Digital Watermarks Using Discrete Wavelet Transformation and Spectrum Spreading

Ryousuke TAKAI
Hosei University Graduate School Engineering Division,
System Engineering Major
3-7-2 Kajino-Cho Koganei-Shi Tokyo, 184-8584, Japan

and

Kenji NAGASAKA
Department of System and Control Engineering
Faculty of Engineering
Hosei University
3-7-2 Kajino-Cho Koganei-Shi Tokyo, 184-8584, Japan

ABSTRUCT

In recent years, digital media makes rapid progress through the development of digital technology. Digital media normally assures fairly high quality, nevertheless can be easily reproduced in a perfect form. This perfect reproducibility takes an advantage from a certain point of view, while it produces an essential disadvantage, since digital media is frequently copied illegally. Thus the problem of the copyright protection becomes a very important issue. A solution of this problem is to embed digital watermarks that is not perceived clearly by usual people, but represents the proper right of original product.

In our method, the image data in the frequency domain are transformed by the Discrete Wavelet Transform and analyzed by the multi resolution approximation, [1]. Further, the spectrum spreading is executed by using PN-sequences.

Choi and Aizawa [7] embed watermarks by using block correlation of DCT coefficients. Thus, we apply Discrete Cosine Transformation , abbreviated to DCT, instead of the Fourier transformation in order to embed watermarks.

If the value of this variance is high then we decide that the block has bigger magnitude for visual fluctuations. Henceforth, we may embed stronger watermarks, which gives resistance for image processing, such as attacks and/or compressions.

Key Words:
Digital watermarks, Discrete Wavelet Transformation, Discrete Cosine Transformation, Spectrum Spreading, PN-sequences

1. INTRODUCTION

Recent development of information technology and 24 hours Broadband connections as a current environment of internet, we can send, receive and utilize tremendous amount of digital media every time.

At the same time, each article of digital media must be respected its copyright, so that copyright protections become big issue of information security.

Hence the introduction of digital watermarks is an excellent solution of this problem. Usual requirements for digital watermarks are its secrecy, to keep the quality of digital media and the robustness for signal processing, especially the compression of data.

For high quality audio data of CD-DA Standard, we already embed enough digital watermarks in success, [2]. Next submitted results, “ Digital Watermarking and PN-Sequences (in Japanese)” follows, which points out the effects of the difference of PN-Sequences in the direct spectrum spreading and modified discrete cosine transformation is so powerful that almost all effects diminishes of different PN-Sequences in the spectrum spreading process, [5].

Hence, we embed digital watermarks in color image in their frequency domain [6], which becomes a standard method. Therefore, Discrete Fourier Transformation (abbreviated to DFT), Discrete Cosine Transformation [3] (abbreviated to DCT) and Discrete Wavelet Transformation [1] (abbreviated to DWT) play important role in the image processing.

In this note, we execute firstly DWT to the image in concern, and then DCT to multi-resolution approximation (abbreviated to MRA) components. In Section 2, two transforms : DWT and DCT, are explained in detail. In Section 3, we discuss on the spectrum spreading and PN-Sequences. In our case, PN-Sequence works as a cryptographic key. How to embed digital watermarks are the main body of this note and Section 4 devotes to it. Taking into account to the deviations of the 4 block centers' image pixels is important idea. Section 5 contains two examples embedded digital watermarks and SNR (Signal-Noise-Ratio) is shown in Table 1 and 2. Final Section is devoted to concluding remarks and future problems.

2. DWT and DCT

DWT

Discrete Wavelet Transformation (DWT) on the treated image gives the following two decompositions : The first component consists of MRA and another component consists of multi-resolution representation (abbreviated to MRR). Here, the MRA component represents the part of the image (LL in Fig. 1) with a half resolution and MRR components represent the difference information on the parts (HL, HH and LH in Fig. 1) of image, where HL signifies the vertical direction, HH the diagonal direction and LH signifies the horizontal direction.

In other words, MRA component expresses the low frequency component and MRR the high frequency component.

It is of course possible to repeat DWT to MRA components so that this component decomposes of two components as before. Repeating DWT forms a hierarchical structure in the image which makes various resolution levels embedded digital watermarks possible. The Haar base is used as our mother wavelet of DWT.

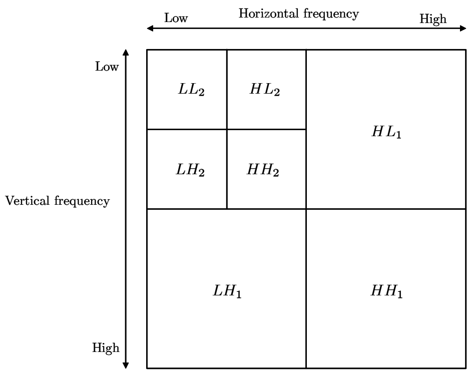


Fig. 1 Haar Transformation of 2-D image

DCT

Discrete Cosine Transformation (DCT) formulas are the followings ;

$$F(u,v)=\frac{2c(u)c(v)}{\sqrt{N_xN_y}}\sum_{x=0}^{N_x-1}\sum_{y=0}^{N_y-1}f(x,y)\times\cos\left\{\frac{(2x+1)u}{2N_x}\pi\right\}\cos\left\{\frac{(2y+1)v}{2N_y}\pi\right\}, \quad (1)$$

$$f(x,y)=\sum_{x=0}^{N_x-1}\sum_{y=0}^{N_y-1}\frac{2c(u)c(v)}{\sqrt{N_xN_y}}F(u,v)\times\cos\left\{\frac{(2x+1)u}{2N_x}\pi\right\}\cos\left\{\frac{(2y+1)v}{2N_y}\pi\right\}, \quad (2)$$

where

$$c(u),c(v)=\begin{cases}\frac{1}{\sqrt{2}}, & if \quad u,v=0,\\ 1, & otherwise.\end{cases}$$

By DCT, we obtain DCT coefficients, which has the correlation between blocks and the low frequency components concentrates in the leftmost highest regions. In the above formulas, $f(x,y)$ denotes the value of the pixel on (x,y) position and $F(u,v)$ represents the DCT coefficient.

3. SPECTRUM SPREADING AND PN-SEQUENCE

Our embedding digital watermarking system configuration is given below ;

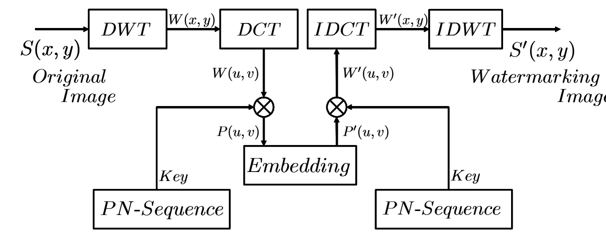


Fig. 2 Embedding Watermarking System

Spectrum Spreading communication system is known to be tough against interference, hence we use direct spectrum spreading by multiplying PN-Sequence to the original signal. Let $a(t)$ be original signal and let $c(t)$ be PN-Sequence, where PN-Sequence is physically generated random numbers of ±1 by Clutter Box of HMI company. The spreading signal $x(t)$ is transformed by

$$x(t)=a(t)\times c(t). \quad (3)$$

Then by transforming inverse spreading, the inverse spreading signal $y(t)$ is expressed by

$$y(t)=x(t)\times c(t)=a(t)\times c^2(t)=a(t), \quad (4)$$

since $c(t)$ is the same PN-Sequence for spectrum spreading (3), which guarantees $c^2(t)=1$ for all t, then the original signal $a(t)$ is again obtained in (4).

Thus we use PN-Sequence as the spectrum spreading key and also as the inverse, which makes the security level of the embedding digital watermarking system higher.

4. EMBEDDING DIGITSL WATERMARKS

Original color image is represented by three values of RGB, then we transform RGB signal to luminosity signal Y, difference of color signal $C_R = R - Y$ and $C_B = B - Y$, where

$$Y = 0.30R + 0.59G + 0.11B$$

holds for luminosity signal Y. DWT executes to luminosity signals Y and we obtain MRA components of Y. These components is divided into 8×8 blocks, each of which DCT is applied to get DCT coefficients $C_{x,y}(i,j)$, where (x,y) denotes the position of the block in the MRA components and (i,j) expresses the position in the block, as shown below.

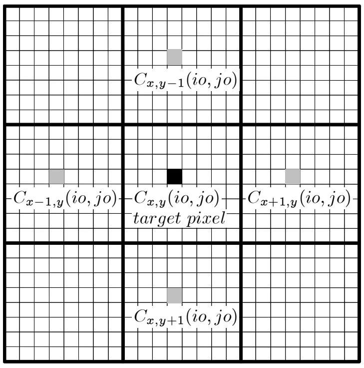


Fig. 3 Position of the Embedded Watermark

We collect 3×3 blocks into one group and the DCT coefficient $C_{x,y}(io,jo)$ is the target for embedding 1 bit digital watermark, where (io,jo) is the center position of the 8×8 block that occupies in the center of a group of 9 blocks.

Now, according to the following criterions, we embed a digital watermark $p_{x,y}$. $M_{x,y}$ denotes the mean of DCT coefficients $C_{x+m,y+n}(io,jo)$ where m, n runs ±1, respectively ; that is $M_{x,y}$ is the mean of the every center of 4 blocks surrounding the block with target pixel. $V_{x,y}$ signifies the change of values in DCT coefficient.

(i) If $p_{x,y} = 0$ and $C_{x,y}(io,jo) < M_{x,y}$,
then new DCT coefficient is equal to $M_{x,y} + V_{x,y}$.

(ii) If $p_{x,y} = 1$ and $C_{x,y}(io,jo) > M_{x,y}$,
then new DCT coefficient is equal to $M_{x,y} - V_{x,y}$.

(iii) If $p_{x,y}$ or $C_{x,y}(io,jo)$ do not satisfy the conditions above (i), (ii), then no change occurs.

The determination of the change of values $V_{x,y}$ is as follows ;

(i) If $SD_{x,y} < Z$, then $V_{x,y} = kSD_{x,y} + V_{\min}$.

(ii) If $SD_{x,y} \geq Z$, then $V_{x,y} = V_{\max}$.

Here $SD_{x,y}$ is the standard deviation of 4 center DCT coefficients $C_{x+m,y+n}(io,jo)$ where m, n runs ±1, respectively. Other quantity k, $V_{\min}$, $V_{\max}$ and Z are parameters determined according as the intensity of embedding digital watermarks.

In order to extract the embedded digital watermarks, we only need following ;

(i) If $C'_{x,y}(io,jo) > M_{x,y}$, then $p_{x,y} = 0.$

(ii) Otherwise, $p_{x,y} = 1,$

where $C'_{x,y}(io,jo)$ is the target DCT coefficient with the embedding watermark.

After embedding digital watermarks, the inverse DCT and further the inverse DWT give color image $S'(x,y)$ with digital watermarks.

5. SIMULATION RESULTS

We apply our embedding watermarking to two color images : Mandrill and Milkdrop, each of which is 256×256 pixels and 8 grades for R, G, B color components, respectively.

Embedding digital watermarks is executed as in the preceding Section, and we determine the values of parameters, such as k =1.5, $V_{\min}$ =2, $V_{\max}$ =20 and Z =12, to which we refer Choi and Aizawa [7]. Embedding positions are arranged in order ; (1, 2), (2, 2), (4, 0), (3, 0), (0, 5), (3, 3), (0, 3), and (2, 4) in MRA components and 1, 2, ⋯ , 8 bits are embedded for each group.

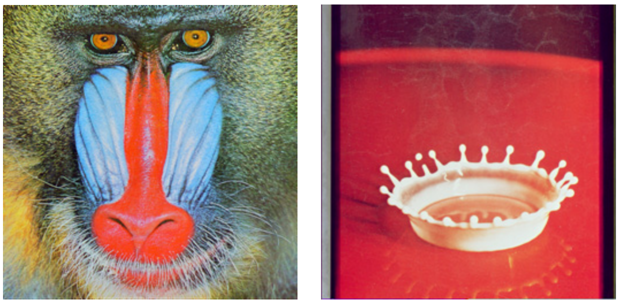
In order to estimate the quality of color image with embedded digital watermarks, SNR is a standard tool, where the method 1 implies no spectrum spreading and the method 2 implies spectrum spreading. Thus,

$$SNR = 20\log_{10}\frac{255}{\sqrt{N}},$$

$$N = \frac{1}{256}\sum_{x=0}^{255}\sum_{y=0}^{255}\left(Y(x,y) - Y'(x,y)\right)^2,$$

where, $Y(x,y)$ denotes the original luminosity signal and $Y'(x,y)$ the luminosity signal with embedded digital watermarks. Fig. 5 is a color image without spectrum spreading but with embedded digital watermarks. Fig. 6 is a color image with spectrum spreading and embedded digital watermarks.

From Fig. 7 to Fig. 10, the difference between original luminosity image and that with embedded digital watermarks.



Mandrill **Milkdrop**

Fig. 4 Original Image

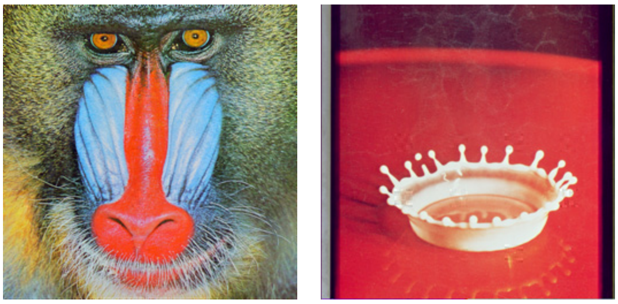


Fig. 5 Watermarking Image by Method 1 (8bits per one group)

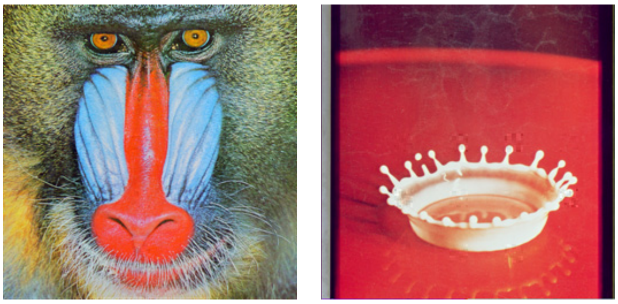


Fig. 6 Watermarking Image by Method 2 (8bits per one group)

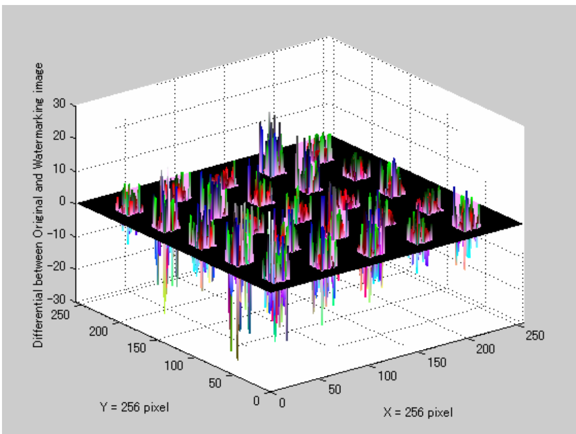


Fig. 7 Differential between Original and Watermarking Image (method 1, Mandrill)

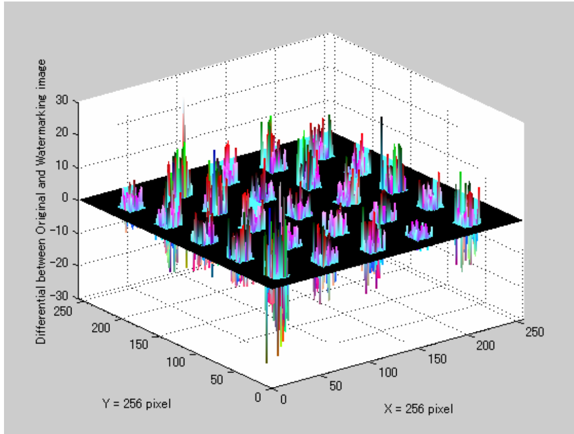


Fig. 8 Differential between Original and Watermarking Image (method 2, Mandrill)

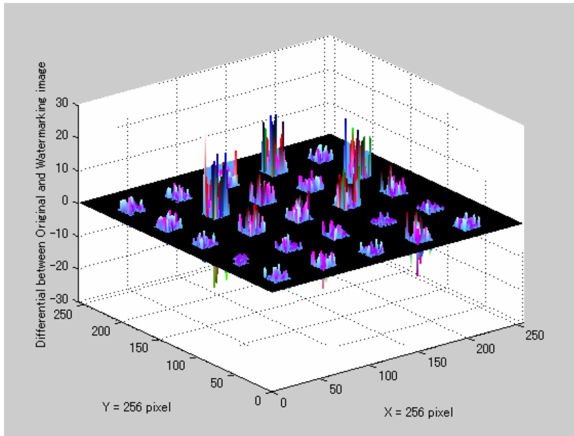


Fig. 9 Differential between Original and Watermarking Image (method 1, Milkdrop)

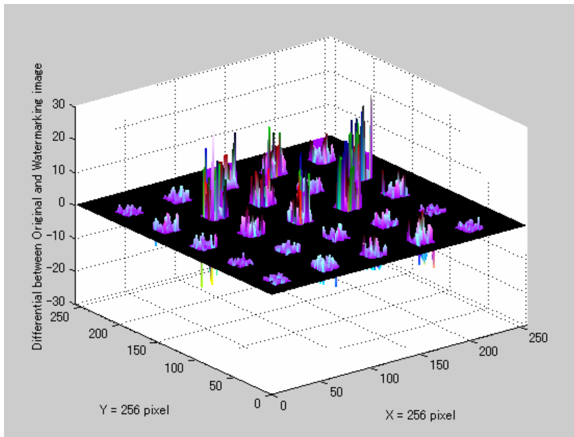


Fig. 10 Differential between Original and Watermarking Image (method 2, Milkdrop)

For any method, we can realize embedding digital watermarks on almost all regions of color images and further, the changing values $V_{x,y}$ is greater for Mandrill image than for Milkdrop image, since the variance of luminosity signals of Mandrill image is greater than that of Milkdrop image.

Table 1 SNR (Mandrill))

Bits	Position	SNR [db] method 1	SNR [db] method 2
1	(1,2)	52.6049	51.1538
2	(2,2)	47.2743	46.3834
3	(4,0)	45.6444	44.7136
4	(3,0)	44.0556	43.5314
5	(0,5)	43.6247	42.9614
6	(3,3)	43.4257	42.4466
7	(0,3)	42.9941	41.7698
8	(2,4)	42.1557	41.1878

Table 2 SNR (Milkdrop)

Bits	Position	SNR [db] method 1	SNR [db] method 2
1	(1,2)	55.2672	51.0157
2	(2,2)	52.6109	50.0449
3	(4,0)	51.1923	49.2029
4	(3,0)	50.0905	46.3695
5	(0,5)	48.4321	46.0877
6	(3,3)	48.1545	45.8953
7	(0,3)	46.3470	45.1730
8	(2,4)	46.1056	44.5600

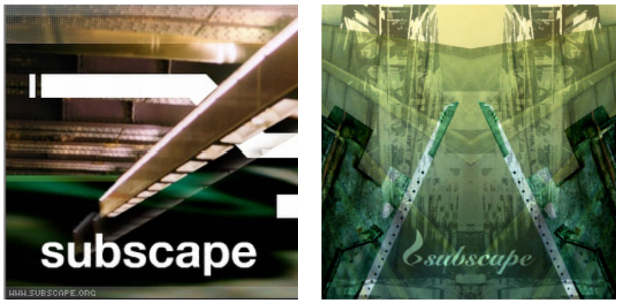
Tabale 1 and Table 2 are the list of SNR for method 1 and method 2 applied to Mandrill image and Milkdrop image, respectively. The great variance of luminosity signals in Mandrill image may accept stronger embedding digital watermarks, which is an advantage of this method, nevertheless SNR vary a little smaller than that of Milkdrop image.

As for the use/nouse of spectrum spreading, SNR of method 2 varies smaller than those by method 1, since the use of PN-Sequence as a key might destroy the magnitude of DCT coefficients, or hence this spectrum spreading ignore the differences in variances for embedding

We apply our digital watermark system to some products. A web designer Akitane Chiba (www.subscape.org) provides several illustrations. A photographer Masaki Kanezashi provides some photographs. We express our deep thanks to the above artists for the permission to apply our digital watermark system. To illustrations and photographs, we embed watermarks by Method 1.

Table 3 SNR (Illustrations and Photographs)

Image	Embedded information	Number of bits	SNR[db]
Illustration (a)	subscape.org	84	43.2874
Illustration (b)	subscape.org	84	44.4414
Photograph (a)	masaki_kanezashi	112	44.3242
Photograph(b)	masaki_kanezashi	112	46.5812



(a) (b)

Fig. 11 Illustrations


(a) (b)

Fig. 12 Photographs

6. CONCLUDING REMARKS AND FUTURE PROBLEMS

In this note, we treat color images and propose an embedding digital watermarking method. Firstly we execute DWT to a color image, and then DCT to MRA components. Then we use PN-Sequence to direct spectrum spreading. By using the same PN-Sequence multiplied to execute inverse spreading, we are able to obtain original color image. Thus, PN-Sequence is applied like as an encryption key and at the same time as a decryption key, with which the security level of digital watermarking is improved.

Another point is to consider the distribution of DCT coefficients for MRA components via DWT. If the variance of DCT components is higher, then stronger embedding digital watermarking may possible. On the other hand, stronger embedding digital watermarks might decrease the quality of color image, which can be observed from the Table 1 and 2 of SNR. It is of course an advantage to take into account the magnitude of fluctuations for embedding digital watermarks. The strength of embedding digital watermarks is relevant to the quality of color image with watermarking, which seems a kind of trade-off situation.

Regarding the above trade-off situation, it is certainly big issue how to determine the values of free parameters k, $V_{\min}$, $V_{\max}$ and Z.

From Fig. 4 to Fig. 12, our simulation shows the success of our embedding digital watermarking system.

7. REFERENCES

[1] Hiroki Nakano, Shizuo Yamamoto and Yasuo Yoshida, **Signal processing and image processing by wavelet transformation** (in Japanese), Morikita Publisher, 1997.

[2] Hiroyuki Takano and Kenji Nagasaka, "Advanced Digital Watermarking System for High Quality Audio Data", **Proceedings of the 4-th ARS Conference of the IASC**, Korea, 2002, pp. 257-260.

[3] Hitoshi Takaya and Shogo Muramatsu, **The foundation of multimedia technology, -Introduction to DCT-** (in Japanese), CQ Publisher, 1996.

[4] Junji Onishi and Kineo Matsui, "A method of watermarking with multiresolusion analysis and PN-sequence" (in Japanese), **Journal of the Institute of Electronics, Information and Communication Engineers**, D-2 Vol.Ⅱ J80-D-2 No.11, 1997, pp. 3020-3028.

[5] K. Nagasaka, H. Takano, T. Takahashi and R. Takai, "Digital Watermarking and Random number Sequences" (submitted).

[6] Kineo Matsui, **A foundation of digital watermarking** (in Japanese), Morikita Publisher , 1998.

[7] Yoonki Choi and Kiyoharu Aizawa, "Digital watermarking technique using block correlation of DCT coefficients" (in Japanese), **Journal of the Institute of Electronics, Information and Communication Engineers**, D-2 Vol.Ⅱ J83-D-2 No.7, 2000, pp. 1620-1627.

[8] Yukiji Yamauchi, **Spectrum Spreading Communication** (in Japanese), Tokyo Denki University Publisher, 1994.