Improved Digital Image Watermarking Algorithm Based on Dwt and Svd

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Abstract: In view of the low robustness and poor concealment of traditional digital image watermarking algorithms, this paper proposes an improved digital image watermarking algorithm based on discrete wavelet transform and singular value decomposition. It first uses discrete wavelet transform to transform the carrier image into the wavelet domain to obtain multiple different frequency bands; then it uses singular value decomposition to train the coefficients of different frequency bands so that it can embed the watermark into the singular value of the carrier image according to the scale factor. In the watermark embedding and extraction process, in order to get a balanced state of the concealment and robustness, it searches the optimal scale factor according to particle swarm optimization algorithm. Experiments show that compared with similar algorithms, the proposed algorithm has stronger robustness and better concealment.

1. Introduction

In modern society, digital media has been widely used in various fields. The property rights of digital media products are also subject to great threats, such as copyright infringement and tampering with information. To better protect the interests of information-sharing parties, digital watermarking technology has emerged and has mushroomed. It has also achieved typical applications. For example, in the IBM digital library project, the designer uses the watermark image to change the local brightness of the carrier image to realize the embedding of the watermark [12]. Digital watermarking technology is a specially formulated, unperceptible mark that is hidden in digital products such as digital images, audio, and video using digital embedded methods, which determines the copyright owner, confirms the authenticity of the source of the digital product content, distinguishes the buyer, provides additional information related to the digital product, authenticates the ownership of the certificate, and tracks the infringement. In general, digital watermarking includes image watermarking, text watermarking, audio watermarking, video watermarking, and so on. Due to the wide range of applications of the image, digital image watermarking technology develops rapidly and gradually tends to mature [9].

Digital image watermarking refers to embedding implicit labels in image data by means of signal processing. In other words, people who share information do not directly perceive the embedded information. Only the copyright owner can use professional detectors to determine the presence or absence of embedded information. In general, the complete process of digital watermarking images includes generation, embedding and extraction. The watermark embedding process also includes two categories according to different processing domain [13]: airspace technology and transform domain technology. As the name suggests, airspace technology refers to embedding the watermark into the airspace domain directly, it can modify the pixel value of the image. The transform domain means that the image is first subjected to some mathematical transformation and then it embeds the watermark into the transform domain. The watermark embedding of airspace technology is easy to implement, but this method is vulnerable to external noise and it has weak anti-attack ability and poor robustness. Therefore, its development has been greatly restricted. While transform domain technology solves the problem of embedding strength and guarantees the imperceptibility of the watermark, and it has stronger robustness to compression, rotation and external noise, but it can easily lead to the degradation of the watermark image quality [14]. Discrete Wavelet Transform

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(DWT) [5]and Discrete Cosine Transform (DCT) [6] all belong to the transform domain digital watermarking method. At present, many kinds of digital watermarking method emerge endlessly, making the technology more mature and perfect.

Researchers have proposed many digital image watermarking methods. Zear A proposes a digital watermarking technique combining with DWT and DCT, and he testes the performance of the watermarked image under conditions such as Gaussian noise [15]. Mehta R and Rajpal N propose a watermarking scheme based on DWT and human visual characteristics. It adds the watermark composed of binary pseudo-random sequences to the DWT coefficients of the three detail bands of the image adaptively [6]. Chaitanya K proposes a color digital watermarking in RGB model using singular value decomposition [8]. Makbol N proposes an image watermarking algorithm combining with SVD and IWT, which embeds the watermark into the singular values of each frequency band [10]. Mishra A firstly performs three-level DWT on the carrier image, and then he embeds the image singular value into the singular value after third-level low-frequency sub band block SVD. The embedding intensity is adjusted by the multi-scale factor optimized by the firefly algorithm. The algorithm has good transparency and exhibits good robustness against various watermark attacks. However, it has a large time overhead [11].

This paper proposes an improved digital image watermarking algorithm using DWT and SVD. It first uses DWT to transform the carrier image into wavelet domain, then the resulting frequency band is subjected to SVD transformation [16], and it can embed the watermark into the singular value of the carrier image according to the scale factor. In the process of calculating the optimal scale factor, the particle swarm optimization algorithm is added to improve the performance. Experimental results show that compared with the same type of algorithm, the proposed algorithm shows strong robustness and concealment for embedded watermarked images.

The main contents of this paper are as follows: Chapter 2 mainly introduces the theoretical basis, including singular value decomposition and discrete wavelet transform. Chapter 3 mainly introduces the proposed digital image watermarking algorithm. Chapter 4 is simulation experiments, results discussion and analysis. Finally, the full text is summarized in Chapter 5.

2. Theoretical basis

2.1 Singular Value Decomposition

Singular value decomposition [18, 3] can diagonalize the matrix, the digital image might be treated as an integer matrix and singular value decomposition to perform orthogonal transformation on the digital image is used. Singular value decomposition divides a given matrix into three small matrices, including U , V and S . U is left singular matrix, V is right singular matrix, S is singular matrix. Assuming that $A \in \mathrm{R}^{m\times n}$, U and V can be expressed as:

$$\begin{aligned} U &= (u_1, u_2, ..., u_m) \in \mathrm{R}^{m\times m} \\ V &= (v_1, v_2, ..., v_m) \in \mathrm{R}^{m\times n} \end{aligned} \tag{1}$$

and

$$S = U^T AV = diag(\delta_1, \delta_2, ..., \delta_p) \tag{2}$$

Among them, $p = \min\{m, n\}$, $\delta_1 \geq \delta_2 \geq ... \geq \delta_p \geq 0$. δ is singular value; u is left singular vector; v is right singular vector. Since A is a matrix which has n dimensions, the diagonal elements of the matrix S have a maximum value n . A can be regenerated with some of the elements in S , but the quality of the regenerative matrix A_S will drop a lot. Since U and V represent orthogonal matrixs, they have the following constraints: $UU^T = I_n$, $VV^T = I_n$.

2.2 Discrete Wavelet Transform

Discrete wavelet transform (DWT) [17] is the commonly used techniques in image watermarking. It can effectively remove the effect of noise. Discrete wavelet transform can divide the image in three directions of horizontal, vertical and diagonal lines into four different components, which can be respectively denoted as $(LL),(LH),(HL),(HH)$. Since the human senses are more sensitive to the sub-bands of the low-frequency part (LL), the watermark of the digital image is usually embedded in the remaining three sub-bands to keep the quality of the original image at a very high level. DWT is actually a transformation from time domain signal to frequency domain signal, and the final output is actually an analog signal with combines both sine and cosine functions, and the entire process uses a recursive algorithm to calculate the transform coefficients [4]. Fig 1 shows the complete process of a single-layer discrete wavelet transform. First of all, discrete wavelet transform divides the signal into two parts according to the given filters (such as low-pass and high-pass filter), which are approximate coefficients and detail coefficients, where the approximate coefficient is also called the low frequency part, and the detail coefficient is also called high frequency. Then the system forwards this decomposition result to another set of filters for further decomposition.

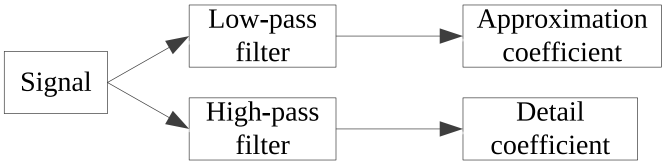


Fig.1 Schematic Diagram of Single-Layer Discrete Wavelet Transform

3. Proposed digital image watermarking algorithm

3.1 Watermark Embedding

This section describes the watermark embedding. Firstly, it uses DWT to transform the carrier image into the wavelet domain and the resulting frequency band is subjected to singular value decomposition transformation. According to the scale factor, it embeds the watermark into the singular value of the carrier image. Specific algorithm processes are as follows.

According to DWT, it transforms the carrier image into wavelet domain, then the three available frequency bands LL, LH, HL are obtained and they are used as the embedded frequency band.

Perform SVD transformation on the obtained three frequency bands $(i = LL, LH, HL)$, which is shown in formula (3):

$$I_i = U_i S_i V_i^T \tag{3}$$

Modify the singular value of the frequency band according to formula (4). In formula (4), α represents scale factor and W represents watermark.

$$S_i' = S_i + \alpha W \tag{4}$$

Perform singular value decomposition transformation on S_i' again, which is shown in formula (5):

$$S_i' = U_{wi} S_{wi} V_{wi}^{\ T} \tag{5}$$

Generate the watermark sub bands I_{wi} of each module based on the obtained matrix S_{wi}, U_i and V_i, which is shown in formula (6).

$$I_{wi} = U_i S_{wi} V_i^T \quad (6)$$

By performing inverse DWT on the watermark sub band I_{wi}, the watermark image H_W can be obtained.

Fig.2 is the Concrete Process of Watermark Embedding.

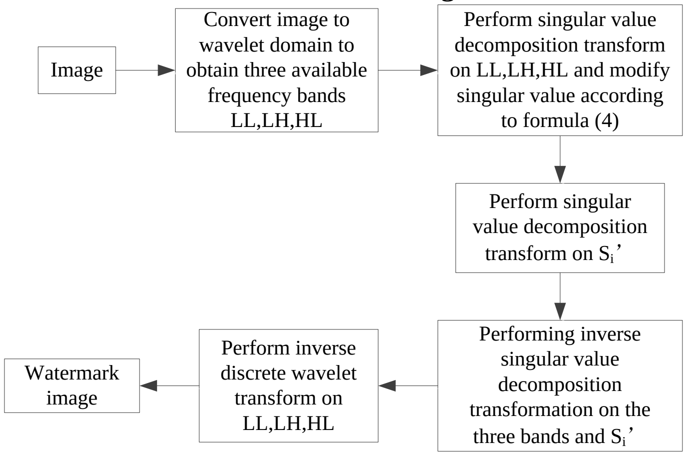


Fig.2 Flow Chart of Watermark Embedding

3.2 Watermark Extraction

The steps of extracting the watermark from the distorted watermark image $H_W{}^*$ are as follows.

Perform one-dimensional discrete wavelet transform on the watermark image so that $I_W{}^*$ and LL, LH, HL can be obtained.

Perform singular value decomposition transformation on the three frequency bands $I_i\left(i = LL, LH, HL\right)$, as shown in formula (7):

$$I_i^* = U_i^* S_{wi}^* V_i^{*T} \quad (7)$$

Perform inverse singular value decomposition transformation on matrix U_{wi} and V_{wi} to obtain an approximate value of S' on three frequency bands LL, LH, HL, as shown in formula (8):

$$S_i'^* = U_{wi} S_{wi}^* V_{wi}{}^T \quad (8)$$

The approximation value of the watermark on the three frequency bands LL, LH, HL is given by formula (9).

$$W_i^* = \frac{S_i'^* - S_i}{\alpha} \quad (9)$$

Fig.3 is the Specific Process of the Watermark Extraction.

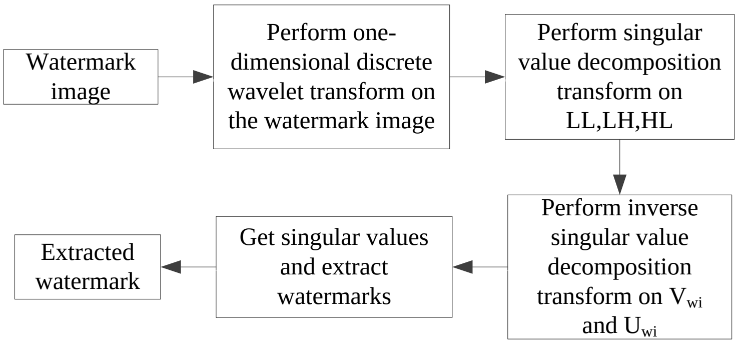


Fig.3 Flow Chart of Watermark Extraction

3.3 Optimization of the Scale Factor

The particle swarm optimization algorithm [4] is an optimization scheme driven by the social behavior of birds or fish, which is based on swarm intelligence. The optimal solution is found by the motion of particles in space. It also shows good results in continuous optimization and discrete optimization problems. Particle swarm optimization is a branch of heuristics, and it attempts to obtain better candidate solutions to optimize complex problems [1]. Assuming that in the dimension search space of N , $x_i = (x_{i1}, x_{i2}, ..., x_{iN})$ is the position of particle i , $v_i = (v_{i1}, v_{i2}, ..., v_{iN})$ is the velocity of particle i , $p_i = (p_{i1}, p_{i2}, ..., p_{iN})$ is the optimal historical position. Based on the above analysis, $g_i = (g_{i1}, g_{i2}, ..., g_{iN})$ is the optimal position of all the particles. Therefore, formula (10) and formula (11) show the updation of velocity and position.

$$v_{id}^{t+1} = wv_{id}^{t} + c_1 r_1 (p_{id}^{t} - x_{id}^{t}) + c_2 r_2 (p_{gd}^{t} - x_{id}^{t}) \tag{10}$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \tag{11}$$

The method of watermark embedding and extraction are introduced above. It can be seen that the factor which has a great impact on the performance of the algorithm is the scale factor α . When α is small, the algorithm can provide good concealment, but at this time the robustness of the algorithm is poor; when α is large, the robustness of the algorithm will be better, but the concealment will become worse. In order to make the concealment and robustness of the algorithm reach a balanced state, this paper uses the particle swarm optimization algorithm to find the optimal scale factor. The robustness of the watermark is expressed by a normalized correlation coefficient, as shown in formula (12):

$$Robustness = correlation\left(W, W^{*}\right) \tag{12}$$

$correlation()$ represents a correlation function that can be defined as:

$$correlation\left(X, X^{*}\right) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} X_{(i,j)}\ XOR\ X_{(i,j)}^{*}}{n \times n} \tag{13}$$

Assuming that the attack type of the watermark image is A , and they can be put into the frequency band M , the average robustness of the algorithm is shown in formula (14):

$$Robustness_{average} = \frac{\sum_{i=1}^{A} correlation\left(W, W*\right)}{M \times A} \tag{14}$$

Where W denotes the original watermark, W^{*} denotes the extracted watermark. In this paper, peak signal-to-noise ratio (PSNR) is the metrics to measure the concealment performance of the watermark. PSNR can reflect the degree of similarity on watermark image and carrier image, the higher the PSNR is, so does the similarity between watermarked image and original image, that is to say, the better the watermark concealment performance is. Assuming that the carrier image (X) and the watermark image (X^{*}) are both $n \times n$, and their maximum pixel is $X_{\max}$, then the peak signal-to-noise ratio can be expressed as:

$$PSNR = 10\log_{10}\left(\frac{n \times n \times \left(X_{\max}\right)^{2}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(X(i,j) - X^{*}(i,j)\right)^{2}}\right) \tag{15}$$

In the particle swarm optimization algorithm, each scale factor can be regarded as a particle vector with a size of 256. In this paper, the particle population of the particle swarm optimization algorithm is set as 40 and the learning factor as $C1 = C2 = 2$, the maximum number of iterations is 200.

4. Simulations

4.1 Parameter Setting

The grayscale images used in this experiment are shown in Fig 4. Among them, “Li Na” in Fig 4a, “House” in Fig 4b, and “Pepper” in Fig 4c are carrier images, their size are set as 512×512. $'W1'$ in Fig 4 is a watermark image, whose size is set as 256×256.

a b c d

Fig.4 Carrier Image and Watermark Image

4.2 Discussion and Results

Perform simulations on the proposed algorithm and the algorithms in [10] and [12]. Table 1 shows the specific descriptions and simulation parameters. In the algorithm proposed in [12], it uses DWT+SVD to process the image and it uses differential evolution algorithm to optimize the scale factor. In the algorithm proposed in [10], it uses IWT+SVD to process the image and it do not consider the optimization of the proportional factor.

Table 1 the Similarities and Differences between Our Algorithm and Similar Algorithms

	Algorithm in [12]	Algorithm in [10]	Proposed algorithm
Domain	DWT+SVD	IWT+SVD	DWT+SVD
Subband	All	All	LL,LH,HL
Host size	512×512	512×512	512×512
Insert position	Main ingredient	Singular value	Singular value
Watermark size	256×256	256×256	256×256
Scale factor	Optimized by differential evolution algorithm	0.05(LL),0.005(others)	Optimized by particle swarm optimization algorithm

After embedding the watermark $'W1'$ to the image, the PSNR of the three images under the three algorithms are shown in Table 2. Compared with the other two algorithms, the PSNR of proposed algorithm is the highest, that is to say, the image obtained by our proposed algorithm in the watermark embedding has a higher degree of closeness to the original image, and the concealment performance of the watermark is also better than other two algorithms.

Table 2 Psnr of Images under Watermark Embedding of Different Algorithm

Carrier image	PSNR (dB)		
	Algorithm in [12]	Algorithm in [10]	Proposed algorithm
Li Na	37.337	44.725	47.141
House	36.864	43.621	45.665
Pepper	36.526	43.492	45.847

Attacks on watermark images include noise attacks, filtering, clipping, rotation, scaling, and so on. Firstly, noise attack on the image is subjected. Gaussian noise and salt-and-pepper noise are respectively subjected to the watermarked “Li Na” image, then the normalized correlation coefficients under the three algorithms are calculated and the results are shown in Table 3 and Table 4. As can be seen from the table, as the noise gradually increases, the normalized correlation coefficient becomes smaller and smaller, and the quality of the extracted watermark becomes worse and worse. However, it can be clearly seen that compared with the other two algorithms, the robustness of proposed algorithm is better.

Table 3 Normalized Correlation Coefficient Values under Gaussian Noise Attack

Noise intensity	0.01	0.02	0.03	0.04
Algorithm in [12]	0.876	0.841	0.812	0.781
Algorithm in [10]	0.926	0.885	0.856	0.837
Proposed algorithm	0.944	0.932	0.908	0.889

Table 4 Normalized Correlation Coefficient Values under Salt and Pepper Noise Attack

Noise intensity	0.01	0.02	0.03	0.04
Algorithm in [12]	0.927	0.903	0.883	0.837
Algorithm in [10]	0.984	0.951	0.926	0.861
Proposed algorithm	0.998	0.976	0.942	0.905

Perform different degrees of JPEG compression attack tests on the watermarked images, Fig 5 is the result.

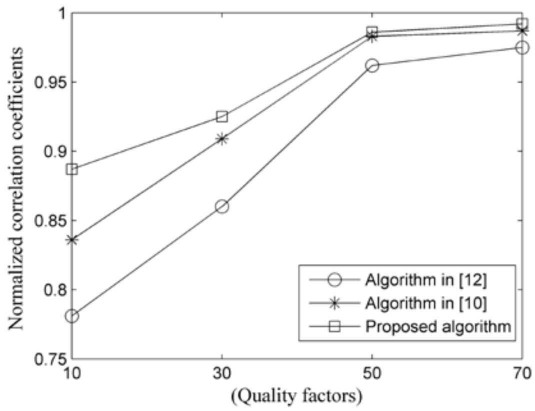


Fig.5 Normalized Correlation Coefficients for Jpeg Compression with Different Quality Factors

The results of Fig 5 show that the normalized correlation coefficients of the three algorithms become smaller and smaller with the increase of compression degree. When the noise intensity is 0.1, the normalized correlation system values obtained by the three algorithms are the highest. The proposed algorithm, the literature [10] algorithm and the literature [12] algorithm can reach 0.998, 0.984 and 0.927 respectively. Compared with the other two algorithms, the proposed algorithm has better robustness, which proves that the digital image watermarking algorithm based on DWT has strong robustness against JPEG lossy compression attacks.

Perform filtering attack tests on watermark images. Two types of filtering are considered: mean filter and Gaussian filter. The results are shown in Table 5. For the mean filter, the watermarking performance of the three algorithms are very good; for Gaussian filter, when the parameter is small, the three algorithms can extract the watermark very well, but as the parameter increases, compared with the other two algorithms, the normalized correlation coefficient of the proposed algorithm is always above 0.9. The proposed algorithm shows an obvious advantage.

Table 5 Normalized Correlation Coefficient Values under Different Filtering Attacks

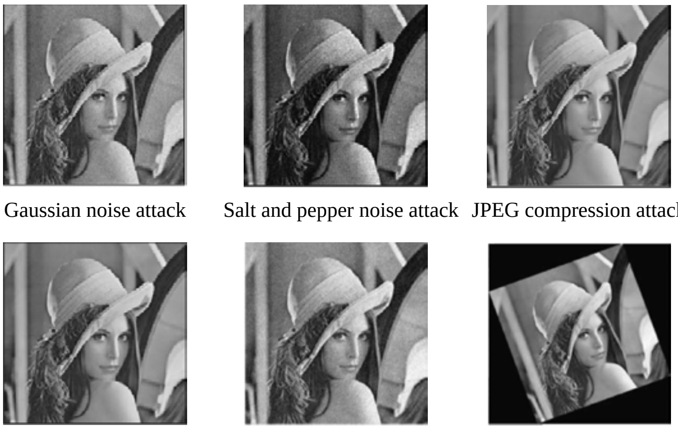
Type of attack	Mean filter	Gaussian filter		
Value of parameter	3×3	0.4	0.5	0.6
Algorithm in [12]	0.929	0.923	0.856	0.771
Algorithm in [10]	0.972	0.965	0.935	0.809
Proposed algorithm	0.976	0.971	0.944	0.834

Finally, geometric attack tests on the image are performed. The images are scaled, cropped, rotated and the results are shown in Table 6. The proposed algorithm has strong resistance to rotation and scaling, mainly because the singular value of the image reflects the intrinsic characteristics of the image, and the proposed algorithm uses particle swarm optimization algorithm to optimize the proportional factor, rotation and scaling have little effect on the singular value of the watermark. So, it can get better results, and the other two algorithms are less effective against rotation and scaling attacks. For the shearing attack, the effect of the proposed algorithm and the algorithm in [10] is not much different, and they are better than the algorithm in [12].

Table 6 Normalized Correlation Coefficient Values under Different Geometric Attacks

Type of geometric attack	Zoom 0.5 times	Cut 20 pixels on each side	Rotate 30°
Algorithm in [12]	0.944	0.937	0.949
Algorithm in [10]	0.984	0.986	0.984
Proposed algorithm	0.989	0.988	0.987

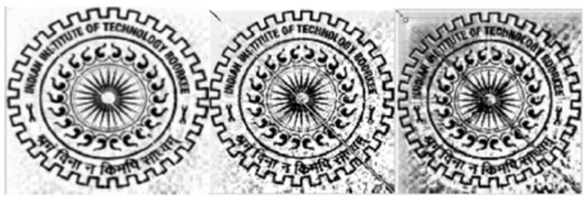
Fig 6 shows the partial images of the watermarked “Li Na” image after Gaussian noise attack, salt and pepper noise attack, JPEG compression attack, mean filter attack, Gaussian filter attack, and rotation attack. It can be seen from Fig 6 that the proposed algorithm can still extract the original image from the image embedded in the watermark information very well even though it has experienced attacks of different degrees and modes, which shows that the proposed algorithm can resist all kinds of attacks. Fig 7a and Fig 7b show the extracted watermarks '$W1$' from the three bands LL, LH, HL after performing Gaussian noise and a 30° rotation attack.



Gaussian noise attack　Salt and pepper noise attack　JPEG compression attack

Mean filter attack　Gaussian filter attack　Rotary attack

Fig.6 Watermark Image after Attack



a

b

Fig.7 Extracted Watermark

The algorithm proposed in [12] does not directly use the singular value for watermark insertion, but instead it uses the principal component to replace the singular value. This can eliminate the false alarm problem, but it also reduces the concealment and robustness of the algorithm. The reason is that the change of the principal component will cause the singularity matrix changing, and the image information is mostly stored in the singular matrix, so it is easy to have low robustness. In this paper, the algorithm inserts the watermark into the singular value, which does not change the image information, so it can obtain better robustness. In addition, the algorithm uses particle swarm optimization to optimize the scale factor, and it is superior to the algorithm in [10] in terms of concealment and robustness. In this paper, the performance of the algorithm is also tested on the other two carrier images, and it can obtain similar experimental results on the “Li Na” image.

5. Conclusion

This paper proposes an improved digital image watermarking algorithm based on discrete wavelet transform and singular value decomposition. It makes full use of the intrinsic characteristics of image singular values. It first performs discrete wavelet transform on the original carrier image, and then it performs SVD transform on the obtained frequency band. According to the particle swarm optimization algorithm, it finds the optimal scale factor to complete the watermark embedding and extraction. The proposed algorithm has the following advantages: Because the stability of the image singular value is very good, and the image energy after the discrete wavelet transform is more concentrated, so the algorithm is not only robust to the geometric attack, but also to the JEPG compression and filtering, the algorithm also shows strong robustness. At the same time, the improvement of robustness does not significantly degrade the watermarked image. The proposed algorithm is relatively easy to implement and can meet the needs of practical applications. Because it needs to know the orthogonal matrix of the watermark after the singular value decomposition, the proposed algorithm belongs to the unblind watermark. The next research direction is to implement the blind watermark through the algorithm design.

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