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# ECG Signal Compression using Normalization and Thresholding

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**ABSTRACT**:
In this paper, ECG signal compression using normalization and thresholding of discrete cosine transform (DCT) and Wavelet Transform (WT) signal coefficients is studied. First ECG signal is transformed using Linear Transforms (DCT and WT). The transformed coefficients (TC) are then normalized by dividing the TC by $n = round\left(\sqrt{2\log N}\right)$ (where, $N$ is number of samples). To reduce the range of TC, the normalized coefficients (NC) are thresholded by bisection algorithm. The thresholding is done in a way so that error between actual PRD (percent root mean square difference) and UPRD (user specified percent root mean square difference) remains within the specified limits. The binary look up table is made to store the position of zeroed and non-zeroed coefficients and this table is encoded by Huffman coding. The non-zero thresholded coefficients are then quantized and encoded by arithmetic coding. The results presented in this paper are compared with [9], where the same ECG compression techniques used without normalization. The comparison indicates that the normalization of DCT and WT coefficient before thresholding improves the performance. The results are presented on different ECG signals of varying characteristic.

**Keywords:** Discrete cosine transform, ECG Signal, quality controlled compression, Wavelet Transform, Normalization.

## INTRODUCTION

The aim of ECG compression is to reduce the ECG data as much as possible with maintaining clinically acceptable signal quality [1]. Techniques for ECG compression which have been reported in the literature fall mainly in two categories: (1) direct compression and (2) transformational methods. In most cases, direct methods are superior to transform methods with respect to simplicity and error. However, transform methods achieve higher compression rates and are insensitive to noise contained in original ECG signal [2]. Paper [3] developed a quality controlled compression method using wavelet transform. Paper [4] proposed ECG compression based on the adaptive wavelet coefficients quantization combined to a modified two-role encoder. In paper [5] designed a block based ECG compressor using wavelet packet (WP). WP based techniques are efficient than discrete wavelet transform (DWT) based method [6] for ECG compression [5]. In paper [9] the various transforms are compared at high and low PRD and conclusion is that at low PRD discrete cosine transform performs better than Laplacian pyramid (LP), Wavelet transform (WT) and Essentially non-oscillatory cell-average (ENOCA). The methods mentioned above, involve the transformation, thresholding, quantization and encoding steps for ECG compression. Paper [7] represents compression using multiscale recurrent patterns with period normalization. Paper [8] also used the period normalization, thresholding, quantization and encoding for compression of ECG signal using video codec technology. In [7] and [8] transformation is not used. Here the procedure begins with the segmentation of the ECG signal, in which each period of the heart beating is identified and separated. Since each period can have different duration, a period normalization process is then proceeded to ensure that the size of each period is adjusted to be the same.

In general for ECG compression the steps involved are transformation, thresholding, quantization and encoding. In this paper in addition to above steps one more step of normalization is introduced between transformation and thresholding. This paper studies the improvement in compression ratio (CR) due to addition of normalization step in between transformation and thresholding. The transformation is done using DCT and WT (Linear Transforms) because at low PRD DCT performs better and at high PRD Wavelet Transform performs better in case of Linear Transforms [9]. The results presented in this paper are compared with [9], where the method used is same but without normalization. The comparison shows that normalization of DCT and WT coefficients gives the better performance in terms of CR.

## PERFORMANCE METRICS

For the performance analysis, the metrics like compression ratio (CR), the percentage of root mean square difference (PRD) and visual study of the error signal are used. In this paper PRD is selected to maintain minimum required quality of the reconstructed signal. Error signal is expressed as $e = x_i - \hat{x}_i$ , CR is defined as the ratio of the number of bits in the original signal to the number of bits in the compressed signal and PRD is calculated as:

$$PRD = 100 \times \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{\sum_{i=1}^{N} x_i^2}} \qquad (1.1)$$

where $x_i$ and $\hat{x}_i$ are the i[th] sample of original and reconstructed ECG signal of length $N$ [6].

## METHODOLOGY

The proposed technique is implemented in four steps:

i. the transformed coefficients (TC) are normalized
ii. the normalized coefficients (NC) are thresholded using bisection algorithm
iii. the thresholded coefficients are quantized and
iv. Final stage is the entropy coder that provides the final compressed bitstream.

The pseudo code for the algorithm is explained as follows [3][4].

Step 0: Initialization

Get the user-specified PRD (UPRD);
Select the threshold TH in the range [THmin, THmax] where the range may be initialized by [0, TCmax].
Where TCmax is maximum value of Transformed coefficients divided by n.

Get the convergence precision ϵ = 1%;
Transform the ECG signal using linear transforms (DCT and WT).

Step1: Divide the transform coefficients (TC) by $n = round\left(\sqrt{2\log N}\right)$, where N is the number of samples to reduce the range of the transformed coefficients.

Step2: Take a copy of normalized coefficients and select threshold TH=(THmin+THmax)/2

Step3: Multiply the thresholded coefficients by n

Step4: Inverse the multiplied coefficients

Step 5: Compute the PRD

Step 6: if (PRD< UPRD)
Then THmin=TH;
Else THmax=TH;

Step7: if $\left|PRD - UPRD\right| / UPRD > \varepsilon$
Then go to Step2

Step8: Construct the binary lookup table to represent the zero and non-zero coefficients obtained after thresholding in Step2. This binary lookup table is encoded using Huffman coding [10].

Step9: The non-zero coefficients are quantized using Max-Lloyd algorithm [11] [12] followed by Arithmetic coding [10]

Step10: End.

## RESULTS AND DISCUSSION

The efficiency of the proposed algorithm is tested by experimentation on the well known ECG database, MIT-BIH Arrhythmia [13]. Each record contains 11 bit resolution and 360 Hz a sampling frequency. The ECG signal is transformed using Linear Transform (DCT and WT). In the WT, ECG signal is decomposed to four levels using biorthogonal swapped filters. The results presented in Table 1 and Table 2 represent the CR at fixed PRD=0.5, PRD=1, PRD=1.5 and PRD=3 respectively for different ECG signals with and without normalization. Keeping the UPRD constant that means quality of reconstructed signal. From the result it can be observed that the CR improves with normalization. For example, in case of record MIT-BIH 104 at UPRD=1.5, CR is 17.54 for DCT and CR is 13.17 for WT without normalization and with normalization CR increases to 22.56 for DCT and it increases 16.69 for WT.

Next, to show the performance of ECG compression with and without normalization using linear transforms (DCT and WT) on different signal at different PRD (ranging from 0.5 to 3), results are presented graphically in Figures 1-3. Figures 1-3 show that CR improves with the introduction of normalization.

Further, for visual comparison of ECG compression with normalization using Linear transforms (DCT and WT), the original and reconstructed signals (normal rhythm MIT-BIH 117, and abnormal rhythm MIT-BIH 232 [5]) along with error signals are shown in Fig.4 to Fig.7. The closer look on figures (Fig.4 to Fig.7) reveals that reconstructed signal is almost identical to the original signal.

## CONCLUSION

In this paper, ECG compression with normalization of transform coefficients has been studied. The results obtained are presented in tabular as well as graphical form. From the results it has been concluded that addition of normalization process before thresholding has improve the CR. The work can be extended for non-linear transforms and other Linear transforms.

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**Table 1. Performance of ECG compression with normalization and without normalization using DCT on different ECG signals**

| DCT, [1]Qbits=14, Samples=43200, Time=2 min | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Signal | [2]UPRD=0.5 | | | [2]UPRD=1 | | | | [2]UPRD=1.5 | | | | [2]UPRD=3 | | | |
| | [3]BPRD | [4]QPRD | CR | [3]BPRD | [4]QPRD | CR | CR [9] | [3]BPRD | [4]QPRD | CR | CR [9] | [3]BPRD | [4]QPRD | CR | CR [9] |
| **104** | 0.49 | 0.54 | 16.10 | 0.99 | 1.01 | 19.23 | - | 1.50 | 1.52 | 22.56 | 17.54 | 2.97 | 2.99 | 22.93 | - |
| **221** | 0.49 | 0.52 | 13.20 | 0.99 | 1.01 | 15.81 | - | 1.50 | 1.52 | 24.32 | 15.99 | 3.02 | 3.01 | 48.21 | - |
| **201** | 0.50 | 0.53 | 13.25 | 0.99 | 0.99 | 15.54 | - | 1.49 | 1.49 | 23.91 | 17.75 | 2.98 | 2.99 | 51.07 | - |
| **203** | 0.49 | 0.52 | 15.17 | 1.00 | 1.01 | 21.05 | - | 1.50 | 1.50 | 22.77 | 15.70 | 2.97 | 2.98 | 24.29 | - |
| **210** | 0.49 | 0.52 | 12.98 | 0.99 | 1.00 | 14.21 | - | 1.49 | 1.51 | 19.86 | 15.00 | 2.97 | 2.97 | 40.18 | - |
| **233** | 0.50 | 0.52 | 16.01 | 1.00 | 1.01 | 31.95 | 18.36 | 1.49 | 1.50 | 35.52 | - | 2.97 | 2.97 | 39.36 | - |
| **109** | 0.49 | 0.51 | 13.40 | 0.99 | 0.99 | 23.56 | 17.53 | 1.49 | 1.49 | 32.42 | - | 3.00 | 3.00 | 48.13 | - |
| **112** | 0.49 | 0.53 | 24.16 | 0.99 | 1.00 | 49.37 | 33.94 | 1.48 | 1.49 | 57.44 | - | 3.01 | 3.01 | 62.26 | 40.60 |
| **121** | 0.49 | 0.52 | 20.85 | 1.00 | 1.01 | 56.62 | 37.66 | 1.48 | 1.49 | 80.81 | - | 3.01 | 3.01 | 93.69 | 51.69 |
| **122** | 0.49 | 0.52 | 20.06 | 0.99 | 1.01 | 35.50 | 22.27 | 1.50 | 1.51 | 38.89 | - | 3.00 | 3.01 | 49.00 | 26.89 |
| **124** | 0.50 | 0.53 | 28.20 | 1.00 | 1.01 | 49.45 | 26.15 | 1.50 | 1.51 | 51.87 | - | 3.01 | 3.02 | 58.06 | 28.38 |
| **115** | 0.50 | 0.55 | 17.47 | 1.00 | 1.01 | 53.65 | 22.07 | 1.49 | 1.50 | 53.51 | - | 2.99 | 2.99 | 50.59 | - |
| **103** | 0.50 | 0.52 | 14.02 | 0.99 | 0.99 | 20.78 | - | 1.49 | 1.49 | 32.31 | - | 2.98 | 2.98 | 43.07 | - |
| **205** | 0.50 | 0.54 | 14.72 | 1.00 | 1.01 | 37.69 | - | 1.50 | 1.51 | 46.44 | - | 2.99 | 3.00 | 45.23 | - |

**[1]Qbits- bits used for quantization** **[2]UPRD- user defined PRD**
**[3]BPRD- PRD before quantization** **[4]QPRD- PRD after quantization**

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**Table 2. Performance of ECG compression with normalization and without normalization using WT on different ECG signals**

**Wavelet Transform, [1]Qbits=14, Samples=43200, Time=2 min**

| Signal | [2]UPRD=0.5 | | | [2]UPRD=1 | | | | [2]UPRD=1.5 | | | | [2]UPRD=3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [3]BPRD | [4]QPRD | CR | [3]BPRD | [4]QPRD | CR | CR [9] | [3]BPRD | [4]QPRD | CR | CR [9] | [3]BPRD | [4]QPRD | CR | CR [9] |
| **104** | 0.50 | 0.50 | 12.50 | 0.99 | 1.00 | 13.67 | - | 1.49 | 1.49 | 16.69 | 13.17 | 3.00 | 3.00 | 29.75 | - |
| **221** | 0.50 | 0.50 | 12.37 | 0.99 | 1.02 | 12.93 | - | 1.50 | 1.50 | 15.33 | 12.45 | 2.98 | 3.00 | 25.64 | - |
| **201** | 0.50 | 0.50 | 12.67 | 0.99 | 0.99 | 13.21 | - | 1.51 | 1.53 | 16.64 | 13.50 | 2.98 | 2.98 | 33.37 | - |
| **203** | 0.49 | 0.49 | 12.43 | 0.99 | 1.01 | 13.83 | - | 1.50 | 1.50 | 16.04 | 12.63 | 2.99 | 2.99 | 26.48 | - |
| **210** | 0.49 | 0.50 | 12.50 | 0.99 | 1.00 | 12.54 | - | 1.50 | 1.52 | 14.93 | 12.27 | 2.98 | 3.00 | 28.19 | - |
| **233** | 0.50 | 0.50 | 13.32 | 0.99 | 1.00 | 22.37 | 15.41 | 1.49 | 1.50 | 25.78 | - | 2.97 | 2.98 | 31.86 | - |
| **109** | 0.49 | 0.49 | 12.15 | 1.00 | 1.01 | 17.13 | 13.61 | 1.49 | 1.50 | 23.84 | - | 3.00 | 3.00 | 48.88 | - |
| **112** | 0.49 | 0.50 | 20.93 | 0.99 | 1.00 | 38.69 | 25.14 | 1.51 | 1.51 | 55.05 | - | 3.00 | 3.00 | 95.49 | 43.54 |
| **121** | 0.50 | 0.49 | 18.57 | 1.00 | 1.01 | 40.68 | 28.58 | 1.50 | 1.50 | 79.20 | - | 2.97 | 2.97 | 124.26 | 54.29 |
| **122** | 0.50 | 0.50 | 14.67 | 1.00 | 1.00 | 22.17 | 16.33 | 1.50 | 1.50 | 35.21 | - | 3.01 | 3.01 | 65.78 | 33.25 |
| **124** | 0.49 | 0.50 | 19.14 | 0.99 | 0.99 | 35.84 | 25.47 | 1.50 | 1.50 | 58.12 | - | 3.00 | 3.00 | 75.86 | 41.30 |
| **115** | 0.50 | 0.50 | 13.82 | 0.99 | 0.99 | 28.54 | 20.00 | 1.49 | 1.50 | 37.03 | - | 2.99 | 2.99 | 61.68 | - |
| **103** | 0.49 | 0.52 | 11.83 | 0.99 | 0.99 | 14.10 | - | 1.50 | 1.50 | 18.98 | - | 3.00 | 3.00 | 56.08 | - |
| **205** | 0.49 | 0.49 | 12.93 | 1.00 | 1.00 | 21.66 | - | 1.49 | 1.49 | 34.98 | - | 3.01 | 3.01 | 54.39 | - |

**[1]Qbits- bits used for quantization** **[2]UPRD- user defined PRD**
**[3]BPRD- PRD before quantization** **[4]QPRD- PRD after quantization**

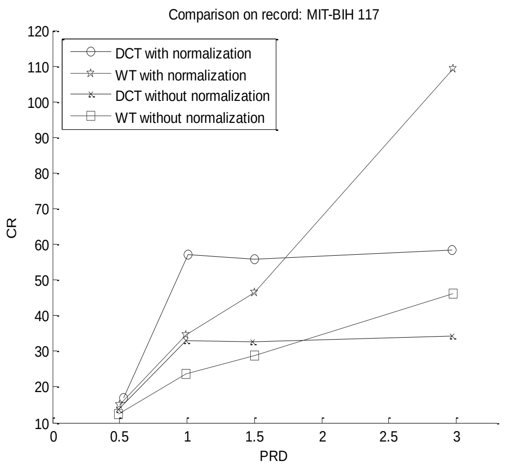


Fig. 1 Comparison of ECG compression with normalization and without normalization using Linear Transforms on record, MIT-BIH 117

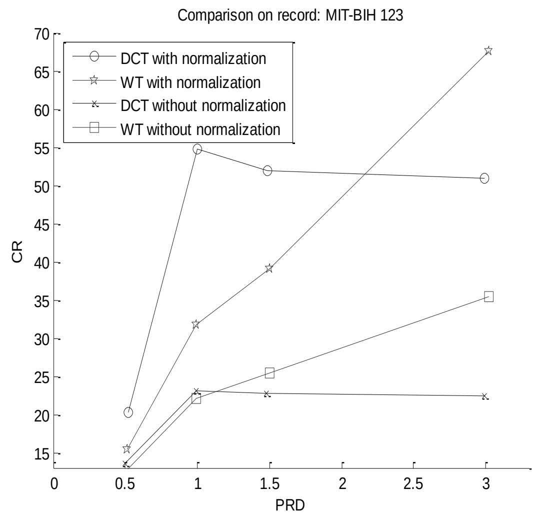


Fig. 2 Comparison of ECG compression with normalization and without normalization using Linear Transforms on record, MIT-BIH 123

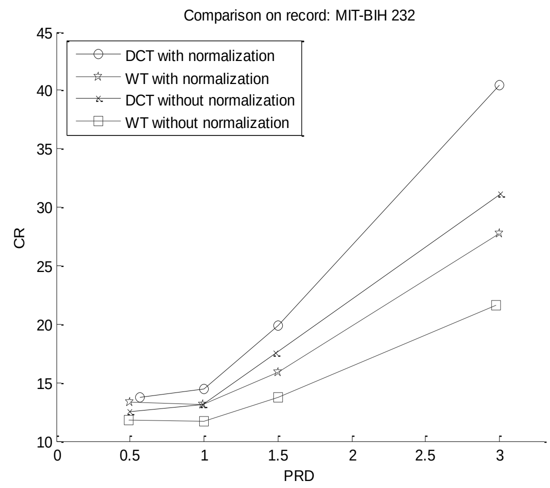


Fig. 3 Comparison of ECG compression with normalization and without normalization using Linear Transforms on record, MIT-BIH 232

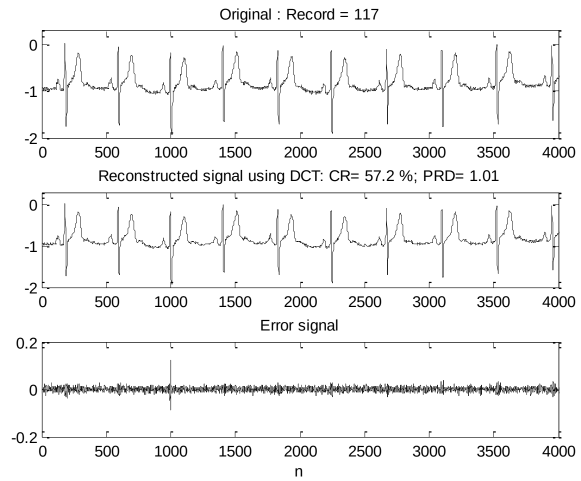


Fig. 4 Compressed waveform of record 117 using DCT with normalization at UPRD=1.

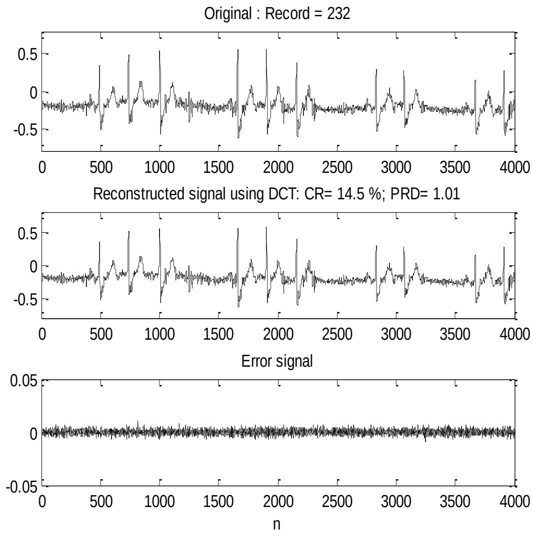


Fig. 5 Compressed waveform of record 232 using DCT with normalization at UPRD=1.

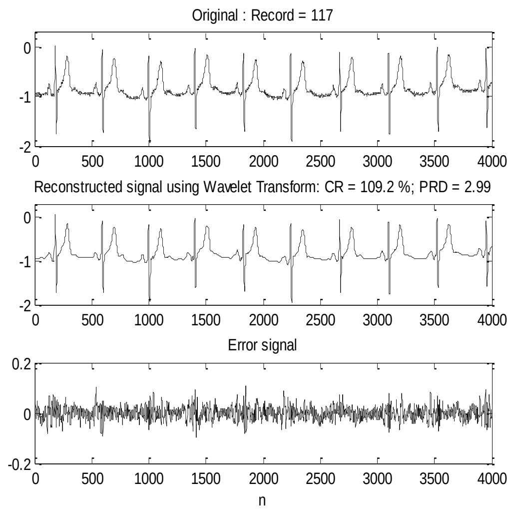


Fig. 6 Compressed waveform of record 117 using WT with normalization at UPRD=3.

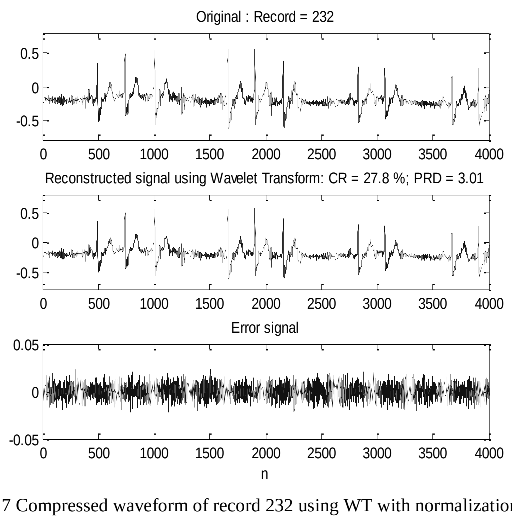


Fig. 7 Compressed waveform of record 232 using WT with normalization at UPRD=3.