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Hybrid Watermarking Algorithm Using Clifford Algebra With Arnold Scrambling and Chaotic Encryption

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ABSTRACT With the widespread use of color images, the copyright protection of those images using watermarks is one of the latest research topics. The use of color images as watermarks has advantages over binary and irreplaceable grayscale images. Color images are intuitive, rich, and lively; they have large amounts of copyright protection information and more easily recognized by human vision. To improve the security of watermark information and embedding positions and improve the algorithm's robustness against various attacks, a Quaternion Fourier transform (QFT) based algorithm, based on Arnold transform and chaotic encryption, is proposed in this paper. Geometric algebra (GA) can deal with color images in vector form with each component of RGB handled individually. We used Quaternion, which is a sub-algebra of GA, and effectively handled color image processing by using Fourier transformation. After deriving the calculation process of the QFT with strong security by Arnold scrambling and chaotic encryption, this paper proposes a digital watermarking algorithm that resists geometric attacks by using color images as carriers. The robustness and quality of the proposed watermarking algorithm is tested with different with many statistical measures. Experimental outcomes show that the proposed approach is the best to solve conflict problems between quality and robustness. Also, the proposed approach exhibits worthy robustness against many attacks, such as, conventional attacks, and geometrical attacks.

INDEX TERMS QFT, Arnold scrambling, chaotic encryption, Clifford algebra.

I. INTRODUCTION

With the development of the network age and growing computer information technology, digital multimedia products have become a necessity in people's daily life, and, correspondingly, people's requirements for digital products have continued to grow. Therefore, the biggest problem now is the copyright protection of digital products. Solving this problem has become the focus of digital watermark research [1]–[3]. Digital watermarking technology embeds copyright information directly into the data itself, achieving the invisibility and

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security of the data, thereby achieving the purpose of copyright protection [5]. Digital watermarking technology can be embedded in the invisible technology of identifying digital products, and it has developed greatly. Digital watermarking technology embeds specific information about the digital media copyright owner, the user-designated logo or serial code, etc. into the protected information in a specific way [6]. When a copyright dispute arises, the digital watermark is extracted by a corresponding algorithm. The existence of the watermark should be based on the principle of not damaging the appreciation value and using data value instead.

Digital watermarking technology is divided into two categories: spatial domain and frequency domain [7].

Spatial domain watermarking is based on the modification of pixel location. Frequency domain based watermarking technology embeds watermark information into corresponding frequency coefficients through frequency domain transformation. This technology has better invisibility and robustness. Fazli *et al.* [8] and others [9], [10] proposed a watermarking algorithm combining Discrete Wavelet Transform (DWT) or Discrete Cosine Transform (DCT) with Singular Value Decomposition (SVD) and Arnold transform. Hu *et al.* [48] developed improved algorithm to make SVD watermarking more effective by using sign correction, level shift, mixed modulation and orthonormal restoration. This method had better invisibility and robustness and accomplished the blind extraction of watermark information, but it did not fully consider the watermark's embedding strength. Only the robustness analysis was performed on the watermark, without a simulated attack. Jing Liu *et al.* [11] proposed a digital watermarking scheme with Dual-Tree Complex Wavelet Transform- Discrete Cosine Transform DTCWT-DCT and a Henon Map using multiple watermarking techniques. This technique focused on finding a region of interest (ROI) and used the zero watermarking with chaotic scrambling to improve the security of the watermarking algorithm against geometric attacks. This technique was good for security, but it decreased performance speed as finding an ROI and performing a Henon Map is time-consuming, and the time needed will increase if color images are used in three different channels. Another approach is using 2D-DCT [49], performed on image blocks which are partitioned in small segments, and some fixed coefficients in the middle frequency are selected as embedding position of watermark. Then, the watermark embedding and extraction procedure are completed by modifying the relationship of size between the selected middle-frequency coefficients with the proposed rules.

Currently, image processing using DWT and Fourier transform (FFT) has increased year by year. FFT, a powerful tool for signal processing, is likened to a “prism of mathematics,” [12] which can be applied to research in multiple disciplines. In the field of image processing, FFT can realize the functions of image enhancement: denoising, segmentation, feature extraction, compression, and so on. In digital watermarking research, the FFT algorithm has also achieved results. In researching watermarking quantum images [12], taking a grayscale image as the carrier, watermarking was achieved by embedding watermark information in the images' Fourier coefficients. The idea of fractional Fourier transform (FrFT) has also recently been reflected in digital watermarking research. Singh *et al.* [13] proposed that the combination of FrFT and random phase coding in digital watermarking of optical images can conceal watermark information and resist some basic attacks. Ante Poljicak *et al.* [14] proposed that the image degradation is evaluated first, after embedding the watermark, and then, based on the evaluation results, the circular area of the Fourier frequency domain coefficient corresponding to the optimal

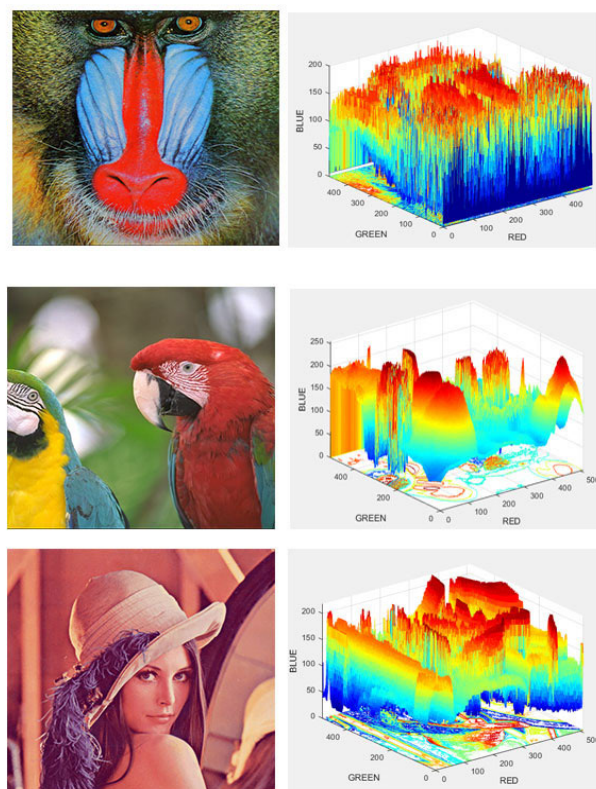


FIGURE 1. Color images and intensity of RGB spectrum.

radius of the image is selected to achieve maximum-intensity embedding. Bhatnagar *et al.* [15] proposed an algorithm to normalize the quality matrix of the image and then embed the information in response to the existing problems of singular value decomposition watermarking in the Fourier transform domain. Lin *et al.* [16] established a distortion model of the image after printing and scanning, analyzed the pixel and geometric distortion caused by this process, combined this with the research of spread spectrum theory, and proposed to embed watermark information in the Fourier-Mellin domain, which could resist rotation and distortions, such as panning and shearing. Dong and Qi [17] needled out the issues where digital watermarks could not resist rotation, translation, and shear attacks, discovered the FFT coefficients corresponding to Log-Polar Mapping coefficients, and embedded watermarks in FFT coefficients to avoid polar coordinate inversion. Based on the errors introduced by the transformation, Kang *et al.* [18] proposed a method combining synchronous template embedding based on the extracted template information to determine the scale suffered by the watermark image, which could resist attacks such as print scanning.

All the above-discussed methods are much better in grayscale watermarking, but in the field of color image digital watermarking, the algorithm combining the FFT and quaternion theory is increasingly showing advantages. Since

the three components of the pure quaternion exactly match the three channels of the color image, the algorithm can be applied to color image processing. Although some methods can make grayscale images clear, they are ineffective when applied to color images, and problems such as gradient flipping, halo artifacts, color distortion, and over-enhancement will impact image quality. Also, most methods do not consider the correlation of the three primary colors (R, G, B) in the color image, and they are usually divided into channels. Such a processing method will change the color mechanism of the original image. Fig. 1 shows how the intensity of each image is different at different levels, which makes it difficult to embed watermarks in particular positions. The first group to introduce quaternions into the field of digital watermarking was Sangwine [19]; they first decomposed the quaternions along a certain direction ($\mu = 2j + 8k$) into parallel and horizontal components, and then the watermark information embedding in a parallel direction completed the watermark embedding. Subsequently, many researchers discovered the weakness of the method's robustness and gradually improved the algorithm. Jiang [20] proposed a fast algorithm based on the computational complexity of the QFT and used a quantized index method to embed the digital watermark into the realities of the transformed coefficients. Overall, the visual imperceptibility of the watermark image was improved, to a certain extent. Tsui *et al.* [21] proposed a QFT digital watermarking method combined with the human visual system to eliminate chromatic aberrations in the Commission International Eclairage (CIE) channel. Hosny and Darwish [44] constructed watermarking algorithm using Quaternion Legendre-Fourier moments (QLFM) in polar coordinates, and proposed geometrically invariant color image watermarking scheme. In another work, they [45] presented medical image watermarking scheme based on Polar Complex Exponential Transform (PCET) and quaternion PCET (QPCET) for both gray-level and color medical images, respectively. In this paper, parallel implementation of multicore CPUs and GPUs which reduces the time of watermarking and increase performance. In 2019, Hosny and Darwish [47] constructed a novel kind of quaternion moments, i.e., Quaternion Radial Substituted Chebyshev Moments (QRSCM), which used the quantization technique on selected-magnitude and performance of watermarking with QRSCM in polar coordinates is further improved. Zhiqiu Xia *et al.* [46] proposed another approach using Quaternion Polar Harmonic Transforms (QPHT) with chaotic mapping which is lossless watermarking focused on quality of image in embedding as well as in extraction of watermark. Our approach is difficult which uses QFT with encryption of images (both host and watermark) which increase security in frequency domain transformation of image.

Cai-Yin *et al.* [22] and others [23], [24] used quaternion digital-to-analog modulation to embed a watermark in the amplitude in the Fourier frequency domain. Wang *et al.* [25] combined the least squares support vector machine with the algorithm of quaternion fast Fourier transform, analyzed

the distortion of the watermark image by using the idea of machine learning, then corrected it.

At present, the research of digital watermarking has entered a new stage; the early stages of the extensive use of various mathematical tools for modeling have passed. Some impractical algorithms have gradually been replaced and abandoned, and feasible arithmetic methods have been retained and developed. However, digital watermarking research requires the support of multidisciplinary theories, and the theoretical research foundations of each discipline are different. Some of the problems in theoretical research are: how to build a practical and effective watermark model, how to increase the watermark information embedding capacity, etc. The application problems are: how to build a watermarking protocol platform that can serve the public, how to realize the positioning and correction of webpage information, how to reduce the operating cost of watermarking technology, and how to promote it to ordinary consumer groups. Among those, the spatial domain and the quaternion frequency domain watermarking algorithms still have the following problems:

- How to effectively utilize QFT with other techniques (such as Arnold scrambling and chaotic mapping) to improve the quality of watermarking and the correlation between the original and watermarked image.
- How to improve the ability of quaternion digital watermarking to resist signal processing attacks and geometric attacks. Research on digital watermarking based on QFT is still in the early exploration stage, and various algorithms have basically realized the modeling process of embedding and extraction of digital watermarking. However, the form of resistance to attack is limited and the robustness is not strong, which cannot fully reflect the superiority of applying quaternions to color image watermarking.
- How to improve the effect of the masking function of the spatial watermark and enhance the preprocessing ability of the watermarked image. Previous algorithms had shortcomings, such as small embedding, masking functions that could not make clear judgments on images; poor visual perception ability and weak robustness, which led to slower innovation of digital watermarking algorithms; an inability to meet the needs of the application; and a failure to fully reflect the characteristics of the airspace algorithm with relatively simple and fast calculation speed.

Based on the above analysis, a new color watermarking algorithm based on QFT is proposed, which uses the three components of the RGB image separately and provides a robust watermarking algorithm with high security. Additionally, this algorithm is secure due to applying Arnold transform on watermark images before the embedding process. The further addition of chaotic encryption enhances the robustness of the watermarking algorithm and optimizes the strength of the embedded watermark. The paper is organized as follows:

Section II provides the introduction of Clifford algebra, sub-algebra Quaternions, and QFT with Arnold scrambling and chaotic encryption. Section III discusses the proposed algorithm with the steps of preprocessing the watermark, embedding it, then extracting it. Results and performance evaluations are discussed in Section IV. Finally, Section V concludes the paper and suggests future steps of this research.

II. PRELIMINARIES

In this section, we give an overview on Clifford algebra quaternions and QFT by using geometric algebra with the other author’s implementation methodologies. First, the geometric properties of Clifford algebra are discussed. Then, geometric product and projection operations in three-dimensional Clifford algebra space are discussed. Later, the Fourier transform and its calculation formula in Clifford algebraic space are introduced. Then, the existence theorem of Clifford algebra is studied.

A. CLIFFORD ALGEBRA AND QUATERNION

Clifford algebra, also known as geometric algebra, was developed from Clifford algebra and Grassmann. Since its appearance, many physicists have applied it to deal with time and space problems in physics. After over a hundred years of hard work by physicists and mathematicians, Clifford algebra has evolved into a more mature geometric theory [26]. With the development of computer technology, some researchers have applied Clifford algebra theory to the field of information processing, including computer vision, robotics, image processing, etc., and achieved significant results. For example, the literature [27] applies Clifford algebra theory to image processing and proposes a model for image and pattern matching using Clifford algebra. The sub-algebra of Clifford algebra is a quaternion. A quaternion is a number in a four-dimensional space. It has one real part and three imaginary parts. The quaternion q can be expressed as:

$$q = a + bi + cj + dk \tag{1}$$

a, b, c, d are real numbers, i, j, k are imaginary units, and the following relationships are satisfied:

$$\begin{aligned} i^2 = j^2 = k^2 = ijk = -1 \\ ij = k, jk = i, ki = j \\ ji = -k, kj = -i, ik = -j \end{aligned}$$

When $a = 0$, q is called a pure quaternary imaginary number. Module $|q|$ and conjugate \bar{q} are defined as follows:

$$|q| = \sqrt{a^2 + b^2 + c^2 + d^2} \tag{2}$$

$$\bar{q} = a - bi - cj - dk \tag{3}$$

There are two quaternions, q_1, q_2 , as follows:

$$q_1 = a_1 + b_1i + c_1j + d_1k \tag{4}$$

$$q_2 = a_2 + b_2i + c_2j + d_2k \tag{5}$$

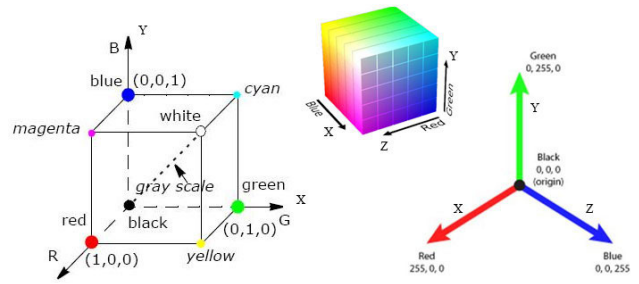


FIGURE 2. Color distribution of 3 dimensional RGB vector space in cubical format.

Addition, subtraction, and multiplication operations are defined as follows:

$$q_1 + q_2 = a_1 + a_2 + (b_1 + b_2)i + (c_1 + c_2)j + (d_1 + d_2)k \tag{6}$$

$$q_1 - q_2 = a_1 - a_2 + (b_1 - b_2)i + (c_1 - c_2)j + (d_1 - d_2)k \tag{7}$$

$$\begin{aligned} q = q_1 * q_2 = (a_1a_2 - b_1b_2 - c_1c_2)(a_1b_2 + b_1a_2 \\ + c_1d_2 + d_1c_2)i(a_1c_2 - b_1d_2 + c_1a_2 + d_1b_2) \\ \times j(a_1d_2 + b_1a_2 - c_1b_2 + d_1a_2)k \end{aligned} \tag{8}$$

The quaternion representation of color images is generally used in the literature [28]. Let the three imaginary components of the quaternion represent the three primary color components of red (R), green (G), and blue (B). The real part is 0, so that:

$$f(x, y) = f_R(x, y) + f_G(x, y) + f_B(x, y) \tag{9}$$

Each pixel of a color image is represented as a pure quaternion RGB, which represents the R, G, and B components of the color image, and x and y represent the coordinates of the image matrix in which the pixel exists.

The RGB color model is a unit cube in a three-dimensional rectangular coordinate color system, as shown in Fig. 2. On the main diagonal of this unit cube, the amounts of each primary color are equal, producing dark to bright gray or gray. (0, 0, 0) is black, (1, 1, 1) is white, and the other six corners of the cube are red, yellow, green, cyan, blue, and magenta. RGB’s three primary colors are additive primary colors; red, green, and blue can be superimposed to produce other colors, as shown in Fig. 2. Because the three primary colors have 256 brightness levels, they are superimposed to form 16.7 million colors. A continuous image can be discretized into a digital image represented by a two-dimensional matrix by sampling. Each pixel of the image corresponds to an element in the matrix. For grayscale images, the elements of the matrix represent the brightness of the corresponding pixels. For color images, the color of each pixel is represented by the three primary colors in the RGB color model, so each matrix element needs to store the three values of R, G, and B.

In this way, a color image can use a pure quaternion matrix. To represent the quaternion-based color image processing is

to process its quaternion matrix. Compared with the traditional sub-channels or the method of transforming an image into a grayscale image, the quaternion method can better reflect the integrity of color images, whether for theoretical innovation or practical application, providing a new direction.

B. QFT IN COLOR IMAGE PROCESSING

A color image is composed of three independent components. For example, in RGB space, it consists of R, G, and B components. HIS space consists of H, I, and S components, and so on.

For a color image $I(x, y)$ of size $X \times Y$, X and Y respectively represent the positions of the rows and columns of the matrix where the pixel is located: $X \in [0, X - 1]$, $Y \in [0, Y - 1]$. Let three imaginary quaternions represent the three primary color components of red (R), green (G), and blue (B). With a real part of 0, the color image $I(x, y)$ can be expressed as

$$I(x, y) = R(x, y)i + G(x, y)j + B(x, y)k \quad (10)$$

For any quaternion $f = f_r + f_i i + f_j j + f_k k$, it can be expressed in the form of modulo and phase as $|f| e^{\mu\phi}$. It can be seen that a color image can be expressed as a quaternion matrix and has the modulo and phase just like ordinary complex numbers. For the convenience of analysis, the image is expressed as:

$$f(x, y) = f_r(x, y) + f_i(x, y)i + f_j(x, y)j + f_k(x, y)k \quad (11)$$

For color images, the discrete Fourier transform of $f_r(x, y) = 0, f(x, y)$ can be defined as.

$$F(u, v) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} e^{-\mu 2\pi(\frac{xu}{X} + \frac{yv}{Y})} f(x, y) \quad (12)$$

The corresponding inverse transform is defined as

$$f(x, y) = \frac{1}{\sqrt{MN}} \sum_{u=0}^{X-1} \sum_{v=0}^{Y-1} e^{\mu 2\pi(\frac{xu}{X} + \frac{yv}{Y})} F(u, v) \quad (13)$$

In the formula, μ is a unit pure quaternion; the real part of μ is 0, the module is 1, and $\mu^2 = -1$. It can be seen from the above formula that different μ can be selected, and the result can be expressed by different parameters for μ .

$$\mu = \mu_i i + \mu_j j + \mu_k k \quad (14)$$

Here, we call $F(x, y)$ the spatial domain and $F(u, v)$ the frequency range, so $F(u, v)$ can be regarded, as the spectrum $F(u, v)$ of the color image is also a quaternion, which can be expressed as:

$$F(u, v) = F_r(u, v) + F_i(u, v)i + F_j(u, v)j + F_k(u, v)k \quad (15)$$

C. IMAGE SECURITY AND ENCRYPTION

1) ARNOLD SCRAMBLING

Arnold transform, also called cat mapping, was proposed by V. I. Arnold in the research of ergodic theory, and then it was applied to digital images [31]. The digital images can be changed by the Arnold transform, which can change the

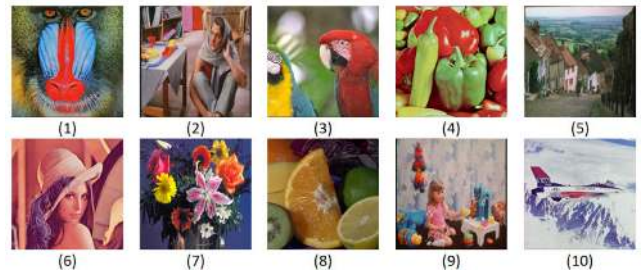


FIGURE 3. Selected color host images for watermarking.



FIGURE 4. Different colored watermark images.

coordinates of pixels. An $N \times N$ image can be displayed in matrix form, and its Arnold transformation formula is as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ab \\ cd \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \text{ mod } N, x, y \in \{0, 1, \dots, N - 1\} \quad (16)$$

The coordinates in the original image are (x, y) , and (x', y') is the new position of the pixel, corresponding to the (x, y) point after transformation. If all the pixels in the $N \times N$ image are processed by formula 3-2, an Arnold transform is completed. If you want to perform an Arnold transform k times for an $N \times N$ sized image, the transformation formula is as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} ab \\ cd \end{bmatrix}^k \begin{bmatrix} x \\ y \end{bmatrix} \text{ mod } N, x, y \in \{0, 1, \dots, N - 1\} \quad (17)$$

Someone later pointed out a more general form of transformation that can accomplish the same thing as the Arnold transform:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1k \\ 1k + 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \text{ mod } N, x, y \in \{0, 1, \dots, N - 1\} \quad (18)$$

The advantage of this conversion form is that the value of k can be obtained by the implementer of the watermark scheme and saved as a key form, which increases the security of the watermark information.

Arnold transform is a type of periodic transform; if we continuously scramble an image, we can transform the transformed image into the original image.

2) CHAOTIC ENCRYPTION

Chaotic system is a kind of non-linear dynamic with characteristics such as pseudo-randomness, high sensitivity to initial values, and non-linearity, which makes it very suitable for image encryption [8], [11].

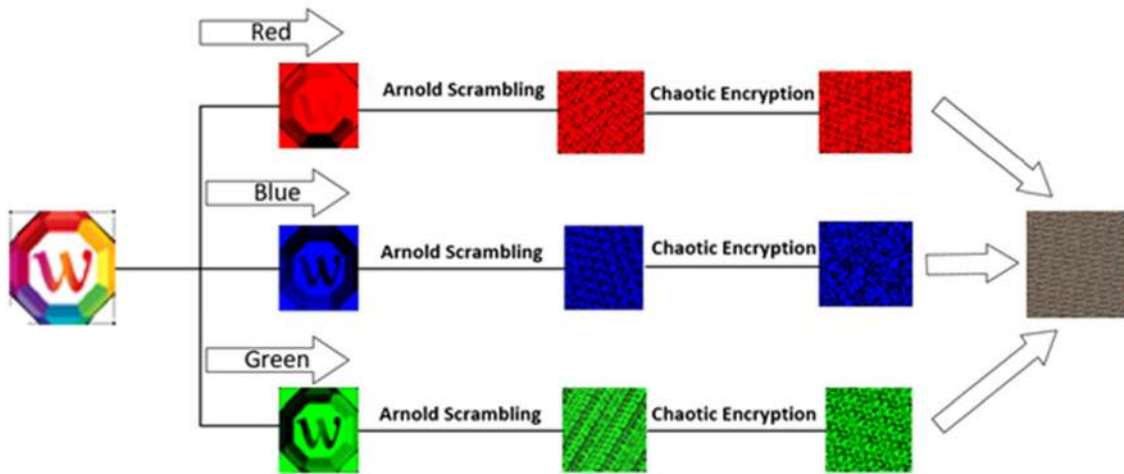


FIGURE 5. Watermark preprocessing.

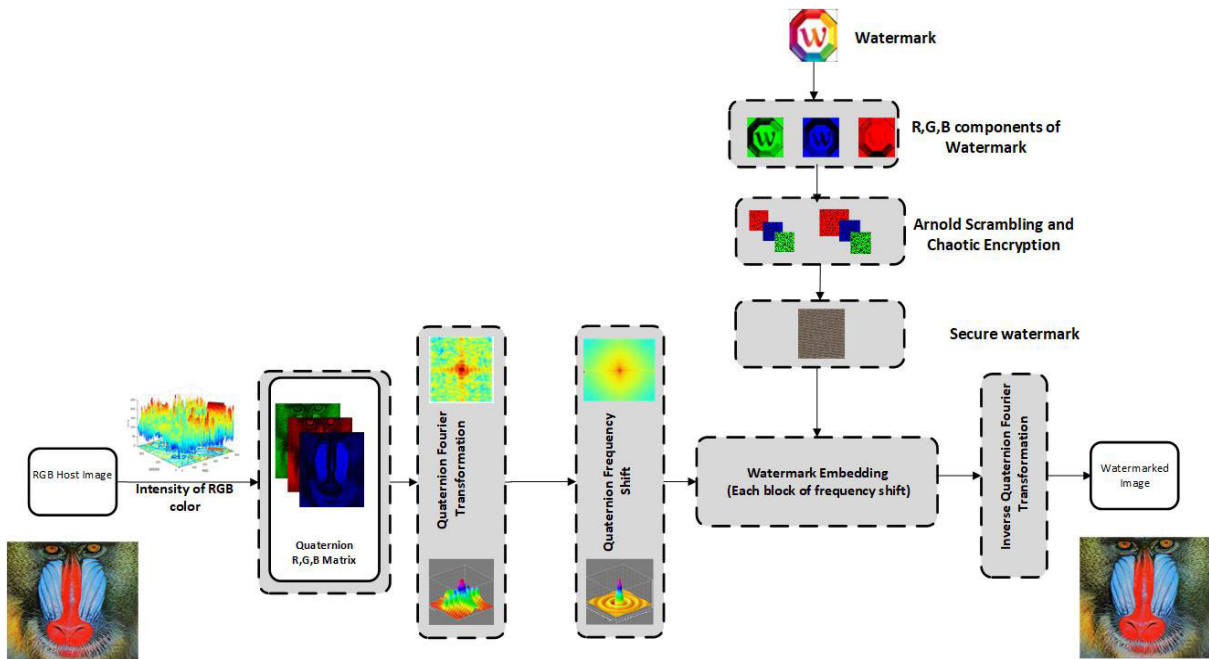


FIGURE 6. Watermark embedding.

At present, logistic mapping is a widely used and simple one-dimensional chaotic system, which is defined as:

$$x_{k+1} = \mu x_k (1 - x_k) \tag{19}$$

When $x_k \in (0, 1)$ and $3.5699456 < \mu \leq 4$, the logistic map is in a chaotic state [11], [12]. This mapping is used in this paper to scramble the pixel values of the Arnold-scrambled watermark information to achieve double encryption. The perturbation of the pixel values can make the encrypted image more effectively resist various statistical attacks to improve the robustness of the algorithm.

Let the size of the watermark image W be $M * N$, set the parameter μ and the initial value x_0 , use formula (2) to generate $M * N$ chaotic sequences, convert them into a matrix R of $M * N$, and use formula (3) to get Disturbance matrix $R1$.

Equation (3) is defined as follows:

$$R1(i, j) = \text{round}((1000 * R(i, j)) \text{ mod } (255)) \tag{20}$$

Among them, $\text{round}()$ is a rounding function, and $\text{mod}()$ is a remainder function. According to the definition of the logistics map, we know that $R(i, j) \in (0, 1)$, so $R1(i, j) \in [0, 255]$. An XOR operation is performed on the corresponding elements of the watermark image W and the scramble matrix $R1$ to obtain the scrambled, encrypted watermark image.

III. STUDY DESIGN AND PROPOSED ALGORITHM

This section will give details about dataset, watermark preprocessing, watermark embedding and watermark extraction.

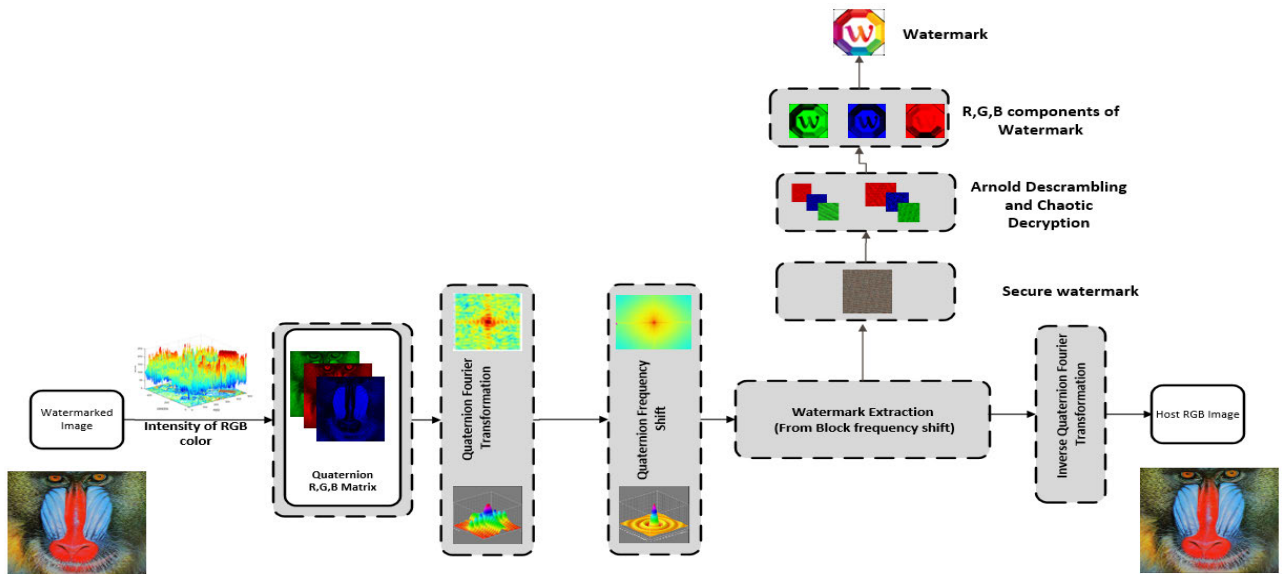


FIGURE 7. Watermark extraction.

A. DATASET

This study is focused on color image watermarking, so dataset of 10 color images from USC-SIPI [29] and Kodak Image Dataset [30]. All images are having 24 bit colors and resolution of 512 * 512 as shown in Fig 3. For embedding 4 Color watermark of size 40 * 40 are used as shown in Fig 4.

B. WATERMARK PREPROCESSING

In preprocessing, we generate watermark after reading the color image which is to be encrypted, and then extract the three pixel layers R, G, and B of this image; for different pixel layers, different encryption key. The encryption key *Key* here refers to the parameters a, b, c, and d used in the Arnold transformation eq (16), which can be expressed as: $Key = (a, b, c, d)$, that is, different keys are used for different. The pixel layers are R, G, and B layers. The Arnold transform is performed here, where R, G, and B represent Red, Green, and Blue, respectively. A new two-dimensional digital matrix is obtained by superposing these three digital matrices of the same size. The matrix is an encrypted digital image. The specific implementation steps are as follows:

Step 1: Read a color image and convert it into a matrix to obtain a preprocessed image. Let the pre-processed image be an image of size $N \times N$.

Step 2: The preprocessed image is divided into M sub-images, where M is 2^n . For each sub-image, perform steps 3, 4 and 5 as follows.

Step 3: For a sub-image, extract its three layers of pixels, R, G, and B, and convert each of them into a two-dimensional matrix to obtain three such matrices.

Step 4: Apply Arnold transform on the pixel matrix of each layer.

Step 5: The three layers of encrypted pixels after the Arnold transform process are superimposed to form an encrypted image of the combined image.

Step 6: Use the chaos map to randomly generate a positive integer n.

Step 7: After the M sub-images are processed as above, the encrypted images of the M sub-images are combined to form an encrypted image of the pre-processed image.

The histogram of the double-encrypted image after the disturbance of Arnold and Logistic chaos the distribution is more uniform, which is very different from the histogram of the original image. This can effectively protect the original image and resist the attacks of statistical analysis.

C. WATERMARK EMBEDDING

As discussed earlier, the aim of this research to develop novel watermarking algorithm which embed watermark in an undetectable and robust manner. To achieve this, frequency domain is useful for embedding on overall all parts of the portion. So, the strength of the watermark is spread over the whole image after the inverse image data to the spatial domain, which produces the robust watermarking approach with less observed changes.

Steps for embedding the watermark image $g_0(x, y)$ into host image $f(m, n)$ are as follows:

(1) After Arnold transformation and chaotic encryption on the watermark image $g_0(x, y)$, check if it is not a square matrix, first fill it into a square matrix and then transform it to get $g(x, y)$ and after transformation becomes $G(u', v')$;

(2) Do the $f(m, n)$ using QFT to obtain the domain graph $F(u, v)$;

(3) Perform frequency shift and find block of appropriate position, and replace the high-frequency information of

TABLE 1. PSNR, SSIM and NC value of different color host images with different watermarks.

Host Image	WM 1			WM 2			WM 3			WM 4		
	PSNR (db)	SSIM	NC	PSNR (db)	SSIM	NC	PSNR (db)	SSIM	NC	PSNR (db)	SSIM	NC
Image 1	48.29	0.96	0.96	42.10	0.96	0.94	44.10	0.93	0.97	43.04	0.92	0.98
Image 2	47.44	0.93	0.97	41.68	0.99	0.98	42.02	0.97	0.94	42.19	0.93	0.98
Image 3	45.11	0.98	0.97	49.66	0.95	0.96	44.31	0.99	0.96	47.91	0.96	0.96
Image 4	49.37	0.98	0.95	41.88	0.93	0.99	41.99	0.96	0.91	51.18	0.98	0.92
Image 5	46.11	1.00	0.96	44.49	0.99	0.94	41.53	0.95	0.97	44.00	0.96	0.92
Image 6	47.48	0.96	0.94	50.88	0.96	0.95	45.66	0.93	0.98	42.42	0.92	0.97
Image 7	45.49	0.98	0.94	51.08	1.00	0.98	42.38	0.91	0.97	46.48	0.97	0.96
Image 8	44.13	1.00	0.98	48.54	0.98	0.97	51.88	0.99	0.96	43.06	0.96	0.98
Image 9	51.25	0.99	0.99	42.53	0.91	0.93	41.90	0.95	0.95	50.97	0.98	0.97
Image 10	49.77	0.97	0.97	41.84	0.99	0.95	49.03	0.95	0.93	43.42	0.99	0.99

$F(u, v)$ to obtain the frequency domain map $F_0(u, v)$ with embedded watermark information:

(4) Perform inverse Quaternion Fourier transform on $F_0(u, v)$ to obtain the image to be embedded with watermark information, and record it as $f_0(m, n)$. The process flow shown in Fig 6.

D. WATERMARK EXTRACTION

The watermark extraction steps taken the same sequence of the watermark hiding steps. The watermark extraction steps are executed as follow:

- (1) Use the QFT on $f_0(m, n)$ to obtain $F_0(u, v)$
- (2) Extract $G(u', v')$; from the high-frequency information in $F_0(u, v)$. Here we need to use the size of $G(u', v')$;
- (3) Use QFT to perform inverse Fourier transform on $G(u', v')$; to get $g(x, y)$.
- (4) For $g(x, y)$ inverse cat face transformation, you need to know the number of transformations:
- (5) Determine whether $g(x, y)$ a complemented square matrix operation is. If it is, according to the size of the original $g_0(x, y)$, delete the filled part to get the original secret image. The process flow shown in Fig 7.

IV. RESULTS & DISCUSSIONS

The Clifford algebra Fourier transformation using quaternion creates new opportunities in image processing, especially in color image features extraction and color balancing. This work focuses on the spectral properties of the image and uses in-depth QFT to process the image components within the frequency domain. Using this technique, various image processing methods are easy to apply, such as filtering or color segmentation. Filtering in the frequency domain using quaternion has a great advantage in the color scheme separation of each component. Clifford Algebra (CA) provides a better framework to solve image processing problems in the frequency domain in which the frequency of the image is not monochrome. Each color channel (R, G, and B) has separate processing using individual handling methods, which can

reduce the quality of output and does not utilize the proper relationship between the shading of the colors [36]. Therefore, CA allows the image spectrum to process the whole rather than individual components [33], [34] and allows the segmentation of those colors because of its ability to process each vector individually at each angle [36]. Other developed approaches that are discussed in section I deal with gray images but color images in remote sensing emit a large amount of noise. Because of smaller objects and much noise, it would be difficult to differentiate objects based on monochrome or gray colors. There is an urgent need for color image processing, especially in this domain, so that clear classification of objects can be conducted with clear enhanced features. Many algorithms have already been developed for image segmentation [36], object recognition and detection [37]–[40], disaster tracking [41], and path finding and distance calculation [41] in satellite images, but these mostly deal with gray scale and not the color scale. This study could lead towards the solution of all of these issue solutions using geometric algebra.

The primary goal is to deal with colors individually, within each of its components at particular angles. Different classical approaches have already explored Clifford algebra in image processing [26]–[31] and some are being extended towards 3D images and video processing. Here, we explored quaternions with their possible utilization of processing color images and the use of Clifford algebra mathematical operations.

In order to make the digital watermarking technology reliable and user-reliable, a certain measurement index is often needed to evaluate the performance of the watermarking algorithm. In general, the evaluation criteria of digital watermarking have the following aspects.

A. IMPERCEPTIBILITY

It mainly refers to the concealment of digital watermarks used for printing, also called invisibility, imperceptibility, or transparency. The vector is the same as the original vector,

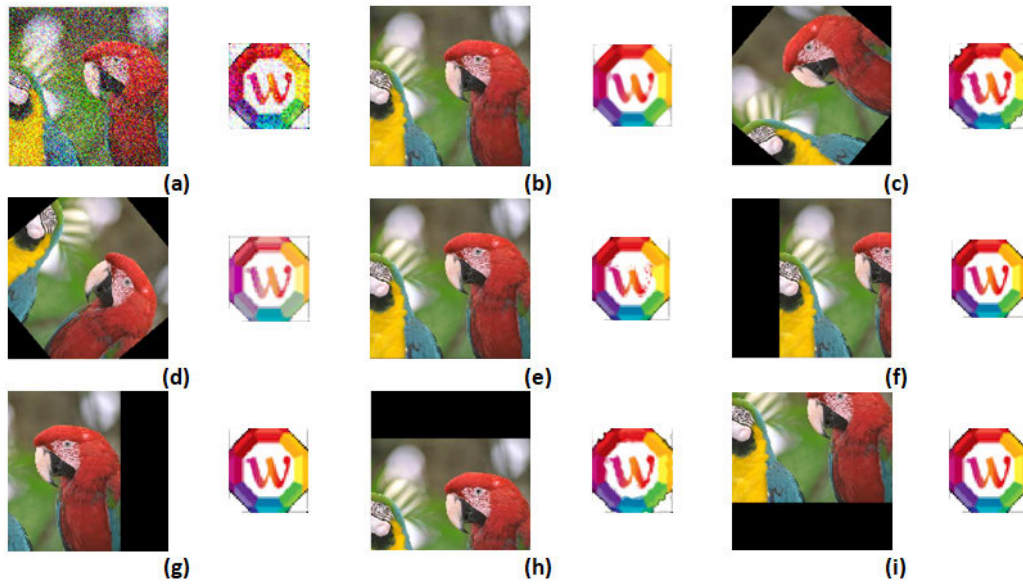


FIGURE 8. Different geometric and conventional attacks with extracted watermarks (a) Gaussian noise (b)JPEG compression (c) Rotation left anticlockwise (30°) (d) Rotation left clockwise (30°) (e) Translation right (30°) (f) Translation left (30°) (g) Translation left (30°) (h) Translation down (30°) (i) Translation up (30°).

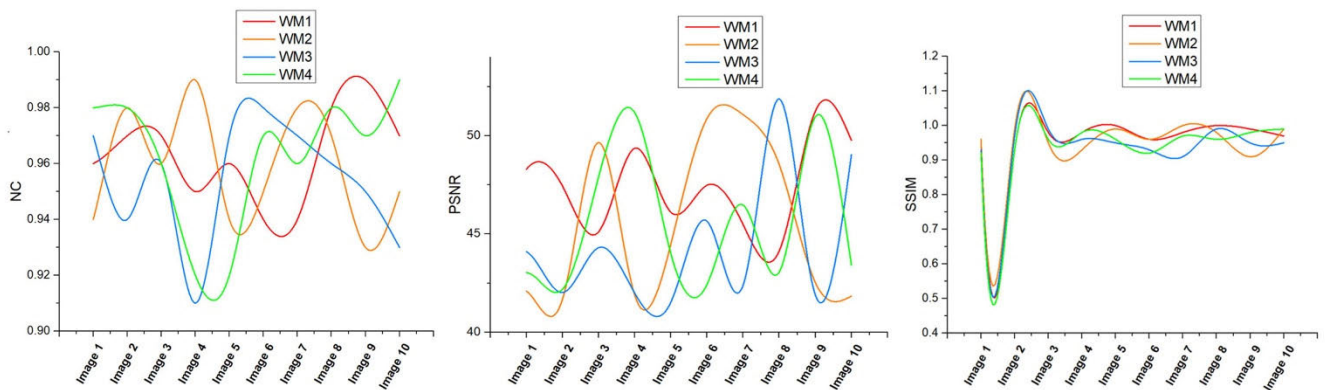


FIGURE 9. Graphical representation of NC, SSIM and PSNR after implementation of proposed algorithm.

or at least visually the same. That is, the embedding of the watermark does not affect the visual effect of the carrier and normal use. PSNR (Peak Signal-to-Noise Ratio) indicates the invisibility of the watermark. The calculation formula of PSNR can be expressed as follows:

$$PSNR = 10 \log_{10} \frac{MAX^2}{MSE} \text{ (db)} \tag{21}$$

$$PSNR_C = \frac{1}{3} (PSNR_R + PSNR_G + PSNR_B) \tag{22}$$

$$MSE = \frac{1}{M \times N} \sum_{m=1}^M \sum_{n=1}^N [f(m, n) - f_w(m, n)]^2 \tag{23}$$

Among them, MAX is the peak value of the signal, if it is an image; it refers to the color level of the image. For example, the peak value of the pixel value of an 8-bit image is $2^8 = 256$, and the value of MAX is 256; MSE (Mean Square Error)

is the mean square error between the original carrier data and the detection data; f and f_w are the original carrier and the watermark, respectively. In this paper, the PSNR of color images is calculated by averaging the PSNRs of R, G, and B components ($PSNR_R$, $PSNR_G$, and $PSNR_B$), which is defined in equation (22). Table 1 shows that the NC value of all images is nearly 1 which shows proposed algorithm is highly invisible.

Another method for evaluation is Structural Similarity Index Measure (SSIM) which measures the similarity in images in a way closer to how human eyes perceive the image. It can be computed as follows:

$$SSIM(f, f_w) = \frac{(2\mu_f \mu_{f_w} + C_1)(2\sigma_{ff} + C_2)}{(\mu_f^2 + \mu_{f_w}^2 + C_1)(\sigma_f^2 + \sigma_{f_w}^2 + C_2)} \tag{24}$$

The range of SSIM is $[-1, 1]$, if the two images have SSIM 1 shows the images are closely same.

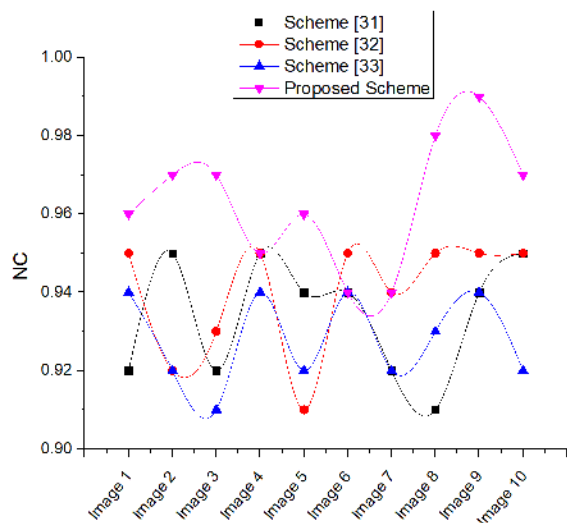


FIGURE 10. Performance comparison of different color image watermarking algorithms with proposed method.

B. ROBUSTNESS

Robustness plays a very important role in digital watermarking technology. Robustness refers to the ability to not change or lose the digital watermark embedded in it due to certain changes in the carrier data, that is, the ability of the watermark information to resist changes in the watermarked carrier data. “Change” here refers to intentional or unintentional watermarking attacks or other processing operations, such as filtering, encoding compression, cropping, rotation, noise, and so on. Usually digital watermarking algorithms must be robust to resist various watermarking attacks. Watermark robustness is generally measured by the value of Normalized Correlation (NC). The NC value can be calculated using the following formula: (25), as shown at the bottom of the next page. NC is a positive number not greater than 1, the larger the value, the better the algorithm’s robustness, that is, the extracted watermark. The more similar to the original watermark; the NC value is 1 in the most ideal case.

Table 1 shows the robustness and performance of the proposed algorithm after embedding watermarks of Fig 4 in all images Fig 3. It can be seen that algorithm robustness is high in almost all types of watermarks embedding beside that imperceptibility is also much satisfactory which makes more secure. Table 2 shows the resistance of our proposed algorithm against conventional and geometric attacks. Gaussian Noise and JPEG compression percentage giving NC value almost more than 90%.

Fig 8 shows the effectiveness of the proposed algorithm after extraction of the watermark with different types of geometrical and conventional attacks. Fig 9 gives the view of embedding of all watermarks with different images and compare the NC, SSIM and PSNR. NC value for all watermark with every image is approaching more than 90% and SSIM almost similar to 100%. Majority of the previous color image watermarking schemes use different methods for watermark

TABLE 2. PSNR and NC value against geometric and conventional attacks.

Attack Type	Strength of Attack	PSNR (dB)	NC
Conventional attack			
Gaussian noise	2%	18.98	0.96
	4%	16.08	0.92
	8%	13.32	0.91
JPEG Compression	10%	30.55	0.88
	15%	32.03	0.90
	20%	33.48	0.85
Geometric Attacks			
Clockwise Rotation	5°	15.72	0.90
	20°	12.32	0.92
	30°	12.19	0.87
Anticlockwise Rotation	4°	16.54	0.95
	30°	12.19	0.91
	50°	11.98	0.87
Scaling	× 0.4	-	0.85
	× 0.8	-	0.98
Translation (Right)	8%	11.63	0.91
	20%	10.63	0.96
	30%	10.17	0.87
Translation (Left)	3%	12.83	0.85
	8%	11.79	0.88
	25%	10.62	0.97
Clipping (X Axis)	8%	-	0.92
	15%	-	0.87
Clipping (Y Axis)	8%	-	0.91
	10%	-	0.99

addition. Table 3 and Fig 10 shows the comparative analysis with the other color watermarking algorithms. It can be seen that our algorithm is approaching almost greater NC value than the other color image watermarking algorithms which shows our algorithm is more robust than others.

Different types of watermarking algorithms exist and they used different approaches for watermarking. They either embed the watermark in all the three channels, R, G and B, equally or convert the image to another color space such as HSI or YCbCr and employ the Y component to embed the watermark information. The proposed method considers R, G, B channels differently and different measures are used for integrating the identification watermark in individual color channels so as to keep the distortion level minimal. All the existing frequency domain techniques that have been

TABLE 3. PSNR and NC value comparison of color image processing techniques.

Host Image	Scheme [21]		Scheme [32]		Scheme [33]		Proposed Scheme	
	PSNR (db)	NC	PSNR (db)	NC	PSNR (db)	NC	PSNR (db)	NC
Image 1	48.29	0.92	47.04	0.95	49.12	0.94	51.73	0.96
Image 2	47.44	0.95	47.36	0.92	42.32	0.92	41.57	0.97
Image 3	45.11	0.92	49.45	0.93	46.75	0.91	46.54	0.97
Image 4	49.37	0.95	45.27	0.95	43.70	0.94	51.32	0.95
Image 5	46.11	0.94	47.10	0.91	45.01	0.92	49.78	0.96
Image 6	47.48	0.94	49.07	0.95	49.07	0.94	49.71	0.94
Image 7	45.49	0.92	44.57	0.94	47.59	0.92	50.67	0.94
Image 8	44.13	0.91	46.55	0.95	51.71	0.93	50.58	0.98
Image 9	51.25	0.94	50.07	0.95	45.35	0.94	49.75	0.99
Image 10	49.77	0.95	49.20	0.95	46.46	0.92	50.33	0.97

TABLE 4. Performance comparison of proposed method using NPCR, UACI and entropy.

Validation Method	Scheme [21]	Scheme [32]	Scheme [33]	Proposed Scheme
NPCR %	99.16	99.56	99.59	99.604
UACI%	33.11	32.61	32.81	33.46
Entropy	7.994	7.993	7.993	7.998

TABLE 5. Comparison of invisibility testing with other color image watermarking approaches.

	Scheme [48]		Scheme [49]		Proposed Algorithm	
	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
Lena	56.02	0.959	37.66	0.93	56.7	0.97
Baboon	57.02	0.959	37.72	0.93	57.04	0.96

developed for complex spectra and FFTs should generalize to quaternion spectra and FFTs.

Further validation of proposed method has been done by Number of Pixels Change Rate (NPCR) [42], Unified Average Change Intensity (UACI) [42] and Entropy.

NPCR finds the difference between the original image with the watermarked image as follows:

$$NPCR = \frac{\sum_{i,j} D(i,j)}{MN} * 100 \tag{26}$$

where $D(i,j)$ can be calculated as follows:

$$D(i,j) = \begin{cases} 0 & P(i,j) = C(i,j) \\ 1 & P(i,j) \neq C(i,j) \end{cases} \tag{27}$$

UACI measures the intensity of the original and watermarked image as follows:

$$UACI = \sum_{i,j} \frac{|C_1(i,j) - C_2(i,j)|}{255} * 100 \tag{28}$$

NPCR and UACI ideal values are 99.6094% and 33.46% for the grey images [43].

Entropy measures the uncertainty of the variables as follows:

$$E = \sum_{i=1}^{256} P(i) \log \left(\frac{1}{P(i)} \right) \tag{29}$$

Here $P(i)$ is the probability of the randomness of pixels. Larger the entropy value better the security. The ideal value of entropy is 8 [43].

Proposed algorithm NPCR and UACI are almost approaching the ideal values as shown in Table 4. This suggested that any small change occurring to original images would result in the obvious variation of encrypted images, showing that the algorithm presents strong sensitivity of plain text. Entropy value is also approaching the 8 which means more secure algorithm. Key sensitivity analysis also being done for the proposed algorithm for which our algorithm is sensitive if any bit on input side is changed all scrambling by chaotic

$$NCC = \frac{\sum_{p=1}^3 \sum_{i=1}^M \sum_{j=1}^N [W(i,j,p) \times W'(i,j,p)]}{\sqrt{\sum_{p=1}^3 \sum_{i=1}^M \sum_{j=1}^N [W(i,j,p)]^2} \sqrt{\sum_{p=1}^3 \sum_{i=1}^M \sum_{j=1}^N [W'(i,j,p)]^2}} \tag{25}$$

sequence is not satisfactory thus making the proposed algorithm more secure. Table 5 shows the comparison of invisibility testing with new approaches having similar strategy. Our proposed algorithm SSIM is high with better PSNR which shows invisibility of proposed algorithm is high.

There may be some cases in which non-commutatively quaternion multiplication will require careful analysis. There is further scope for the use of QDFT on monochrome images, due to the true two-dimensional nature of the transform, as pointed out by Ell [40] and discussed briefly above.

V. CONCLUSION

With the rapid development of Internet technology, color images are growing in people's lives, and copyright management of color images is imminent. Therefore, research on practical color image watermarking algorithms has become the focus of attention. In this paper, advance use of color image processing is used and Quaternion algebra vector methodology is implemented in frequency domain to perform watermark embedding and extraction. Based on the robustness of the color image watermarking algorithm, this paper conducts research on its resistance to geometric attacks, and has obtained preliminary results. Experimental results show that the algorithm has good performance. In the follow-up work, we will further apply Clifford algebra to analyze the image information to further improve the performance of the watermark embedding algorithm.

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