Research on Color Image Watermarking Algorithm Based on Quaternion Fourier Transform

Yongqiang Ma¹, Shunli Wang¹, Wei Sun¹, Jing Bian¹, YinBo Liu¹

School of Computer Science, Jining Normal University, Wulanchabu, Inner Mongolia, 012000, China

¹Corresponding author’s e-mail: nsd-myq@126.com

Abstract. This paper mainly proposes a color image digital watermarking algorithm based on quaternion Fourier transform (QFT). We can describe color image as a quaternion matrix, then we can use QFT to get its frequency domain information. By using Fourier transform, we can embed the watermarking information into the frequency domain information. By using inverse QFT, we can get a color image that contain watermarking information. All of the steps can be reversible, so the watermarking extraction process is opposite to the embedding process. The advantage of processing color image by quaternion theory is that three color channels of the image can be treated as a whole.

1. Introduction

With the rapid development and maturity of the Internet and multimedia technology, the efficient storage management, fast transfer sharing and real-time analysis and processing of multimedia resources have gradually become essential parts of people's work and life. In view of the advantages of digital information being open, compatible, and shared, most media resources will exist in digital form and spread in the Internet environment. The rapid development of the Internet has made it easier and more convenient for people to obtain the digital multimedia resources they need.

But everything has dual character. The Internet is also a "double-edges sword", which brings convenience to people but also a lot of negative impacts. The security of digital media resources has been greatly threatened and challenged in the open Internet environment. Many resources have been copied, tampered and disseminated without the permission of the copyright owner. Many criminals have made huge profits by this method, which not only damages the legitimate rights and interests of the copyright owner, but also seriously affected the healthy development of the digital media industry. In addition, e-commerce and telemedicine have developed rapidly in recent years, and a large number of forged transaction bills and patient medical records have appeared in the Internet, which undoubtedly caused a crisis of trust in the security of these network applications. Therefore, strengthening the security protection of digital media resources has become a research hotspot, and copyright protection and content authentication of digital multimedia have also become important research topics.

The traditional information security protection of digital multimedia generally used digital encryption and digital signature technology. Although the multimedia information security is protected to a certain extent, there are many defects in practical applications. In digital encryption technology, if the digital media works are decrypted, the problems of illegal copying, tampering and re-dissemination cannot be solved. Digital signature technology can only be used to determine the authenticity of digital media content, and it is difficult to mark the exact location of tampering.
In response to the shortcomings of traditional technology, a more effective digital media information security protection technology, which called digital watermarking, has been proposed in recent years, and it has received increasing attention from researchers all over the world.

Digital watermarking technology is an important branch of the current information security field. As an active authentication method for copyright protection and authenticity authentication, it has become an important means of protecting multimedia information security. Digital images are the most important part of multimedia resources, and digital image watermarking has also become the core research direction in digital watermarking technology. It has played an important role in digital image content authentication and copyright protection. In the open Internet environment, digital image watermarking technology hides the watermarking information into the image content which should be protected. When implementing the copyright protection process, it is necessary to ensure that the visual quality of the carrier image is not significantly reduced. After the attack, most of the hidden watermarking information can still be extracted.

2. Color image
Images are an important carrier for humans to obtain information. With the rapid development of computer hardware equipment and the rapid increase of computing speed, digital image processing technology has also developed very well. Color images carry more information than grayscale images, and color image processing has become an important research area in signal processing disciplines. Unlike grayscale images, color images have three color channels, and there is a spectral relationship between them. Many methods for processing grayscale images cannot be used to process color images directly, which also makes color image processing more difficult.

Color images have three color channels, so we need to use three-dimensional vectors to represent them. We most commonly use RGB color space to represent color images. It is based on the principle of three primary colors. In the RGB color space, light of any color can be obtained by superimposing three colors of red, green and blue. Other color spaces include HSV space and YUV space.

The application of quaternions in color image processing is receiving increasing attention. Based on quaternion theory, ELL and others in the UK have done a lot of work in color image processing. In 2001, S.C.Pei[1] and others used traditional two-dimensional Fourier transforms to implement QFT based on the work that ELL and Sangwine did with QFT. It was pushed and summarized in detail. In recent years, some domestic scholars have also made some achievements in quaternion color image processing. Xing Yan[2] of Hefei University of Technology has proposed a color image decomposition algorithm and a digital watermarking algorithm. This algorithm requires that the watermarked image should be a grayscale image. Gai Qi[3] of Nankai University proposed a color image information hiding technique.

The above results show that the three components of a color image should be considered as a whole, which allows us to understand problems that were difficult to solve in the past, obtain the characteristics of color images, and obtain new research methods and corresponding results. However, the research on quaternion representation and processing of color images is still in its infancy, and its theoretical system needs to be further improved.

3. Quaternion Fourier Transform
Quaternion was proposed by Irish mathematician W.R.Hamilton in 1843, who generalized complex space to four-dimensional space[4][5].

The quaternion is a number in a four-dimensional space that has a real part and three imaginary parts. Where \(q\) represents the quaternion, and we defined it as

\[
q = a + bi + cj + dk
\]

(1)

Where \(a, b, c, d\) is the real part and \(i, j, k\) are the imaginary part. The conditions it holds can be expressed as

\[
i^2 = j^2 = k^2 = ijk = -1
\]

(2)
\[ \begin{align*}
ji &= -k, kj = -i, jk = -j \\
ij &= k, jk = i, ki = j
\end{align*} \] (3)

When \( a = 0 \), we can consider \( q \) as a pure quaternary imaginary number.

The \(|q|\) can be given by

\[ |q| = \sqrt{a^2 + b^2 + c^2 + d^2} \] (5)

There are two numbers \( q_1 \) and \( q_2 \), they can be expressed by

\[ q_1 = a_1 + b_1 i + c_1 j + d_1 k \] (6)
\[ q_2 = a_2 + b_2 i + c_2 j + d_2 k \] (7)

In the RGB color space, any color can be represented by a three-dimensional vector, so each pixel can be represented by a pure quaternary imaginary number. The three components R G and B are used as \( i, j, k \) coefficients \([6][7]\), so the color image can be represented by a quaternion matrix. In subsequent research, we can process the color image as a whole instead of dividing the whole into three grayscale images for processing.

For a general complex-valued function, its Fourier transform is given by

\[ F(u, v) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} f(x, y) e^{-i(ux + vy)} dx \, dy \] (8)

Quaternion Fourier Transform (QFT) can be expressed by

\[ F_{LR}(u, v) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} e^ {\mu \text{Re} f(x, y)} e^{-\mu \text{Im} f(x, y)} dx \, dy \] (9)

\[ F_L(u, v) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} e^{-\mu \text{Re} f(x, y)} f(x, y) dx \, dy \] (10)

\[ F_R(u, v) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} f(x, y) e^{-\mu \text{Im} f(x, y)} dx \, dy \] (11)

\[ f(x, y) = f_1(x, y) + f_2(x, y)i + f_3(x, y)j + f_4(x, y)k \] (12)

In image processing, the Fourier transform we use can be expressed as a discrete form, so the Quaternion Fourier Transform (QFT) can be given by

\[ F(u, v) = \frac{1}{\sqrt{MN}} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} e^{\frac{-\pi}{M} mu} e^{\frac{-\pi}{N} nv} f(m, n) \] (13)

\[ f(m, n) = \frac{1}{\sqrt{MN}} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} e^{\frac{\pi}{M} mu} e^{\frac{-\pi}{N} nv} F(u, v) \] (14)

4. Basic framework of digital image watermarking

Digital watermarking technology is essentially to rationally optimize these key steps such as watermark preprocessing, embedding location selection, embedding method design, and extraction method design, and seek to optimize design problems under constraints such as robustness, imperceptibility and security. For a complete digital watermarking system, it usually consists of two steps: digital watermarking embedding and digital watermarking extraction \([8][9]\).

4.1. Watermarking embedding process

We should define a digital image product \( O \), the key of the Embedding method can be expressed by \( K \), the embedding method can be expressed by \( F \). Then, the data information \( W \) that represented the copyright of the carrier is combined with the carrier by the \( F \) method to obtain a new carrier \( W' \), and the process is represented by

\[ W' = F(O, K, W) \] (15)

The key \( K \) and watermark embedding function \( F \) are known only by the designer who designs the embedding algorithm. When the multimedia product some body used was theft, if they who want to
steal the information have not the key that we defined in advance, they could not crack the embedding algorithm, it is hard to obtain the useful information of the digital image generally. The embedding process of digital watermarking technology is shown in figure 1.

Figure 1. Watermarking embedding process.

4.2. Watermarking extracting process
Non-blind extraction and blind extraction form the extracting operation of watermarking. The non-blind extracting watermarking refers to the process of extracting watermark information with the help of the original carrier and the digital product embedded with watermark. On the contrary, blind extraction means that the original image is not needed. Both of the two methods, the key of the embedded method needs to be recorded in advance, and the embedded information is extracted by using the extraction scheme and the recorded key, the selected method is recorded as $E$ and the extracted watermark we can call it $W''$, and it is given by

$$ W'' = E(I, W', K) \quad (16) $$

Watermarking extraction process can be expressed in figure 2.

Figure 2. Watermarking extraction process.

5. Conclusion
This paper proposed a new method based on the advantages of quaternion and Fourier transform. Its aim was to improve the robustness against attacks and it was used for color image watermark embedding and extraction. The quaternion discrete Fourier transform were applied in digital watermark algorithm.

We can describe color image as a quaternion matrix, then we can use QFT to get its frequency domain information. By using Fourier transform, we can embed the watermarking information into the frequency domain information. By using inverse QFT, we can get a color image that contain watermarking information.

This study point out the advantage of processing color image by quaternion theory. Three color channels of the image can be treated as a whole.

Acknowledgments
We would like to thank professor WANG and professor SONG for stimulating discussions with respect to the topic of this paper. This work was supported by Research Program of Science and technology at Universities of Inner Mongolia Autonomous Region (NJZZ20246).
References

[1] Pei, S.C., Ding, J.J., Chang, J.H. (2001) Efficient Implementation of Quaternion Fourier Transform, convolution and correlation by 2-D FFT. IEEE Transactions on Signal Processing., 49: 2784–2798.

[2] Xing, Y. (2009) Research on Quaternion and Its Applications in Graphics and Image Processing. Hefei University of Technology Publishing, Hefei.

[3] Gai, Q. (2009) Color Image Information Hiding Technology Based on Quaternion Theory. Nankai University Publishing, Tianjin.

[4] Chen, S.X., Feng, Y.B. (2014) Double Zero-Watermarking Algorithm Based on Quaternion and for Color Image. Computer Applications and Software., 31: 263–267.

[5] Sun, J., Yang, J.Y., Fu, D.S. (2014) Color Images Watermarking Algorithm Based on Quaternion Frequency Singular Value Decomposition. Information and Control., 33: 144–148.

[6] He, B. (2016) Zero Color Image Watermarking Based on Radon Transform and Quaternion Real Matrix Representation. Optical Technique., 42: 166–171.

[7] Lukac, R., Smolka, B., Martion, K., Plataniotis, K.N. (2005) Vector Filtering for Color Imaging. IEEE Signal Processing Magazine, 22: 74–86.

[8] Liu, F.M., Zhai, H.C., Yang, X.P. (2003) Kinoform-based iterative random phase encryption. Acta.Phys.Sin., 52: 2462–2465.

[9] Sangwine, S.J., ELL, T.A.J., Moxey, C.E. (2001) Vector phase correlation. Electronics Letters., 37: 1513–1515.