Audio Forensic marking using Quantization in DWT-SVD Domain

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Abstract— **In this paper, we proposed an audio forensic marking technology which can trace illegal distribution of audio contents. The forensic mark was embedded in the double transformation domain, DWT-SVD, using the quantization method for the purpose of the multi-step tracing. DWT is used for the multiple embedding and detection, and SVD is used for the embedding the forensic mark into the specific frequency domain of DWT. For enhancement of the detection performance, the block code is used.**

The algorithm can embed 1024bits into 32,768 sample space. When the audio signal is compressed by 128kbps mp3, the BER is 0.49% and the value of NC(normalized correlation) is 0.99.

Keywords— **DWT, SVD, Quantization, Forensic Mark**

I. Introduction

Rapid development of the multimedia service via the network satisfies the convenience and user demand because it can make user possible to use the multimedia in the various methods. On the other hand, there is possibility that the service can deliver several contents with infringing copyright. Especially, the distribution of the digital audio such as MP3 and WMA(windows media audio) will be infringed if there is no technical measure for the audio content, and this will restrict music creation and hamper the growth of the music market.

Forensic marking technology is more active copyright protection technology because it can embed the owner information as well as the user information to trace the illegal copy and distribution. Because forensic marking technology includes the user information with the owner information it should provide higher payload than watermarking payload. Even though the forensic marking has technical difficulty, it is a good technical measure and there are many researches about it.

The traditional image watermarking generally uses single transform domain [1-4] like as DWT(Discrete Wavelet Transform) and SVD(Singular Value Decomposition), or multiple domain [5-6] for the purpose of the robustness improvement. In the audio watermarking, there are also many studies to use single transform domain [7-9] and multiple domain [10-11] like as DWT-DCT(Discrete Cosine Transform), DWT-CCT(Complex Cepstrum Transform). Even though there are many researches for the audio forensic marking, they focus on a goal, the robustness or high payload. So, a new algorithm which has the robustness and high capacity to trace illegal distribution should be studied.

In this paper, we used double transform domain to ensure the robustness of the forensic mark and the tracing of the illegal distribution. DWT is used for the multiple embedding and extracting, and SVD is used for robustness of the forensic mark, For the purpose of improvement for extracting the mark we designed a block code.

II. The Algorithm for Audio Forensic Marking

A. Generation and Reconstruction of the Forensic Mark

The forensic information which is embedded into the original content consists of a binary image with four 2x2 block code. In the case of that two diagonal pixels (2,4) have value 1 and other pixels(1,3) are 0, it represents bit 1, on the contrary to this, it means bit 0.

To consider the several attacks to the forensic marked audio signal, the forensic information is recovered by comparing the diagonal pixels of the block pattern.

$$Pic(2) + Pic(4) \geq \beta1(Pic(1) + Pic(3)) \rightarrow \text{bit } 1$$

$$Pic(2) + Pic(4) < \beta2(Pic(1) + Pic(3)) \rightarrow \text{bit } 0$$

If the compared result does not satisfy above condition and it satisfies below condition, the algorithm decides there is no forensic information.

$$\beta 2(Pic(1)+Pic(3))<Pic(2)+Pic(4)<\beta 1(Pic(1)+Pic(3))$$

where $\beta 1$ is greater than 1 and $\beta 2$ is less than 1.

B. Forensic Mark Embed Domain

The forensic mark information is embedded into SVD components of the transformed audio in the DWT domain. If there is much information to embed, the several subbands of the DWT can be used or a subband of them can be divided for ensuring the embedding space.

Because the singular value of SVD has good stability, the variation of the singular value is small against to the audio modification. Therefore the singular value reflects the mathematical characteristic of the audio signal.

We select DWT-SVD domain as the embedding domain for the forensic mark information, so the proposed algorithm can embed and extract the information with high payload and safety.

C. Forensic Mark Embedding Algorithm

The embedding process of the forensic mark is performed in the DWT-SVD domain and it can be expressed by Eq.(1).

$$I_h=IDWT(S_{bh}x(U_bxU_{bh})x(V_bxV_{bh})^T) \quad (1)$$

where S_{bh} is quantized singular value which is generated by SVD for the coefficients of the DWT of the original audio, and I_h is a forensic marked audio.

U_b and V_b are U and V components (orthogonal matrix) from SVD of the each quadrant coefficient, and U_{bh} and V_{bh}, are U and V components (orthogonal matrix) from SVD of S_h which is forensic marked component. The SVD matrix decomposition is expressed by $X=U \times S \times V^T$ and it is decomposed into a triangular matrix S and two orthogonal matrixes, U and V.

Fig. 1 shows the embedding procedure of the forensic mark.

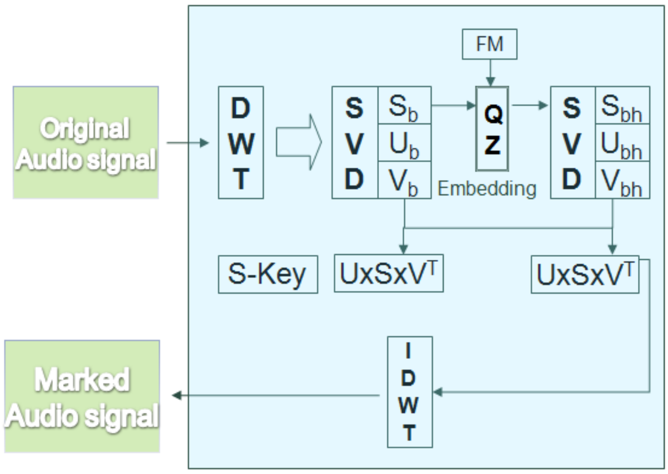

Figure 1. Forensic Mark Embedding Scheme

The original audio is rearranged as 2D signal and performed 2-depth DWT. A subband of 3 subbands, LH, HL, HH is chosen and then performed SVD. After SVD, we can get S_b and U_b, V_b. The forensic mark is embedded into S_b by quantization method. In the below pseudo code, Q is quantization coefficient.

```
TP=floor(Sb(j)/Q);
if (mod(TP, 2))==FM(i,j)
        Sh(j)=TP*Q+Q/2;
else
        Sh(j)=TP*Q-Q/2;
end
```

Next, SVD matrix decomposition to S_h which includes the hologram is performed and S_{bh}, U_{bh} and V_{bh} are generated. The coefficient value of DWT subband is composed by using U_bxU_{bh}, V_bxV_{bh} and S_{bh}. At same time, the extraction key, S-Key is generated by U_b, V_b and S_{bh}. Finally the forensic marked audio which is arranged as 2D signal is made by IDWT of the DWT subband coefficients.

D. Forensic Mark Extracting Algorithm

In the extracting process of the forensic mark, the forensic marked audio is rearranged as 2D audio signal and then DWT is applied to the 2D signal. The SVD matrix decomposition is performed to the coefficient of the DWT subband, and the forensic mark is extracted by using the extraction key, S-Key.

The matrix decomposition is executed from the forensic marked audio like Eq.(2) and it generates a triangle matrix and two orthogonal matrixes by Eq.(3). According to the property, that the transpose matrix of the orthogonal matrix is same as the inverse matrix, Eq.(4) is caused by multiplication for the transpose matrixes of the orthogonal matrixes U_b, V_b and the orthogonal matrixes generated from Eq.(2) respectively. The forensic marked signal S_h' is derived from Eq.(5)

$$SVD(DWT_b(I_h)) \rightarrow S_{bh}x(U_bxU_{bh})x(V_bxV_{bh})^T \quad (2)$$

$$SVD(S\text{-}Key) \rightarrow S_{bh}xU_bxV_b^T \quad (3)$$

$$U_e=U_b^Tx(U_bxU_{bh})=U_{bh}$$
$$V_e=V_b^Tx(V_bxV_{bh})=V_{bh} \quad (4)$$

$$S_h' = S_{bh}xU_exV_e^T \quad (5)$$

S_h' is an approximation of S_h which is generated in the embedding process of the forensic mark and it is used as an input to recover the forensic mark.

The extracting process of the forensic mark from the marked audio is shown in Fig. 2.

First, the forensic marked audio is transformed by 2-depth DWT, then the subband embedded the forensic mark is chosen. S_{bh} and U_bxU_{bh}, V_bxV_{bh} are generated by singular value decomposition of the subband coefficients. SVD matrix decomposition of S-Key generates S_{bh} and U_b,V_b and the algorithm generates the transpose matrixes of U_b and V_b. The transposed matrixes are multiplied to U_{bh} and V_{bh} respectively. Next, the approximation, S_h' of S_h is generated by U_e, V_e and S_{bh}. Finally, the forensic mark is extracted from S_h' using the quantization method. The final step is shown in Eq.(6).

$$FM(i,j)=mod(floor(S_h'(j)/Q),2) \quad (6)$$

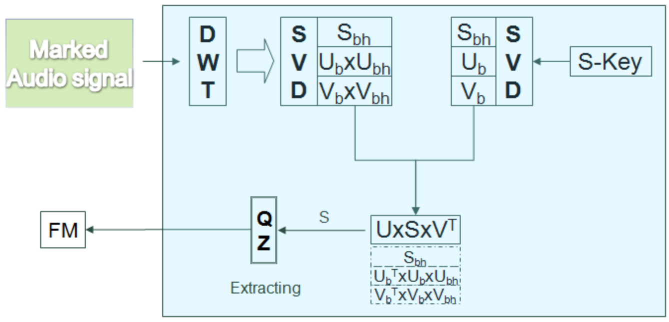

Figure 2. Forensic Mark Extracting Scheme

III. EVALUATIONS

For the evaluation of the proposed algorithm, we used CD quality, 44.1 KHz sampling rate and 16bits. The minimum sample length for embedding the forensic mark is 32,768(0.743sec) samples. Fig. 3 depicted the forensic mark information which is used in this algorithm. The left block code expresses bit 1 and another one is bit 0. Four data samples are used to express the bit information. The block code pattern can be modified by the purpose. For example, if the application is needed robustness, the code pattern size can be extended to double size, but the embedded information will be reduced.

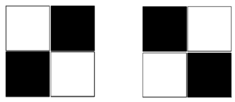

Figure 3. 2x2 block code

Fig. 4 shows the generated forensic mark by using block code. The mark size is 64x64 and the information size is 1024bits because the block code is 2x2 and the mark has 32x32 block codes. This is the forensic mark to embed into the original audio. Even though the audio signal is one-dimensional signal, because we rearranged the audio to two-dimensional signal, the forensic mark is 2D format.

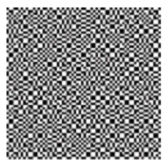

Figure 4. Original Forensic Mark Image

Fig. 5 shows the original audio signal and Fig. 6 shows the forensic marked audio signal. The sample size is 32768 samples for 44.1 KHz and time length is 0.743sec. The signal to noise ration of the marked audio is 27.9 dB.

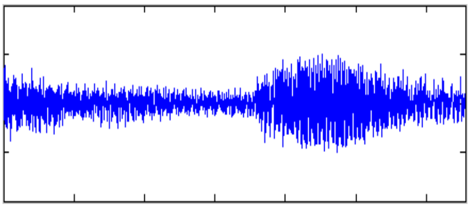

Figure 5. Original Audio Signal

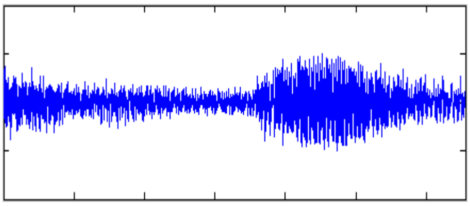

Figure 6. Forensic Marked Audio Signal

Fig. 7 depicts the extracted forensic mark from compressed audio with 128kbps MP3.

Figure 7. Extracted Forensic Mark Image

The embedded information which is recovered from the forensic mark shows 0.49% bit error rate and the normalized correlation between the original forensic information and the extracted forensic information is 0.99.

IV. CONCLUSIONS

In this paper, the forensic mark is generated by using block code and the proposed algorithm can efficiently embed the mark into an audio signal in the DWT-SVD domain. Also, the algorithm uses quantization method and double transform domain, thereby the proposed algorithm is useful for high capacity and robustness.

For the future work, our research team is going to study the robustness to several attacks and equipping several domains such as DWT-DCT, DCT-SVD, and DWT-CCT.

ACKNOWLEDGMENT

This research is supported by Ministry of Culture, Sports and Tourism (MCST) and Korea Culture Content Agency (KOCCA) in the Culture Technology (CT) Research & Development Program 2009.

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