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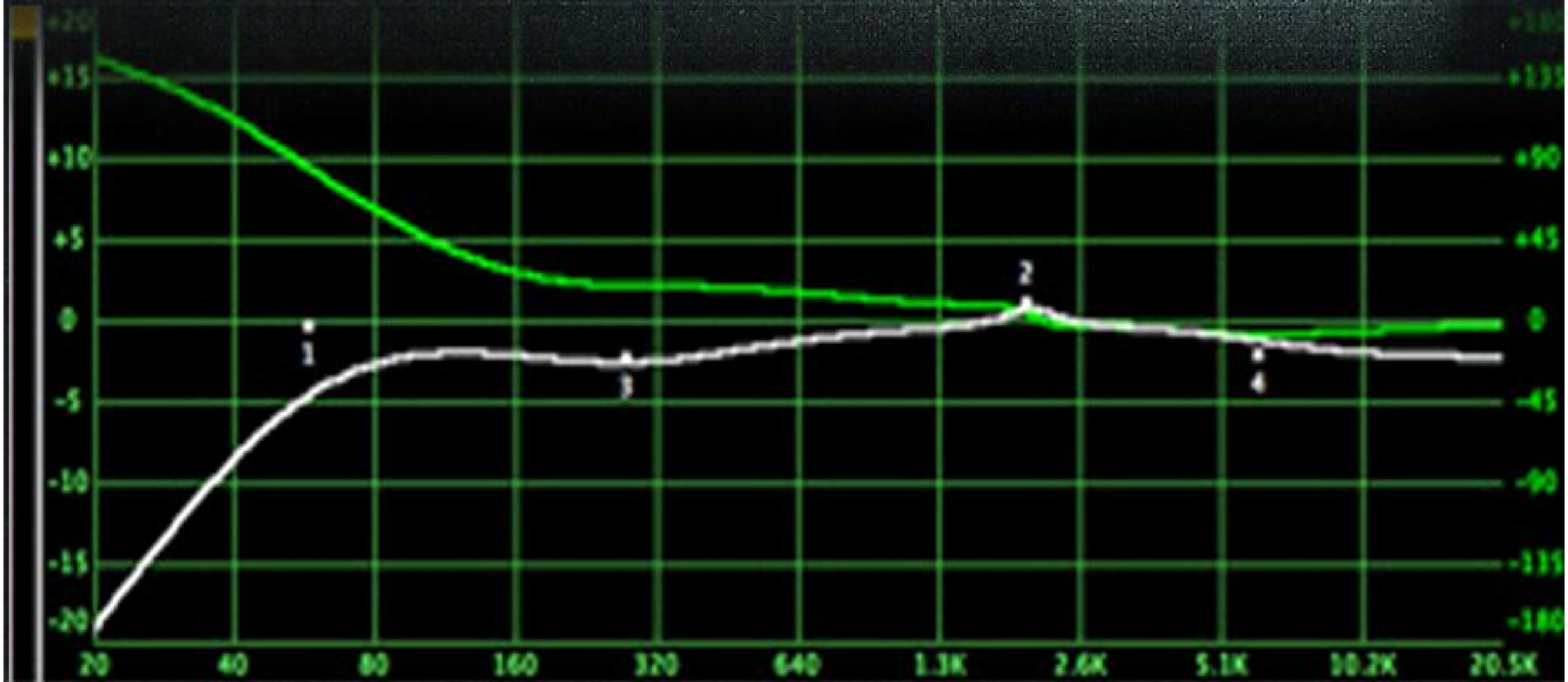

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Table of Contents

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Pages

Performance Evaluation of Percent Root Mean Square Difference for ECG Signals Compression

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Abstract

Electrocardiogram (ECG) signal compression is playing a vital role in biomedical applications. The signal compression is meant for detection and removing the redundant information from the ECG signal. Wavelet transform methods are very powerful tools for signal and image compression and decompression. This paper deals with the comparative study of ECG signal compression using preprocessing and without preprocessing approach on the ECG data. The performance and efficiency results are presented in terms of percent root mean square difference (PRD). Finally, the new PRD technique has been proposed for performance measurement and compared with the existing PRD technique; which has shown that proposed new PRD technique achieved minimum value of PRD with improved results.

Keywords: ECG compression, thresholding, wavelet coding.

1. INTRODUCTION

Wavelets are useful tools for data compression and have been applied for numerous problems such as ECG, pattern recognition and the ECG detection characteristics points. ECG signal is a very attractive source of information for physicians in diagnosing heart diseases [1]. Nowadays, ECG compression is being used tremendously because of the data reduction of ECG signal in all aspects of electrocardiography and considers an efficient method for storing and retrieving data. Normally, 24-hour recordings of ECG signals are desirable to detect and monitor heart abnormalities or disorders. Therefore the ECG data in digital form becomes one of the important issues in the biomedical signal processing community [2,3].

ECG compression is a well-established and potential area of research with numerous applications such as diagnosis, taking care of patients and signal transfer through communication lines. Wavelet transform is a powerful and efficient technique in signal processing for compressing ECG signals [4].

Many studies have done on the PRD calculation using the different denominators such as mean, without mean and baseline 1024. However no information is available on the PRD calculation using the approach of median as a denominator. The main objective of this paper is to compare the result of PRD with preprocessing and without preprocessing of ECG data and proposed new PRD technique with median.

2. ECG SIGNAL COMPRESSION ALGORITHMS

The main concern of the compression is the removal of redundant and irrelevant information from the ECG signal. There are many compression algorithms that have been presented and these algorithms are based on Wavelet transform.

3. WAVELET TRANSFORM

The wavelet transform or wavelet analysis is the most recent solution to overcome the shortcomings of the Fourier transform. Wavelet analysis is a form of “multi-resolution analysis”, which means those wavelets are better suited to represent functions which are localized both in time and frequency. This fact makes Wavelets useful for signal processing where knowledge of frequencies and the location of wavelets are essential for in time information.

Wavelet Functions are generated from one single function by scaling and translation

(1)

Where a is the dilation and b is the location parameter of the wavelet.

The basic idea of wavelet transform is to represent any function f as the linear superposition of wavelet [1]. Discrete coefficients describing the scaling and translations are called wavelet coefficients. The wavelet transform can be implemented by subband coding for perfect reconstruction of the signals. The decomposition of signal with the pair of low-pass and high-pass filter those are suitable designed to form quadrature mirror filters (QMFs). The output of each analysis filter is downsampled by a factor of two. The inverse transform is obtained by selecting the highest layer, where the wavelet coefficients are upsampled by a factor of two and then filtered with the synthesis QMF pair. The low-pass and high-pass outputs of the synthesis filters are combined to get the low-pass signal for the next lower level [9].

A brief description on each method along with relevant literature information (other research’s work) is discussed below.

Hilton [5] has presented wavelet and wavelet packet method. This approach was based on embedded zero wavelet (EZW) coding to get the best-reconstructed signal for a given rate under the constraints that the encoding is embedded. The wavelet packet bases inherit the properties of the wavelets they are built from, such as orthonormality and smoothness.

Lu et al. [6] have presented a new approach of set partitioning hierarchical tree (SPIHT) algorithm for ECG signals. The SPIHT algorithm has achieved remarkable success in image coding. The authors have modified the algorithm for the one-dimensional case for generating a bit stream progressive in quality [6].

Chen et al. [7] have suggested a new wavelet-based Vector quantization (VQ) ECG compression approach. Wavelet transform coefficients are quantised with uniform scalar dead zone quantiser. The Exp-Golomb coding is used to code the length of runs of the zero coefficients. The algorithm is quite robust to different ECG signals because no a priori signal statistic is required.

Benzid et al. [8] present a new quality-controlled, wavelet-based, compression method for ECG signals. Wavelet coefficients are thresholded iteratively for guarantee of predefined goal percent root mean square difference (GPRD) is achieved within acceptable boundary. The Quantization strategy for extracted non-zero wavelet coefficients (NZWC) is coded using 8 bit linear quantizer. Finally, the Huffman coding is used to achieve high quality of reconstructed signals.

Rajoub [9] has used Energy packing efficiency (EPE) approach for the compression of ECG signals to achieve desired clinical information. Wavelet coefficients are thresholded on the desired energy packing efficiency and significant map is compressed efficiently using the run length coding.

Alshmali and Amjed [10] commented on the EPE compression approach proposed by Rajoub. The authors have claimed that the several important points regarding accuracy, methodology and coding were found to be improperly verified during implementation. This paper discusses these findings and provides specific subjective and objective measures that could improve the interpretation of compression results in these research-type problems.

Manikandan and Dandapat [11] have presented a wavelet threshold–based method for ECG signal compression. Significant wavelet coefficients are selected based on the energy packing efficiency and quantized with uniform scalar zero zone quantizer. Significant map is created to store the indices of the significant coefficients. This map is encoded efficiently with less number of bits by applying the significant Huffman coding on the difference between the indices of the significant coefficients.

Benzid et al. [12] have applied pyramid wavelet decomposition for ECG signals using the bior4.4 wavelet up to 6th level. The resultant coefficients got through the iterative threshold until a fixed percentage of wavelet coefficients will be reached to zero. Then the loss less Huffman coding has been used to increase the compression ratio.

Manikandan and Dandapat [13] have presented a target distortion level (TDL) and target data rate, wavelet threshold–based ECG signal compression techniques. These are based on the energy packing efficiency, uniform scalar zero zone quantizer and differencing integer significance map.

Tohumoglu and Sezgin [14] have presented new approach based on EZW algorithm. The purpose of this paper to apply the modified EZW algorithm for ECG signal compression and evaluate the performance with respect to different classes of wavelets and threshold values.

4. PROPOSED METHOD

ECG signals for the experiment have been taken from MIT BIH arrhythmia database for record 117. We divided signals into frames and each frame length is 1024. At first, the ECG signal is preprocessed by normalization, mean removal and zero padding. The objective of preprocessing is to get the magnitudes of wavelet coefficients which would be less than one and is reduced reconstruction error. Preprocessing can be described by the following equation [9]:

(2)

Where y_i preprocessed signal,   is the original signal and m_x is defined as

(3)

The preprocessed and un-processed ECG signals are decomposed by using the discrete wavelet transform up to the fifth level using the different families of wavelet to obtain the wavelet coefficients *(WC)*. A threshold method of ECG signals is applied on the discrete wavelet coefficients. Threshold method has been described by the following equation:

$$Thres\text{-}coefficients = f_{TH}(WC,\ C_{Number}) \qquad (4)$$

Where f_{TH} is the function of designed algorithm, WC is the wavelet coefficients and C_{Number} is number of coefficients selected. The threshold mechanism will automatically select the number of coefficients based on the value of C_{Number}. The process of threshold removes the unnecessary information from the ECG signal. Now we can fix the number of threshold coefficients required during the threshold process. A binary map is used to store the significant information of the coefficients after scanning the threshold coefficients. The run length coding scheme is used to compress the significant map [9].

5. RESULTS AND DISCUSSION

To measure the performance for different compression methods, the distortion between original signal and reconstructed signal is measured by PRD. In the following, the most popular measures are presented [8]:

x 100 (5)

x 100 (6)

x 100 (7)

$$\times\ 100 \qquad (8)$$

Where x_{ori} denotes the original signal, x_{rec} denotes the reconstructed signal and n denotes the number samples within one data frame, $mean\ (x_{ori})$ denotes the mean of original signal and $median\ (x_{or})$ denotes median of original signal. PRD1 was used by [5,9] which depend on the dc level of the original signal. PRD2 is considered as a quality measure, it is very simple and also used to evaluate the reliability of the reconstructed signal. PRD3 can be found as an example in [10] where they used the mean of the original signal. Median is a more suitable parameter to calculate the average values of data as compared to mean.

From Table 1, it can be seen that the PRD value 0.3335% of without preprocessing (PRD1$_{WO}$) achieved the minimum value than PRD value0.335% with preprocessing (PRD1$_{W}$) in BiorSpline (bior4.4). Difference between PRD1$_{W}$ and PRD1$_{WO}$ shows not much difference but shows lower values than without preprocessing in most cases. Table1 also showed that the PRD$_{New}$ technique is achieved lower values than PRD3 values in different wavelet of families. Difference between PRD3 (mean) and PRD$_{New}$ (median) is remarkable with all positive values. This shows the significance of median parameter in calculating PRD. Figure 1 shows the trend of PRD with respect to wavelet family for proposed method of ECG signals. From figure 1, it can be seen that PRD$_{New}$ is achieved minimum values as compared to PRD3 values. Figure 2 and 3 show the original and reconstructed signals for the record of 117. The proposed method preserves all clinical information and also removes the noise in the original signal which is shown in figure 3.

Table 1: PRD COMPARISON RESULT OF PREPROCESSING AND NEW PRD TECHNIQUE

Wavelet Family No.	Name.	PRD1$_{W}$ %	PRD1$_{WO}$ %	Difference between PRD1$_{W}$ & PRD1$_{WO}$ (%)	PRD3%	PRD$_{New}$ %	Difference between PRD3 & PRD$_{New}$ (%)
1	haar	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
2	db1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
3	db2	0.3796	0.3641	0.0002	7.3633	7.1099	0.0025
4	db3	0.3566	0.3472	0.0001	6.9185	6.6804	0.0024
5	db4	0.3563	0.348	0.0001	6.9134	6.6752	0.0024
6	db5	0.3512	0.3619	-0.0001	6.8151	6.5809	0.0023
7	db6	0.3554	0.3683	-0.0001	6.8954	6.658	0.0024
8	db7	0.3612	0.3885	-0.0003	7.0026	6.7613	0.0024
9	db8	0.3577	0.4162	-0.0006	6.9412	6.7024	0.0024
10	db9	0.3722	0.4423	-0.0007	7.2148	6.9666	0.0025
11	db10	0.3765	0.4919	-0.0012	7.2945	7.0431	0.0025
12	sym2	0.3796	0.3641	0.0002	7.3633	7.1099	0.0025
13	sym3	0.3566	0.3472	0.0001	6.9185	6.6804	0.0024
14	sym4	0.347	0.3432	0.0000	6.7343	6.5026	0.0023
15	sym5	0.3474	0.3469	0.0000	6.7406	6.509	0.0023
16	sym6	0.3431	0.3557	-0.0001	6.6584	6.4294	0.0023
17	sym7	0.3499	0.3701	-0.0002	6.787	6.5536	0.0023
18	sym8	0.3402	0.3734	-0.0003	6.6034	6.3757	0.0023

19	coif1	0.3835	0.3731	0.0001	7.4379	7.1823	0.0026
20	coif2	0.3484	0.3612	-0.0001	6.76	6.5268	0.0023
21	coif3	0.3438	0.3896	-0.0005	6.672	6.4422	0.0023
22	coif4	0.3412	0.4501	-0.0011	6.622	6.3939	0.0023
23	coif5	0.3442	0.5414	-0.0020	6.6775	6.4473	0.0023
24	bior1.1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
25	bior1.3	0.5999	0.613	-0.0001	11.5962	11.1979	0.0040
26	bior1.5	0.5958	0.6456	-0.0005	11.5266	11.1317	0.0039
27	bior2.2	0.3465	0.3352	0.0001	6.726	6.4944	0.0023
28	bior2.4	0.3383	0.3401	0.0000	6.5656	6.3392	0.0023
29	bior2.6	0.3404	0.3599	-0.0002	6.6057	6.3778	0.0023
30	bior2.8	0.3438	0.3842	-0.0004	6.6703	6.4402	0.0023
31	bior3.1	0.4552	0.4388	0.0002	8.8384	8.5344	0.0030
Wavelet Family No. Name.		**PRD1$_W$ %**	**PRD1$_{WO}$ %**	**Difference between PRD1$_W$ & PRD1$_{WO}$ (%)**	**PRD3%**	**PRD$_{New}$ %**	**Difference between PRD3 & PRD$_{New}$ (%)**
32	bior3.3	0.3712	0.37	0.0000	7.2119	6.9632	0.0025
33	bior3.5	0.3428	0.3582	-0.0002	6.6578	6.4278	0.0023
34	bior3.7	0.3398	0.3641	-0.0002	6.593	6.3656	0.0023
35	bior3.9	0.3359	0.3901	-0.0005	6.5227	6.2974	0.0023
36	bior4.4	0.335	0.3335	0.0000	6.5012	6.2771	0.0022
37	bior5.5	0.3474	0.3529	-0.0001	6.7446	6.5123	0.0023
38	bior6.8	0.3376	0.3725	-0.0003	6.5529	6.3275	0.0023
39	rbio1.1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
40	rbio1.3	0.3585	0.3445	0.0001	6.9571	6.7175	0.0024
41	rbio1.5	0.3486	0.3504	0.0000	6.7667	6.5338	0.0023
42	rbio2.2	0.5549	0.5525	0.0000	10.7275	10.359	0.0037
43	rbio2.4	0.396	0.4069	-0.0001	7.6756	7.4122	0.0026
44	rbio2.6	0.3847	0.4157	-0.0003	7.4594	7.2024	0.0026
45	rbio2.8	0.3845	0.4351	-0.0005	7.4584	7.202	0.0026
46	rbio3.1	4.8656	4.4473	0.0042	93.903	90.6597	0.0324
47	rbio3.3	0.78	0.7925	-0.0001	15.0346	14.518	0.0052
48	rbio3.5	0.517	0.574	-0.0006	9.9859	9.6431	0.0034
49	rbio3.7	0.4618	0.5549	-0.0009	8.9417	8.635	0.0031
50	rbio3.9	0.4425	0.5595	-0.0012	8.5795	8.2852	0.0029
51	rbio4.4	0.3707	0.3793	-0.0001	7.1867	6.9396	0.0025
52	rbio5.5	0.3522	0.37	-0.0002	6.8319	6.5965	0.0024
53	rbio6.8	0.3621	0.4058	-0.0004	7.0238	6.7824	0.0024
54	dmey	0.371	42.1938	-0.4182	7.1887	6.9413	0.0025

A summary of the performance results for signal compression is shown in Table 2. Table 2 gives the comparison of the proposed method with other existing methods for the record 117 on the basis of PRD and CR. From Table 2, it can be seen that the PRD value of 2.6% with CR 8:1 for the record of 117 achieved by Hilton. Using the SPIHT approach by Lu et al, it was found that the PRD value is 1.18% with CR 8:1 for the 117 record. From Table 2, it can be seen that the PRD value of 1.04% with CR 27.93:1 for the record of 117 achieved by Benzid.

Table 2: PERFORMANCE RESULTS FOR COMPRESSING RECORDS USING THE DIFFERENT METHODS

METHOD	SIGNAL	CR	PRD %
Hilton [5]	117	8:1	2.6%(PRD1)
Lu et al[6]	117	8:1	1.18%(PRD1)

Benzid [8]	117	27.93:1	1.04% (PRD1)
Rajoub [9]	117	22.19:1	1.06% (PRD1)
Manikandan [11]	117	8.5:1	0.956% (PRD1)
Benzid [12]	117	16.24:1	2.55% (PRD1)
Proposed	117	8.70:1	0.335%($PRD1_W$)

Using the energy packing efficiency approach by Rajoub, it was found that the PRD value produced 1.06% with the CR 22.19:1 for the 117 record. Table 2 also has shown that the PRD value of 0.956% with CR 8.5:1 for the record of 117 achieved by Manikandan. Using the fixed the percentage of wavelet coefficient approach by Benzid, it was found that the PRD value produced 2.55% with the CR 16.24 for the 117 record. In this investigation, it can be seen that the PRD value of $PRD1_W$ 0.335% with CR 8.70:1 for the record of 117 achieved by our proposed method using Biorspline(bior) wavelet family which is much lower than reported existing PRD values.

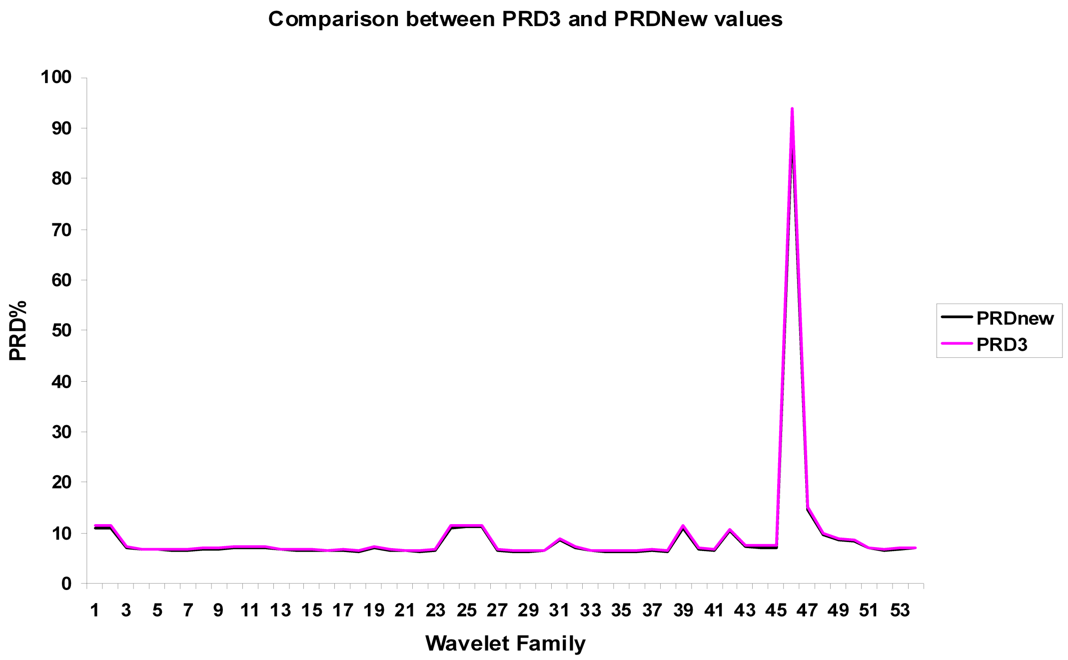

FIGURE 1: comparison of mean and median values of PRD for ECG signals

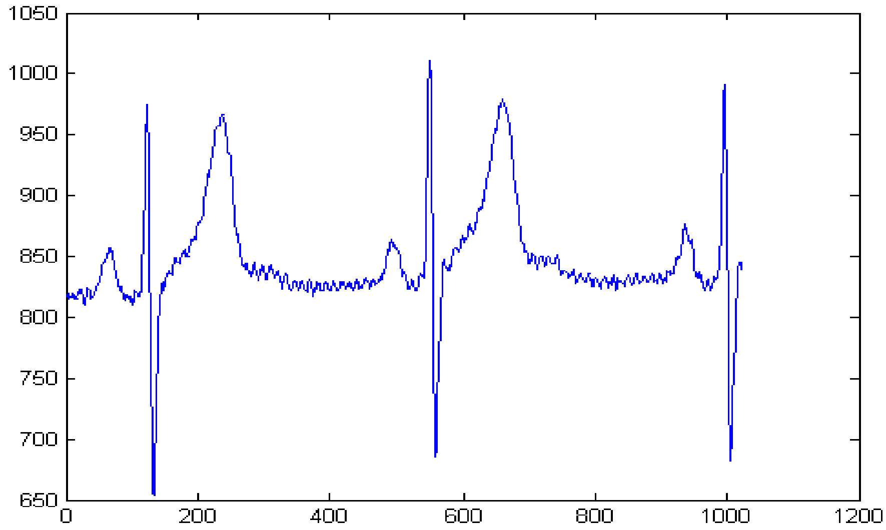

FIGURE 2: Original ECG Signals from the Record 117

6. CONSLUSION & FUTURE WORK

A new PRD technique for ECG signal is proposed in this paper. In this paper, a study of ECG signal compression using preprocessing and without preprocessing approach on the ECG data is described. The conclusions can be drawn from the study that there is no significant difference in PRD values (results) of preprocessing and without preprocessing of ECG data when use proposed method. The test results of PRD (median) technique has shown the superior performance compare to that of PRD (mean) formula for all the experimented wavelet families. Future research work on the entropy coding of the wavelet coefficients is being carried out in the research center.

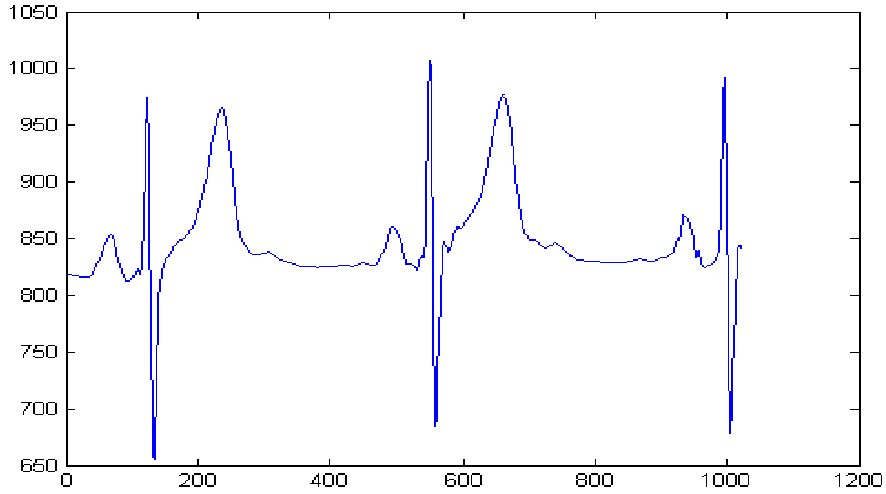

FIGURE 3: Reconstructed ECG Signals from the Record 117 without noise

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Elements space and amplitude perturbation using genetic algorithm for antenna array sidelobe Cancellation

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Abstract

A simple and fast genetic algorithm (GA) developed to reduce the sidelobes in non-uniformly spaced linear antenna arrays. The proposed GA algorithm optimizes two vectors of variables to increase the Main lobe to Sidelobe power ratio (M/S) of array's radiation pattern. The algorithm, in the first phase calculates the positions of the array elements and in the second phase, it manipulates the amplitude of excitation signals for each element. The simulations performed for 16 and 24 elements array structure. The results indicated that M/S improved in first phase from 13.2 to over 22.2dB meanwhile the half power beamwidth (HPBW) left almost unchanged. After element replacement, in the second phase, by using amplitude tapering further improvement up to 32dB was achieved. Also, the simulations shown that after element space perturbation, some antenna elements can be merged together without any performance degradation in radiation pattern in terms of gain and sidelobes level.

Keywords: Genetic algorithm; antenna array; sidelobe cancellation

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1. INTRODUCTION

There are several popular methods available to reduce the sidelobes in the antenna pattern. The most popular techniques are to taper the amplitude using different window functions such as Kaiser or Dolph Cheyshev [1]. Phase tapering of input signals also is very popular way for antenna array radiation pattern optimization. Phase manipulation of inputs signal into antenna elements is technically efficient way to form and shift the main beam in desired direction and also it can be used for null steering in order to mitigate the effect of interferers in the system [2]. Amplitude manipulation of excitation signals of the array elements basically help to improve the main beam power to sidelobe power ratio [3]. The most efficient method in order to both shifting the main beam and reducing the sidelobes is based on full amplitude/phase control of signal fed into array elements. However as long as the sidelobe cancellation is our main interest, the amplitude tapering is adequate to reduce the sidelobes level. In the other hand, the element space perturbation can be an alternative technique to improve M/S by taking advantage of element position as a variable in the arrays [4]. Element space perturbation has attracted the researcher's attention since early 1970. In [4] the array factor had been reshuffled base on elements position in the array, result in linear equations which then solved by iteration techniques. The result of this technique is considerable reduction in sidelobes. However, this technique is sensitive to choose a parameter controlling the amount of sidelobe reduction for each cycle of iteration. In addition, the complexity of this technique is high since it needs matrix inversion and also it needs to check the resulting antenna pattern after each cycle of iteration. Therefore, it burden in real time element perturbation applications.

Similarly, much research has been conducted base on element space perturbation. However, it is rare to see the researches which merge the amplitude tapering and element space perturbation together for antenna radiation pattern optimization. The element perturbation provides us a degree of freedom for antenna array radiation pattern optimization which should be used beside the other techniques despite increase in complexity. In this research a simple decimal GA algorithm is applied to take advantage of both amplitude and element space perturbation successively, to reduce the sidelobes level. The method is quiet efficient for the application such as radar communication, which the main concern is minimizing the sidelobes. In such an application the position perturbation is only applied during the design and manufacturing process. Therefore time limitation is no longer a constraint criterion for element perturbation. However, for other applications in which real time sensor positioning is needed, the system burden from time constraint. In this case, if both amplitude and position perturbation has applied at the same time on the system the time limitation of the system would be due to element position calculation, because, the amplitude tapering operation takes much shorter time than servo motor operation. Therefore, the critical time is just the time to calculate the amplitude of each signal fed to the arrays elements. In this paper, we use genetic algorithm to calculate the antenna element position and amplitude of excitation feeds. The technique is very simple and efficient. The GA, in the first phase finds the best place of element in order to have minimum level of sidelobe, and then the amplitude of each signal furthermore is manipulated to have further sidelobe cancellation. The subsequent section provides the clear picture of this technique.

2. THE LINEAR ARRAY STRUCTURE

The array structure considered for this research is linear. However, the technique can be applied to any type of array with unknown geometrical shape. The array factor of linear array antenna with M antenna elements and equal distance of d can be written as equation (1).

$$AF1 = \sum_{k=1}^{M} e^{j(k-1).\frac{2\pi}{\lambda}.d(\sin(\theta)-\sin(\theta_0)).\cos\phi} \qquad (1)$$

Where, λ is the wavelength of the impinging signal, θ represent the azimuth angle of radiation pattern while the φ represent the elevation angle and θo is the azimuth angle of the desired impinging signal. The array factor with uniform distance and different amplitude of excitation signal can be written as equation (2)

$$AF2=\sum_{k=1}^{M} w(k).e^{j(k-1).\frac{2\pi}{\lambda}.d(\sin(\theta)-\sin(\theta_0)).\cos\phi} \qquad (2)$$

Change in the position of the elements can be set in the equation as a coefficient of d which is the distance between uniform linear array elements. Therefore, the modified array factor with two vectors of variables namely W and D can be rewritten as equation (3). This equation is used as a fitness function in developed genetic algorithm in following section.

$$AF3=\sum_{k=1}^{M} w(k).e^{j(k-1+D(k)).\frac{2\pi}{\lambda}.d(\sin(\theta)-\sin(\theta_0)).\cos\phi} \qquad (3)$$

3. THE GENETIC ALGORITHM

The decimal genetic algorithm due to its simplicity is developed to calculate both position and amplitude of each element in the array. The structure of the GA is similar to the algorithm we have developed in [5]. However, the only difference comes from fitness function which needs to be modified. In addition, in this research real continues decimal number as chromosomes are used. Since, we only deal with the position and amplitude of each element which are real decimal continues numbers.

3.1 THE FITNESS FUNCTION

The two stage fitness function can be explained as follow. In the first stage, the element space perturbation is operated. In this phase, the signals amplitude for all antenna elements is equal. In this case, the fitness function can be represented by Equation (4).

$$f=\frac{P_M}{\max(abs(\underset{sidelobe}{P_S}))} \qquad (4)$$

Where, P_M and P_s are the normalized main beam and sidelobe power respectively and they can be calculated using following Equations (5) and (6).

$$P_M=(normalaized(AF))^2 \qquad \theta\text{=Main beam angle} \qquad (5)$$

$$P_s=(normalaized(AF))^2 \qquad \theta\text{=Sidelobes angle} \qquad (6)$$

Where, AF can be calculated by using equation (3) if w (k) is assumed unity for all antenna elements. The results of GA at this stage will give us the optimum value of D(k). After achieving optimum value of antenna elements location, the algorithm calculates the optimum antenna weights result in further improvement of M/S. At this stage again we use the fitness function represented by equation (4), however, the array factor can be calculated using equation (3) with variable w (k) and constant D (k). In this case, the value of D (k) is the results of former GA process.

4. SIMULATION RESULTS

The simulations have done for two linear arrays with 16 and 24 numbers of antenna elements. Table 1 is shown the resulted statistical information of the simulations.

#.of array elements	Technique	HPBW degree	Sidelobe dB
16	Without perturbation	6	-13.20
16	Space perturbation	6.9	-22.22
16	Space & Amplitude perturbation	8	-31.00
24	Without perturbation	4	-13.20
24	Space perturbation	4	-22.00
24	Space & Amplitude perturbation	5	-31.18

Table 1: HPBW and sidelobe reduction

The results indicate that the M/S in both cases, 16 and 24 elements is about -13.2 dB. This value decreases to -22.00 dB for both cases after one hundred iterations in first phase. The M/S further improved to approximately -31 dB in second phase of the algorithm.

16 elements antenna array			
Element number	Element disposition	amplitude value	Eliminated elements
1	0.0039	0.2880	-
2	0.4295	0.5160	-
3	0.8272	0.6146	-
4	0.9388	0.7866	-
5	0.9890	0.7326	x
6	0.8326	0.8471	-
7	0.7856	0.6291	-
8	0.3027	0.8509	-
9	0.3129	0.7003	-
10	0.0032	0.8770	-
11	0.0671	0.7115	-
12	-0.1806	0.7211	-
13	-0.1467	0.6458	-
14	-0.1872	0.5776	-
15	0.1691	0.5074	-
16	0.8741	0.2996	-

Table 2: The value of element disposition and weights for 16 elements linear array

The results in Table 2 and 3 show the disposition of each element in the array as well as the optimum amplitudes of excitation signal for each element. As the results are indicated, some of the elements have to relocate from their original place about one unit. This means that these elements can be merged with the elements after or before them. Cross mark in column four of these two tables show the elements which can be combined or eliminated in the array. The results shown after combining these elements from the array, the results have been left almost unchanged.

16 elements antenna array			
Element number	Element displacement	amplitude value	Eliminated elements
1	-1.1137	0.2099	-
2	-0.6527	0.3241	-
3	0.1296	0.3958	-
4	0.8235	0.5948	-
5	1.0755	0.5172	x
6	0.9541	0.5763	-
7	0.9633	0.6492	x
8	0.9818	0.7511	-
9	0.9939	0.7206	x
10	0.9615	0.9031	-
11	1.3268	0.7163	x
12	0.2962	0.5698	-
13	0.8127	0.8359	-
14	0.2729	0.5069	-
15	0.4268	0.7687	-
16	0.0722	0.5927	-
17	0.8222	0.5405	-
18	-0.7532	0.6323	x
19	0.1809	0.8129	-
20	0.5072	0.4846	-
21	0.3343	0.3880	-
21	0.6957	0.4681	-
23	1.2027	0.2865	-
24	1.6351	0.1506	-

Table 3: The value of element displacement and weights for 24 numbers of elements

Note that the combination of the elements which are close together must be done prior to the second phase of the algorithms otherwise the elements combination and elimination would degrade the M/S and disfigure the antenna radiation pattern.

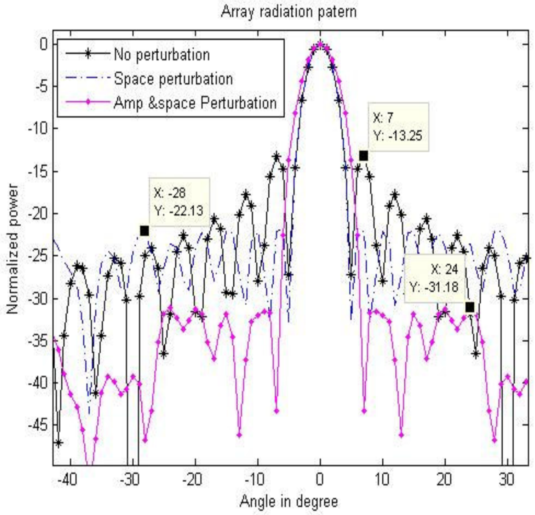

Figure 1: Results for 16 elements linear antenna array

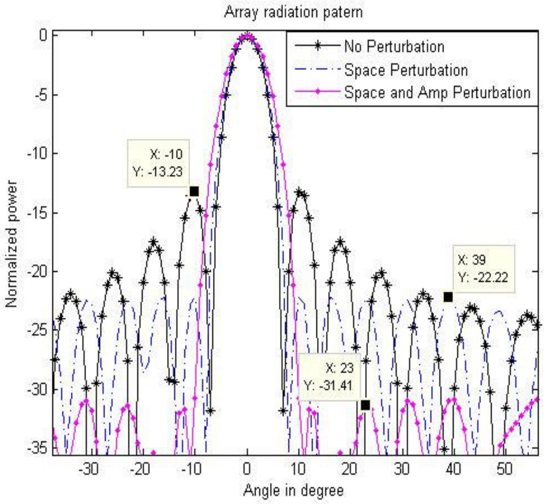

Figure 2: Results for 24 elements linear antenna array

Figure 1 and 2 are shown the resulting radiation pattern after applying the GA for two continues phases. The star solid line is original beam pattern without any perturbation. The dashed lines are the results after the first phase of the GA coming from elements disposition. Finally the dotted line is results of GA algorithms after space and amplitude perturbation which has the lowest amount of sidelobes. In regards of HPBW, different number of simulation has been done, in essence it can be concluded that the element space perturbation can keep the HPBW as the same as its original value, however the amplitude perturbation change the HPBW in all cases and it can not be avoided.

5. CONCLUSION

Satisfactory results indicate that the integrated space and amplitude perturbation using GA can be a excellence technique to reduce the sidelobes. The GA algorithm provides more flexibility to play with the variable and set the variety of constraint to achieve desirable results. Although the iteration time of GA seems high for real time application, the flexibility and ease of solution still make it worth for future applications.

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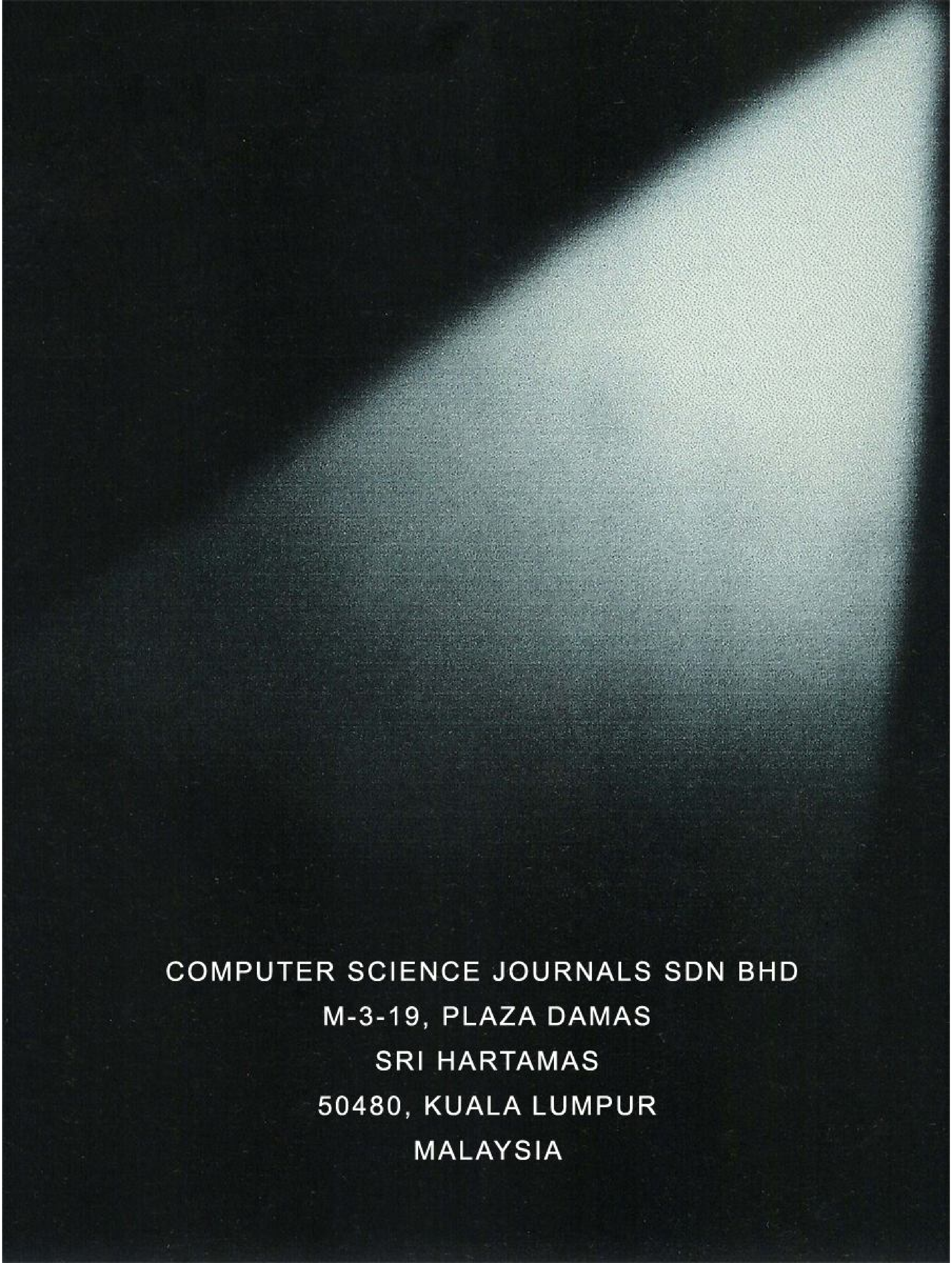

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