms. The trends of all the indexes are almost the same for both compression methods. All the indexes decrease exponentially with increasing avL. WEWPRD and WEDD have the same value for every avL, it means that one of these methods is redundant in this work. MSEWPRD_RMWSE and MSEWPRD_RWSE have lower sensitivity than other methods. From these figures (especially for avL from 0.3 to 0.6) is obvious, that the wavelet based SPIHT algorithm introduces lower distortion than fractal based algorithm.

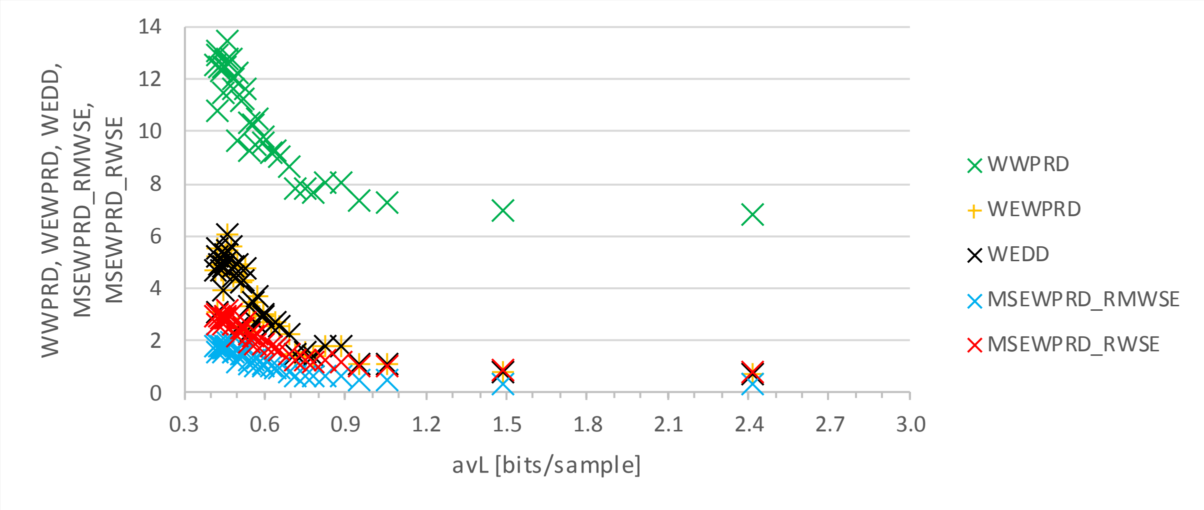

Figure 3: Trend of WWPRD, WEWPRD, WEDD, MSEWPRD_RMWSE and MSEWPRD_RWSE in dependence of avL for improved single cycle fractal based algorithm.

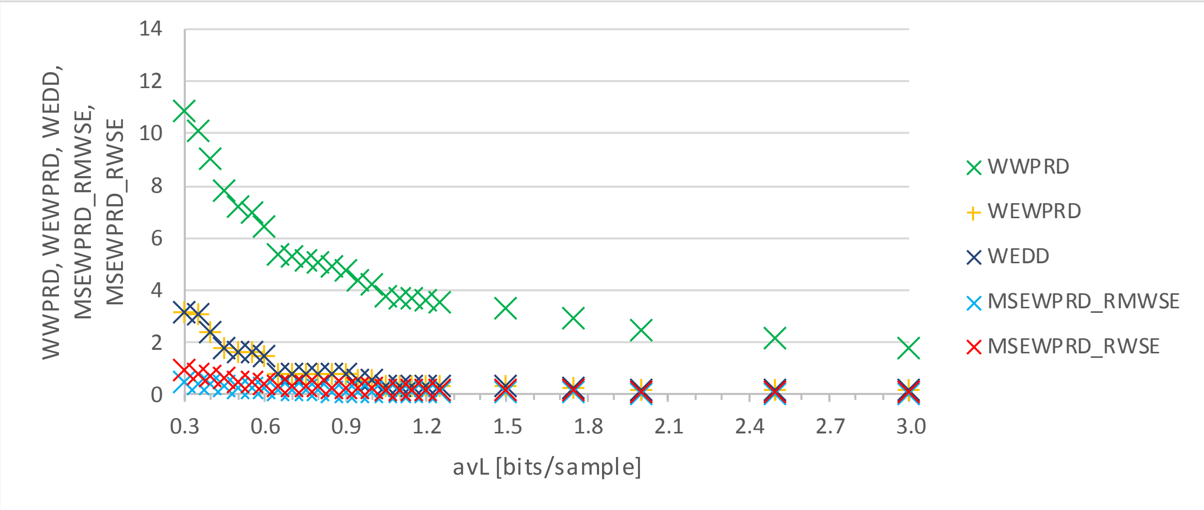

Figure 4: Trend of WWPRD, WEWPRD, WEDD, MSEWPRD_RMWSE and MSEWPRD_RWSE in dependence of avL for wavelet based SPIHT algorithm.

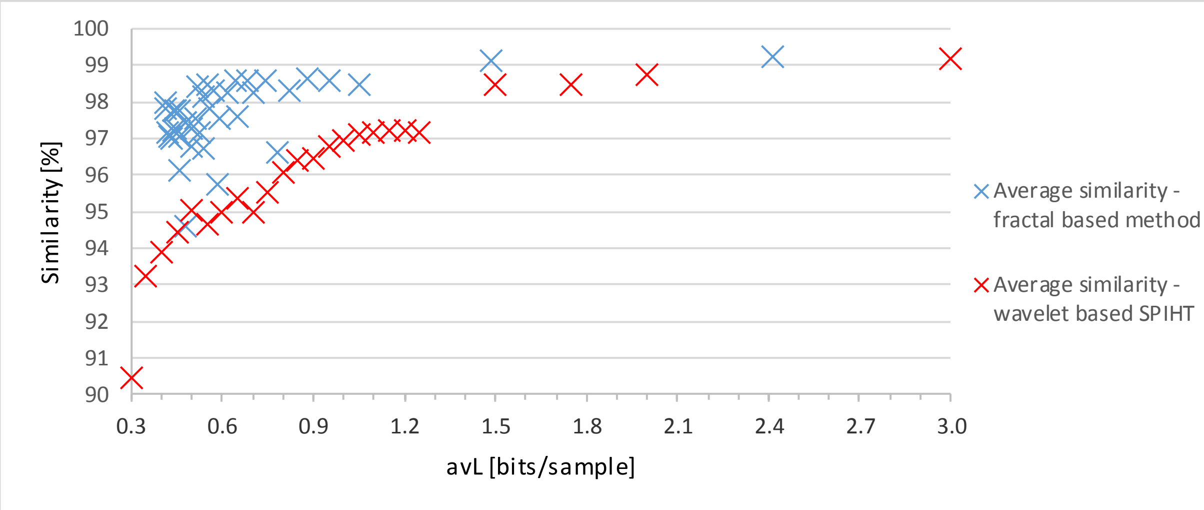

Figure 5: Trend of mean similarity of original and compressed signals in dependence of avL.

	Similarity of original and compressed signals [%]								
	QRS	QRSonset	QRSoffset	T	Toffset	P	Ponset	Poffset	Mean
Fractal	99.7535	98.8316	98.9608	99.5025	98.1467	94.5386	95.6116	95.9954	97.6676
SPIHT	99.9613	98.3999	98.4337	97.4318	94.0795	93.2525	94.5378	94.6389	96.3419

Table 1: Mean similarity of original and compressed signals.

The results of delineation of original and compressed signals are shown in Figure 5 and Table 1. In Figure 5 there are shown average similarity values (from 5 signals) for both compression methods. The trend is again almost the same for both compression methods. The similarity between original and compressed signal increases with avL. From Figure 5 follows, that signals compressed by fractal based method are more accurate and more similar to the original signals.

Conclusion followed from Figure 5 is confirmed by values in Table 1, where the average value for every type of PoI and method are shown. From the Table 1 is evident, that the highest similarity have QRS, QRSonset and QRSoffset. On the other hand, P, Ponset and Poffset have the lowest average similarity. It is probably caused by high magnitude of QRS complex and lower magnitude of P wave.

4. CONCLUSION

There are many types of algorithms for evaluation of compression effectiveness and quality. No unified approach for evaluation of compressed ECG quality exists. PRD or PRDN are the most commonly used indexes. As follows from results, only PRD (PRDN) is not enough for ECG signal quality evaluation. According to objective evaluation algorithms without diagnostic information, the wavelet based SPIHT algorithm is comparable with fractal based algorithm, according to wavelet based indexes with diagnostic information, the SPIHT algorithm is better than the fractal based one and according to similarity algorithm, the fractal based method is better than SPIHT. Using only one objective method, two compression algorithms cannot be compared correctly. It is good to combine a few evaluation methods of different type; visual inspection is useful as well. Another contribution of this paper is the fact, that all used indexes have similar trend for different compression methods.

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