

Secure Forensic marking in DWT-DFRNT Dual Domain

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Abstract— In this paper, we proposed a secure audio forensic marking algorithm through the process of embedding information into the discrete wavelet transformation-discrete fractional random transformation (DWT-DFRNT) domain using the quantization method. We hid information in the QR code, encoded it with the block code that we developed. The block code and QR code improve the detection performance by bit error correction which is generated at the detection process. The DWT used for making a robust domain against to several attacks and the DFRNT was applied to increase the algorithm security by randomly scrambling the information so that they could be embedded in unpredictable locations in a certain frequency space. The experimental result showed that the information contained in the QR code was accurately extracted from the forensic mark within the error correction range. The experiment results also showed that the security of the algorithm was ensured, as a tiny change in the DFRNT or the scrambling-converted parameters led to extraction failure.

Keywords— Forensic mark, QR code, Discrete Fractional Random Transform (DFRNT), Quantization

I. INTRODUCTION

As developing the digital technology, the illegal distribution of the digital content on the network is a hot social issue. Especially, there are a lot of audio manias, so that the audio content has been distributed rapidly. This makes the musician disappointed and the market is getting shrunk. Therefore, copyright owners want to develop some technologies to protect their content and to make fair use environment.

Forensic marking technology is a more positive copyright protection technology because it contains not only ownership information, but also information about the user who has been given the content, so that a user who has made an illegal duplication may be tracked and identified. On the other hand, forensic marking technology to follow up user information faces a technological challenge in that it should be able to provide a greater amount of information than conventional watermarking technology and have the capacity to safeguard robustness and security.

Since the audio forensic marking began with a first fundamental study, the method of embedding them into the

time domain [1], studies have been conducted on methods of robustly embedding forensic marks into the frequency domain; these include discrete cosine transform (DCT), DWT, singular value decomposition (SVD), and cepstrum transform (CT) [2–5]. Recently, studies have also been carried out on methods that use dual domains such as DWT-DCT, DWT-SVD, DCT-SVD, and WT-complex cepstrum transform (CCT) [6–9]. However, because most of the studies have focused on a single purpose such as robustness or mass embedment, there is the need for a study considering all aspects of the problem, including robustness, algorithm security, and extraction performance.

In this study, therefore, we implemented a quantization algorithm using QR code and block code pattern in the DWT-DFRNT dual domain to ensure tracing the illegal distribution with robustness and security.

II. PROPOSED FORENSIC MARKING ALGORITHM

A. Embedding Domain and Generation of Forensic Mark

In this paper, DWT-DFRNT dual domain was used for embedding the forensic information and a 1D audio signal was converted to a 2D signal to be used as the input for the 2D-DWT. The 2D-DWT-converted audio signals can be decomposed into H (LH), V (HL), and D (HH), which have different frequency characteristics from one another. One time of 2D-DWT allows for the embedment of at least three forensic marks. This not only robustly embeds the forensic marks into a certain frequency band, but also allows the information about the copywriter and user, including the secondary copywriter or those with the neighbouring copyright, to be additionally embedded into the content circulated by the copywriter of the content. This shows the pathways by which the contents are circulated and thereby enables effective multi-stage circulation tracking.

DFRNT[10] accepts the specific frequency coefficients generated by the 2D-DWT as the input data for the DFRNT which is generally performed in the method that follows.

Firstly, matrix P is generated using C generated as a random seed value, which is one of the parameters shown in Equation (1):

$$P = \frac{C + C^T}{2} \quad (1)$$

To generate an eigenvector from matrix P, SVD (Singular Value Decomposition) matrix decomposition is performed with respect to P, as shown in Equation (2):

$$[V_R, S, U] = SVD(P) \quad (2)$$

Here, the generated V_R is the matrix composed of N orthogonal eigenvectors, as in Equation (3):

$$V_R = [V_{R1}, V_{R2}, \dots, V_{RN}] \quad (3)$$

Next, the $N \times N$ diagonal matrix D_α^R is generated using α and m , other parameters of DFRNT, as in Equation (4):

$$D_\alpha^R = \text{diag}[1, \exp(-i \frac{2\pi\alpha}{m}), \dots, \exp(-i \frac{2(N-1)\pi\alpha}{m})] \quad (4)$$

Then, R^α is calculated by Equation (5) using V_R and D_α^R . The calculated R^α and the DFRNT input signal K are substituted in Equation (6) to obtain K_R , the final output of the DRFNT:

$$R^\alpha = V_R D_\alpha^R V_R^T \quad (5)$$

$$K_R = R^\alpha K (R^\alpha)^T \quad (6)$$

In this way, DFRNT can transform the input signals to arbitrary unpredictable signals with three parameters and restore them through inverse transformation.

The information that is embedded into the audio signal is generated as a barcode through a 2D barcode encoder; the generated barcode is put into the block code encoder that we designed for the coding to a binary image. It then undergoes scrambling and finally produces the forensic mark image.

Since the error correction of the 2D barcode is focused on the correction of bust error rather than random error, other possible errors other than bust error are corrected by such methods as block coding.

Figure1 shows 2×2 block code pattern used in the block code encoder.

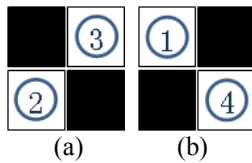


Figure 1. Block code Pattern

Figure1 (a) means 1bit(white), (b) means -1bit(black). Decoding is processed by Equation (7) and (8); +1 bit is restored by Equation (7) and -1 bit by Equation (8). Considering the cases where the detected forensic mark is under various types of attack, the coefficient β is used for effective restoration.

$$PIC(2) + PIC(3) \geq \beta(PIC(1) + PIC(4)) \quad (7)$$

$$PIC(2) + PIC(3) \leq \beta^{-1}(PIC(1) + PIC(4)) \quad (8)$$

The image that has been encoded by the block code goes through scrambling. Since scrambling mixes the image pixel values in a meaningless order, it enhances the reverse engineering security of the embedded information.

B. Forensic Mark Embedding Algorithm

The forensic marks generated through the procedures of 2D barcode generation, block coding, and scrambling are embedded into the DWT-DFRNT domain. The marks changed into 2D-barcode by the barcode generator and encoded by block code encoder. The forensic mark is generated by scrambling of the encoded barcode. The scrambling process includes a pre-processing of padding the black pixels in the rim.

On the other hand, the original audio signal undergoes 2D-DWT and DFRNT, as shown in Equation (9). Firstly, the original signal is decomposed into the H, V, and D sub-band elements through the two-stage 2D-DWT and the sub-band coefficients are put into the DFRNT function. The DFRNT not only has the random seed value r , but also two parameters α and m , as in Equation (4). Here, the superscript sb refers to one of the sub-bands H, V, or D:

$$T = DFRNT(DWT_{2D}^{sb}(X), \alpha, m, r) \quad (9)$$

The FM information is embedded to the sub-band coefficient value T that has gone through the DFRNT through the quantization process shown in Equations (10) and (11); where mod means modulus operator and Q is quantization coefficient.

$$T(i) = \left\lfloor \frac{T(i)}{Q} \right\rfloor \cdot Q + \frac{Q}{2}, \text{ if } \text{mod}\left(\left\lfloor \frac{T(i)}{Q} \right\rfloor, 2\right) = FM(i) \quad (10)$$

$$T(i) = \left\lfloor \frac{T(i)}{Q} \right\rfloor \cdot Q - \frac{Q}{2}, \text{ if } \text{mod}\left(\left\lfloor \frac{T(i)}{Q} \right\rfloor, 2\right) \neq FM(i) \quad (11)$$

Through the procedure, the forensic mark information is embedded into T . Equations (10) and (11) shows how +1 bit and -1 bit are embedded, respectively.

The T to which the information has been embedded again goes through the inverse DFRNT (IDFRNT). The IDFRNT is performed by simply changing the sign of α , the parameter for the DFRNT, as shown in Equation (12):

$$IDFRNT(T, \alpha, m, r) = DFRNT(T, -\alpha, m, r) \quad (12)$$

Therefore, the process of the sequential IDFRNT and inverse DWT (IDWT) can be expressed as Equation (13):

$$Y = IDWT_{2D}^{sb}(DFRNT(T, -\alpha, m, r)) \quad (13)$$

Through the process, we finally obtain the audio signal Y to which the forensic marks have been embedded.

C. Forensic Mark Extracting Algorithm

Forensic mark extraction is the opposite of the embedment process that includes 2D-DWT and DFRNT, re-quantization, re-scrambling, block code decoding, 2D barcode generation, and reconstruction.

Firstly, the audio signal Y to which forensic marks have been embedded is decomposed through 2D-DWT into sub-band frequency elements that then go through DFRNT. The DFRNT parameters should have the same values that have been used for the forensic mark embedment at this time:

$$T' = DFRNT(DWT_{2D}^{sb}(Y), \alpha, m, r) \quad (14)$$

The signal T' generated by the DWT-DFRNT dual transformation is re-quantized by Equation (15):

$$FM'(i) = \text{mod}\left(\left\lfloor \frac{T'(i)}{Q} \right\rfloor, 2\right) \quad (15)$$

After the image FM' restored re-quantization is descrambled, the actual information excluding the black pixels at the rim is extracted. The extracted part which is input of the block code decoder is recovered as 2D-barcode image. The 2D-barcode may not be perfectly identical to the original one for some reasons such as attacks. The forensic information can be recovered by inputting the extracted 2D-barcode to the barcode Reconstructor.

III. EVALUATIONS

The sampling rate of the sample audio used for the experiment in this study was 44100 Hz. The segment size, which is the embedment unit, was selected as 65536 Sample (1.48s) to be suitable for the DWT. The used 2D barcodes were QR codes of the 21×21 cell and The robustness experiment was performed to evaluate robustness through the attacking experiment using “Stirmark for audio”, an audio watermark experimental tool.

Figure 2 (a) shows the 2D barcode generated from the embedded information, where the size of the cell is 21×21 . Figure 2 (b) shows the image that went through the preprocessing procedure for scrambling after it had been obtained by encoding of the 2D barcode in Figure 2 (a) into the 2×2 block code pattern. The internal binary image size is 42×42 and the entire image size, including the black pixels at the rim, is 64×64 . Figure 2 (c) shows the forensic mark image generated by scrambling.

The forensic mark was embedded into the V band of the 2D-DWT. The Q value for the embedment was set to be 0.05 and the acquired SNR was 26.10 dB. The message hidden in the QR code was “Always be my baby”.

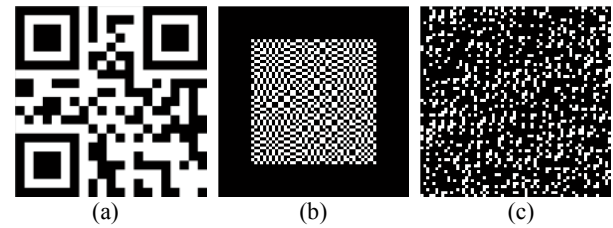


Figure 2. Forensic mark Generation by Block code Patterns

Figure 3 shows (a) the extracted forensic mark image, (b) the image after re-scrambling ($r2=38$), and (c) the restored 2D barcode. The experimental result showed that $BER=0.56\%$ and $NC=0.99$ in Figure 3 (b) and $BER=0\%$ and $NC=1$ in Figure 9 (c). This indicates that the 2D barcode was perfectly restored.

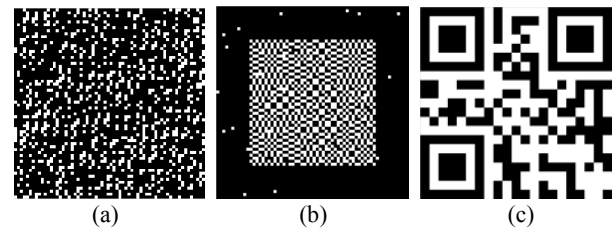


Figure 3. 2D-barcode Recovery by Block code Patterns

In multi-stage distribution tracking, information should be embedded into music contents in stages. The extraction results after embedding the information into the V band, then the H band, and later the D band showed that the re-scrambled image had a bit error within 2%, but the 2D barcode restored through block code decoding had no bit error. The SNRs calculated following the embedment were 22.77 dB and 21.01 dB, respectively, indicating that the SNR values decreased in stages by the information embedment.

To evaluate the security of the DFRNT, we changed the partial parameters of the DFRNT function and determined whether the extraction was possible. As shown in Table 1, a small change in the three parameters r s (random seed), α , and m caused the BER to become so great that the information hidden in the QR code could never be restored. Hence, it was shown that the DFRNT greatly contributed to security by increasing the calculation complexity of the algorithm.

TABLE 1. SECURITY EVALUATION BY DFRNT

Original Image	DFRNT		
	$r: 1 \rightarrow 2$	$\alpha: 0.01 \rightarrow 0.02$	$m: 3 \rightarrow 4$
			
Forensic mark	/	/	/
			
Re-scrambling	BER=49.83%	BER=48.63%	BER=34.58%

			
2D-barcode	BER=48.52%	BER=46.71%	BER=26.98%

In the case of changing the order of scrambling, the mark didn't extracted, then the algorithm ensures the security for reverse engineering.

Table 2 shows the result after attacks were made, including compressor, "add noise", and low pass filtering. The state of the QR code was at the level where the embedded messages could be restored in all cases. In the cases of "add noise" and low pass filtering, three symbols of the restored 2D barcode were partially damaged but they could be restored by the standard code system and put into the 2D barcode restorer so that the restoration rate of the embedded information could be increased.

TABLE 2. EXPERIMENTAL RESULTS AFTER STIRMARK ATTACKS

Original Image	Stirmark for audio (b=2)		
	Compressor	Add noise(900)	Low pass filtering
			
Re-scrambling	BER=6.12%	BER=3.63%	BER=10.88%
			
2D-barcode	BER=0.45%	BER=0.22%	BER=2.95%

IV. CONCLUSIONS

In this study, we ensured robustness and security by embedding forensic marks into the DWT-DFRNT dual domain generated from a QR code image through block coding. The 2D-DWT domain gives robustness and is suitable for multi-stage embedding, while the DFRNT domain contributes to the security of the algorithm by randomly mixing the information so that it may be embedded in an unpredictable position of a certain frequency band. The block coding and QR code are required to increase the extraction performance by reducing the error taking place during the extraction.

The experimental result showed that the forensic marks were secure because the extraction failed when the embedment/extraction key composed of a series of parameters was partially changed. The result also showed that the bit error is less than 3% to a number of attacks by Stirmark and multi-stage illegal distribution may also be followed up.

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