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# Embedding Binary Image Watermark in DC Components of All Phase Discrete Cosine Biorthogonal Transform

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***Abstract***

*Watermarking technique provides the possibility for copyright protection. Discrete cosine transform (DCT) is the most popular tool used in watermarking algorithm. But the watermarking algorithm based on DCT is not the most ideal choice in terms of the complexity and robustness. All phase discrete cosine biorthogonal transform (APDCBT) owns the characteristics of high frequency attenuation and good applications in image coding, image denoising and other fields of digital image processing, which provides an efficient method for watermarking. In this paper, a new watermarking algorithm based on APDCBT is proposed. Besides, the binary image watermark is scrambled by Arnold transform to enhance its privacy and robustness greatly in our algorithm. The watermark information is embedded in direct-current (DC) components considering DC components have much larger perceptual capacity. Compared with the DCT algorithm, the proposed algorithm has stronger robustness in embedding and extracting the watermark. Experimental results show that our algorithm can satisfy the imperceptibility and robustness very well. Furthermore, our algorithm is tested against four kinds of attacks: JPEG compression, Gaussian noise, salt & pepper noise and rotation.*

***Keywords:*** *digital image watermarking; all phase discrete cosine biorthogonal transform (APDCBT); Arnold transform; normalized correlation (NC) value*

## 1. Introduction

With the rapid development of information technologies and the wide applications of network, digital image watermarking has become an increasingly popular research area. The conventional methods of information encryption are not safe enough because the document can be copied easily. As a new method against the failure of encryption, digital watermarking has been proposed as an effective way to protect the ownership of digital documents, especially the ownership of digital images. Especially digital image watermarking techniques have been widely researched in recent years. There are two kinds of digital image watermarking techniques [1]: spatial domain technique [2] and frequency domain technique [3] [4]. The simplest spatial domain technique method is the least significant bit (LSB) algorithm [5], in which the watermark information is embedded into the LSB or multiple bit layers of images. In the frequency domain we can insert watermark information into the coefficients of a transformed image. Firstly, the original image is transformed into the frequency domain, and then the transformed coefficients are modified by the watermark information. One of the most typical frequency domain watermarking techniques is based on discrete cosine transform (DCT) [6], which is robust to compression, filter and other transformation on image, and is compatible with the JPEG compression. In recent years, watermarking algorithms based on

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discrete wavelet transform (DWT) [7] [8] and other hybrid transforms [9] have been proposed successively. How to improve the robustness and security is a key problem for protecting image copyright. The safety of the watermarking system will be enhanced further by encryption technology and spread spectrum security.

In this paper, we propose a new watermarking algorithm based on all phase discrete cosine biorthogonal transform (APDCBT) [10] and Arnold transform. In the process of quantization, we will adopt uniform quantization to replace the complex quantization table due to the good high frequency attenuation characteristics of APDCBT. Moreover, we embed the watermark information in direct-current (DC) components to achieve more robustness because DC components have much larger perceptual capacity than alternating-current (AC) components [11]. The main goal of this paper is to present a novel watermarking algorithm that allows to assess the performance of a given binary image watermark and shows stronger robustness and invisibility.

The rest of this paper is organized as follows. Section 2 describes watermarking algorithm based on DCT for image. We propose a new watermarking algorithm based on APDCBT for image in Section 3. Simulation experiment and analysis of the proposed method are presented in Section 4. Conclusions and remarks on possible further work are given finally in Section 5.

## 2. DCT-based Watermarking Algorithm for Image

DCT has been widely used in many watermarking algorithms. Koch presented a block DCT domain watermarking algorithm [12], in which the image is segmented into blocks by 8×8 pixels and transformed by DCT. The watermarking information is embedded into middle frequency coefficients. Next we will introduce the watermarking algorithm based on DCT and Arnold transform.

### 2.1. Arnold Transform

Arnold transform, also known as cat mapping, was presented as a class of cutting transform during the research of ergodic theory by V. I. Arnold. Arnold transform is commonly used for image scrambling [13]. Its operation is simple and practical. The Arnold transform can be expressed as

$$\begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} (\bmod N), \tag{1}$$

where $(x, y)$ denotes the pixel value of the original image and $(\hat{x}, \hat{y})$ denotes the pixel value of the transformed image. $N$ is the order of the image. This transformation is one-to-one, and this kind of transformation can continue the iteration.

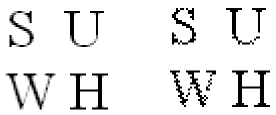
The image is scrambled after one Arnold transform. It is easy to restore the original initial state according to periodicity and transform times based on Arnold. In fact, the Arnold transform period is determined by the size of an image but the period does not increase lineally with the increasing size of an image. Scrambling degree can show the degree of image scrambling. Arnold transform is cyclical. When transform iteration times achieves a certain number, we will get the original image. Table 1 shows the cycles of Arnold transform for watermarking image in different orders.

**Table 1. The Cycles of Arnold Transform for Watermarking Image in Different Orders**

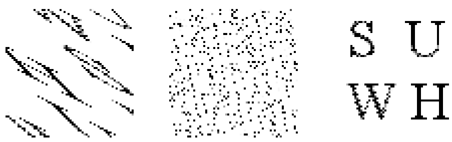
| *N* | Period | *N* | Period | *N* | Period | *N* | Period |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 16 | 12 | 90 | 60 | 180 | 60 |
| 2 | 3 | 20 | 30 | 100 | 85 | 190 | 90 |
| 3 | 4 | 30 | 60 | 110 | 30 | 200 | 150 |
| 4 | 3 | 32 | 24 | 120 | 60 | 210 | 120 |
| 5 | 10 | 40 | 30 | 128 | 96 | 220 | 30 |
| 6 | 12 | 50 | 150 | 130 | 210 | 230 | 120 |
| 7 | 8 | 60 | 60 | 140 | 120 | 240 | 60 |
| 8 | 6 | **64** | **48** | 150 | 300 | 250 | 750 |
| 9 | 12 | 70 | 120 | 160 | 120 | 256 | 192 |
| 10 | 30 | 80 | 60 | 170 | 90 | -- | -- |

Figure 1 shows an original image watermark whose size is $64\times64$. It contains four letters "S", "D", "U" and "W" which are initials of "Shandong University, WeiHai". Its Arnold period is 48 according to Table 1. Original gray-level image watermark is displayed in Fig. 1(a). Fig. 1(b) is the watermark after binarization processing. And the scrambling degree comes to top when the numbers of transform times are both 1 (Fig. 2(a)) and 20 (Fig. 2(b)) which better reflect the scrambling cases. After 48 times transform, scrambled watermark is back to the original watermark (Fig. 2(c)). By using the Arnold algorithm not only the information is hidden, but also the transform times is taken as the decryption key to enhance system security and confidentiality. It is convenient to select a transform time of an image by the scrambling degree in digital watermarking application.




(a) (b)

**Figure 1. Original Image Watermark: (a) Original Gray-level Image Watermark, (b) Binary Image Watermark after Binarization Processing**




(a) (b) (c)

**Figure 2. Different Times of Arnold Transform: (a) 1 Time, (b) 20 Times, (c) 48 Times**

**2.2. Watermark Embedding Scheme**

Step 1. Watermark is scrambled by Arnold transform and transform times is taken as encrypt key. Encrypted image is converted to one-dimensional order from two-dimensional structure.

Step 2. Host image is transformed by DCT and some intermediate frequency DCT coefficients are selected according to human vision system (HVS) in which watermarking information will be embedded. Set the value $s$, which can control the embedded intensity. If the value of the watermark information is zero, a smaller weighted value $s/4$ is chosen, otherwise a larger $3s/4$ is chosen.

Step 3. Quantify the image according to luminance quantization table and then perform a zig-zag scanning.

Step 4. Watermarked image is transformed to spatial domain by inverse zig-zag scanning, inverse quantization and inverse DCT.

### 2.3. Watermark Extraction Scheme

Step 1. Watermarked image is transformed to frequency domain by DCT and the DCT coefficients are ordered.

Step 2. Original image is transformed to frequency domain by DCT and the DCT coefficients are ordered.

Step 3. According to weighted values, inverse operation is executed. Decrypted watermarking image and the scrambled watermarking image are then acquired.

Step 4. The extracted watermark is obtained according to the periodicity of the binary image watermark and the original transform times.

## 3. APDCBT-based Watermarking Algorithm for Image

On the basis of all phase digital filtering, three kinds of all phase biorthogonal transforms (APBTs) based on the Walsh-Hadamard transform (WHT), DCT and inverse DCT (IDCT) were proposed and the matrices of APBT were deduced in [10]. Similar to DCT matrix, they can be used in image compression transforming the image from spatial domain to frequency domain too. Taking APDCBT for example, the process of two-dimensional APBT will be introduced as follows.

### 3.1. APDCBT

APDCBT is a new transform which can be employed in image compression, image denoising, image demosaicking and so on. It has got very good applications in the field of image processing. In Eq. (2), $\boldsymbol{X}$ is the data of an $N \times N$ image block, and $\boldsymbol{V}$ represents APDCBT matrix with size of $N \times N$ respectively. After two-dimensional APDCBT transform, transform coefficients block $\boldsymbol{Y}$ can be denoted by

$$\boldsymbol{Y} = \boldsymbol{V}\boldsymbol{X}\boldsymbol{V}^{\mathrm{T}}, \tag{2}$$

$$\boldsymbol{V}(m,n) = \begin{cases} \dfrac{N-m}{N^2}, & m = 0,1,\cdots,N-1,\ n = 0, \\ \dfrac{1}{N^2}\left[(N-m)\cos\dfrac{mn\pi}{N} - \csc\dfrac{n\pi}{N}\sin\dfrac{mn\pi}{N}\right], & m = 0,1,\cdots,N-1,\ n = 1,2,\cdots,N-1, \end{cases} \tag{3}$$

where $\boldsymbol{V}^{\mathrm{T}}$ is the transpose matrix of $\boldsymbol{V}$. We use

$$\boldsymbol{X} = \boldsymbol{V}^{-1}\boldsymbol{Y}(\boldsymbol{V}^{-1})^{\mathrm{T}}, \tag{4}$$

to reconstruct the image, where $\boldsymbol{V}^{-1}$ is the inverse matrix of $\boldsymbol{V}$.

### 3.2. Watermarking Algorithm Based on APDCBT

Huang et al. [11] proposed that more robustness can be achieved if watermarks are embedded in DC components since DC components have much larger perceptual capacity than AC components. Moreover, compared with DCT, APDCBT can gather the image energy in the low frequency part better. The watermarked image quality will be impaired greatly if we insert the watermark into intermediate frequency. So the idea that we insert watermark in the position of DC components, not only makes the use of APDCBT possible but also improves perceptual capacity.

Fig. 3 shows our watermarking algorithm based on APDCBT, including both embedding scheme and extraction scheme. In our algorithm, the host image is segmented into blocks by 8×8 pixels and transformed by APDCBT. In the following flow chart, we omit the processes of the quantization and scanning. As the above mentioned, we employ uniform quantization on the basis of APDCBT's characteristics to reduce the algorithm complexity and adopt zig-zag scanning.

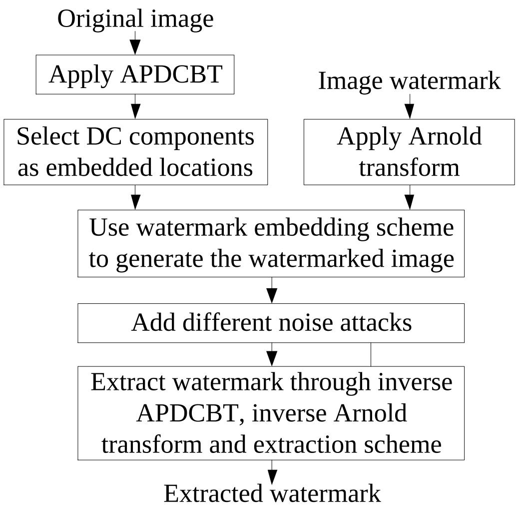



**Figure 3. Flow Chart of Watermarking Algorithm based on APDCBT**

## 4. Simulation Experiment and Analysis

The algorithm is tested on MATLAB 7.14 with a computer of Intel (R) Core (TM) i3-2100 3.10GHz CPU, 2GB memory. We apply our algorithm to various standard test images. Here we give the results of $512\times 512$ 8bits/pixel gray-level image "Lena.bmp" in Fig. 4 and 64×64 binary image watermark in Fig. 5. The robustness is tested under four types of attacks: JPEG compression, Gaussian noise, salt & pepper noise and rotation.

### 4.1. Performance Evaluation

In order to evaluating the imperceptibility and robustness of a watermarking algorithm objectively, we use the following three indexes.

(1) Peak Signal-to-Noise Ratio (PSNR)

PSNR evaluates the imperceptibility of the algorithm. For an image with size of $M\times N$, the PSNR is defined as

$$\mathrm{PSNR}=10\lg\left[\frac{255^2 MN}{\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left[x(i,j)-\hat{x}(i,j)\right]^2}\right](\mathrm{dB}), \tag{5}$$

where $x(i,j)$ and $\hat{x}(i,j)$ denote the pixel values in row $i$ and line $j$ of the host image and the watermarked image respectively.

(2) Bit Error Rate (BER)

BER evaluates the data transmission accuracy of the algorithm. For a watermark with size of $m\times n$, the BER is defined as

$$\mathrm{BER}=\frac{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left|\hat{\omega}(i,j)-\omega(i,j)\right|}{L}, \tag{6}$$

where $\omega(i, j)$ and $\hat{\omega}(i, j)$ denote the pixel values at the location $(i, j)$ of the original watermark and the recovered watermark respectively. $L$ expresses the length of the watermark information.

(3) Normalized Correlation (NC) Value

NC evaluates the robustness of the algorithm and reveals the correlation between the original watermark and the extracted watermark. NC is defined as

$$\mathrm{NC} = \frac{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\omega(i, j)\times\hat{\omega}(i, j)}{\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\omega(i, j)\times\omega(i, j)}. \tag{7}$$

### 4.2. Comparison of Invisibility

We control embedding intensity of the watermark information and compare BER and NC values at different PSNR values. Fig. 6 shows the watermarked images at PSNR=40dB. Due to the characteristics of energy accumulation and high frequency attenuation of APDCBT, the watermarked image will be impaired (Fig. 6(a)) if we choose the intermediate frequency as the location of embedding watermark. By contrast, we get good subjective visual quality if we embed the watermark information in DC components (Figure 6(b)).

**Figure 4. Original Lena Image**

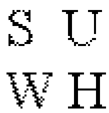



**Figure 5. Binary Image Watermark**

(a) (b)

**Figure 6. Watermarked images based on APDCBT: (a) Watermarked image embedding watermark in AC components, (b) Watermarked image embedding watermark in DC components**

Further, we calculate BER and NC values of extracted watermarks at different PSNR values, as shown in Table 2. With the increasing of watermark information intensity, the quality of the extracted watermark gets poor and the PSNR values decrease, which brings about the increasing of BER and the decreasing of NC. From Table 2 we also can reach the conclusion that watermarking algorithm based on APDCBT outperforms the one based on DCT not only in BER but also in NC. Due to the binary image watermark is simple and the amount of watermark information is small, the results are not significant. With the increasing of image watermark complexity, APDCBT will show more obvious advantages.

**Table 2. BER and NC values of Two Algorithms in Different PSNR Values**

| PSNR/dB | BER | | NC | |
|---|---|---|---|---|
| | DCT | APDCBT | DCT | APDCBT |
| 30 | 0.0994 | 0.1052 | 0.8986 | 0.8933 |
| 35 | 0.0461 | **0.0449** | 0.9532 | **0.9537** |
| 40 | 0.0112 | **0.0105** | 0.9885 | **0.9893** |
| 45 | $2.4414\times10^{-4}$ | **$2.4213\times10^{-4}$** | 0.9997 | **0.9998** |

### 4.3. Comparison of Robustness

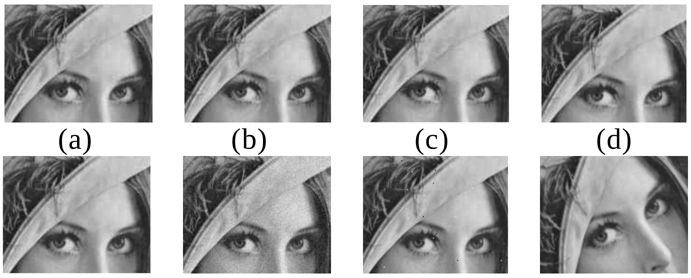
The performance of our watermarking algorithm is tested and compared with the original watermarking based on DCT. We use BER and NC values to test the robust under different attacks: JPEG compression attack with quality factor (QF)=30, 35, 40, 45 and 50, Gaussian noise (the mean is 0, the variance is 0.01), salt & pepper noise (the density is 0.001), and rotation (30°).

Figure 7 shows watermarked images with different noise attacks. Figure 8 displays local enlarged images of these watermarked images clearly. The experimental results of two algorithms after attacks are given in Table 3 and Table 4. Tables 3 and 4 show that BER is close to 0 and NC close to 1 when QF is greater than 50. Further, from the result data we can perceive that the BER values are smaller and the NC values are larger by using our algorithm. It means that our algorithm not only guarantees the correctness of the extracted watermarks, but also improves the robustness.

(a) (b) (c)

(d) (e) (f) (g) (h)

**Figure 7. Watermarked images adding different noise attacks: (a) JPEG compression (QF=30), (b) JPEG compression (QF=35), (c) JPEG compression (QF=40), (d) JPEG compression (QF=45), (e) JPEG compression (QF=50), (f) Gaussian noise, (g) Salt & pepper noise, (h) Rotation (30°)**



(a) (b) (c) (d) (e) (f) (g) (h)

**Figure 8. Local Enlarged Images of Watermarked Images in Figure 7 respectively**

**Table 3. BER Values of Two Algorithms after Attacks**

| Noise Attack | | BER | |
| --- | --- | --- | --- |
| | | DCT | APDCBT |
| JPEG Compression | QF=30 | 0.1155 | **0.1152** |
| | QF=35 | 0.0759 | **0.0552** |
| | QF=40 | 0.0166 | **0.0088** |
| | QF=45 | 0.0085 | **0.0019** |
| | QF=50 | 0.0000 | **0.0000** |
| Noising Attack | Gaussian | 0.1255 | **0.1228** |
| | Salt & Pepper | 0.0460 | **0.0352** |
| Geometrical Attack | Rotation | 0.0461 | **0.0449** |

**Table 4. NC Values of Two Algorithms after Attacks**

| Noise Attack | | NC | |
|---|---|---|---|
| | | DCT | APDCBT |
| JPEG Compression | QF=30 | 0.8802 | **0.8807** |
| | QF=35 | 0.9532 | **0.9404** |
| | QF=40 | 0.9885 | **0.9917** |
| | QF=45 | 0.9997 | **0.9981** |
| | QF=50 | 1.0000 | **1.0000** |
| Noising Attack | Gaussian | 0.8759 | **0.8770** |
| | Salt & Pepper | 0.9532 | **0.9658** |
| Geometrical Attack | Rotation | 0.9532 | **0.9537** |

Figure 9 and Figure 10 display the extracted watermarks according to the DCT watermarking algorithm and APDCBT watermarking algorithm. From the point of subjective vision, the advantage of our algorithm is not significant. On the whole, our algorithm extracts watermarks successfully.

In conclusion, the simulation experiments and attack tests above indicate that image watermarking technique based on APDCBT shows stronger robustness and invisibility. The experimental results illustrate that our algorithm is steady valid, robust and security.

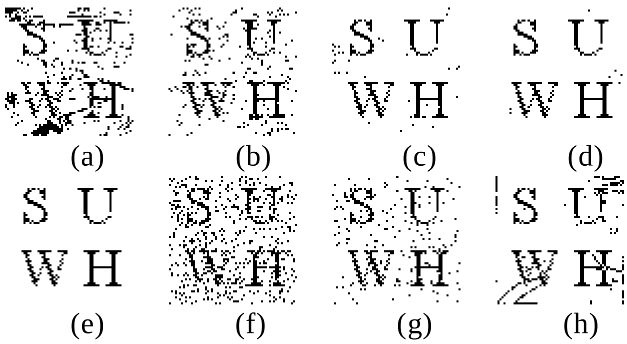


**Figure 9. Extracted Watermarks based on DCT in that Order (Figure 7) with Different Attacks**

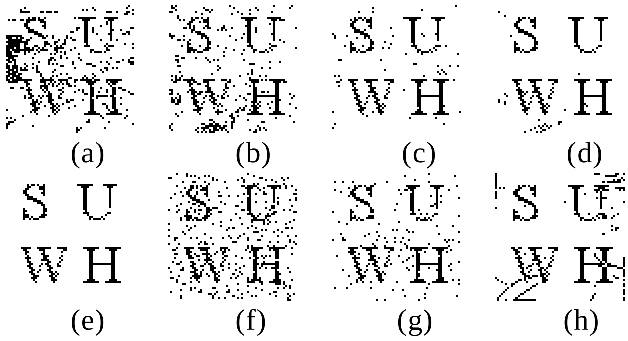


**Figure 10. Extracted Watermarks based on APDCBT in that Order (Figure 7) with Different Attacks**

## 5. Conclusion

In this paper, we have proposed a watermarking algorithm for digital image based on APDCBT and Arnold transform. The experiment results show that it has a good performance on imperceptibility and robustness. It is more robust to some common image processing including JPEG compression attack, Gaussian noise, salt & pepper and rotation than a DCT algorithm. Applying the Arnold transform to the watermark makes the results even better. Besides, it also saves lots of memory space. These are very important features for some environments that lack of resources such as mobile phone and other embedded systems.

For further work, we can apply all phase inverse discrete cosine biorthogonal transform (APIDCBT) to watermarking techniques in view of APIDCBT's better coding and high frequency attenuation properties.

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