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A Novel Blind Watermarking of ECG Signals on Medical Images Using EZW Algorithm

Mohammad S. Nambakhsh, Alireza Ahmadian*, Mohammad Ghavami, Reza S.Dilmaghani and S. Karimi-Fard

Abstract— **In this paper, we present a novel blind watermarking method with secret key by embedding ECG signals in medical images. The embedding is done when the original image is compressed using the embedded zero-tree wavelet (EZW) algorithm. The extraction process is performed at the decompression time of the watermarked image. Our algorithm has been tested on several CT and MRI images and the peak signal to noise ratio (PSNR) between the original and watermarked image is greater than 35 dB for watermarking of 512 to 8192 bytes of the mark signal. The proposed method is able to utilize about 15% of the host image to embed the mark signal. This marking percentage has improved previous works while preserving the image details.**

I. INTRODUCTION

Exchange of database between hospitals needs efficient and reliable transmission and storage techniques to cut down the cost of health care. This exchange involves large amount of vital patient information such as bio-signals and medical images. Interleaving one form of data such as 1-D signal, over digital images can combine the advantages of data security with efficient memory utilization [1], but nothing prevents the user from manipulating or copying the decrypted data for illegal uses. Embedding vital information of patients inside their scan images will help physics to make a better diagnosis of disease. In order to solve these issues, watermark algorithms have been proposed as a way to complement the encryption processes and provide some tools to track the retransmission and manipulation of multimedia contents [2][3]. A watermarking system is based on an imperceptible insertion of a watermark (a signal) in an image. This technique is adapted here for interleaving graphical ECG signals within medical images, to reduce storage and transmission overheads as well as helping for computer aided diagnostics system.

In this paper we present a new watermarking method combined with the EZW-based wavelet coder. The principle is to replace significant wavelet coefficients of ECG signals by the corresponding significant wavelet coefficients belonging to the host image which is much bigger in size than the mark signal. This paper presents a brief introduction to watermarking and the EZW coder that acts as a platform for our watermarking algorithm.

M. S. Nambakhsh is with the Department of Biomedical Systems & Medical Physics, Tehran University of Medical Sciences, and Research Center for Science and Technology in Medicine, TUMS, Tehran, Iran nambakhsh@razi.tums.ac.ir

A. Ahmadian (corresponding author) is an Associate Professor at the Tehran University of Medical Sciences, TUMS, Dept. of Biomedical Systems & Medical Physics and Research Center for Science and Technology in Medicine, TUMS, Tehran, Iran ahmadian@sina.tums.ac.ir

M. Ghavami is a Reader in UWB Communications with the Ultra Wideband Communication Research, King's College London, University of London, UK mohammad.ghavami@kcl.ac.uk

R. S. Dilmaghani is a Lecturer with the Ultra Wideband Communication Research, King's College London, University of London, UK reza.shams_dilmaghani@kcl.ac.uk

S. Karimi-Fard is with the Department of Biomedical Systems & Medical Physics, Tehran University of Medical Sciences, and Research Center for Science and Technology in Medicine, TUMS, Tehran, Iran karimifard@razi.tums.ac.ir

II. EZW IN IMAGE

The EZW algorithm was originally developed by Shapiro [4] to find the best transmission order of the wavelet coefficients which is the absolute value of decreasing order. This algorithm has already been applied to medical images and the electrocardiogram with good success [1].

The wavelet transform is a dyadic decomposition of an image [5] achieved by a pair of quadratic mirror filters (QMF). In two-dimensional separable dyadic discrete wavelet transform (DWT), each level of decomposition produces four bands of data, one corresponding to the low pass band (LL), and the other three corresponding to horizontal (HL), vertical (LH), and diagonal (HH) high pass bands. Fig. 1 shows this concept.

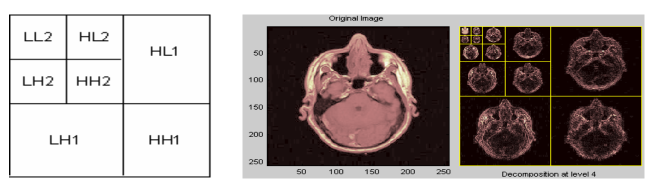


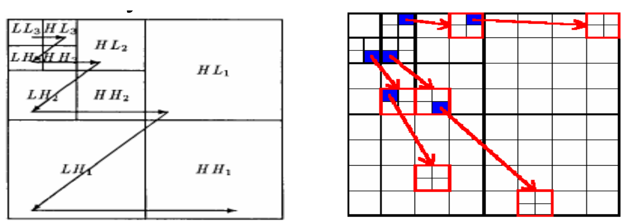
Fig. 1. levels of decomposition.

Two distinct properties of the EZW algorithm make it an effective means of compression, as compared with traditional approaches. Firstly, the EZW algorithm exploits the hierarchy of the wavelet coefficients, and establishes a connection between coefficients from different sub-bands, allowing multiple coefficients to be encoded simultaneously. Secondly, coefficients are encoded in order of importance using bit prioritization [1]. After performing the 2-D DWT on the image, the resulting wavelet coefficients are coded by using a decreasing sequence of thresholds, that is $T_0, T_1, \ldots, T_{N-1}$:

$$T_i = \frac{T_{i-1}}{2} \quad \text{and} \quad T_0 = 2^{\log_2(\max\{|\gamma(x,y)|\})} \tag{1}$$

where $\gamma(x, y)$ is the amplitude of wavelet coefficients and T_0 is the initial threshold value. The algorithm executes recursively two successive passes by considering significant coefficients in each pass related to the current threshold only, i.e., absolute value is higher than current threshold.

In the first pass called the dominant pass, we look through significant coefficients related to the current threshold according to a scan order given in Fig. 2(a) using the hierarchy given in Fig. 2(b). The algorithm then provides positions and signs of the significant coefficients in a predefined path that associates the absolute value of the parent coefficients with respect to their children ones. These are symbols P, N, Z and IZ.



(a) (b)

Fig. 2. (a) Scan order of wavelet coefficients. (b) Quad-tree relationship between coefficients.

III. EZW IN SIGNALS

The EZW algorithm can be applied to signals similar to an image. In this case decomposed signal coefficients have dyadic tree instead of quad tree [5]. This is illustrated in Fig. 3. As it can be seen, each coefficient has two correlated coefficients in lower scale and so on. We will use this similarity between images and signals to embed a signal inside an image which is the topic of the next section.

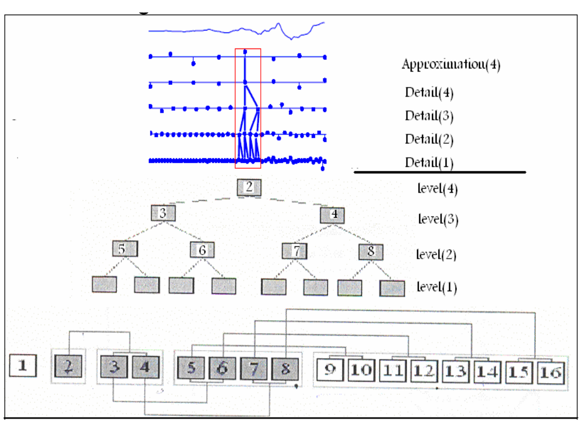


Fig. 3. Dyadic tree of a decomposed signal

IV. PROPOSED WATERMARKING ALGORITHM

The multi-resolution watermarking with a secret key algorithm developed in this paper is blind because during the EZW decoding only the secret key, which includes the header information, is used to extract the embedded information. There are two processes for embedding the mark signal during EZW coder: The first is the insertion process and the second is the extraction process which is presented in two subsections. The following notations will be used:

- INT_i: Thresholds interval $[T_i, T_{i+1}]$
- T_{sig}: Maximum threshold of matrix of the decomposed signal
- T_{imag}: Maximum threshold of matrix of the decomposed image

A. Watermark Insertion Process

We performe up to 5 levels of wavelet decompositions using Db2 [6] as mother wavelet to obtain matrixes of wavelet coefficients of host image and signal. Then, we specify maximum threshold of both matrixes (equation (1)). In the encoding process of the EZW coder the image starts to be coded. After this, we look for the dominant pass with a threshold same as the maximum threshold of the signal (T_{sig}). At the beginning, those belonging to this interval (INT_i) are replaced with similar coefficients belonging to the last scale of the image matrix in current interval (INT_i) according to a predefined path (scan order) of the matrix (Fig. 4). This means that once the coefficients of D4 are replaced with coefficients of image at scale 4 (Fig. 5), then the rest of replacement at lower scales can be done by using the child-parent tree (Figs. 2 and 3). Note that this predefined path can be changed by the user. Fig. 4 shows 3 different paths. Subsequently, sub-trees (coefficients in the lower scale according to Fig. 3) of the embedded signal coefficients are replaced with sub-trees (see Fig. 2(b)) of image coefficients in a lower scale. Fig. 5 illustrates replacement in the algorithm in a general way.

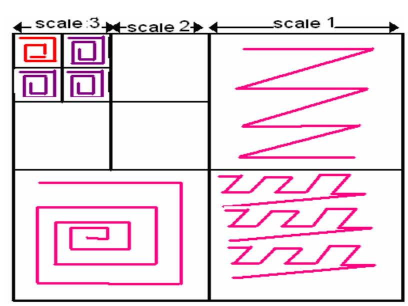


Fig. 4. Three predefined paths for embedding.

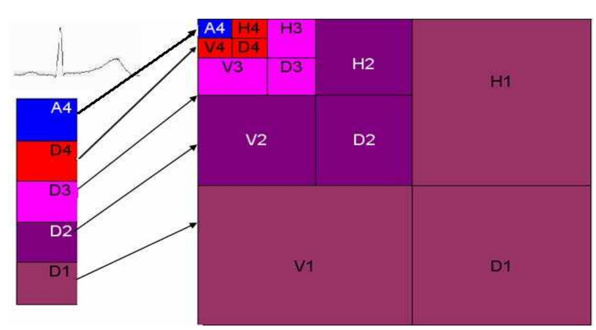


Fig. 5. Corresponding scales of replacement.

According to the human visual system (HVS) coefficients located in lower scales are less sensitive than those in higher scales and details (H, V, D) are also less sensitive than approximate (A). Therefore more significant coefficients are embedded inside a less sensitive region of an image.

We perform the following process which tries to insert the wavelet coefficients of the watermark:

1. *Initialization*: Specifying the secret key (way of scanning, i.e, Morton scan in EZW coder, prioritization of detail sub-bands of an image for embedding (H, V, D or V, D, H, ...) and selecting one way of embedding dyadic tree of the signal inside a quad tree of the image out of six ways, maximum level of decomposition for signal and image, size of the signal, maximum threshold of the signal and etc.)
2. *Encoding*: Making list of mixed symbols P, N, Z, IZ:

```
i=0;
Ti=Tmax-imag;
Tm=Tmax-signal;
While i>=0
INT =[Ti  Ti-1[ ;
Check Threshold (Ti);
If Ti<= Tm
   Find {Si} ∈ INTi in signal detail last scale (n=number of coefficients)
   Find {Ci} ∈ INTi in image details last scale (H,V,D)
   Replace Si with Ci
   Replace sub-tree of Si inside sub-tree of Ci
End
EZW(Dominant pass & subordinant pass);
i=i+1;
Ti+1=Ti/2
End;
```

   This process is nearly similar for the embedding of signal approximation within the image approximation.

3. *Decoding*: Reconstruction of image/signal by IDWT and inverse EZW process.

B. Watermark Extraction Process

In the extraction process we nearly repeat most of the steps in the insertion process but in the reverse order, and the wavelet coefficients of the compressed watermarked image are constructed. Then, scanning is performed on the matrix in a predefined way using the secret keys to find signal coefficients. In this step, we only need the wavelet coefficients matrix of the watermarked compressed image to construct the extracted wavelet coefficients of the ECG signal. By using the secret key we find coefficients in highest detail coefficients of the matrix (in Fig. 5, D4 will be constructed from H4, V4, D4 by the secret key) and then according to their position other coefficients in the lowest scale will be found. Finally matrix of wavelet coefficients of the ECG will be constructed, and then 1-D and 2-D inverse discrete wavelet transform (IDWT) is applied to the matrix in order to reconstruct the extracted watermark and the compressed watermarked image respectively.

V. EXPERIMENTAL RESULTS

Eight grey scale MRI and CT images of size 256×256 and 512×512 pixels have been watermarked by embedding two different watermarks of size 512 and 1024 bytes (Figs. 6,7,8).

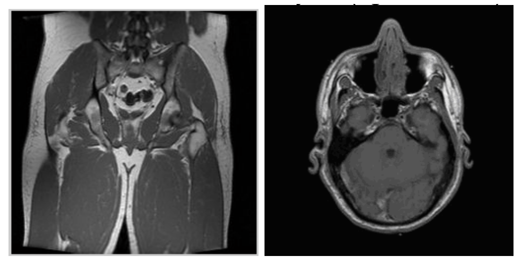


Fig. 6. Original images.

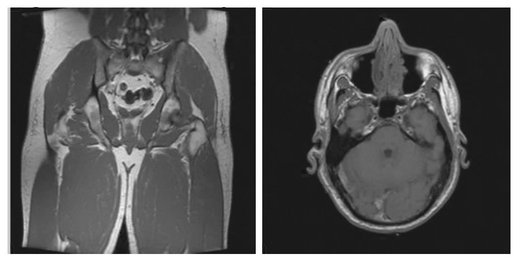


Fig. 7. Watermarked images (signal size=512 bytes).

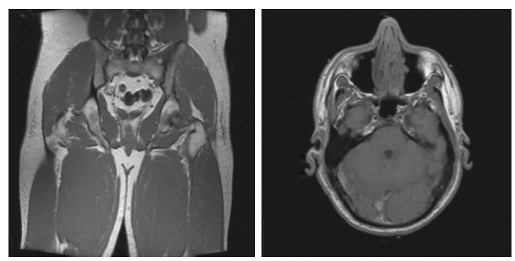


Fig. 8. Watermarked images (signal size=1024 bytes).

As it is shown, the watermarked images are perceptually or visually acceptable. The original mark ECG signal (1KB) together with it's reconstruction after extraction are shown in Fig. 9.

We have used several mother wavelets such as Db2 to Db6 and different Cohen filters and found out that Db2 and Db6 are best for our experiments [6]. The PSNR calculated between the original image and the compressed watermarked and original signal and extracted one is more than 35 dB for all experiments as shown in Fig. 10 and Table. 1. This proves the imperceptibility of the embedded watermarks, the property of unchanged remaining extracted signal and the ability to find the signal accurately.

Beta factor (β) is for evaluation of the degradation of details or edges throughout the image. A β close to one shows less degradation. We have calculated β of the watermarked image as shown in Fig. 11 and Table. 1 using the following equation:

$$\beta = \frac{\sum\sum[(\Gamma I - \bar{\Gamma} I)(\Gamma w I - \Gamma \bar{w} I)]}{\sqrt{\sum\sum(\Gamma I - \bar{\Gamma} I)^2 (\Gamma w I - \Gamma \bar{w} I)^2}} \quad (2)$$

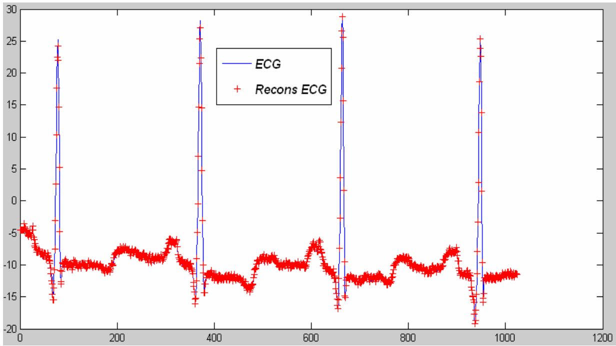


Fig. 9. Original signal (continues lines) and extracted signal ('+' lines).

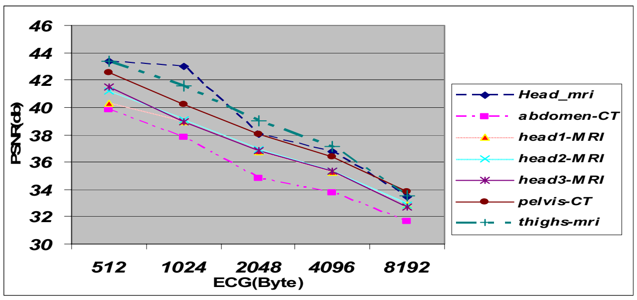


Fig. 10. Variation of PSNR vs. mark size for different images.

where ΓI is the high passed Laplasian filter of the original image, $\bar{\Gamma} I$ is its mean value and wI is the watermarked image.

The proposed method of selecting the insertion sites ensures both watermarking constraints: Imperceptibility, since the watermark coefficients of highest scale are almost identical or even equal to those that they are been replaced with, and robustness since the substituted coefficients are significant, and they will not be lost in the quantization step. Moreover, if the watermark extraction process does not find the considered approximated coefficients in the watermarked image matrix at the location indicated by the key, it will search an equivalent value somewhere else. And blindness because extraction algorithm must find highest detail and approximate according to the information of secret key.

Cross correlation (CC%) have been calculated between the original and extracted signals for evaluation of percentage of the unchanged signal. S/I (signal/image) is the percent of signal embedded within the image as shown in Table. 1.

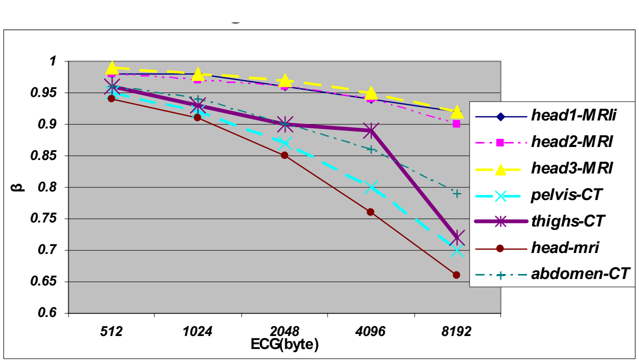


Fig. 11. Variation of β vs. mark size for different images.

TABLE I

RESULTING PARAMETERS OF THE NUMERICAL SIMULATIONS.

Image	Image Size	Signal (Byte)	Signal NMSE	Image PSNR (db)	Signal PSNR (db)	CC % Signal	β	S/I (%)
HeadMRI	256×256	512	.0008	43.47	58.59	99.88	0.94	.9
	256×256	1024	.0094	42.96	53.66	99.56	0.91	1.8
	256×256	2048	.0317	38.01	42.39	93.97	0.85	3.6
	256×256	4096	.0375	36.75	41.78	92.38	0.76	7.2
	256×256	8192	0.069	33.45	39.05	87.57	0.66	14.4
abdomenCT	256×256	512	.0008	39.87	58.59	99.88	0.96	.9
	256×256	1024	.0036	37.84	51.76	99.34	0.94	1.8
	256×256	2048	.0005	34.83	59.74	99.90	0.90	3.6
	256×256	4096	.0167	33.72	45.22	96.29	0.86	7.2
	256×256	8192	.0275	31.63	43.04	94.35	0.79	14.4
Head1MRi	256×256	512	.0008	40.29	58.59	99.88	0.98	.9
	256×256	1024	.0005	38.96	59.79	99.9	0.98	1.8
	256×256	2048	.0005	36.78	59.85	99.90	0.96	3.6
	256×256	4096	.0006	35.25	59.24	99.87	0.94	7.2
	256×256	8192	.0011	32.85	56.84	99.77	0.92	14.4
bnHeadMRi	512×512	512	.0008	48.36	58.59	99.88	0.89	.2
	512×512	1024	.0005	45.58	59.75	99.90	0.85	.4
	512×512	2048	.0005	43.57	59.85	99.90	0.78	.8
	512×512	4096	.0006	41.85	59.24	99.87	0.68	1.6
	512×512	8192	.0010	39.29	57.16	99.79	0.56	3.2

VI. CONCLUSIONS

The proposed watermarking algorithm is blind because it only needs an initial key in the extraction process. We have included two processes in the EZW coder. The first one uses an embedded ECG signal in the host image after the decomposition step. The second process intervenes after the decomposition of the compressed watermarked image in order to extract watermarks. The proposed algorithm has proved its imperceptibility since the embedding process here means a substitution of original coefficients by the equivalents (in sense of EZW significance) from the watermark. The great advantage of this method is to enable decoding the host image and the mark signal progressively. This enables extracting the mark signal in a progressive approach from low to high resolution. The outcome of this method is to make an optimum balance between the resolution of host image and the size of the mark by controlling the maximum scale to be scanned in EZW algorithm. This presents a novel resolution controlled watermarking.

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