A Novel Algorithm for Robust Audio Watermarking in Wavelet Domain

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Abstract A novel algorithm for digital audio watermarking in wavelet domain is proposed. First, an original audio signal is decomposed by discrete wavelet transform at three levels. Then, a discrete watermark is embedded into the coefficients of its intermediate frequencies. Finally, the watermarked audio signal is obtained by wavelet reconstruction. The proposed algorithm makes good use of the multiresolution characteristics of wavelet transform. The original audio signal is not needed when detecting the watermark correlatively. Simulation results show that the algorithm is inaudible and robust to noise, filtering and resampling.

Key words discrete wavelet transform; intermediate frequencies; digital audio watermark

With the sharp blossoming of the Internet, it becomes more and more important to protect the intelligent property rights (IPR). Watermarking is an effective solution. It takes advantage of the redundancy of the human visual system (HVS) and auditory system (HAS) to identify the copyright by embedding some secret information relevant to IPR holders.

The invisible watermarking algorithm should satisfy the demands on imperceptivity, low complexity, robustness, determinacy and safety. However, imperceptivity and robustness are two conflicting requirements, between which there must be a trade-off in an effective watermarking algorithm. As for audio watermarking must possess the following features:

1) Secrecy. i.e, audibility must not be influenced after the watermark signal is embedded into the original audio signal, which is fundamentally requested.

2) Robustness. i.e, the quality of the audio signal declines at a rush when an unauthorized person or community tries to eliminate or change the embedded watermark information.

The embedded information must be extracted at some correctable probability with slight damages against some common signal processing operations, such as noise polluting, filtering, resampling and loss compressing, etc.

Similar to static image, the realizable audio watermarking has two approaches: time domain and transform domain. For transform domain methods, the choice of frequency band in the transform domain is critical: watermark information is easily eliminated by low passing filter (LPF) if embedded in low frequencies, and also by high passing filter (HPF) in high frequencies[1].

A novel algorithm is proposed in this paper, in which a watermark signal is embedded in the coefficients of the intermediate frequency based on wavelet transform. Simulation indicates the watermarking is strongly robust at last.

1 Frequency Band Choice of the Audio Signal

The energies of the audio signal after DWT processing are aggregated to the low frequencies,
which cannot be influenced by loss-compression, low-pass filtering and resampling processing, etc. So the embedded watermark is sure to be robust, but its audibility cannot be ensured as HAS is sensitive in low frequencies. Although the watermark will be easily lost during loss-compression and high-pass filtering processing if it is embedded in high frequencies, it will not make significant influence on HAS\(^2\). Thus, an excellent watermarking technique is to combine the two virtues above by embedding the watermark into the coefficients of layer 2 or higher layers in wavelet transform domain. The embedded watermark will not be corrupted by all means of attacks as it is distributed in the whole audio domain after wavelet reconstruction. In this paper, we choose the higher frequency DWT coefficients of the 3rd layer for embedding the watermarks.

2 Embedding Algorithm in Wavelet Domain

The embedding steps are as follow:

1) Decompose the original audio signal in wavelet domain at level \(L\) and then obtain the decompose vector \(C = \{CA_1, CD_{L-1}, CD_{L-2}, \cdots, CD_1\}\), where \(CA_k\) is the low frequency coefficients at level \(L\) and \(CD_k\) is the detailed coefficients at level \(k\), \(1 \leq k \leq L\).

2) Choose the embedding area in discrete wavelet transformed area: in order to ensure the imperceptivity of the watermark and in the mean time considering the requirements of robustness, we choose the \(CD_k\) instead of \(CA_k\) in Ref.[3] among the detailed coefficients as the embedding area.

3) Choose the \(N\) strongest coefficients with large magnitude and compose the vector \(V^I\), then mark their index and constitute the vector \(V^I\). \(I\) and \(V^I\) are saved as a key for detecting the watermark. We Embed the watermark by means of the following equation and the other coefficients remained unaltered

\[CD_j^I(I(j)) = CD_j(I(j)) + \alpha w \quad 1 \leq j \leq N\]

where \(I(j)\) represents the index of the \(j\)th important coefficients; \(\alpha\) is the scale coefficients which determines the watermark strength, its value varies in 0~1. Increase the value of \(\alpha\) will enhance the robustness and impair the transparency. On the contrary, the robustness will be impaired and the transparency enhanced. \(w\) is the watermark that will be embedded. We choose a section of sine wave as the watermark with the length of \(N\).

4) Execute inverse discrete wavelet transform to the altered coefficients: reconstruct the signal by

\[C = \{ CA_L, CD_{L-1}, CD_{L-2}, \cdots, CD_1 \} \]

and then the final watermarked signal \(A'\) is obtained.

3 Extraction Method

1) Perform discrete wavelet transform at level \(L\) to the signal \(A'\) which is to be detected, extract the detailed coefficients \(CD_k^I\).

2) Extract the transformed coefficients of \(CD_k^I\) in responding location of \(I\) and constitute the vector \(V^I\).

3) Extract the watermark \(w\) according to the equation below

\[w' = (V^I - V) / \alpha\]

4) Compute the correlation coefficient of the \(w'\) and \(w\) following the equation below

\[\text{sim}(w, w') = \frac{\sum w'(i)w(i)}{\sum w(i)w(i)}\]

If \(\text{sim}(w, w')\) is greater than a given threshold, then the watermark exists, otherwise it doesn’t exist.

4 Simulation Results

Simulation experiments have been done for the above scheme. Four kinds of music: pop, blues, rock and jazz are selected. This different music has different characters of frequency spectrum and can test the efficiency of the algorithm. Each music section is digital audio signal of 16 bits, 44.1 kHz. Wavelet decomposition is implemented by Daubechies-4
wavelet base with level 3. The sine wave is served as watermark and shown in Fig.3a. The scale factor $\alpha$ is set to 0.6. Fig.1 is the original audio signal and the watermarked signal obtained according to our method is shown in Fig.2. In subjective tests, most of the audience cannot hear the difference between the watermarked signal and the original. Favorable results are obtained in testing other kinds of music. The experiment results of correlation coefficients of the watermarked signal and the original of above music are 0.9228, 0.9206, 0.8273 and 0.9510, respectively.

When transmitted, the digital audio signal will suffer all kinds of distribution and attacks. In order to test the robustness of the algorithm, deal the watermarked signal with the following operation:

1) Add noise: add white Gaussian noise to the watermarked signal, the extracted watermark by detected algorithm is shown in Fig.3b and the correlation coefficient is 0.8966.

2) Lowpass filter: apply the butterworth filter with the cutoff frequency of 22.05 kHz, the extracted watermark is shown in Fig.3c.

3) Resampling: execute down sampling from 44.1 kHz to 22.05 kHz on the watermarked signal first, then perform inner insertion from 22.05 kHz to 44.1 kHz, the extracted watermark is shown in Fig.3d. and the correlation coefficient is 0.9156.

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