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A New Digital Image Hiding Algorithm Based on Wavelet Packet Transform and Singular Value Decomposition

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Abstract

The paper presents a new digital image hiding algorithm based on wavelet packets transform and singular value decomposition. The low-frequency sub-band of wavelet packets transform has strong anti-jamming capacity and the singular value has very strong stability. The presented algorithm implements bit plane decomposition on the secret image and wavelet packet decomposition on the carrier image. Then, it hides the bit planes with important information into the singular value matrix of the low frequency coefficient matrix, and also hides the bit planes with secondary information into the remainder sub-band matrix with higher entropy energy. The hiding location is adaptively determined by the carrier image. The experimental results indicate that, the proposed image hiding algorithm has strong robustness and anti-attack, and it also has good invisibility and big capability.

Keywords: *image hiding, singular value decomposition, wavelet packets transform, bit plane decomposition, entrogy energy*

1. Introduction

With the rapid development of multimedia and the increasing bandwidth of network, digital images are becoming the main media form of the present information society. However, the problems of information security such as illegal copying, modifying and pirating of digital images are increasingly common. The problem on how to give an effective method for image encryption has become a very active research field nowadays [1-2]. Some encryption algorithms have been frequently cracked in recent years. Image hiding is an important method to confuse illegal destroyer so as to play a protecting function. The main idea of image hiding is to hide a secret image into another carrier image [2]. Image hiding methods can be divided into either spatial-domain or frequency-domain. The algorithms based on spatial-domain are discussed in the references [3-4]. In these algorithms, the hidden information is always stored in the least significant bits of the pixels of the carrier image. Spatial-domain techniques are easy realized, but have poor stability. Moreover, hidden information is easily damaged for spatial-domain techniques. In contrast, frequency-domain hiding algorithms are better in terms of rigidity robust and conducive to ensuring security of secret information [5-13].

This paper proposes a new and effective image hiding algorithm. The proposed method is an integration of several techniques including bit plane decomposition, singular value decomposition and wavelet packet transform. The experimental results indicate that the proposed algorithm has strong robustness and anti-attack, and it also has good invisibility and big capability.

2. The Theoretical Basis of Proposed Algorithm

2.1. Sigular Value Decomposition

Taking the image matrix *A as* $M \times M^{'}$ *s* non-negative matrix, rank *(A)=r, r ≤ M,* then resolving this to Matrix $A^{'}$ s singular value is as follows:

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$$A = USV^T = \sum_{i=1}^{r} \alpha_i \mu_i v_i^T \quad (1)$$

In the above formula,

$$U = \begin{bmatrix} u_1 \\ ... \\ u_m \end{bmatrix}, V = \begin{bmatrix} v_1 \\ ... \\ v_m \end{bmatrix}, S = \begin{bmatrix} \alpha_1 & & \\ & ... & \\ & & \alpha_m \end{bmatrix} \quad (2)$$

The singular value satisfies the equation:

$$\alpha_1 \geq \alpha_2 ... \alpha_r \geq \alpha_{r+1} = ... = \alpha_m = 0 \quad (3)$$

Non-zero singular values are equal to matrix's rank. From the above we see that the SVD unit also satisfies: $Av_i = \alpha_i \mu_i$ and $\mu_i^T A = \alpha_i v_i^T$. Generally speaking, matrix A has many minor singular values, so the matrix can use a relatively lower matrix approximation. Supposing $k \leq r$, the approximate matrix $\tilde{A}_k = \sum_{i=1}^{k} \alpha_i \mu_i v_i^T$, $E = A - \tilde{A}$ (error matrix). Matrix A's singular value is the average non-negative real number and is also unique. The singular value has relative stability towards disturbance and unchangeableness towards matrix transformation. In linear algebra, the matrix feature value shows the matrix feature, while the matrix singular value is better than its feature value in manifesting its feature. The Image matrix singular value reflects the image's ¨energy feature ¨while its corresponding singular vector reflects the image's "geometrical feature". Since the image's singular value is not very sensitive to the change of image grayness, its very slight alteration will not affect the image vision quality.

2.2. Wavelet Packet Decomposition

Wavelet packet decomposition provides more multi-resolution analysis than wavelet decomposition. It further decomposes the high frequency part. Figure 1 and Figure 2 show the process.

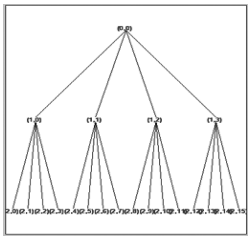


Figure 1. Two Level Wavelet Packet Decomposition

LL2	LH2	VV2	VW2
HL2	HH2	WV2	WW2
NN2	NM2	GG2	GF2
MN2	MM2	FG2	FF2

Figure 2. Diagram of Wavelet Packet Decomposition

The low frequency part contains the main energy of image. When the secret information hides into this region, it can resist kinds of attacks such as the filtering, cropping, rotating and so on, and it has good robustness. The high frequency part corresponds to the image details. The hidden image can obtain better invisibility, but has poor robustness.

3. The Proposed Algorithm Description

3.1. The Preprocessing of Secret Image

Firstly, implementation of chaos encryption is processed on the secret image, then operation of bit plane decomposition is performed on the encrypted image. The size of plane cannot become greater than coefficient matrix after two level wavelet packet decomposition of the carrier image.

3.2. The Processing of Carrier Image

By implementing wavelet packet decomposition on the carrier image, we can get image coefficient matrix WP_t of 16 different frequency sub-bands as shown in Figure 2. Then we take operation of singular value decomposition on the matrix WP_t according to the formula (1), where $t = LL2、LH2、HL2、HH2$ and we can get the following formula.

$$WP_t = U_t S_t V_t^T \tag{4}$$

After calculating of the energy entropy of the 12 remaining respective coefficient matrix, then we sort them from larger to small according to the energy entropy. Finally we can get the sorted coefficient matrix WP_g, where $t = VV2、VW2、\cdots\cdots FG2、GG2$, and satisfies the following requirements $1 \le g \le 12$ and $WP_g > WP_{g+1}$. It generates a signature vector which is used to extract the secret image.

3.3. Hiding Process of the Secret Image

Step 1: Hiding the main information bit planes $B_k \ (k = 7, 6, 5, 4)$ into the singular value matrix S_t as follows:

$$W_t = S_t + \lambda_t B_k \tag{5}$$

Firstly, by modifying the singular values, the transformation of the modified W_t is taken as follows:

$$W_t = S_t + \lambda_t B_k = U_{t1} S_{t1} V_{t1}^T \tag{6}$$

We can use the new singular value matrix S_{t1} to reconstruct wavelet coefficient WP_t' according to the formula (4).

$$WP_t' = U_t S_{t1} V_t^T \tag{7}$$

Where $t = LL2、LH2、HL2、HH2$, WP_t' will be used to reconstruct the carrier image hidden the secret image.

Step 2: Hiding the secondary information bit plane $B_k \ (k = 3, 2, 1, 0)$ into the singular value matrix WP_g as follows:

$$WP_g' = WP_g + \mu_k B_k \tag{8}$$

Where $g = 1,2,3,4$

Step 3: Wavelet coefficients which are obtained from step 1 and step 2 is used to reconstruct the carrier image contains the secret image.

3.4. Extraction of the Secret Image

Step 1: By taking implementation of 2 level wavelet packet decomposition on the hidden image, we can get image coefficient matrix HWP_t, where parameter t satisfy the following conditions.

$t = LL2'、LH2'、HL2'、HH2'、VV2'、VW2'、WV2'、WW2'、NN'、NM'、MN'、MM'、GG'、GF'、FG2'、GG2'$

Step 2: Implementation of the singular value decomposition on coefficient matrix HWP_t is performed.

$$\mathrm{A}_t = U_t' S_t' V_t'^T \tag{9}$$

V_{t1} and U_{t1} in the formula (6) is used to calculate the W_t' as follows:

$$W_t' = U_{t1} S_t' V_{t1}^T \tag{10}$$

The following formula (11) shows bit plane matrix extracted.

$$B_k' = (W_t' - S_t) / \lambda_t \tag{11}$$

Where $t = LL2'、LH2'、HL2'、HH2'$， $k = 7, 6, 5, 4$

Step 3: Using marked vector and matrix to determine coefficient matrix HWP_g containing bit planes. We can get the rest matrix of the bit planes by using the formula (8).The formula (12) describes the process.

$$B_k' = (HWP_g - WP_g) / \mu_k \tag{12}$$

Where $k = 3,2,1,0$

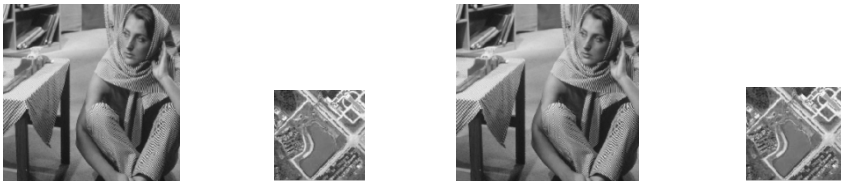
Step 4: All the binary bit planes is combined to recover the gray image and to extract the secret image.

4. Experimental Result

Taking 512 × 512 gray woman image as the carrier image, and 128×128 gray map image as the secret image. PSRN is used to quantitatively measure the image hidden invisible.

The normalized cross-correlation coefficient (NC) is used to measure the similarity between the secret image and the original secret image. It is also used to test the robustness of the algorithm under attacking. The original value of secret image PSRN=52.173, NC=1 without attacking.

Figure 3 shows the process of the hiding and extracting algorithm. The secret image is restored with good robustness and invisible without attacking.



(a) Carrier image (b) Secret image (c) Hidden image (d) Restored image

Figure 3. The Hiding and Restored Image

With implementation of various attackings on the hidden image such as cropping, filtering, rotation and so on, the extracted image after attacking is shown in Figure 4.

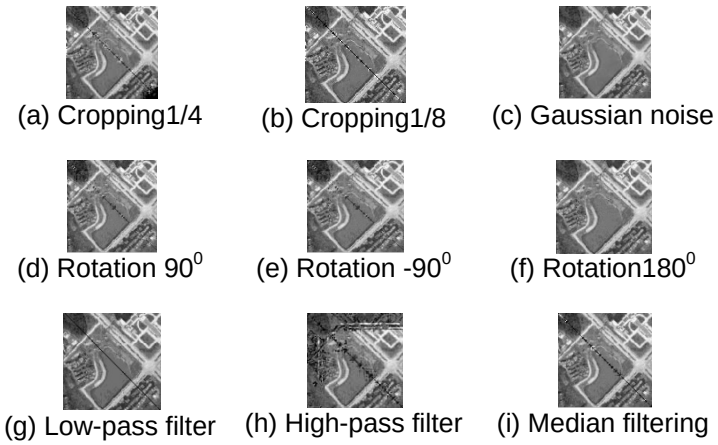


Figure 4. The Extracted Image after the Attacking

4.1. Quantitative Analysis of Robustness

In order to evaluate the robustness of the proposed algorithm, we implement various attackings on the hidden image and compared with the results of Reference [14] and Reference [15]. The experimental results are shown in Table 1 and Table 2.

Table 1. Comparison of NC Values between the Proposed Algorithm and Reference [14]

Attacking	Pattern	Proposed	Ref [14]
Gaussian noise	0.01	1	0.943
Cropping	1/4	0.99697	0.3869
Median filtering	3×3	0.99857	0.9561

Table 2. Comparison of NC Values between the Proposed Algorithm and Reference [15]

Attacking	Pattern	Proposed	Ref [15]
Gaussian noise	0.01	1	0.970
Rotation	-90	0.99923	0.943
	180	1	0.980
	90	0.99948	0.947
Cropping	1/8	0.9992	0.888
	1/4	0.99697	0.815
	1/2	0.96836	0.701
Median filtering	3×3	0.99857	0.986
	5×5	0.99704	0.982
	7×7	0.9811	0.965
Low- pass filtering	Gauss ambiguity	0.99232	0.911
High-pass filtering	Sharpening	0.99471	0.955

According to the results in the above tables, we can see that the proposed algorithm has better robustness under kinds of attacking.

4.2. Quantitative Analysis of Invisibility

Another important evaluating indicator to measure the image hiding effect is analysis of invisibility. From the Table 3, We can conclude that the proposed algorithm has a higher PSRN value with good invisibility.

Table 3. Quantitative Evaluation of Propsed Algorithm

Algorithm	Proposed	Ref [14]	Ref [15]
PSRN/DB	52.175	50.7049	30.36

5. Conclusion

In the paper a new digital image hiding algorithm based on wavelet packets transform and singular value decomposition was proposed. The experimental results are satisfied with good robustness and invisibility. The algorithm can effectively resist various image processing and attacking. The using of chaotic encryption algorithm improves the safety coefficient of communication and the ability of anti-attack.

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