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An Improvement of Embedding Efficiency for Watermarking Based on Genetic Algorithm

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Abstract. *This study suggests an optimization efficiency method based on the genetic algorithm (GA) for automated watermarking. In the block coding of the automated watermarking algorithm, adding a hidden massage is an important element in the successful implementation of watermarking. The coding matrix specifies the output and embedding rate of hidden information. The optimization of the coding matrix is done on adjusting GA to assess the main massage. The obtained results by the proposed scheme are compared to previous literature methods, the experimental findings reveal that the suggested scheme produces being stable, more robust and improves embedding efficiency without altering the embedding rate.*
Keywords: Watermarking, Genetic algorithm, Coding matrix, Embedding efficiency.

1. **Introduction.** Automated watermarking is to add a deep massage in digital multimedia products, due to authentically multimedia play an essential role in people's daily lives[1][2]. Because the multimedia products are easily pirated and illegally copied on the network as it is easy to spread [3][4]. Therefore, how to securely transmit multimedia data and copyright protection of multimedia works have always been paid attention from the scholars recently[5][6]. Automated watermarking is one of the challenging issues in the field of information security [7]. As digital watermark also is an evolving safety area, derived from a Greek word that means covered writing[8]. A digital watermark is the study of the hiding of data in such a way that nobody but the sender and receiver can predict it[9]. It gives an alternative idea to hide the credential data, as opposed to encryption, where messages are encrypted and not visible to the world [10].

The techniques of digital watermarking can be divided into two categories. On the one side, the digital watermarking algorithm for a spatial domain integrates watermark information by changing the pixel values of the carrier file[11]. Since pixel values can be easily changed in different image processing processes, the knowledge of the embedded watermark is easily lost. The practicality is, therefore, relatively weak. On the other hand, it is a soft watermarking algorithm for the transforming domain such as DCT, DWT, DFT[12].

There are some critical works included as follows. Information hiding aroused the attention of the public of transmitting confidential information and channel; Digital watermarking embedded copyright information; the security information into multimedia to ensure the security of owner's rights and media information[13] [14], and Discrete wavelet transform (DWT) and discrete cosine transform (DCT) were applied for the solution to digital image watermarking [15]. The contradiction between the information integration rate and the integration must be further improved, and the speed processing in media transmission has remained unchanged[16]. Information security has dramatically improved using a combination of digital watermarks and other methods, such as cryptography [17].

A metaheuristic is one of the most effective ways of dealing with combinatorial cryptography issues to achieve reliable and optimal solutions [18][19]. The genetic algorithm (GA) [20] is the most potent tool of metaheuristic algorithms [21]. In this paper, a new solution to digital watermarking with block coding usually matured coding theory to embed secret information into the media is proposed by adjusting the GA. Designing the coding matrix is a key technique of the proposed scheme, which is to design the coding matrix used to be a model for the fitness function[21]. The optimal coding matrix is obtained by applying GA that can improve embedding efficiency under the condition of a constant embedding rate.

The rest of the paper is structured as follows. Section 2 reviews the digital watermarking technology as the related work. Section 3 introduces a solution to digital watermarking with block coding. Section 4 discusses the simulation results of the proposed scheme for selected images. Section 5 gives a conclusion.

2. Digital Watermarking Technology Based on Block Encoding.

In the research of digital watermarking technology based on block coding, the secret information is usually embedded into the carrier image by using mature coding theory[22]. It is necessary for mature coding as a critical factor to design the coding matrix for algorithms[23]. A method is proposed in reference [24], that utilizes a unit augmented matrix. In a group of pixels of length *m+1* bits of the carrier, m-bit secret information can be embedded in the carrier by modifying $[m/2]$ bits at most. Encoding matrix of $m \times 2m$ size is constructed by using the m-order unit matrix and its inverse matrix[25]. This method can embed m-bit secret information in a pixel group of length $2m$ and modify only $[m/2]$ bit pixels. A method of information hiding based on the Hamming code that can embed m-bit information in a 2^{m-1} pixel group with modifying 1-bit pixel[26].

Initialize an encoding matrix $H_{(m\times n)}$ is expressed as follows.

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,n} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,n} \\ h_{3,1} & h_{3,2} & \cdots & h_{3,n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m,1} & h_{m,2} & \cdots & h_{m,n} \end{bmatrix}, \mathrm{X} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} \tag{1}$$

Then the carrier image is divided into blocks which size is $1 \times n$ and named as $X_{(1\times n)}$. The coding matrix H is expressed in the form of a column vector as in Eq.(2).

$$\begin{cases} H = [v_1, v_2, v_3, \ldots, v_n] \\ v_j = [h_{1,j}, h_{2,j}, h_{3,j}, \ldots, h_{m,j}] \end{cases} \tag{2}$$

Suppose the secret information to be embedded is $S_{(m\times 1)}$. Before embedding the secret information into the carrier, calculate the product of the coding matrix and the carrier vector c:

$$\mathrm{c} = \mathrm{H}\cdot\mathrm{X} = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,n} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,n} \\ h_{3,1} & h_{3,2} & \cdots & h_{3,n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{m,1} & h_{m,2} & \cdots & h_{m,n} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} \sum\limits_{j=1}^{n}(h_{1,j}x_j) \\ \sum\limits_{j=1}^{n}(h_{2,j}x_j) \\ \sum\limits_{j=1}^{n}(h_{3,j}x_j) \\ \vdots \\ \sum\limits_{j=1}^{n}(h_{m,j}x_j) \end{bmatrix} \tag{3}$$

According to Eq.(3) and Eq.(2), it can be refereed as in Eq.(4).

$$\mathrm{c} = \mathrm{H}\cdot\mathrm{X} = x_1v_1 \otimes x_2v_2 \otimes x_3v_3 \otimes \ldots \otimes (x_nv_n) \tag{4}$$

where c indicates that the result of the exclusive OR operation obtained by selecting the column vector of the coding matrix H by using the carrier vector X. Calculate the exclusive or d of c with embedded information S.

$$d = c \otimes S \tag{5}$$

where d indicates the content that needs to be modified for c by changing c to S. If $d_i = 0$, then $c_i = S_i$, it means no need to modify c_i. If $d_i = 1, c_i \neq S$, then inverting c_i. In summary, if $c = S$ is to be made, it is necessary to modify c to make $(d = \overrightarrow{0})$ that is, $c' = c \otimes d$. d can be represented by the column vector of the coding matrix H in Eq.(6).

$$\begin{aligned} \mathrm{d} = \mathrm{HZ} = (z_1v_1) \otimes (z_2v_2) \otimes (z_3v_3) \otimes \ldots \otimes (z_nv_n) = \sum v_j, \\ \mathrm{j} \in \{\mathrm{j}|z_j = 0, z_j \in \mathrm{Z}\} \end{aligned} \tag{6}$$

In the coding matrix, for all the values of d, there is a vector $Z_{(1\times n)}$ that holds the above equation. Then c' can be expressed as follows.

$$\mathrm{c'} = \mathrm{H}\cdot\mathrm{X} \otimes \sum v_j \tag{7}$$

In the logical operation, suppose $c = ax \otimes by$ and $a, b, x, y \in [0, 1]$. If $y = 0$, then $c = ax$, then let $y = 1$ and the result as following Eq. (8).

$$\mathrm{c'} = \mathrm{ax} \otimes \mathrm{by} \leftrightarrow c \otimes b \tag{8}$$

If $y = 1$, then $c = ax \otimes by$. Let $y = 0$, the c' would be expressed as follows.

$$\mathrm{c'} = \mathrm{ax} \leftrightarrow (\mathrm{ax} \otimes \mathrm{b}) \otimes \mathrm{b} \leftrightarrow \mathrm{c} \otimes \mathrm{b} \tag{9}$$

From this expression, it is possible to invert y in $c = ax \otimes by$, and the result is equivalent to $c' = c \otimes b$. Similarly, if the element x_j in the vector X is inverted and the transformed vector is denoted as Y. We can get HX as follows.

$$\mathrm{H}\cdot\mathrm{Y} = \mathrm{H}\cdot\mathrm{X} \otimes v_j \tag{10}$$

Therefore, if the elements in the multiple carrier vectors are inverted, the result is equivalent to the HX being exclusive to the column vector corresponding to the position of

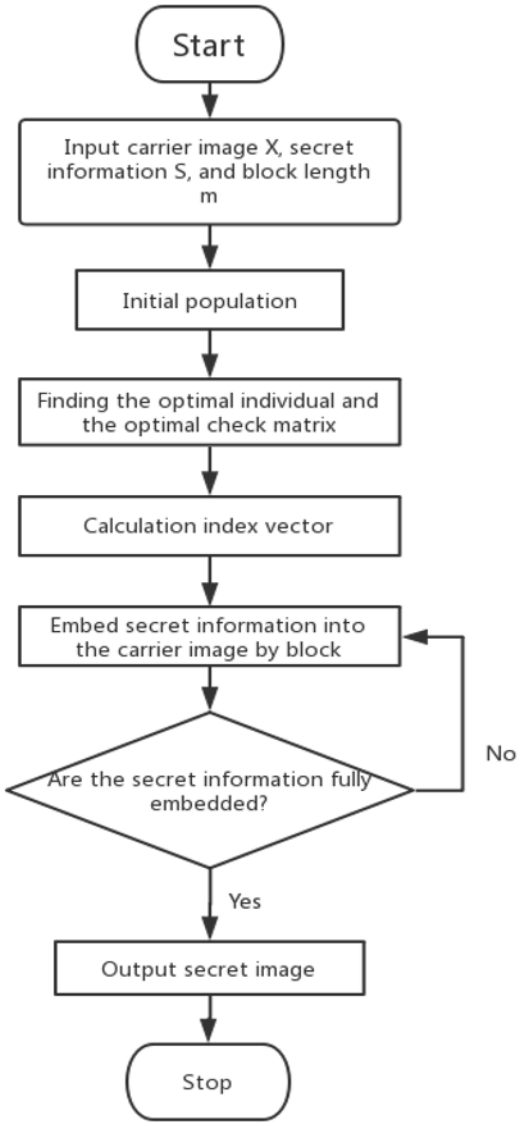


Figure 1. Flowchart of finding optimal coding matrix

the negated element in the encoding matrix H. According to Eqs.(10) and (7), the result is expressed as follows.

$$c' = H \cdot Y,\ Y = \begin{cases} y_i = x_i, i \neq j \\ y_i = \sim\ x_i, i = j \end{cases} \tag{11}$$

This makes it possible to hide the watermark information in the image by modifying the carrier vector using the coding matrix. Where Y is a carrier vector carrying secret information obtained by embedding the secret information in the carrier vector X to modify the X. Because $c' = HY$, and $c' \otimes S = \overrightarrow{0}$, when extracting information, you only need to block the secret image according to the same rule, and then use Eq.(12) to extract the hidden image from the secret image. Watermark information S' in it.

$$\text{S'} = \text{H} \cdot \text{Y} \tag{12}$$

where S' is the hidden image from the secret image as the watermark.

3. **Improving Embedded Watermarking Using GA.** This section presents a solution to improving watermark embedding efficiency based on an intelligent optimization

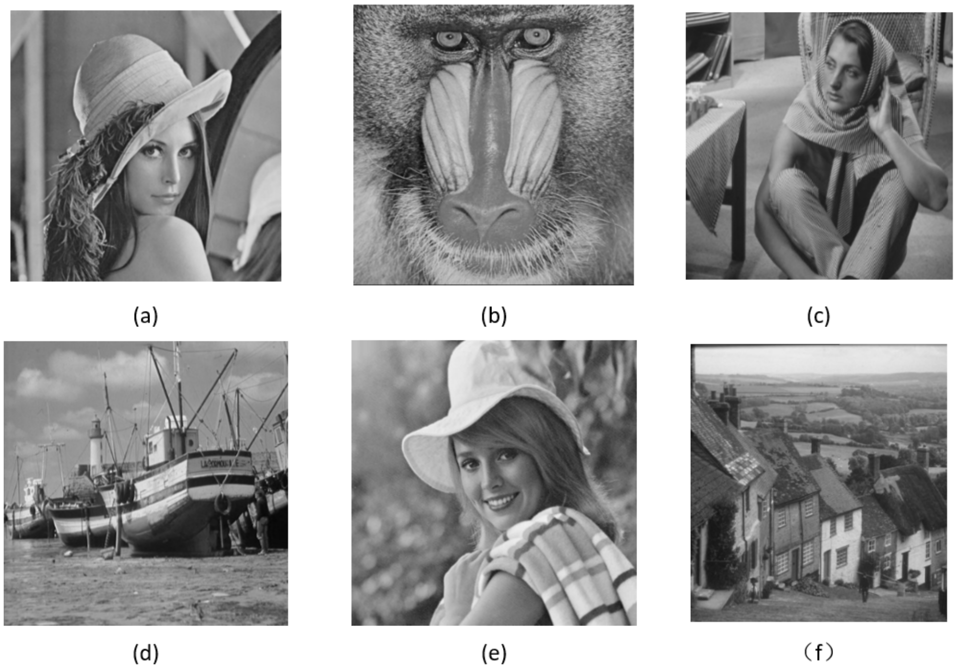


FIGURE 2. The selected image color with each color image with a multidimensional and multimodal model

algorithm. After the carrier image and the secret information are given, the coding matrix is optimized by the smart calculation algorithm. And finally, an optimal coding matrix that can achieve higher embedding efficiency for the given carrier and secret information is obtained by GA. Then the confidential information is embedded by using the coding matrix in the carrier image. Assuming that the length of the secret information is m bits, the coding matrix is presented as follows.

$$H = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 & 1 \\ 0 & 1 & 0 & \cdots & 0 & 1 \\ 0 & 0 & 1 & \cdots & 0 & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1 & 1 \end{bmatrix}_{m\times(m+1)} \tag{13}$$

The first m column of H is an m-order identity matrix, and the $m+1th$ column is an m-dimensional column vector in which all elements are "1". The number of "1"s in d and the number of "0"s are represented by Nd^1 and Nd^0, respectively. When embedding information, if $Nd^0 = m$, no modification to the vector is required; If $Nd^1 < Nd^0$, then $1 \leq Nd^1 \leq [m/2]$, the first m row of X is $XORed$ with d, and the $m+1th$ row of X remains the same; If $Nd^1 > [m/2]$, that is, $1 \leq Nd^0 \leq [m/2]$. Invert the $m+1th$ line of X and then XOR the first m rows of X with the inverted d. The above operation is to invert the $m+1th$ row of the matrix X, which is equivalent to the exclusive OR of d and the $m+1th$ column of H. Since the $m+1th$ column of H is a column vector in which all elements are "1", it is equivalent to inverting d.

In summary, for H, when $1 \leq Nd^1 \leq [m/2]$, embedding m-bit information requires modifying the Nd^1 bits of the carrier. When $Nd^1 > [m/2]$ and $Nd^0 < [m/2]$, it is necessary to modify the Nd^0+1 bits of the carrier. The method proposed in this paper can use the coding matrix H to embed m-bit secret information in the payload by modifying the $[m/2]$ bit in the pixel group of length $m+1$ bits. The optimal coding matrix H is obtained by applied adjusting GA. A coding matrix is expressed as follows if each row

FIGURE 3. Secreted Test Marks of Watermarks (WMs)

TABLE 1. Corresponding PSNR and the standard deviation of the value of the Otsu function.

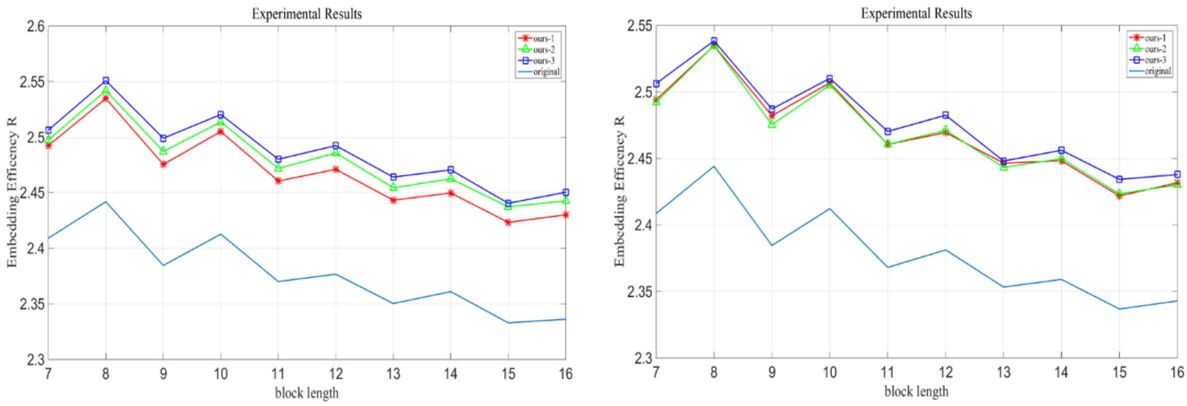
Selected Images	WM01	WM02	WM03	WM01	WM02	WM03
	PSNR			**Otsu value**		
Img1	55.10	51.62	53.14	0.91	0.97	0.93
Img2	50.31	49.66	50.17	0.95	0.93	0.93
Img3	49.03	45.56	47.90	0.96	0.98	0.97
Img5	47.22	46.58	46.59	0.97	0.95	0.97
Img5	55.40	51.92	53.44	0.92	0.98	0.94
Img6	50.61	49.96	50.47	0.96	0.94	0.94

of the coding matrix H is swapped, the result H' is equivalent to taking all the rows of the pattern out for full alignment. There is a total of $m!$ possible cases, where the "!" represents factorial.

$$H = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 & 1 \\ 0 & 1 & 0 & \cdots & 0 & 1 \\ 0 & 0 & 1 & \cdots & 0 & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1 & 1 \end{bmatrix} \sim \begin{bmatrix} 0 & 0 & 1 & \cdots & 0 & 1 \\ 1 & 0 & 0 & \cdots & 0 & 1 \\ 0 & 1 & 0 & \cdots & 0 & 1 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1 & 1 \end{bmatrix} = \mathrm{H}' \tag{14}$$

When the value of m is relatively small, all the possible cases of H' can be enumerated, and the best one can be selected from them. But it is difficult to selected the best one in all the possible cases of m! when the value of m is extremely large. A variable of m is taken as a minimum of 4 and a maximum of 16. When $4 \leq m \leq 7$, enumerate all possible cases of the coding matrix and select the best coding matrix therefrom. When $8 \leq m \leq 16$, the number of bits to be modified by the carrier will be required as an adaptive value. Next, the genetic algorithm is used to search for the optimal coding matrix. As shown in Figure 1, the flowchart of the specific implementation method is as follows:

- *Step*1 Enter the carrier image X and the secret information S and the block length of the secret information m. Divide X and S into a series of sub-blocks of length $m+1$ and m, respectively, and denote them by X^i and S^i (i is the serial number of the block). The number of partitions depends on the length of S and the size of m. In addition, ensure that there is enough position in the carrier image to embed the information.



a) The GA with a variety of population sizes (N_p is set to 40, 60, and 80, respectively)

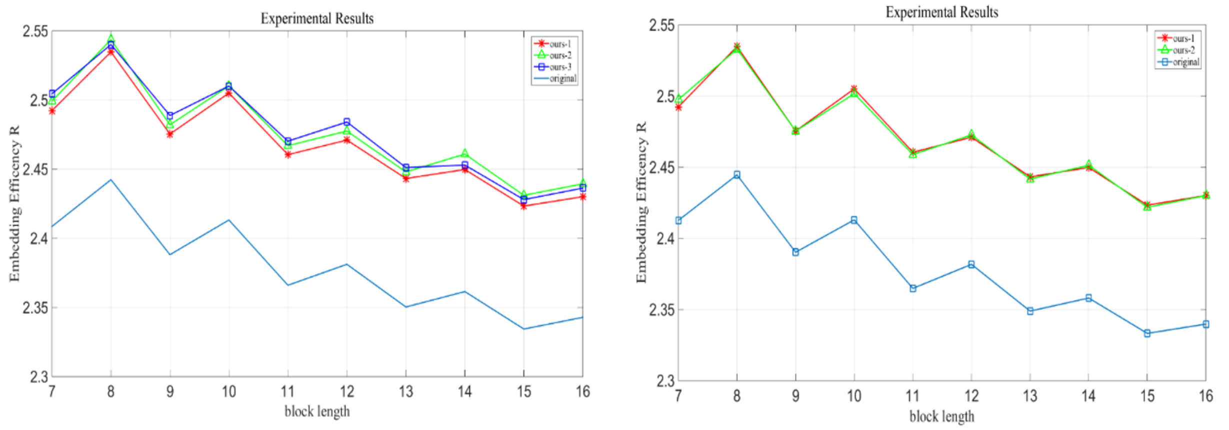
b) A variety of crossover rate (c_r is set to 0.8, 0.85, and 0.9, respectively)

FIGURE 4. Comparison of the proposed scheme with the method of the DWT-DCT image digital watermarking; sub figures: a) the proposed scheme with a variety of population sizes (40, 60, and 80, respectively); b) the proposed scheme with a variety of crossover rate (c_r is set to 0.8, 0.85, and 0.9, respectively)

- *Step*2 Initialize the population. Individuals are represented by POS, each of which contains two variables $POS.X$, $POS.Y$ of dimension $[m/2]$. $POS.X(i)$ and $POS.Y(i)$ are elements in POS, which have a value range of $[1, m]$. The role of $POS.X(i)$ and $POS.Y(i)$ is to swap the $POS.X(i)$ and $POS.Y(i)$ lines of the coding matrix.
- *Step*3 The number of bits modified by the embedded secret information is used as the fitness, and the population is iterated and optimized by the genetic algorithm. The result outputs the optimal coding matrix H_{best} and the optimal individual POS_{best}.
- *Step*4 Before embedding the information, calculate the index vector and initialize the index vector $Indx = [1, 2, 3, ..., m]$. The vector $Indx$ is the index vector of matrix H in Eq.(14). Then the values of $indx(POS.X(i)_{best})$ and $indx(POS.Y(i)_{best})$ in POS_{best} are interchanged to obtain the optimized coding matrix index vector.
- *Step*5 The secret information is embedded in the carrier using the index vector $Indx$ and the best coding matrix best H_{best}. For example, if the $i-th$ block is embedded with secret information, if $d_j^i \neq 0$, the $X^i(Indx(j))$ is inverted, that is, $Y^i(Indx(j)) = \overline{X^i(Indx(j))}$.
- *Step*6 Repeat the loop until the criterion max-iteration has been reached or the secret information is embedded.

4. **Experimental Results.** Six images are chosen as carriers for verification of testing the efficiency of the proposed scheme for optimal matrix blocked of automated watermarking. Figure 2 shows the nine used images as carriers for verification of testing optimal blocks matrix. Figure 3 lists three secreted test marks of the watermark (WM). The randomly generated five different watermarks secret data are embedded in the above six carrier images as experimental results. The size of the watermark made each time is the same as the watermark embedding capacity allowed by the carrier image.

The embedding efficiency of the watermark needs to enhance the limited computation of the traditional method and the embedding rate. The embedding efficiency is the amount of data that can be embedded by 1-bit information of the modified carrier on average,



a) A variety of mutation rate (p_m is set to 0.01, 0.05, and 0.1, respectively)

b) A variety of crossover rate (c_r is set to 0.6, 0.8, and 0.9, respectively).

FIGURE 5. Comparison of the proposed scheme with the method of the DWT- DCT image digital watermarking; subfigures a) the proposed scheme with a variety of mutation rate (0.01, 0.05, and 0.1, respectively); b) the proposed scheme with a variety of crossover rate (cr is set to 0.8, 0.85, and 0.9, respectively).

and the calculation method. A parameter of embedded amount is calculated as follows.

$$R = \frac{L_s}{D} \tag{15}$$

where L_s is the length of the secret information, and D is the number of bits that need to be modified to embed the secret information in the carriers. A metric of the signal-to-noise ratio ($PSNR$), the calculation time, and the standard deviation δ of the $Otsu$ function value obtained from 30 consecutive runs are used to evaluate the segmentation performance and stability of the algorithms. The signal-to-noise ratio is calculated as $PSNR\,(dB) = 20\lg\left(\frac{255}{RMSE}\right)$ where $RMSE = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[I\,(i,j) - \tilde{I}\,(i,j)\right]^2}$ I and $\tilde{I}$ is the original image and the divided image with size $M \times N$. The standard deviation of the value of the $Otsu$ function is calculated as $\delta = \sqrt{\frac{1}{k-1}\sum_{i=1}^{k}\left(f_i - f\right)^2}$, where $k = 30$ is the number of continuous operations, andf_i and $\overset{\simeq}{f}$ respectively represent the $i-th$ Otsu function value and k is average value of the $Otsu$ function after two consecutive runs. The obtained optimal results of the proposed scheme with adjusting GA for image digital watermarking are compared with the traditional method of using DWT and DCT (original method without optimal block matrix) [14]. The parameter setting for algorithms is listed as follows: a probability of crossover c_r is set 0.6; the mutation rate p_r is set to 0.05; the number of individuals N_p is set to 60, and the maximum number of iterations is $Maxgen$ set to 200.

A standard difference in the value of the $Otsu$ function as a standardized correlation can measure the strength of the watermarking system, which measures the similitude between the original watermark image and the extracted watermark image. Any watermarking method is exceptionally reliable, where the standard deviation value is near one. The $PSNR$ and the standard deviation value of the $Otsu$ function are shown in Table

TABLE 2. Comparison of the proposed scheme based on the optimization block-coding-matrix by GA with the scheme based on DWT- DCT.

Selected images	**Proposed scheme**			Scheme based on DWT- DCT		
	WM01	WM02	WM03	WM01	WM02	WM03
	PSNR					
Img1	54.04	50.56	52.08	38.38	35.70	33.05
Img2	49.25	48.60	49.11	39.58	36.90	34.26
Img3	48.07	44.60	46.94	39.69	37.00	34.36
Img5	46.16	45.52	45.53	39.38	36.69	34.05
Img5	49.25	48.60	49.11	39.58	36.90	34.26
Img6	47.77	44.30	46.64	39.39	36.70	34.06
	Otsu value					
Img1	0.91	0.97	0.93	0.59	0.66	0.73
Img2	0.94	0.93	0.93	0.54	0.57	0.64
Img3	0.96	0.98	0.97	0.54	0.57	0.64
Img5	0.97	0.95	0.97	0.56	0.61	0.67
Img5	0.95	0.97	0.96	0.53	0.56	0.62
Img6	0.96	0.94	0.96	0.55	0.60	0.66

1. The results show that the quality of extracted watermark images is high when the factor is gained. When the Otsu value is close to one, the robustness of any automated watermarking system is high.

Figure 4 shows the comparison of the proposed scheme with the method of the DWT-DCT image digital watermarking; sub figures: a) the proposed scheme with a variety of mutation rate (0.01, 0.05, and 0.1, respectively); b) the proposed scheme with a variety of crossover rate (c_r is set to 0.8, 0.85, and 0.9, respectively). Figure 3 depicts the comparison of the proposed scheme with the method of the DWT- DCT image digital watermarking; sub figures: a) the proposed scheme with a variety of population sizes (40, 60, and 80, respectively); b) the proposed scheme with a variety of crossover rate (cr is set to 0.8, 0.85, and 0.9, respectively). The blue line is the embedding efficiency of the traditional method. Ours-1 and ours-2 represent single-point crossover and multi-point crossover respectively.

Table 2 shows the comparison of the proposed scheme based on the optimization block-coding-matrix by GA with the scheme based on DWT- DCT.

Observed from Figures 4, 5, and Table 2 shows that the proposed scheme produces better results than the scheme based on DWT- DCT in terms of the convergence and the performance accuracy.

5. **Conclusion.** In this paper, we proposed a new optimization efficiency scheme of the digital watermark based on the Genetic Algorithm (GA). Adding a hidden massage into the block coding of the automated watermarking system is an essential element in the successful implementation of the watermarking system. The contradiction between the embedding efficiency and embedding rate of the algorithm is analyzed, and the optimal coding matrix is solved by optimizing GA. In the simulation section, the obtained results

from the proposed scheme were compared to previous literature methods. Compared experimental findings reveal that the suggested process produces the more stable, robust than the competitors. It means that the suggested scheme makes it possible to achieve higher embedding efficiency with the same embedding rate of traditional algorithms.

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