Audio Watermarking Based on Wavelet Transform and Quantization Index Modulation

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Abstract: In this paper, we present a technique for embedding digital watermarks into digital audio signals. Watermarking is a technique used to label digital media by hiding copyright or other information in the underlying data. In the case of digital audio, the main constraint is the trade-off between robustness and imperceptibility, as hearing is one of the most sensitive human senses. In our method, the audio host signal is divided into several frames; each of these frames is decomposed using a wavelet transform. To the wavelet coefficients we apply distortion compensated (DC) quantization index modulation (QIM). For additional security we use dither modulation (DM). As a result, for our proposed method the watermarked host signal has good quality, and is robust over common attacks such as MPEG-1 layer 3 (mp3 compression), low pass filtering, white noise and echo.

1. Introduction

Quantization index modulation (QIM) methods [1] were shown to have very good rate-distortion-robustness trade-offs and are provably better than additive spread spectrum and generalized least bit modulation (LBM) methods, against bounded perturbation. As a special case, distortion compensated (DC)-QIM has optimal performance over Gaussian channels. This method is based on the idea that each quantizer can represent one different symbol of the watermark, and then the host signal is quantized using the quantizer corresponding to that watermark symbol. We propose to use a watermarking technique which operates in the wavelet domain, using dither modulation (DM) mixed with DC-QIM. This technique uses only one base quantizer and several dither vectors. We use a parameter α to scale the minimum distance of the reconstruction points, and this parameter is varied according to the amount of distortion the audio file can support.

2. Proposed Method

We are proposing a watermarking method in the wavelet domain using DC-DM QIM for quantizing the wavelet coefficients and embedding the watermark. The most common wavelet transforms in digital audio watermarking are the Daubechies wavelet with four coefficients and the Haar wavelet. We tested both transforms and the results show very similar behavior. We choose to use the Daubechies wavelet with four coefficients for the system simulation.

2. 1 Embedding

First we segment the audio into blocks of length 512 samples. For each block we apply the wavelet decomposition transform in 5 levels. We obtain L5, LH5, LH4, LH3, LH2, H1 wavelet coefficient blocks, see Fig. 1.

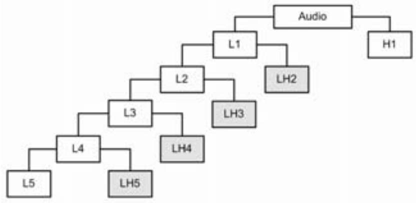

Figure 1. Wavelet decomposition.

As we need robustness against mp3 compression, applying the watermark in low frequencies leads to high distortion in audio file, so instead we choose the LH5, LH4, LH3 and LH2 wavelets for the watermark. In each of these blocks we embed the same bit using DC-DM QIM. We note that the efficiency of QIM methods improves as the dimension increases [1]. After applying quantization, transform the wavelet coefficients in time and reconstruct the audio file, Fig. 2.

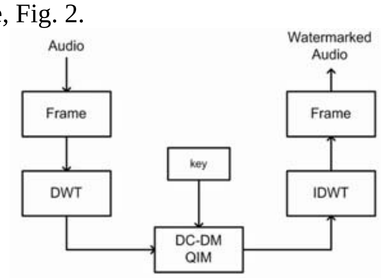

Figure 2. Embedding block diagram.

In the DC-DM QIM block, we select the corresponding dither vector *d(i)* according to watermark index *m*, and add the audio sample *p*. We use QIM with quantization step Δ/α, add a compensation parameter, and finally subtract the same dither vector *d(i)*, Fig. 3.

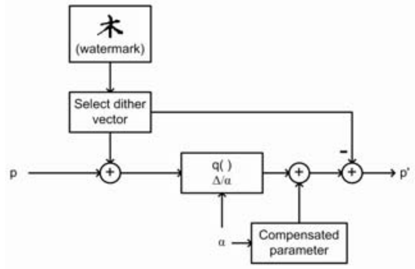

Figure 3. DC-DM QIM quantization.

2. 2 Detection

For detection, we segment the audio file also into blocks of length 512 samples, and decompose it into five-level wavelets. Using only the LH5, LH4, LH3 and LH2 wavelet coefficients blocks, we apply DM-DC QIM decoding and obtain the recovered watermark, Fig. 4. For decoding we apply DC-DM QIM quantization, as explained before but this time it is performed with every dither vector, Fig. 5, and at last we decide, by means of Euclidian distance (Eq. (1)), which reconstruction point is closest to the original watermarked wavelet coefficient. Repeat this process until the recovered watermark is obtained.

$$d = \sqrt{\sum_{i=1}^{n} (p_i' - y_i)^2} \qquad (1)$$

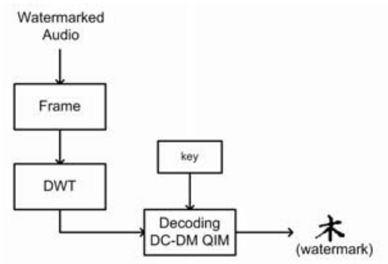

Figure 4. Detection block diagram

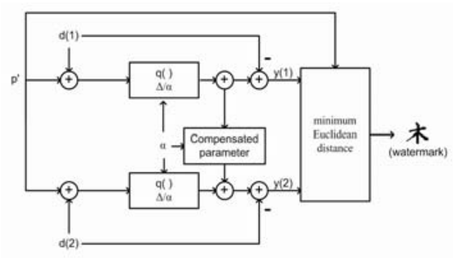

Figure 5. DC-DM QIM detection

3. Experimental Results

We test our algorithm on 16-bit signed stereo audio signal sampled at 44.1 kHz with a duration of 2-3 minutes. The watermark is a 64-by-64 binary image. In this paper we concentrate our effort in robustness and imperceptibility constraints. The quantizer step length is Δ=0.04, with α=0.52. As a way to check that this was a good value of α, we performed a simulation with α between 0 and 1, with a maximum robustness around 25 dB for the watermarked signal, Fig. 6

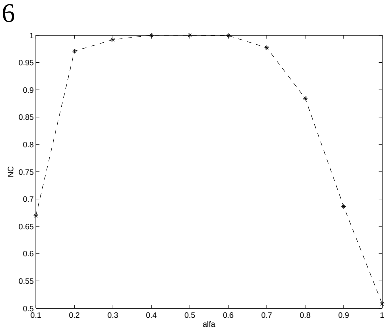

Figure 6. Simulation for $0<\alpha\leq 1$ with a robustness of 25 dB for the watermarked host signal.

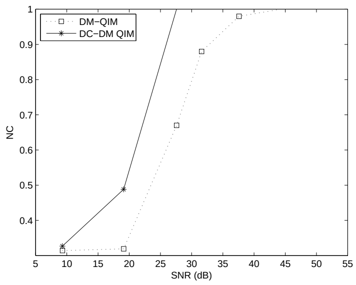

Figure 7. Performance of DM QIM and DC-DM QIM.

To show the advantages of this system over normal DM-QIM, we did a test of DC-DM QIM and normal DM-QIM over a Gaussian channel with different level of noise, Fig. 7 In Table. 1, we can see that most of the recovered watermarks are robust against mp3 compression, amplification and normalization. Although the results obtained for resampling and adding noise were not as good, the quality of the signal after these attacks is very poor, so these audio files do not satisfy the minimum SNR condition.

Table 1. Results after attacks

Attack	SNR	NC
Without attack	58.45 dB	1
Compression mp3 128 kbps	35.56 dB	.9991
Add noise	20 dB	.7023
Add FFT noise	25.26 dB	.8756
Amplify	55.23 dB	1
Normalize	55.23 dB	1
Zero cross attack	40.98 dB	.9997
Echo: 1 second delay	28.23 dB	.95
Resampling 22 kHz	18.23 dB	.6569
Cut: 1000 random samples.	27.89 dB	.8023
Least significant bits to "0"	48 dB	1
Low-pass filter 3 kHz	40 dB	.9426
Invert all samples	25.58 dB	.7963

4. Conclusions

We proposed a robust watermarking in wavelet domain using DC-DM QIM. The results show high quality for the watermarked audio signal, since a small quantizer step was used. Robustness was achieved because several wavelet coefficients were used to embed only one bit. DC-DM QIM appears to be a very good option for bounded distortion applications. The robustness of this method depends on the quality of the watermarked host signal after attacks. If its quality is higher than a threshold, we will decode with high probability of success. In the simulation results, most of the audio file has very poor quality but the recovered watermark can be recognized.

References

[1] B. Chen and G.W. Wornell, "Quantization index modulation: A class of provably good methods for digital watermarking and information embedding," *IEEE Trans. on Information Theory*, Vol. 47, no. 4, pp.1423-1443, 2001.