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A Robust Digital Watermarking Technique for Image Contents based on DWT-DFRNT Multiple Transform Method

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Abstract

Copyright protection of digital content has become one of important issues in digital content marketplace. Digital watermarking may be used as an effective method for identifying the copyright ownership of digital content against unauthorized use and distribution. In this paper, we propose a robust digital image watermarking algorithm based on the multiple transform method, discrete wavelet transform (DWT) and discrete fractional random transform (DFRNT). We adopt a two-dimensional (2D) barcode for hiding information and apply the block code encoding and generate a watermark through them. The generated watermark image is embedded into DWT-DFRNT using quantization technique in order to ensure robustness and imperceptibility of the watermark. Experimental results present that our proposed algorithm has improved the extraction performance by accurately extracting the hidden information in the 2D barcode from the detected watermark. Also, combining the dual transform method, DWT and DFRNT, has improved the imperceptibility and robustness of the watermark against basic image signal processing attacks.

Keywords: *Digital Watermarking, Discrete Wavelet Transform (DWT), Discrete Fractional Random Transform (DFRNT), 2D-barcode, Quantization*

1. Introduction

With the phenomenal growth in digital content marketplace, illegal acts by unauthorized users to copy, edit, and distribute digital contents, which are copyrighted, are also increasing constantly. By the circulation of reproduced or manipulated illegal digital contents, the legal market is being influenced and copyright owners may lose the right for their contents. Thus, copyright protection and authentication of digital contents are emerging as serious problems in digital content marketplace [1, 2]. Digital watermarking [3, 4] can be used as an effective method for identifying the copyright ownership of digital content from illegal manipulation and distribution.

The basic idea of digital watermarking is embedding watermark data, which contains information about the copyright of the digital content, imperceptibly into the digital media content such as images, audio, and video [3, 5]. The hidden watermark data can be used to authenticate the integrity of the original content [6] and it can be extracted in such a way that the embedding process is inversely applied to the watermarked content.

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Digital watermarking techniques can be classified into the spatial domain and frequency domain according to the domain used for embedding watermark. In the spatial domain based watermarking, watermark is embedded into digital contents in such a way that the process modifies the values of selected pixels, but it has weak robustness against common image signal processing and attacks such as noise, filtering, and compression, and may be easily destroyed by distortion [7]. In the frequency domain based watermarking, the process embeds a watermark into the selected portion of frequency domain by modifying the coefficients [8]. The frequency domain based watermarking is known as more robust and imperceptible technique than the spatial domain based watermarking, so the frequency domain is mostly used in recent watermarking methods [5, 9].

In the previous researches, many digital watermarking methods have been proposed. Cox *et al.*, [10] proposed a secure watermarking algorithm using spread spectrum. Darmstaedter *et al.*, [11] proposed a spatial watermarking algorithm by dividing an image into blocks. Comparing to the early watermarking methods, many frequency domain based digital watermarking techniques, such as discrete cosine transform (DCT) [12-14], DWT [15, 16], singular value decomposition (SVD) [17], and DFRNT [18], have been developed to improve their robustness and imperceptibility. In recent years, watermarking techniques based on dual transform domain such as DWT-DCT [19, 20], DWT-SVD [21], and SVD–DCT [22] have also been proposed.

In this paper, we propose a robust digital image watermarking algorithm based on the multiple transform method, DWT and DFRNT domains using 2D barcode in order to improve the extraction performance, imperceptibility and robustness of the watermark against image signal processing attacks such as images compression and noise adding.

2. Related methods

2.1. 2D barcodes

In the watermark generation process, we use 2D barcodes which have various information capacities and the self-error correction function. 2D barcodes widely used in various areas such as newspapers, magazines, posters, TV, the internet, tickets, receipts, and advertisements. 2D barcodes retain information in two directions, horizontally and vertically, and thus the amount of recordable information is drastically greater than in a one-dimensional (1D) barcode. A 2D barcode is also applicable to digital content: A visible mark can be embedded into digital content such as a research article or an image so that it contains the information relevant to the content.

(a) (b)

(c)

Figure 1. Types of 2D-barcode

Figure 1 shows some representative examples of 2D barcodes that have been released and frequently used: (a) the quick response (QR) code, (b) DataMatrix, and (c) PDF417. In

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different forms, all of them show a 2D barcode generated from the same information, the message "123456789." Among them, PDF417 is stack barcode, whereas the QR code and DataMatrix are based on the matrix method. The QR code holds the greatest amount of information, followed by DataMatrix and PDF417. Among the various types of 2D barcodes, the QR code is known to exhibit good performance in many respects, since the code size is small even if it contains a great deal of information, and the code can be scanned and read rapidly.

The information capacity and code size of 2D barcodes are dependent on the module size, error correction level, and types of encoding. Generally, the information capacity increases as the code size of the 2D barcode increases, but decreases as the error correction level rises. For example, a 21 x 21 cell QR code can contain 41 numbers or 25 alphanumeric data if the error correction level is low, but 17 numbers or 10 alphanumeric data if the error correction level is high. The information capacity of a 25 x 25 cell is about two times greater than that of a 21 x 21 cell. Hence, a 2D barcode can be applied to the technology for digital content copyright protection technology, such as forensic marking, thanks to the self-error correction function along with the maximized information capacity, minimized code region, and rapid code reading. This is because the information contained in a 2D barcode can be restored even after it is detected from compression, noise, and attack such as filtering, overcoming a certain range of error. In view of the different applications, a differentiated service can be provided, as the 2D barcode is detected when displaying content so that the information relevant to the content may be given on the screen.

2.2. Multiple transform method

The transform method used in the proposed system consists of a combination of DWT and DFRNT multiple transform in order to ensure the imperceptibility and robustness of the watermark due to the frequency decomposition ability of DWT that extracts robust coefficients and the unpredictable random characteristic of DFRNT.

For the multiple transform, first 2D-DWT [7, 23] is used and a host image signal is converted to a 2D signal to be used as the input for the 2D-DWT. The 2D-DWT-converted image 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 watermarks. This not only robustly embeds the watermarks into a certain frequency band, but also allows the information about the copywriter and user, including the secondary copywriter or those with the neighboring 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 accepts the specific frequency coefficients generated by the 2D-DWT as the input data for the DFRNT, and randomly mixes the data by effecting various changes through the manipulation of the parameters. This leads to increased calculation complexity, so that the statistical characteristics of the data may not be understood by illegal users. The DFRNT [24] is generally performed in the method that follows.

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

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

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

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

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

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

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

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

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

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

$$X_R = R^\alpha X (R^\alpha)^T \quad (6)$$

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

3. Proposed Watermarking Technique

3.1. Watermark generation

The watermark generation process is summarized by the steps as follows.

1) Generate a barcode containing information that is embedded into an image signal through a 2D barcode encoder
2) Put the generated barcode into the block code encoder that we designed for encoding it into a binary image.
3) Produce the watermark 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.

3.2. Watermark embedding algorithm

The watermark embedding algorithm is summarized as follows:

1) First, we generate the watermark image through the 2D barcode and block code encoding.

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2) The host image is decomposed into three sub-bands, H, V, and D, through the two-level 2D-DWT. The 2D-DWT is performed by scanning the image signal in the 8×8 block unit, and some coefficients are chosen among the specified sub-band coefficients of each block according to the key table.
3) Next, the DFRNT is performed on the sub-band coefficients. And then, we embed the watermark image into the sub-band coefficient value using quantization technique.
4) Finally, we performed the inverse DFRNT (IDFRNT) and inverse DWT (IDWT).
5) As the final result, we obtain the watermarked image.

Figure 2 shows the steps in the watermark embedding algorithm.

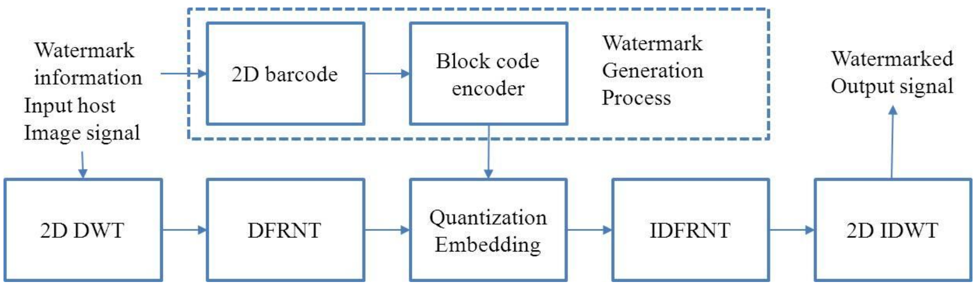


Figure 2. Watermark embedding algorithm

3.3. Watermark extracting algorithm

The watermark extraction process is performed in such a way that the embedding process is inversely applied to the watermarked image signal.

4. Experimental Results

In order to evaluate the performance of our proposed algorithm, we have performed the experiments with respect to the extraction performance, imperceptibility, and robustness of the watermark in various conditions including image compression and noise adding attacks.

We used 512×512 size standard gray level images as the sample host images and a 21×21 cell QR code, and 2×2 block code encoder.

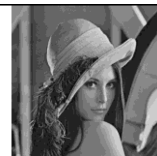
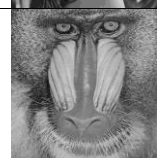
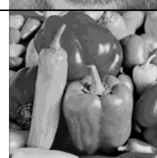
For performing multiple transform, two-level 2D-DWT is performed to decompose the input image signal, 512×512 gray image, into the three sub-band frequencies of H, V, and D. The 2D-DWT is performed by scanning the image signal in the n×n block unit until all pixels of the image signal are transformed. The size of scanning block is set to 8, and the size of the sub-band coefficient matrix generated through performing the two-level 2D-DWT on the image of 512×512 size would be 64×64. Then, DFRNT is performed on each of sub-band frequencies. The default setting values for the parameters of the DFRNT function are set to: $\alpha = 0.01$; $m = 3$; and random seed $rs = 1$. The value of the quantization coefficient Q is determined to be in the range of 20 to 25 according to the quality demand of images.

In order to evaluate the imperceptibility and robustness, we compute the peak signal to noise ratio (PSNR) and Bit Error Rate (BER). BER value is calculated as follows:

$$\mathrm{BER} = \frac{\sum_{i=1}^{P\times P} \omega_i \oplus \omega_i^{*}}{P \times P} \times 100\%$$

The experimental result of the proposed watermark embedding algorithm without being attacked is shown in Table 1. The result verifies that the watermark is imperceptible and there are no visible differences between the two images by comparing the original image signal with the image signal after embedding the watermark into the H band of 2D-DWT. The Q value for embedding was set to 25 and the acquired PSNR is 40.01 dB for Lena image.

Table 1. Image signals before and after embedding watermark

Image content	Original images	Watermarked images
Lena		
baboon		
pepper		
lake		
barbara		
goldhill		

We evaluated the extraction performance of the proposed watermarking algorithm by computing BER and the experimental results are shown in Figure 3. Figure 3 shows (a) the extracted watermark image from the watermarked Lena image, (b) the restored 2D barcode. In the experimental result, the restored 2D barcode gave that BER=0%. This indicates that the 2D barcode was correctly restored.

(a) Extracted watermark (b) Restored QR code

Figure 3. Extraction and restoration of 2D-barcode

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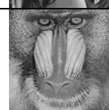
The PSNR values before and after embedding the watermark for the diverse standard images are given in Table 2. In the experimental result, the average PSNR of the test sample images was 40.22dB and BER of the extracted watermark kept 0% in all the sample images.

Table 2. Conformance experiment of the watermarked images

Image content	Sample images	PSNR(dB)	BER(%)
Lena		40.01	0
baboon		40.16	0
pepper		39.60	0
lake		40.32	0
barbara		40.69	0
goldhill		40.51	0

We performed the experiments by carrying out image compression and noise adding attacks, and the extracted and restored QR codes after being attacked are shown in Table 3. In the case of compression attack, JPEG Quality Factor (QF) was set to 65. In the case of noise attack, Noise (g) denotes the Gaussian noise with mean set to 0 and variance set to 0.001, and Noise(s) denotes the Salt & Pepper noise with density set to 0.01.

The experimental results verify that the proposed algorithm ensures the imperceptibility and robustness of the watermark.

Table 3. Extraction results by various attacks

Domain	Attacks		
	Compressor	Noise(g)	Noise(s)
DWT-DFRNT	BER=0.09%	BER=1.84%	BER=1.10%
DWT only	BER=0%	BER=1.56%	BER=0.55%

In addition, we evaluated the extraction performance of the proposed algorithm with reference to BER through comparing the DWT single domain with the DWT-DFRNT multiple transform domain. In the performed experiment, we computed the BER values the

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extracted watermark images fixing the PSNR at 40 dB after being attacked and compared them in the two types of domain.

As given in Table 3, the experimental results verify that while the DWT-DFRNT multiple transform domain has a similar level of extraction performance compare with that of the DWT single domain, and the 2D barcodes of both domains could be restored.

5. Conclusions

In this paper, we have proposed a robust digital watermarking technique for image contents based on DWT-DFRNT multiple transform method.

The watermark generation process has been implemented by using the 2D barcode and block encoding techniques in order to improve the extraction performance of the watermark. The watermark embedding process is completed by transforming the generated watermarks through the multiple transform which takes the benefits of the frequency decomposition ability of DWT and the inherent randomness of DFRNT. The experimental results presented that the proposed system has a good embedding/extraction performance. The embedded watermarks satisfied the imperceptibility and the quality of the watermarked images maintained at a high level, and the embedded 2D barcodes as watermarks could be perfectly restored. The proposed algorithm is also robust against general image processing attacks such as image compression and noise adding.

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