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Evaluation of Two-Set Algorithm in Embedding a Watermark into an Audio Signal

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Abstract: The protection of multimedia data has become a necessity due to the generation of illegal copies, thus, the purpose of this article was to analyze and evaluate the algorithm of two-set in embedding a watermark into an audio signal. Metrics were analyzed as the Perceptual Evaluation of Audio Quality (PEAQ) by calculating the Objective Difference Grade (ODG) to verify the inaudibility of the watermark and the robustness of it against attacks from resampling and Additive White Gaussian Noise (AWGN) by estimating the Bit Error Rate (BER). The process was applied to hundred Waveform Audio Format (WAV) clips classifieds in five musical genders and we obtained an ODG value average of -0.83045 that according to the International Telecommunication Union (ITU), the watermark is slightly perceptible if you listen with extreme care.

I. Introduction

Digital media has become a daily task, since these are new services required by people today, due to the exchange of audio, images, text and video. The problem lies when these files are copied anddistributed without permission of the author. To solve this problem there is digital watermarking, a technique to embed data in the signal to be protected (in this case audio) as an identifier. There are several algorithms to insert watermarks for images and video, however, few algorithms are dedicated to audio files because of the complexity of the Human Auditory System (HAS)[1], hence the purpose of this research is to insert a watermark into audio signals, interpret and evaluate the Two-Set algorithm using modified patchwork and verify the inaudibility and robustness of the watermark to be used as an identifier of the copyright.

The watermark protects files permanently embedded in the audio signal so that the audio quality is not impaired while ensuring that the watermark is imperceptible. On the other hand, the watermark should be robust against attacks or manipulations that are carried out, at one point being the most common is resampling the addition of noise and more to the original signal. Hardly a watermark can be extracted without affecting the original signal; this creates a very attractive tool for copy protection[2]. Figure 1 shows the basic scheme of embedding and detecting a watermark.

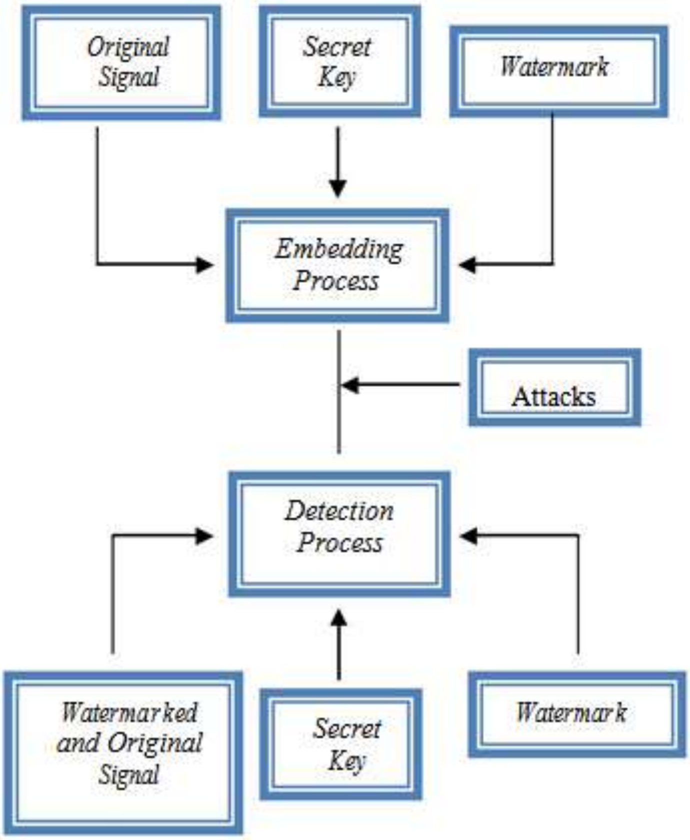

Figure1. Watermark embedding and detecting scheme

The embedding process is performed by the Modified Patchwork technique3] equations derived from the original Patchwork method to increase the robustness (but it should be emphasized that this derivation is not enough to be resistant to many attacks, so it should be possible to combine different watermarking methods), working in the frequency domain under the Discrete Cosine Transform (DCT) and the detection process by Inverse Discrete Cosine Transform (IDCT) and it is possible with a secret key.

Section 2 shows the mathematical development of the algorithm, divided in the embedding process, metrics evaluation and detection process. In Section 3, the method is implemented, it shows the initial parameters and comparing the original signal and the watermarked and checking the results of the PEAQ between different types of audio files tagged and thus verify the inaudibility of the watermark embedded in them, furthermore, it shows the attacks that the watermark survives and its corresponding BER. The conclusions are in Section 4 and finally in Section 5 of the references consulted.

II. Development

The evaluation of the method was built of three parts: the first is the embedding of the watermark in the audio signal; the second part is inaudibility tests and robustness to audio clips marked, finally it detects the embedded watermark after attacks.

The authors of [3] proposed watermark embedding method is known as Two-Set, based on modified patchwork algorithm. It works in the frequency domain and is based on the calculation of the DCT.

2.1. Watermark embedding

The watermark insertion steps[4] are summarized below:

The secret key and the digital watermark are associated to the seed of a random number generatorDivides the audio file into blocks of size *N*and DCT is applied to each block.

We define two subsets of the set processing, one called ***A*** and another ***B***

$$A = \{a_1, \dots, a_n\} \quad (1)$$

$$B = \{b_1, \dots, b_n\} \quad (2)$$

Sample means and the statistical standard error are calculated according to the following equations:

$$\bar{a} = \frac{1}{n}\sum_{i=1}^{n} a_i \quad (3)$$

$$\bar{b} = \frac{1}{n}\sum_{i=1}^{n} b_i \quad (4)$$

$$S = \sqrt{\frac{\sum_{i=1}^{n}(a_i - \bar{a}) + \sum_{i=1}^{n}(b_i - \bar{b})}{n(n-1)}} \quad (5)$$

The embeddingfunctions presented below introduce the watermark:

$$a_i^* = a_i + sign(\bar{a} - \bar{b})\sqrt{C}\frac{S}{2} \quad (6)$$

$$b_i^* = b_i - sign(\bar{a} - \bar{b})\sqrt{C}\frac{S}{2} \quad (7)$$

Where *C* is a constant and sign is the sign function what makes large values larger and small values smaller. Finally, replace the selected itemsandrespectively apply the IDCT in theFrequency domain

2.2. Metrics evaluation

The evaluation metrics are to test the inaudibility of the watermark embedded in the audio clips and check the robustness of it against attacks from resampling and AWGN.

Inaudibility test should evaluate the quality of the audio clips watermarked with the standard ITU BS.1387-1[7] established by ITU for PEAQ provides accurate estimates of audio quality degradation occurring in the watermarked signal compared with the original. This is based on the properties of the human auditory system, modeling the psychoacoustic effects and is verified by calculating the Objective Difference Grade (ODG). The ODG ranges from 0 to -4 and is defined as Table 1

Table 1. Odg values range

Impairment Description	ODG
Imperceptible	0.0
Perceptible, but not annoying	-1.0
Slightly annoying	-2.0
Annoying	-3.0
Very annoying	-4.0

For robustness tests we resampled the signals watermarked by different sampling rates. This process was done by changing the sampling frequency of thesignal watermarked and checking that the embedded bits were the same in the detection process, it was calculated how many erroneous bits exist in the watermarked audio clip, it is the number of bit errors divided by the total number of transferred bits during a studied time interval and its correspondent BER [6] as a unit less performance measure, often expressed as a percentage.

Also, it was added an AWGN to the watermarked clips. The AWGN term refers to the fact that eventually the noise is combined with the desired signal. As the noise gets added (and not multiplied) to the received signal, the spectrum noise if flat for all frequencies and the values of the noise n follows the Gaussian probability distribution function:

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad (8)$$

Where;

$$\mu = 0 \quad (9)$$

$$\sigma^2 = \frac{N_o}{2} \quad (10)$$

It was verified that the watermark survives the AWGN; this was done by calculating the BER in order to obtain the number of erroneous bits that exist in different intensities of Signal to Noise Ratio (SNR) of the AWGN. Figure 2 shows the general outline of the AWGN, note that it is additive and not multiplicative

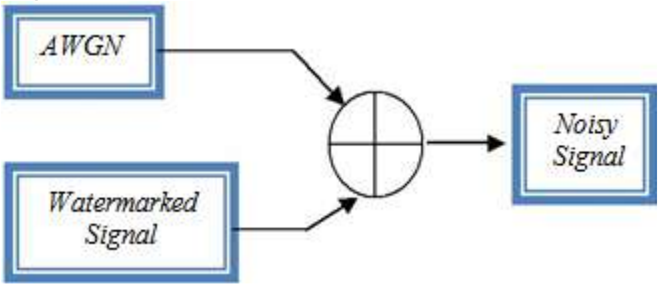

Figure 2. Awgn scheme

2.3. Watermark detection

The following algorithm[4] was used to verify whether the embedded watermark was the same in the discovery process after the attacks. The decoding steps were as follows:

The secret key and the digital watermark are associated to the seed of a random number generator.

Obtain subsets $A_0 = \{a_{01}, \dots, a_{on}\}$ y $B_o = \{b_{01}, \dots, b_{on}\}$ for bit insertion 0 and thesubsets $A_1 = \{a_{11}, \dots, a_{1n}\}$ y $B_1 = \{b_{11}, \dots, b_{1n}\}$ for bit insertion 1.

Averages are calculated for each sample subsets and standard errors for 0 y 1.

We calculate test statistics *S* (see equation 7) and $T2$

$$T^2 = \frac{(\bar{a}-\bar{b})^2}{S^2} \quad (11)$$

T^2 is defined as the highest values of the statisticsobtained.

The seed detected will be that for the parameter T^2 is maximum.

Finally we generate the watermark associated with the seed, getting the embedded bits.

The process was to watermark audio clips;subject to attacks and to detect the survival of the watermark. Below are the results of the evaluation algorithm.

III. Results

The algorithm was applied to a hundred audio clips of music (of which only twenty are reported) divided in five categories, these files were WAV, the watermark embedded was W=[1 0 0 0 0 1 1 0]. First we compared the original signals with the watermarked to verify that no significant alteration in the watermarked clips. Figure 3 shows the spectrum of an audio signal(watermarked and un-watermarked) and we notice a slight difference between the two graphs.

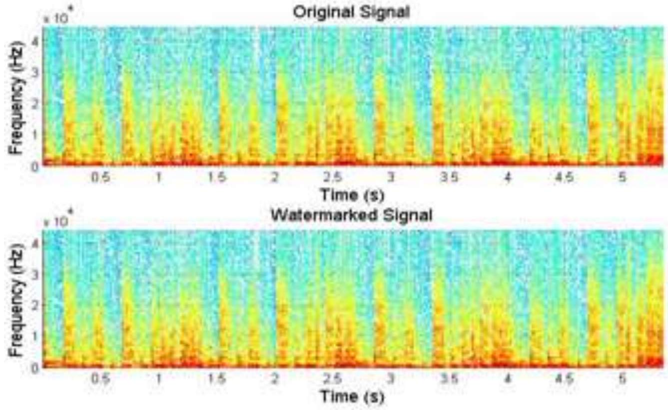

Figure 3. Spectrum of an audio clip, original and watermarked

The red color in the first graph shows the original signal and the second graph the red representswatermarked signal, note a difference between the two tones.

Figure 4 plots the difference between the originalsignal and the watermarked signal.

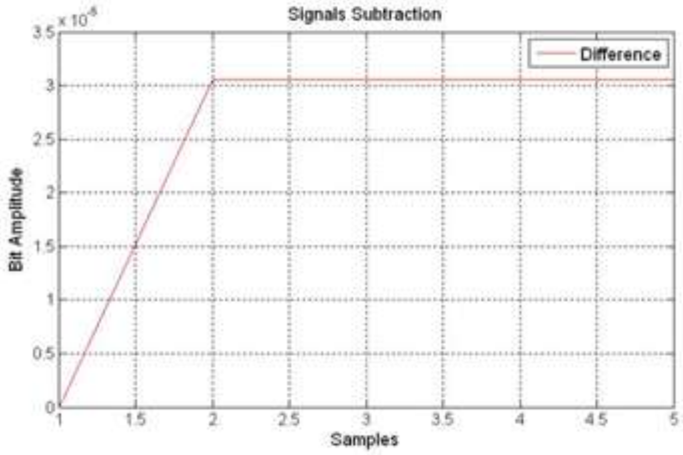

Figure 4. Difference watermarked and un-watermarked signals

Note that the difference between the two signals is the order of 10^{-5}.

To demonstrate the inaudibility of the embedded watermark, we performed the calculation of ODG for each audio clip, which are shown in Table 2.

Table 2. Odg of the audio clips

Category	Track name	ODG
Pop	Dopamina (by Belinda)	-0.753
	Contigo (by Yuridia)	-0.895
	Nada puede cambiarme (by Paulina Rubio)	-0.101
	MentirasPiadosas (by Alejandra Guzmán)	-0.832
Electronic	Las pequeñas cosas (by Jot Dog)	-2.761
	Lentamente (Fey)	-1.676
	Nada de más (by Belanova)	-2.183
	Provócame (by Fey)	-1.752
Banda	Y tú (by Julión Álvarez)	-0.166
	Mujeresdivinas (by Vicente Fernández)	-0.108
	No me quedamás(by Selena)	-0.126
	Ya no (by Limon)	-0.178

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Note that the difference between the two signals is the order of 10^{-5}.

To demonstrate the inaudibility of the embedded watermark, we performed the calculation of ODG for each audio clip, which are shown in Table 2.

Table 2. Odg of the audio clips

Ballad	Chiquitita (by Abba)	-0.419
	Cantacorazón (by Alejandro Fernández)	-0.610
	Sortilegio (by Il divo)	-0.291
	Hasta mi final (by Il divo)	-0.523
Rock	I feel good (by James Brown)	-1.361
	Absolutamente (by Fangoria)	-0.594
	Lejosestamos mejor (by Motel)	-0.431
	Frágil (by Allison)	-0.849

The ODG average value obtained was -0.83045 for twenty clips above, this result indicates that the watermark is slightly perceptible only if you listen carefully but it is not annoying to the human ear.

Comparing the hundred ODG values with Table 1 we obtain Table 3 shows the percentage obtained for each impairment established by the ITU.

Table 3. Obtained percent of the odg

Impairment Description	Obtained Percent (%)
Imperceptible	52.5
Perceptible, but not annoying	23
Slightly annoying	19.5
Annoying	5
Very annoying	0

We could see that most of the embedded watermarks are to be imperceptible. Figure 5 shows the average ODG for each musical category

Average Objective DifferenceGrade

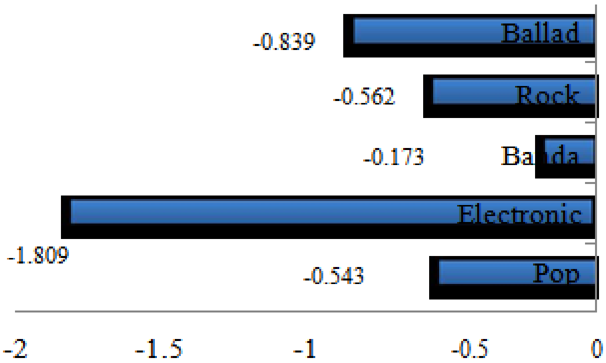

Figure 5. Average odg for each category

Table 4. Ber for each resampling rate

Category	Sampling Frequency (kHz)	Erroneous Bits / Total Embedded Bits	Bit Error Rate (%BER)
Pop	22.05	1/8	12.5
	88.2	0/8	0
	176.4	0/8	0
	192	2/8	25
Electronic	22.05	2/8	25
	88.2	1/8	12.5
	176.4	2/8	25
	192	3/8	37.5
Banda	22.05	0/8	0
	88.2	0/8	0
	176.4	0/8	0
	192	1/8	12.5
Ballad	22.05	1/8	12.5
	88.2	0/8	0
	176.4	1/8	12.5
	192	2/8	25
Rock	22.05	1/8	12.5
	88.2	0/8	0
	176.4	0/8	0
	192	2/8	25

The watermark is more perceptible in the electronic music (Figure 5).

To check the robustness of the watermark[5], we subjected the processed signal to an attack by changing the resampling rate as shown in Table 4 and AWGN attack with different intensities of Signal to Noise Ratio (SNR) showing the results Table 5.

Table 4 shows that most of the clips watermarkedsuffer a distortion in the embedded watermark when resampled to 192kHz and we said that the larger the resampling rate, the greater the distortion of the watermark embed it on audio clips.

The watermark, subject to resampling, was more robust in banda music, pop and rock, and less robust in electronic music and ballads.

In the following table we can see the number of bit errors and their respective BER for different intensities of SNR applied to AWGN was attached to each signal and in which we also see that while the intensity increases the distortion is most noticeable in the watermark as it also increases the power of AWGN. It is noted that for an AWGN signal strength of 1dB and 5dB the watermark is not distorted, instead to an intensity of 10dB and 15dB are a number of erroneous bits.

Being more resistant to resampling the musical categories of pop and band (see Table 5).

Table 5. Beer for each intensities for awgn

Category	SNR Intensities for AWGN (dB)	Erroneous Bits / Total Embedded Bits	Bit Error Rate (% BER)
Pop	1	0/8	0
	5	0/8	0
	10	0/8	0
	15	1/8	12.5
Electronic	1	0/8	0
	5	0/8	0
	10	1/8	12.5
	15	2/8	25
Banda	1	0/8	0
	5	0/8	0
	10	0/8	0
	15	1/8	12.5
Ballad	1	0/8	0
	5	0/8	0
	10	0/8	0
	15	2/8	25
Rock	1	0/8	0
	5	0/8	0
	10	1/8	12.5
	15	2/8	25

Compare the original signal with the watermarked signal, and it was subjected to attacks by resampling and AWGN attacks. The following are conclusions.

IV. Conclusions

A comparison of the signal before being processed and the signal after being processed to verify the visual difference between them.

We tested the ITU BS.1387-1 standard established inaudibility standards applied in this case, to the watermark, checking that it is slightly perceptible, if and only if, listening with dedicated attention.

The sampling frequency of the signals before processing was 44.1kHz but to test the robustness of the method was decreased, and increased the frequency in order to verify what is mentioned in [5] and check if it was more robust with other rates sampling.

Also verify the behavior of the watermark against the addition of AWGN with different SNR intensities.

It is recommended that the watermark is inserted into the top of each block, because if not done in this way, the watermark will be easy to detect and extract.

Below are the references consulted, among the items displayed, a book and a standard ITU.

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