ECG SIGNAL COMPRESSION BASED ON FRACTALS AND RLE

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Abstract: Compression of ECG signal is up to date challenge. There are many methods for ECG compression. This paper focuses on fractal based compression method. The method is implemented in MATLAB and compared with results in source article. New single cycle method for ECG signal compression that combines fractals and run length encoding (RLE) is created. Both methods are compared with method based on wavelet transform (WT) and RLE and up to date wavelet based Set Partitioning in Hierarchical Trees (SPIHT) algorithm.

Keywords: fractal, ECG, electrocardiogram, compression, run length encoding, RLE, wavelet transform, WT, SPIHT

1. INTRODUCTION

Nowadays, the ECG compression is necessary because of increasing data amount and increasing requirements on data transmitting, especially in telemedicine. Usually, loss compression methods are needful to achieve higher compression. Compression is connected with quality loss. The compromise between compression and quality should be found. There are many different compression methods. One of the advanced methods is fractal based compression. This method is described in chapter 2.1 and implemented in MATLAB. New single cycle method based on fractals and RLE is created and described in chapter 2.2. Chapter 2.3 deals with another method using wavelet transform and RLE. This method is implemented as well. The best method for ECG compression is SPIHT algorithm based on WT. All of these methods are tested and compared in chapter 3. At the end of the article, in chapter 4, the discussion and conclusion are done.

2. METHODS

2.1. FRACTAL BASED COMPRESSION METHOD

One of the recent methods for ECG signal lossy compression is fractal based ECG compression. As said in [1], this method achieved compression ratio of 42 and the Percent Root Mean Square Difference (PRD) value less than 1 %.

This algorithm uses ECG signal self-similarity. It does not need ECG signal parameters detection or extraction, so it can be used for compression of normal and abnormal signals as well. Principal is as follows: The original ECG signal is divided into non-overlapping blocks (range blocks). The size of the block is called block size (BS). The domain is created as a down-sampled copy of the original ECG signal. Each range block is compared with domain and the most similar block in domain (domain block) is found. It uses Fractal Root Mean Square (RMS) metric. Domain blocks are overlapping and the distance between them is called jump step (JS). To achieve maximum similarity between the range and domain blocks, affine transforms are used. Fractal (transform) coefficients (shift and scale), affine transformation type and index (domain block location) are calculate and stored as an output. [1]

Unfortunately, in the article [1] there are mistakes in equations. The equations for scale coefficient calculation and RMS are wrong. Right equations are in the article [2]. The equation for PRD value calculation is not normalized, it means that there is no subtraction of mean of the signal (DC component). In [1] there is no other mention about subtracting DC component. PRD value is smaller than normalized PRD (PRDN) value. The authors of [1] achieved compression ratio of 42 and PRD value less than 1 % but they do not mention relevant signal.

Decompression part of the algorithm starts with random signal. Stored coefficients are applied on random signal and the original ECG is approximated. For better approximation, more iterations are necessary. In [1] they repeat the decompression algorithm four times (4 iterations). [1]

2.2. SINGLE CYCLE METHOD USING FRACTALS AND RLE

This is a new method based on the above-mentioned method (fractal based compression [1]). This method uses fractals and RLE and its block diagram is shown in Fig. 1. At the beginning, the DC component is subtracted. We use the fact that ECG signal is quasiperiodic. Instead of whole domain, we use only one cycle of ECG signal. This cycle is down-sampled (mean of two adjacent samples is calculated and rounded) and we can call it domain as well. In terms of compression ratio and quality, the ideal decimation factor is 2. The domain is converted to binary and RLE [3] is applied. The domain is stored. Then it is restored. It means run length decoding and converting to decimal are done. The interpolation by a factor of 2 is performed (mean of two adjacent samples of domain is calculated and this value is put between those adjacent samples). Then the most similar domain block is searched for each range block. Range blocks are obtained after dividing ECG signal into non-overlapping parts. The metric is used the same as in the first method (RMS). We obtain coefficients (shift, scale), type of affine transform and index of the domain block. All of the coefficients we convert to binary, do RLE and store. Stored domain and coefficients represent the compressed signal.

The decompression is done in one iteration. After run length decoding of the coefficients and domain, we convert them to decimal and calculate the final signal in a similar way as in [1]. We do not apply the coefficients on random signal but on the domain (one cycle of ECG) and only in one iteration.

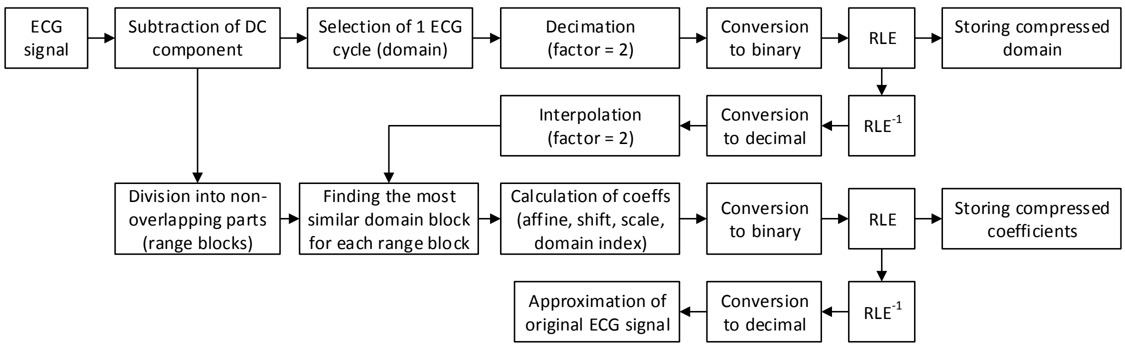

Fig. 1: Block diagram of single cycle method using fractals and RLE.

2.3. WAVELET TRANSFORM AND RUN LENGTH ENCODING

This method is based on wavelet decomposition of the signal [3]. Coefficients in every band except of the low-frequency band are compared against threshold. If they are smaller than the threshold, they are substituted by zero. Then the coefficients are expressed by selected number of bits (in our case 8 bits) and RLE is applied.

The decompression starts with run length decoding, increasing bit resolution and then inverse wavelet transform is done. The results of this method depend on selected decomposition wave, reconstruction wave, level of decomposition, threshold and bit resolution.

2.4. EVALUATION PARAMETERS

The amount of compression is expressed by Compression Factor (CF) [3] as shown in Eq. (1) and Average Value Length (avL) [4] as shown in Eq. (2).

$$CF = \frac{size\ of\ the\ input\ stream}{size\ of\ the\ output\ stream}, [-] \tag{1}$$

$$avL = \frac{size\ of\ the\ output\ stream}{original\ signal\ length}, [bps] \tag{2}$$

The quality of compression is evaluated by normalized Percent Root Mean Square Difference (PRDN) [4]. PRDN is calculated as shown in Eq. (3), where X_O is original signal, X_R is reconstructed signal and $\bar{X}$ is mean of original signal.

$$PRDN = 100 \cdot \sqrt{\frac{\sum_{i=1}^{n}[X_O(n) - X_R(n)]^2}{\sum_{i=1}^{n}[X_O(n) - \bar{X}]^2}}, [\%] \tag{3}$$

3. RESULTS

These algorithms are tested on signal 105 from MIT-BIH arrhythmia database. Length of the signal is 25 000 samples, sampling frequency is 360 Hz and it has 11-bit resolution. [5]

We set a threshold between acceptable and unacceptable quality of compression. This threshold is set on the basis of results in article [4] and original and reconstructed signals observation. The threshold is PRDN = 5 %. Below this value, distortion of ECG signal is very small.

When implementing the fractal based compression algorithm based on article [1], we use the right equations from [2]. Four iterations are not enough to approximate ECG signal well, so we use 15 iterations. We use PRDN instead of PRD. There are two adjustable parameters: block size (BS) and jump step (JS). We set BS from 2 to 20 with step 1 and then from 20 to 100 with step 10. Values of JS are 1, 10, 20 and 50 for each BS.

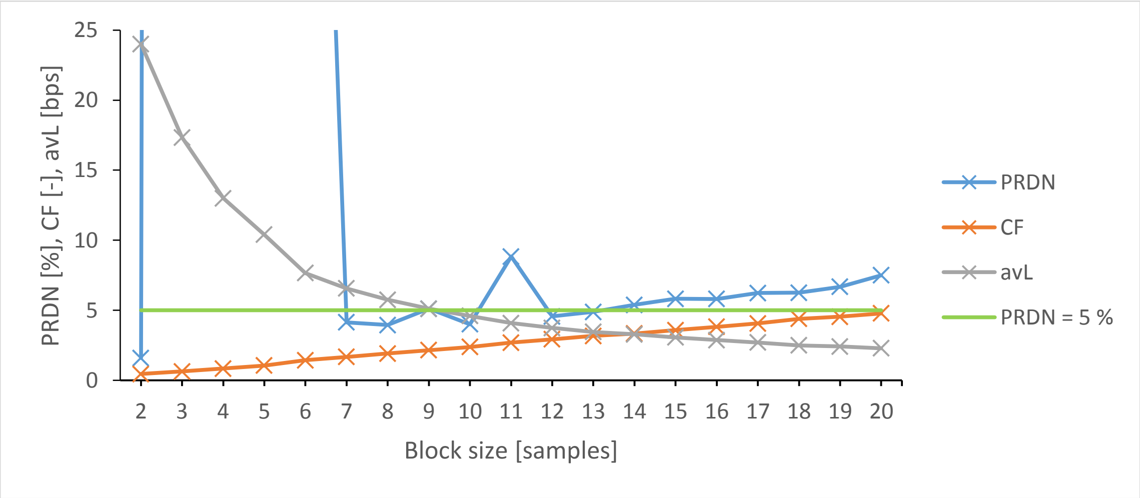

Fig. 2: Development of PRDN, CF and avL in dependence of BS, JS = 1, for the fractal based compression method.

Development of PRDN, CF and avL in dependence of BS is shown in Fig. 2. The JS is set on 1. The compression comes on with the BS = 5. BS from 2 to 4 cause expansion. It is obvious that CF (orange line) increases linearly with increasing BS, avL (grey line) is decreasing exponentially. The green line is threshold set on PRDN = 5 %. Blue line represents development of PRDN. This line is not simply describable by any function. PRDN rises rapidly for BS from 3 to 6. Then it increases almost linearly with higher deviation for BS of 11. The best compression parameters are reached for BS = 13, when CF = 3,1778, avL = 3,4615 bps and PRDN = 4,8884 %.

For other JS and higher BS, trends of development of the parameters (PRDN, CF and avL) are similar like in the Fig. 2. When increasing JS, the time of compression is decreasing but the PRDN is increasing, that is why we set JS = 1. Nevertheless, the best compression parameters mentioned above are not outperformed.

The results for the single cycle method using fractals and RLE are shown in Fig. 3 (JS is set on 1). These results are obviously better than the results of the first method. Trends of CF and avL are the same as in the first method. PRDN increases linearly with increasing BS. The best compression parameters are reached with BS = 17, when CF = 13,5874, avL = 0,8096 bps and PRDN = 4,9488 %.

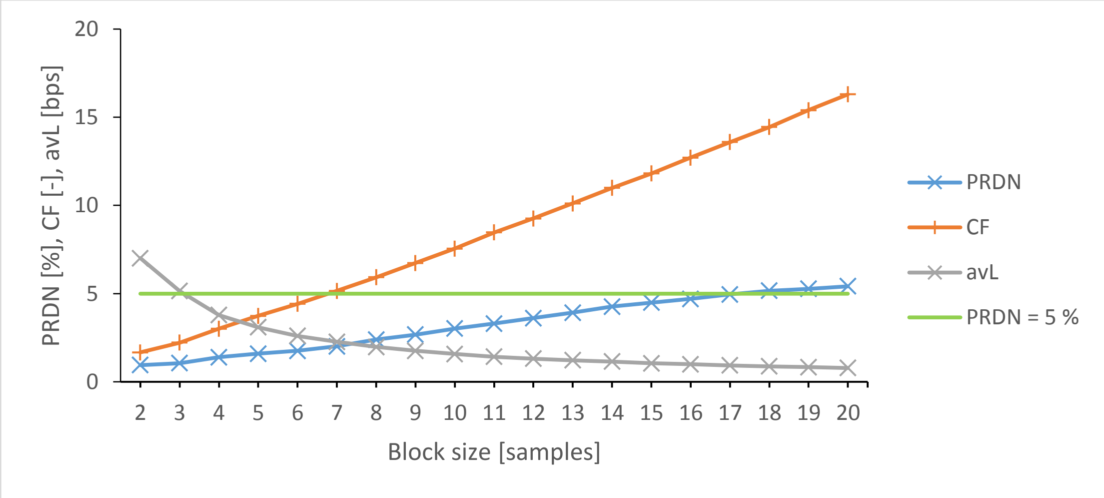

Fig. 3: Development of PRDN, CF, avL in dependence of BS, JS = 1, for the single cycle method.

The third method which uses WT and RLE has the best results of CF = 4,8503, avL = 2,2679 bps, PRDN = 4,9161 % as seen in Tab.1. These results are obtained when the decomposition and reconstruction wavelets are coif4, level of decomposition is 4 and maximum bit depth is 8.

Nowadays, the best results of ECG signal compression are obtained by using wavelet based SPIHT algorithm. We compressed the same signal (105 from MIT-BIH arrhythmia database) by this method using software [6] created by authors of [4]. When we set avL = 0,8096 (the same as in the single cycle method) the PRDN = 5,6135 as seen in Tab. 1.

	Fractal based compression		Result from [1]	Fractal + RLE	WT + RLE	SPIHT
JS	1	10	10	1	-	-
BS	13	35	35	17	-	-
CF	3,1778	8,5556	42	13,5874	4,8503	13,5874
avL [bps]	3,4615	1,2857	-	0,8096	2,2679	0,8096
PRDN [%]	4,8884	16,4011 *1,0433	*1,24	4,9488	4,9161	5,6135

Tab. 1: Comparison of results of fractal based compression method with results from the article [1], single cycle method, method, which uses WT and RLE and SPIHT algorithm.
* means PRD value (PRD without normalization).

As seen in Tab. 1, the best result is obtained using new single cycle method (avL and PRDN are highlighted by the green color). Time of running algorithm 1 (fractal based compression method) is 2 019 seconds, time of running algorithm 2 (single cycle method) is 32 seconds for the same BS = 17 and JS = 1. In this time, both compression and decompression are included. It means that the new method could work in a real time because the compression and decompression time is shorter than the length of the signal (which is almost 70 seconds). From Tab. 1 is obvious, that the new single cycle method is comparable or even better than SPIHT.

4. CONCLUSION

In this paper, four methods for ECG signal compression are compared. The first one is implemented according to the article [1]. This method does not achieve by far such a good compression parameters as written in the article. For the same signal, BS and JS they achieve CF of 42 and we only less than 9, but if we use only PRD instead of PRDN we have more accurate signal (smaller PRD). As a threshold for acceptable signal we set PRDN = 5 %. The highest compression (shortest avL = 3,4615) is achieved with BS = 13 and JS = 1.

The new single cycle method based on fractals and RLE gives better results. The best one is for BS = 17 and JS = 1 and gives avL = 0,8096 bps with PRDN = 4,9488 %. This method is for the same BS = 17 and JS =1 63 times faster than the first method based only on fractals.

The method based on WT and RLE achieves better results than the original fractal based method but worse in comparison with new single cycle method and SPIHT algorithm. The minimum avL is 2,2679 bps with PRDN less than 5 %. This method is outdated and is mentioned only for comparison.

The up to date compression method is SPIHT which is based on WT. The results of this method and single cycle method seem comparable. In this case, single cycle method gives better results.

The single cycle method was tested on 4 signals from MIT-BIH arrhythmia database. The PRDN increases linearly with BS. The slope of the line depends on particular signal. Because results of single cycle method are encouraged, this method will be tested on more signals. After that, one universal BS could be recommended. Better approach is to use the fact, that development of PRDN in dependence on BS is linear. Then we can compress the signal with low BS and high BS, calculate PRDNs and interpolate the line. Where the line crosses the threshold of PRDN = 5 %, this BS will be used for final compression.

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