Color Image Watermarking Based on Octonion Discrete Cosine Transform

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Abstract: There are few watermarking algorithms for color images. In most traditional watermarking algorithms, transforms are applied to each component of the color model individually resulting in less robust experimental results. Therefore, we propose a color image watermarking algorithm which is a high-dimensional algorithm. First, Octonion Discrete Cosine Transform (ODCT) and its inverter transform (IODCT) are proven. Then, a novel color image watermarking technique based on ODCT is proposed. Experimental results show that it not only has good anti to compression ability, but also has robustness to noise, filtering and rotation attacks.

Key words: Octonion, discrete cosine transform, color image watermarking.

1. Introduction

A digital watermark is a kind of marker covertly embedded in a noise-tolerant signal such as an image, video or image data, which is typically used to verify the authenticity or integrity of the carrier signal or to show the identity of its owners. Digital watermarking technology has developed rapidly since 1993 because of its important position in information security. There are many research achievements, and many papers have been published on digital watermarking [1]. Moreover, influential international conferences and academic journals have also been published about digital watermarking [2].

Due to high precision, small data redundancy and high compression ratio, watermarking techniques for high-dimensional data are difficult to apply. Color image is an important part of the digital information, and researches on color image watermarking algorithms have attracted much attention recently [3-6]. Commonly used methods for watermarking are conducted in the transform domain, mainly include Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT) and Discrete Fourier Transform (DFT). Therefore, the color models which are used by these algorithms are RGB model, HSI model, YCbCr model and YIQ model. The components from the above algorithms are regarded as independent area for watermark embedding. However, it is low in efficiency.

Since Ell and Sangwine applied Quaternion theory to color image processing in 1992, there have been more and more color image watermarking algorithms [7], [8]. Nowadays, Quaternion has been widely applied to many fields of the color image processing, such as color image edge detection [9], filtering [10], encryption of digital watermarking [11] and color image matching [12]. Compared with traditional color image processing, color image processing based on Quaternion is a multi-channel method. Thus, it has a great advantage in computing space and retaining color image the relationship between each channel of color image.

However, high-dimensional data may be more complex than three-dimensional data, and a method for higher dimensional data must be put forward also. Only using the Quaternion theory is not enough. With the development of high-dimensional mathematical theory, even new high-dimensional data watermarking algorithms have attracted much attention. Recently, the development of octonion theory has provided a new idea for high-dimensional watermarking algorithms. Therefore, on the one hand, Octonion Discrete Cosine Transform(ODCT) and its inverter transform are proven; on the other hand, color image watermarking algorithm based on ODCT is also put forward.

Experiments show that color image watermarking algorithm based on ODCT is good at self-adaptability, robustness and invisibility.

2. Related Works

2.1. Arnold Scrambling

The purpose of image scrambling is to disorder the image information that eliminate the spatial correlation between pixels and avoid the tampering with the image by attackers. There are many commonly used methods of Scrambling, such as Arnold transformation, Hilbert curve and affine transformation [13]. Arnold transform algorithm is simple and after multiple transformations, image scrambling will return to the original image. Thus, this algorithm is chosen for scrambling the watermark image while attackers did not know the watermark scrambling frequency. Therefore, although attackers extracted the scrambling watermark image from watermark image, it was very difficult to transform scrambling images into meaningful watermark information.

For any $N \times N$ matrix, i and j are the original subscript in the matrix elements. After Arnold transform, the new subscript are i' and j'. Therefore, Arnold transform is defined as:

$$\begin{aligned} i' &= (i+j) \bmod N \\ j' &= (i+2j) \bmod N \end{aligned} \tag{1}$$

where $i, j = 0,1,\ldots N-1$. Matrix will be back to the original state after several transformations. The period T relates to the size of N. Set i and j begin from a point, and it will return to the beginning point after experience several times which is called as period T.

2.2. Octonion Discrete Cosine Transform

Let $e_0, e_1, \ldots, e_7$ be the basis elements of Octonion O [14], and $W = \{(1,2,3),(1,4,5),(2,4,6),(3,4,7),(2,5,7),(6,1,7),(5,3,6)\}$, then $e_0 = e_0^2, e_a e_0 = e_0 e_a = e_a, e_a^2 = -1, a = 1, \ldots, 7$. For any triple of $(a,b,g) \in W$, will have

$$\begin{aligned} e_a e_b &= e_g = -e_b e_a, e_b e_g = e_a = e_g e_b, \\ e_g e_a &= e_b = -e_a e_g \end{aligned} \tag{2}$$

Octonion is also called as Cayley number. For each $x \in O$, x is of the form $x = \sum_{k=0}^{7} x_k e_k$, $x_k \in R$. Octonion algebra is an alternative algebra; this means that the subalgebra generated by any two elements is associative.

Call the object $[x,y,z] = (xy)z - x(yz)$ to be an associator of x, y and z, then for any $x,y,z \in O$, have

$$[x,y,z]=[y,z,x]=[z,x,y],\\ [x,x,y]=0,[x,y,z]=-[y,x,z] \tag{3}$$

Let $a=a_0e_0+a_1e_1+...+a_7e_7$, $b=b_0e_0+b_1e_1+...+b_7e_7$, where $a_k,b_k\in R,k=0,1,\ ...7$. Denote a and b by $a=a_0+\vec{a}$ and $b=b_0+\vec{b}$. $\vec{a}$ is the imaginary part of a, and $\vec{b}$ is the imaginary part of b, then $ab=a_0b_0-\vec{a}\cdot\vec{b}+a_0\vec{b}+b_0\vec{a}+\vec{a}\times\vec{b}$. Especially, if a and b are pure Octonion numbers, then $ab=-\vec{a}\cdot\vec{b}+\vec{a}\times\vec{b}$.

The following is a brief introduction for Octonion presentation of color images:

First, define the coordinate axis which is in eight-dimensional vector space for color image plane $e_0,e_1\ldots,e_7$, and then define the vector function f in eight-dimensional vector space. Consider components of color image R,G,B,H,S,I as the relevant value of the imaginary part e_2,e_3,e_4,e_5,e_6,e_7 of vector function, and the relevant value of imaginary part e_0 and e_1 of vector function is 0. For the color image $f(x,y)$ whose size is $X\times Y$, x and y represent the row and column of matrix in which the pixel $x\in[0,X-1]$ and $y\in[0,Y-1]$. To sum up, Octonion representation of color image $f(x,y)$ is as follow:

$$\begin{aligned} f(x,y)&=f_{r1}(x,y)e_0+f_{r2}(x,y)e_1\\ &+f_i(x,y)e_2+f_j(x,y)e_3+f_k(x,y)e_4\\ &+f_H(x,y)e_5+f_S(x,y)e_6+f_I(x,y)e_7 \end{aligned} \tag{4}$$

Therein, the value of $f_{r1}(x,y)$ and $f_{r2}(x,y)$ is 0, $f_{i,j,k,H,S,I}(x,y)$ is the gray value of R,G,B,H,S,I of color image.

For Octonion analysis and related transform, the Octonion Fast Fourier Transform (OFFT) was proposed [15]. Therein, Octonion Fourier Transform is decomposed into four Plural Fourier Transforms use an existing Fast Fourier Transform [15].

Nowadays, we define Octonion Discrete Cosine Transform of $f(x,y)$ as follows:

$$C(p,s)=\alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}uf(x,y)N(p,s,x,y) \tag{5}$$

$$\begin{cases} \alpha(p)=\begin{cases}\sqrt{\frac{1}{X}} & p=0\\ \sqrt{\frac{2}{X}} & p\neq 0\end{cases}, \quad \alpha(s)=\begin{cases}\sqrt{\frac{1}{Y}} & s=0\\ \sqrt{\frac{2}{Y}} & s\neq 0\end{cases}\\ N(p,s,x,y)=\cos[\frac{\pi(2x+1)p}{2X}]\cos[\frac{\pi(2y+1)s}{2Y}] \end{cases} \tag{6}$$

where u is a unit Octonion which mode is 1, and $u^2=-1$. The result will be different when u is different, and parameter u can be represented as $u=u_2e_2+u_3e_3+u_4e_4+u_5e_5+u_6e_6+u_7e_7$. In this paper, we set $u_2=u_3=u_4=u_5=u_6=u_7=1/\sqrt{6}$.

Then, the formula of Inverter Quaternion Discrete Cosine Transform (IQDCT) can be promoted to Octonion. Therefore, relevant Inverter Octonion Discrete Cosine Transform (IODCT) of $f(x,y)$ can be also defined as:

$$f(x,y)=-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)uC(p,s)N(p,s,x,y) \tag{7}$$

where $f(x,y)$ is spatial domain, and $C(p,s)$ is frequency domain. Also, $C(p,s)$ is Octonion, and it can be represented as:

$C(p,s)$ can be considered as ODCT spatial domain of color image, and $C_{r,1,i,j,k,H,S,I}(p,s)$ is the spectral distribution of R,G,B,H,S,I in Octonion space of color image.

The real part of color image $f(x,y)$ which only includes six imaginary parts is 0. To ensure there are still six imaginary parts after embed the watermark, spectrum $C(p,s)$ would include eight parts. It means that can still use color image components for representation and transmission that it must verify that the real part of Octonion which come from $C(p,s)$ of IODCT is 0. Otherwise, information from this real part will be lost, and image would be distorted. Therefore, calculate the relevant inverter transform, and mark it as $f'(x,y)$.

Next, IODCT relevant to $f(x,y)$ is verified. According to the definition of IODCT, we would calculate each component of $f'(x,y)$ as equation (9); inverter transform of real parts is equation (10):

$$\begin{cases}
f'_{r1}(x,y)= \\
\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_i(p,s)+u_3C_j(p,s)+u_4C_k(p,s) \\
+u_5C_H(p,s)+u_6C_S(p,s)+u_7C_I(p,s)]N(p,s,x,y) \\
f'_{r2}(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_j(p,s)-u_3C_i(p,s)-u_5C_k(p,s) \\
+u_4C_H(p,s)+u_7C_S(p,s)-u_6C_I(p,s)]N(p,s,x,y) \\
f'_i(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_r(p,s)+u_3C_1(p,s)-u_6C_k(p,s) \\
-u_7C_H(p,s)+u_4C_S(p,s)+u_5C_I(p,s)]N(p,s,x,y) \\
f'_j(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_3C_r(p,s)-u_2C_1(p,s)-u_7C_k(p,s) \\
+u_6C_H(p,s)-u_5C_S(p,s)+u_4C_I(p,s)]N(p,s,x,y) \\
f'_k(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_4C_r(p,s)+u_5C_1(p,s)+u_6C_i(p,s) \\
+u_7C_j(p,s)-u_2C_S(p,s)-u_3C_I(p,s)]N(p,s,x,y) \\
f'_H(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_5C_r(p,s)-u_4C_1(p,s)+u_7C_i(p,s) \\
-u_6C_j(p,s)+u_3C_S(p,s)-u_2C_I(p,s)]N(p,s,x,y) \\
f'_S(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_6C_r(p,s)-u_7C_1(p,s)-u_4C_i(p,s) \\
+u_5C_j(p,s)+u_2C_k(p,s)-u_3C_H(p,s)]N(p,s,x,y) \\
f'_I(x,y)= \\
-\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_7C_r(p,s)+u_6C_1(p,s)-u_5C_i(p,s) \\
-u_4C_j(p,s)+u_3C_k(p,s)-u_2C_H(p,s)]N(p,s,x,y)
\end{cases} \tag{9}$$

$$\begin{cases} f'_{r1}(x,y) = \\ \sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_i(p,s)+u_3C_j(p,s)+u_4C_k(p,s) \\ +u_5C_H(p,s)+u_6C_S(p,s)+u_7C_I(p,s)]N(p,s,x,y) \\ f'_{r2}(x,y) = \\ \sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_j(p,s)-u_3C_i(p,s)-u_5C_k(p,s) \\ +u_4C_H(p,s)+u_7C_S(p,s)-u_6C_I(p,s)]N(p,s,x,y) \end{cases} \tag{10}$$

$$\begin{cases} C_r(p,s) = \\ -\alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_2 f_i(x,y)+u_3 f_j(x,y)+u_5 f_H(x,y) \\ +u_6 f_S(x,y)+u_7 f_I(x,y)+u_4 f_k(x,y)]N(p,s,x,y) \\ C_1(p,s) = \\ -\alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_3 f_i(x,y)-u_2 f_j(x,y)+u_5 f_k(x,y) \\ -u_4 f_H(x,y)+u_6 f_I(x,y)-u_7 f_S(x,y)]N(p,s,x,y) \\ C_i(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_4 f_S(x,y)+u_5 f_I(x,y)-u_6 f_k(x,y) \\ -u_7 f_H(x,y)]N(p,s,x,y) \\ C_j(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_4 f_I(x,y)+u_6 f_H(x,y)-u_5 f_S(x,y) \\ -u_7 f_k(x,y)]N(p,s,x,y) \\ C_k(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_6 f_i(x,y)+u_7 f_I(x,y)-u_3 f_I(x,y) \\ -u_2 f_S(x,y)]N(p,s,x,y) \\ C_H(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_7 f_i(x,y)+u_3 f_S x,y)-u_6 f_j(x,y) \\ -u_2 f_I(x,y)]N(p,s,x,y) \\ C_S(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_5 f_j(x,y)+u_2 f_k(x,y)-u_4 f_i(x,y) \\ -u_3 f_H(x,y)]N(p,s,x,y) \\ C_I(p,s) = \\ \alpha(p)\alpha(s)\sum_{x=0}^{X-1}\sum_{y=0}^{Y-1}[u_3 f_k(x,y)+u_2 f_H(x,y)-u_4 f_j(x,y) \\ -u_5 f_i(x,y)]N(p,s,x,y) \end{cases} \tag{11}$$

Put each component of $C(p,s)$ in equation (11) (the expression of each component of $C(p,s)$) into equation (10) of $f'_{r1}(x,y)$ and $f'_{r2}(x,y)$. Get the value of $f'_{r1}(x,y)$ and $f'_{r2}(x,y)$ is 0. The expression of $f'_i(x,y)$ is:

$$f'_i(x,y) = -\sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[u_2C_r(p,s)+ \\ u_3C_1(p,s)-u_6C_k(p,s)-u_7C_H(p,s)+ \\ u_4C_S(p,s)+u_5C_I(p,s)]N(p,s,x,y) \tag{12}$$

Put $C_r(p,s), C_1(p,s), C_k(p,s), C_H(p,s), C_S(p,s), C_I(p,s)$ of equation (11) into equation (12) of $f'_i(x,y)$:

$$f'_i(x,y) = \sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[\alpha(p)\alpha(s)\cdot \\ \sum_{x=0}^{X-1}\sum_{y=0}^{Y-1} f_i(x,y)N(p,s,x,y)]N(p,s,x,y) \tag{13}$$

Equation (14) can be obtained in accordance with the definition of Plural Discrete Cosine Transform and inverter transform:

$$f'_i(x,y) = \sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)[\alpha(p)\alpha(s)\cdot \\ \sum_{x=0}^{X-1}\sum_{y=0}^{Y-1} f_i(x,y)N(p,s,x,y)]N(p,s,x,y) \\ = \sum_{p=0}^{X-1}\sum_{s=0}^{Y-1}\alpha(p)\alpha(s)F(p,s)N(p,s,x,y) = f_i(x,y) \tag{14}$$

Similarly, the following equation can be obtained:

$$f'_j(x,y) = f_j(x,y), f'_k(x,y) = f_k(x,y), \\ f'_H(x,y) = f_H(x,y), f'_S(x,y) = f_S(x,y), \\ f'_I(x,y) = f_I(x,y) \tag{15}$$

After IODCT, the value of $f'_{r1}(x,y)$ and $f'_{r2}(x,y)$ is 0. From equation (14) and (15), the value of every component after inverter transform as the same as before transform, thus the definition of IODCT for color images $f(x,y)$ is established.

3. Watermark Algorithm Based on ODCT

3.1. Watermark Embedding

According to ODCT, there is not any relationship between $f_r'(x,y)$ and $C_1(p,s)$, $C_r(p,s)$ in the process of watermark embedding. Therefore, to guarantee $f_r'(x,y)=0$, $C_1(p,s)$ and $C_r(p,s)$ are embedded into watermark.

Watermark information is embedded into $C_1(p,s)$ and $C_r(p,s)$, the distribution of value of $C_1(p,s)$ and $C_r(p,s)$ are changed. Although watermark information is embedded into the real part of the image spectrum only in the frequency domain, it is embedded in six components R,G,B,H,S,I for the distribution of the image space domain during embedding process one time. Therefore, the error from watermarking is not only scattered to the entire image, but also scattered to the R,G,B,H,S,I. Moreover, it is more difficult of making watermark to be detected. Furthermore, it is better to improve the anti-attack capability of watermarking algorithm. Watermarking algorithm based on ODCT is previewed.

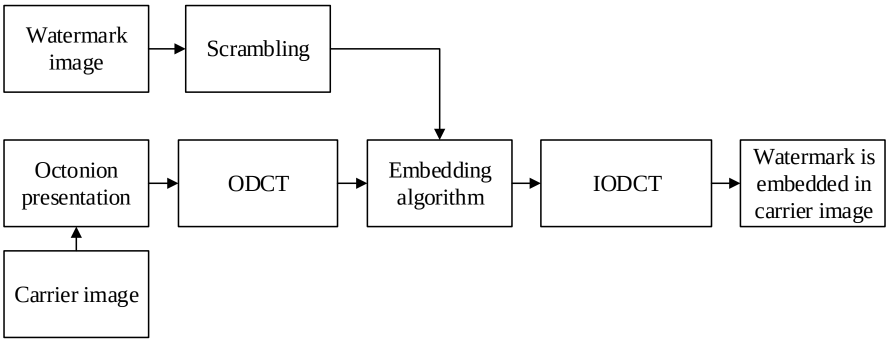

Fig. 1. The flow chart of watermark embedding algorithm.

(1) The color image carrier $f(x,y)$ is divided into R,G,B,H,S,I. Therein, H,S,I from each pixel can be represented by R,G,B.

(2) Color watermark image is divided into R,G,B,H,S,I and Arnold transform will be applied to them respectively.

(3) The six components of $f(x,y)$ are divided into N blocks, the size of each block is 8×8, each block is presented as a matrix of Octonion $f^{(e)}(x,y), e = 1, 2, \dots N$.

(4) Select parameter u and calculated three components of ODCT corresponding to $f^{(e)}(x,y)$, denoted by $C^{(e)}(p,s)$. And then extract the coefficient $C_r^{(e)}(p,s)$ and $C_1^{(e)}(p,s)$ of the real part to embed information, and the remaining coefficient $C_{i,j,k,H,S,I}^{(e)}(p,s)$ remains unchanged.

(5) Select medium frequency coefficients $C_r^{(e)}(p,s)$ and $C_1^{(e)}(p,s)$. Information of color watermark image $w(x,y)$ is divided into N groups, R,G,B information were embedded in the medium frequency coefficients $C_r^{(e)}(p,s)$, H,S,I information were embedded in the medium frequency coefficients $C_1^{(e)}(p,s)$. Then $C_r^{(e)}{}'(p,s)$ and $C_1^{(e)}{}'(p,s)$ are obtained. The formula of embedding process is calculated as follows:

$$\begin{cases} C_r^{(e)}{}'(p,s) = C_r^{(e)}(p,s) + a * w(x,y) \\ C_1^{(e)}{}'(p,s) = C_1^{(e)}(p,s) + a * w(x,y) \end{cases} \tag{16}$$

Therein, a is embedding strength which is the energy value of each component of watermark.

(6) $C^{(e)}{}'(p,s)$ is obtained from $C_r^{(e)}{}'(p,s)$, $C_1^{(e)}{}'(p,s)$ and $C_{i,j,k}^{(e)}(p,s)$, then $f^{(e)}{}'(x,y)$ is obtained from Octonion discrete cosine inverter transform (parameter u).

(7) All blocks $f^{(e)}{}'(x,y)$ are combined according to the sequence, and the color image embedded with watermark will be $f'(x,y)$.

3.2. Watermark Extraction

The watermark extraction is the reverse process of watermark embedding, and the process of watermark extraction is shown in Fig. 2.

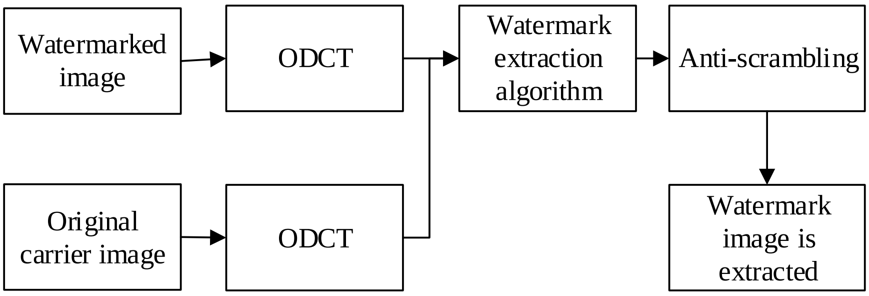

Fig. 2. The flowchart of the watermark extraction algorithm.

The specific steps of the watermark extraction process are as follows:

(1) The color image with watermark $f'(x,y)$ is divided into six parts, then these three parts are divide them into N blocks respectively. The size of each block is 8×8, and mark them as $f_1^{(e)}{}'(x,y), e=1, 2, \ldots N$.

(2) Original color image carrier $f(x,y)$ is divided into six parts, then divide them into N blocks respectively, the size of each block is 8×8, and mark them as $f_2^{(e)}{}'(x,y), e=1, 2, \ldots N$.

(3) Calculate the relevant ODCT of $f_1^{(e)}{}'(x,y)$ and $f_2^{(e)}{}'(x,y)$ (parameter is u), mark them as $C_1^{(e)}{}'(p,s)$ and $C_2^{(e)}{}'(p,s)$.

(4) Calculate the coefficient of each $C_{r1}^{(e)}{}'(p,s)$ and $C_{r2}^{(e)}{}'(p,s)$ corresponding original embed location to extract the watermark information. The extraction process is calculated as follows:

$$w(x,y)=\frac{1}{\alpha}*(C_{r1}^{(e)}{}'(p,s)-C_{r2}^{(e)}{}'(p,s)) \tag{17}$$

(5) Six components of watermark information is extracted by above step are anti-scrambled, and then watermarked image is obtained from fusion.

4. Experimental Results

The following is experiments about watermark embedding and extraction algorithm based on ODCT which are compared with the competing algorithm [16]. Fig. 3 is about the original carrier (one is Lena, the other is Peppers, both are 512×512×24) and original color watermark image (it is badge of South China Normal University, and its size is 64×64×24). The result of ODCT based algorithm will be shown by Fig. 3 and 4.

(a) Lena (b) Peppers (c) watermark

Fig. 3. The original image and watermark image.

(a) (b) (c) (d)

Fig. 4. Watermark algorithm based on ODCT: (a – d) watermarked Lena; extracted watermark from Lena; watermarked Peppers; extracted watermark from Peppers.

The robustness tests of watermarking are assessed by amplifying, noise, filtering, shearing, compressing, rotating and modifying attack to the embedded watermark image, and make a similarity test between the extracted watermark image and the original watermark image.

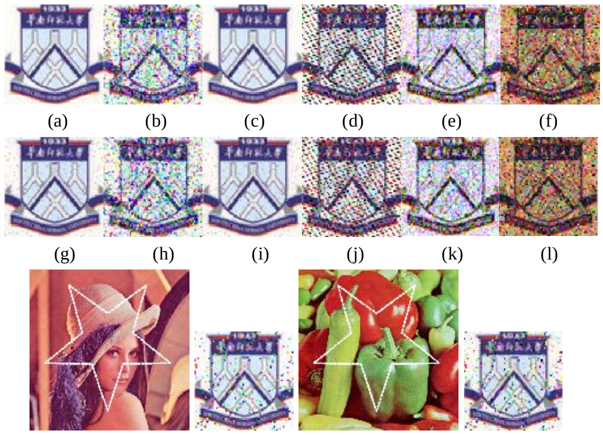

Fig. 5. Robustness test to attack: (a – f) watermark image extracted from watermarked Lena applied by double enlarge, salt and pepper noise, Gaussian filtering, 1/4 shearing, 80% JPEG compression and 10° rotation; (g – l) watermark image extracted from watermarked Peppers applied by double enlarge, salt and pepper noise, Gaussian filtering, 1/4 shearing, 80% JPEG compression and 10° rotation; (m & n) the watermark image extracted from watermarked Lena by Altered; (o & p) the watermark image extracted from watermarked Lena by Modification.

The value of the Peak Signal Noise Ratio (PSNR) and Normalized Correlation Coefficient (NC) of Lena and Peppers is shown by Table 1.

Table 1. PSNR and NC of Watermarked Lena and Peppers Confronted with Different Attack

	Our method				**Competing method [16]**			
	Lena		Peppers		Lena		Peppers	
	PSNR	NC	PSNR	NC	PSNR	NC	PSNR	NC
double enlarge	39.980	0.977	40.584	0.972	36.806	0.980	35.524	0.964
salt and pepper noise	39.615	0.867	40.165	0.857	36.633	0.867	35.399	0.855
Gaussian filter	39.980	0.977	40.584	0.972	36.806	0.980	35.524	0.964
1/4 shearing	29.811	0.817	29.805	0.816	29.419	0.804	29.261	0.796

80% JEPG compression	35.367	0.918	33.313	0.897	34.858	0.942	32.737	0.907
10° rotation	39.548	0.724	37.076	0.713	37.082	0.714	34.946	0.674
modification	36.309	0.938	36.472	0.936	34.711	0.944	33.837	0.927

Compared with competitive watermarking algorithm [16], our algorithm has made some improvements. From the Table 1, our algorithm is superior to the robustness and invisibility of the competitive algorithm [16] after rotation and modification etc.

Especially, the RGB model-based HIS model is considered by our algorithm. Octonion theory is first applied to color image watermarking. However, color image carriers is necessary in extraction process. In the future research, we will focus on extraction of watermarks without the original image carrier.

5. Conclusion

In this paper, the formula of Octonion Discrete Cosine Transform (ODCT) is defined. Moreover, the formula of Inverter Octonion Discrete Cosine Transform (IODCT) is also proved. Then, a color image watermarking algorithm based on ODCT is proposed: R,G,B,H,S,I of color image are transferred by ODCT, so that the watermark information is distributed to R,G,B,H,S,I components. This method not only good has good anti-compression ability, but also has strong robustness and invisibility in terms of noise, image scaling, filtering, rotation and geometric attacks.

Although this novel algorithm performs positive results in experiments, there are some issues must be fixed:

First, in watermark embedding process, the watermark embedding strength must be improved, to make the watermark embedding for the purpose to achieve better adaptability. Furthermore, better balance between watermark robustness and invisibility is achieved.

Second, color image carrier is needed by this algorithm in the watermark extraction process. In the future research, we will focus on how to extract the watermark without the original image carrier and embed multiple watermark images in color image in order to achieve the double protection of copyright and tamper.

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References

[1] Ruanaidh, J. J. K. O., Dowling, W. J., & Boland, F. M. (1996). Watermarking digital images for copyright protection. *Proceedings of the Image and Signal Processing*, *143*, 250-256.

[2] Schyndel, R. G. V., & Osborne, C. F. (1994). A digital watermark. Presented at the International Conference on Image Processing.

[3] Liu, H., Kong, X., Kong, X., & Liu, Y. (2001). Content based color image adaptive watermarking scheme. *Proceedings of the 2001 IEEE International Symposium on Circuits and Systems*.

[4] Zhang, T., & Du, Y. (2009). A digital watermarking algorithm for color images based on DCT. *Proceedings of the 2009 International Conference on Information Engineering and Computer Science*.

[5] Zhang, G., Wang, S., & Nian, G. (2004). A blind watermarking algorithm based on DWT for color image. *Proceedings of the 2004 Joint Conference of the 10th Asia-Pacific Conference on Communications and the 5th International Symposium on Multi-Dimensional Mobile Communications Proceedings*.

[6] Khalili, M., & Asatryan, D. (2012). Effective digital image watermarking in YCbCr color space accompanied by presenting a novel technique using dwt. *Computer Science*.

[7] Sangwine, S. J. (1996). Fourier transforms of colour images using quaternion or hypercomplex, numbers. *Electronics Letters*, *32*, 1979-1980.

[8] Sangwine, S. J. (1998). Colour image edge detector based on quaternion convolution. *Electronics Letters*, *34*, 969-971.

[9] Ouyang, J., Coatrieux, G., Chen, B., & Shu, H. (2015). Color image watermarking based on quaternion Fourier transform and improved uniform log-polar mapping. *Computers & Electrical Engineering*, *46*, pp. 419-432.

[10] Bas, P., Bihan, N. L., & Chassery, J. M. (2003). Color image watermarking using quaternion Fourier transform. *Proceedings of the 2003 IEEE International Conference on Acoustics, Speech, and Signal Processing*.

[11] Wang, X., Zhai, H., Li, Z., & Ge, Q. (2011). Double random-phase encryption based on discrete quaternion fourier-transforms. *Optik - International Journal for Light and Electron Optics*.

[12] Feng, W., & Hu, B. (2008). Quaternion discrete cosine transform and its application in color template matching. *Proceedings of the 2008 Congress on Image and Signal Processing*.

[13] Hamilton, W. R., & Hamilton, W. E. (1866). Elements of quaternions: Longmans, green, and company.

[14] Li, X. (1998). The Octonion analysis. PhD Thesis of Peking University.

[15] Jin, Z. (2010). Octonion fast fourier transform. Master Thesis of South China Normal University.

[16] Jiang, S., Zhang, J., & Hu, B. (2009). An adaptive watermarking algorithm in the hypercomplex space of a color image. *Acta Electronica Sinica*.

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