Proposing a New Image Watermarking Method Using Shearlet Transform and Whale Optimization Algorithm

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1. INTRODUCTION

In recent years, computer networks’ dramatic growth has facilitated multimedia data dissemination such as images, videos, and audios. Multimedia data can be easily copied and published without the owner’s consent. There are different ways to prevent unauthorized disseminations, one of which is digital watermarking. A watermark can be a logo, digital signature, etc., inserted in the host image. Therefore, the image owner can prove the suspicious image from the watermarking image via retrieving the watermark. The main purpose of digital watermarking is embedding the watermark information invisible and usually resistant in digital content [1]. In recent decades many new techniques and concepts have been introduced in the field of image watermarking. They have been used as a tool for detecting changes in digital images as well as image authentication.

A digital watermark is a visible or invisible identification code. It may contain some information about the legal recipient or author of the original data and copyright laws in the form of textual or visual data stored. This digital watermark can be identified or extracted and later used to claim real ownership of the data. The lack of a watermark in the previously watermarking image means the digital data content has changed.

Discrete Cosine Transforms (DCT) [2-4], Discrete Wavelet Transforms (DWT) [5-8], and the Singular Value Decomposition (SVD) Transform [5-14] are the most commonly used frequency domain transformations for watermarking. According to the papers, some hybrid watermarking techniques using the SVD transform can also be mentioned [4-11, 15-17]. Several watermarking studies that use optimization and evolutionary algorithms are Genetic Algorithm (GA) [18-20], Particle Swarm Optimization (PSO) Algorithm [21, 22], and Bee Colony (BC) Algorithm [2, 10, 15, 23] and Wolf Optimization Algorithm [24]. Abdelhakim et al. proposed a resistant watermarking method using the DCT conversion and bee colony algorithm [2]. Seardae et al. proposed a watermarking method in the Wavelet transform domain [24]. Mishra et al. developed a resistant watermarking method using the Shearlet transform and whale optimization algorithm [24].
method in the DWT-SVD transform domain [7]. Ali et al. used the Differential Evolution (DE) algorithm to find the appropriate scaling factor in the DWT-SVD algorithm [5]. Block-based watermarking was suggested by Makbol et al. using Wavelet transform and the SVD transform [8]. Fazli and Moeini developed a resistant watermarking method utilizing a fusion of Wavelet transform and DCT, and the SVD transform [17]. Zhao et al. proposed a new approach using Shearlet transform and the entropy rate [25]. Xiang-yang et al. proposed a watermarking method that employs watermarking in the sub-band with the highest amount of energy [26].

The rest of the paper is organized as follows. In Section 2, we review the Materials and Methods. Section 3 presents the proposed method in this paper. Section 4 illustrates the evaluation of results. Section 5 shows the result of simulations and experiments. Finally, Section 6 concludes this paper.

2. MATERIALS AND METHODS

2.1. Classification of Digital Watermarking Methods Watermark embedding techniques can be divided into two main groups. Below is a brief description of the features of these groups.

In spatial domain techniques, the watermark is added directly to the original image by changing its pixel values. These algorithms are simple, fast, and have a high embedded capacity [27]. These techniques are susceptible to changes that can damage the watermark [28, 29]. Spatial-based techniques’ disadvantages are more than their advantages that cannot withstand many attacks, such as added noise and compression methods [30]. Techniques for this class include Least Significant Bit (LSB) [31], Local Binary Pattern (LBP) [32], and Histogram modification [33].

Compared to spatial domain methods, in transform domain techniques, the goal is to incorporate watermarking into image coefficients. The host image is first transmitted from the spatial domain to the transform domain with a reversible conversion and after inserting the tokens with a suitable embedding algorithm. An important issue in this area is to choose the best place for watermarking to avoid image distortion. The transform field is resistant to change, attack and the watermark can be invisibly embedded in the image [28, 29]. Techniques of this method include DCT [34], Discrete Fourier Transform (DFT) [35], and DWT [6].

2.2. Shearlet Transform A useful feature of Wavelets is their ability to find the image features in horizontal, vertical, and diagonal directions. However, Wavelets are not capable of identifying image-oriented features in other directions because of isotropic bases. To solve this problem and find features in different directions, we can use other multi-scale directional transformations. A qualified feature of these transformations in watermarking operations is that we can embed the watermark in differently oriented sub-bands of image. These multi-scale and multi-resolution transformations include Wavelet, Contourlet, and Shearlet transform. The Contourlets have bases made of a combination of directional and multi-scale filter banks [36].

In 2005, a new approach was proposed by Labate et al. [37], called Shearlet, which obtained a near-optimal approximation [38]. The Shearlet display has been introduced as a multi-directional Wavelet method that provides almost optimal features in recent years. This new representation is based on a resistant and simple mathematical framework that provides a flexible tool for geometric representation of multi-dimensional data and is also more natural for implementation. The Shearlet method is also related to multi-resolution analysis [36]. Figure 1 shows the frequency domain of the Shearlet transform [39].

The continuous 2D Shearlet transform (Shearlet’s mother) in \( \psi \in L^2(\mathbb{R}^2) \) space is defined as Equation (1):

\[
\psi_{\alpha,j}(x) = a^{3j/2} \psi(A^{-j} \cdot (x - t))
\]

\[
= a^{3j/2} \psi \begin{pmatrix} 1 & -a \n & 0 \end{pmatrix} a^{n/2} S_r \cdot a^{n/2} \beta \in R, x \in \mathbb{R}^2 \quad (1)
\]

where \( \psi \) is called the generator function, \( A \) and \( S \) are 2x2 invertible matrices, \( A \) is the parabolic scaling matrices, and \( S \) is the Shear matrices [37], as:

\[
A = \begin{bmatrix} a & 0 \\ 0 & a^{1/2} \end{bmatrix}, \quad S_r = \begin{bmatrix} 1 & s \\ 0 & 1 \end{bmatrix}
\]

(2)

Applying the Fourier transform to the continuous Shearlet transform is obtained using Equation (3):

\[
SH_\psi(f) = \left\langle f, \psi_{\alpha,j} \right\rangle
\]

(3)

Figure 1. The frequency space of the Shearlet transform [39].
The digital image is considered as sampled functions on the network with
\[ \{ \left( \frac{m_1}{M}, \frac{m_2}{N} \right) : (m_1, m_2) \in I \} \]
where \( I = \{(m_1, m_2) : m_1 = a, \ldots, M - 1, m_2 = a, \ldots, N - 1 \} \).
We have acquired a discrete shearlet by discretizing the parameters \( a, s, \) and \( t \). Suppose \( j = \left[ \frac{\log_2 N}{2} \right] \) is the number of levels taken into account. A discrete shearlet transform must be obtained. The scale, shear, and transfer parameters are discretized:
\[ a_i = 2^{-i_1} = \frac{1}{4^j}, \quad j = \infty, \ldots, j - 1 \]
\[ s_{jk} = k2^{j}, \quad 2^{-1} \leq k \leq 2^{j} \]
\[ t_m = (\frac{m_1}{M}, \frac{m_2}{N}) \quad m \in I \]

With these symbols, discrete shearlets are defined as Equation (4):
\[ \psi_{j, s, t_m}(x) = \psi(A_{j, s}^{-1}(x - t_m)) \quad (4) \]
The discrete shearlet transform is defined as Equation (5):
\[ SH_{i,f}(f) = \left\{ f, \psi_{j, s, t_m}(x) \right\} \quad (5) \]

In this paper, a NonSubsampled Shearlet Transform (NSST) is used. The size of all sub-bands of the image is equal, and its proper feature is being shifted invariant.

2.3. Singular Value Decomposition

A new conversion watermarking method called SVD has been studied in recent years. In the SVD transform, one matrix can be divided into three matrices that are the same size as the original matrix. If \( A \) is a square image, its corresponding matrix is represented as \( A \in R^{n \times n} \), where \( R \) represents the range of real numbers, so the SVD of matrix \( A \) is as Equation (6) [40]:
\[ A = U S V^T = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & \cdots & 0 \\ 0 & \lambda_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \lambda_n \end{bmatrix} \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \cdots & v_{nn} \end{bmatrix}^T \quad (6) \]

In the above equation \( U \in R^{n \times n} \) and each column constitutes the eigenvectors of the matrix \( AA^T \). These special vectors are called left eigenvectors. Also \( V \in R^{n \times n} \) represents the matrix that each column represents the eigenvectors of the matrix \( AA^T \). These eigenvectors are called right eigenvectors, and \( V^T \) represents the matrix transpose \( V \), which is an identity matrix \( n \times n \). \( S \in R^{n \times n} \) is a diagonal matrix with real nonnegative layers on the original diameter. Each element has a single non-descending matrix \( A \) value. So all of its elements are zero except for the original diameter. \( \lambda_i \) is a singular value and is defined as follows:
\[ \lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_n = 0 \]

The SVD is a desirable method for matrix decomposition in which the maximum signal energy is packaged using several coefficients. The use of the SVD in digital image watermarking has many advantages, some of which are as follows [41]:
1. Maximum image energy is obtained by the largest singular value coefficients of the image.
2. Singular image values are very stable. When small damage to the image occurs, its values do not change much, so it is highly resistant to various attacks.
3. Image transparency remains almost constant even after embedding the watermark in singular image values.

2.4. Whale Optimization Algorithm

The scaling factor plays an essential role in watermarking operation. An enormous scale factor value makes the watermark image more robust to attacks. A small scale factor value also makes the watermark image more imperceptible. You have to be smart to choose the right scale factor and balance the watermarking image’s resistance and transparency. In this paper, we use Whale Optimization Algorithm (WOA) to select the best scale factor.

The WOA is one of the nature-inspired metaheuristic optimization algorithms [42]. It has shown good performance due to its high convergence speed.

Humpback whales can detect hunting location and circle around them since the optimal position is unknown already in search space. As a result, the WOA algorithm assumes that the current optimal candidate’s best answer is the optimal target or the solution is close to it. In the following, other search agents try to update their positions according to the best search factor, such as Equations (7) and (8).

\[ D = C \times (t) - X(t) \quad (7) \]
\[ X(t+1) = X(t) - \Delta D \quad (8) \]

where \( t \) represents the current iteration, \( A \) and \( \bar{C} \) represent the coefficient vectors. \( X \) indicates the position vector of the best solution to date. \( \bar{X} \) represents the current location vector. The \( A \) and \( \bar{C} \) vectors are calculated using Equations (9) and (10):

\[ A = 2a \bar{r} - \bar{a} \quad (9) \]
\[ \bar{C} = 2 \bar{r} \quad (10) \]

where \( \bar{a} \) linearly decreases from 2 to zero during the iterations, and \( \bar{r} \) represents a random vector in the interval [0,1].
Humpback whales operate at the exploitation phase using two Shrinking encircling mechanisms and spiral updating position. The contraction loop mechanism is performed by reducing the value of $\bar{D}$ in Equation (9). The distance between the whale at position $(X, Y)$ and the hunting at position $(X^*, Y^*)$ is first calculated in the spiral position update phase. In the following, a spiral equation is created between the whale position and the hunting position to simulate the spiral motion of humpback whales with Equation (11):

$$X(t+1)=D\cdot e^{i\cdot \cos(2\pi l)+X'(t)}$$

where $D=|X^*(t)-X(t)|$ and indicates the distance of the $ith$ whale to the prey (best solution obtained so far), $b$ demonstrates a constant that specifies the shape of the logarithmic spiral. $1$ shows a random number in the range [-1,1].

Humpbacks move around the hunt simultaneously, both in the shape of the shrinking circle and along a spiral-shaped path. We assume that a 50% probability can be used by a contraction loop mechanism or a spiral model to model this synchronous behavior and update the whale's position during optimization. The mathematical model is shown in Equation (12):

$$X(t+1)=\begin{cases} X^*(t)-\bar{A}D \\ \frac{D}{|D|}e^{i\cdot \cos(2\pi l)+X'(t)} \end{cases}$$

where $P$ represents a random number in the interval [0,1], vector $\bar{A}$ change-based approach also can be used for hunting search. Humpback whales perform a random search based on each other's position. Therefore, we use random values of $\bar{A}$ greater than one or smaller than minus one to force the search agent to avoid a reference whale. Unlike the extraction phase, we update a search agent's position in the exploration phase based on the randomly selected search agent. This mechanism and $|\bar{A}|>1$ emphasize exploration and allow the WOA algorithm to perform a global search. The mathematical model of this work is given by Equations (13) and (14):

$$D=|\bar{C}\cdot X_{\text{rand}}-\bar{X}|$$

$$X(t+1)=\frac{X_{\text{rand}}-LD}{D}$$

where $X_{\text{rand}}$ is the random location vector selected from the current population.

3. PROPOSED METHOD

This paper proposes an invisible watermarking method based on the SVD technique and WOA algorithm in the Non-subsample Shearlet Transform domain. In the suggested algorithm, the host image, the watermark image, and the watermarking image are defined as $I$, $W$, and $I_w$, respectively.

The watermark embedding algorithm in the host image is as follows:

1. Host image $I$ is parsed into three $I_R$, $I_G$, and $I_B$ matrices.
2. In matrix $I_i : i=R, G, B$, Shearlet transform is executed up to three levels and decomposed into a low-frequency sub-band and some high-frequency sub-bands.
3. In the low-frequency sub-band obtained from the image in step 2, the SVD transform is performed.
4. The dimension of the $W$ watermark image is resized to the sub-dimension of the host image.
5. The watermark image $W$ is split into three $W_R$, $W_G$, and $W_B$ matrices.
6. The watermark image is multiplied by the $T$ scale factor. It is aggregated by the matrix of single values ($S$) obtained from the host image's low-frequency sub-band.
7. The inverse of the SVD transform is obtained by the matrices $U$ and $V$ obtained in step 3 and the matrix $S$ obtained by step 6.
8. The inverse Shearlet transform is executed on the new low-frequency sub-band matrix obtained from step 7. The high-frequency sub-bands obtained from step 2 and the watermarking image $I_i : i=R, G, B$ is obtained.
9. The three $I_R, I_G, I_B$ matrices obtained from step 8 are merged, and the $I_w$ watermarking is created.
10. The $S$ matrix obtained from level 6 is then stored as a key to retrieving the watermark image.

The watermark extraction algorithm is as follows:

1. Watermarking $I_w$ image is divided into three matrices $I_{wR}$, $I_{wG}$, and $I_{wB}$.
2. In matrix $I_{w i} : i=R, G, B$, Shearlet transform is executed for up to 3 levels and decomposed into a low frequency and some high-frequency sub-bands.
3. In the low-frequency sub-band obtained from step 2, the SVD transform is performed.
4. The matrix $S$ obtained during the watermark's embedding phase (the key to retrieving the watermark image) is called.
5. The inverse of the SVD transform is executed on the $U$ and $V$ matrices obtained from step 3 and the $S$ matrix (watermarking operation key).
6. The inverse Shearlet transform is executed on the low-frequency sub-band matrix obtained from the inverse SVD transform operation obtained from step 5. The rest of the high-frequency sub-bands obtained from step 2 and the watermarking image $I_i : i=R, G, B$ is obtained.
7. The three $I_{wR}, I_{wG}$, and $I_{wB}$ matrices obtained from step 6 are merged to create the extracted host image.
8. The $S$ matrix called in step 4 is subtracted from the $S$ matrix obtained in step 3 and then divided into the $T$ scaling factor (alpha), which the WOA algorithm gets its optimal value. (The evaluation function of the WOA algorithm is the Peak Signal to Noise Ratio (PSNR) value between the host and the extracted watermark).
9. The three $W_R$, $W_G$, and $W_B$ matrices are merged to create the extracted watermark.

The watermark embedding and extraction algorithm in the host image are shown in Figures 2 and 3, respectively.

4. EVALUATION OF RESULTS

All implementations and results are obtained using MATLAB 2015 software. Two-color images, Airplane and Lena, are used as host images and Peugeot as the watermark image. The used images were afforded from the USC-SIPI database and are standard images for various image processing operations. Figures 4 and 5 show the host images and the watermark image, respectively. The host image size is 128*128 pixels. The watermark is also a 32x32 pixel color image.

In digital watermarking, it is necessary to maintain quality of the original image. Therefore, two criteria of imperceptibility and robustness are needed to evaluate the watermarking and watermark image. These criteria measure the amount of transparency between two images [43]. PSNR is used to measure imperceptibility. The mean square error (MSE) between the two images is measured using Equation (15) [44].

$$MSE(I_1, I_2) = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (I_1(i,j) - I_2(i,j))^2$$

$M$ and $N$ are the dimensions of the image, $I_1$ and $I_2$ are the primary and the extracted image, respectively.

PSNR is used to estimate the quality of two images. The high PSNR indicates that the two images are very similar [45]. This criterion is expressed in decibel unit (db.) using Equation (16):

$$PSNR(I_1, I_2) = 10 \log \frac{MAX^2}{MSE}$$

Figure 2. Watermarking embedding algorithm

Figure 3. Watermarking extraction algorithm
$MAX_I$ represents the peak signal in the input image, which is 255 in 8-bit images.

Correlation Coefficient (CRC) can be used to measure the robustness of the extracted watermark. The CRC is used to measure the correlation between the two images. The CRC value ranges from zero to one, calculated using Equation (17) [46].

$$CRC = \frac{\sum \sum I_i(j) \cdot I_j(i)}{\sqrt{\sum \sum I_i(j)^2 \cdot \sum \sum I_j(i)^2}}$$ (17)

$I_1$ and $I_2$ are the initial and the extracted image, respectively.

### 5. EXPERIMENTAL AND COMPARATIVE RESULTS

In this section, results of the proposed method are presented in terms of transparency and robustness according to the experiments. In this method, we have applied Shearlet transform to three levels on the input image. The initial scaling factor value for the watermarking operation was set as 0.05, which is obtained experimentally with relatively good strength and transparency. The WOA algorithm is iterated 100 times.

The proposed method in this paper is compared with similar watermarking techniques using NonSubsampled Wavelet Transform (NSWT), NonSubsampled Contourlet Transform (NSCT), DWT_SVD [47], and DST-BSVD [16]. The investigated attacks are as follows: average filter (AF), Gaussian low-pass filter (GP), median filter (MF), Gaussian noise (GN), speckle noise (SN), pepper and salt noise (SP), blurring (BL), motion blur (MB), sharpening (SH), JPEG compression (JPEG), crop (CR), rotation (RO), transition (TR), Vertical flip (FLV), Horizontal flip (FLH).

Comparative results of the extracted watermark transparency based on PSNR criterion and the extracted watermark robustness based on CRC criterion are presented in Table 1. The results of the experiments show that the transparency parameter of the proposed PSNR method is improved on all images compared to the tested methods after AF 3x3, AF 5x5, GP 3x3, GP 5x5, MF 3x3, MF 5x5, RO (5), RO (45), RO (110), FLH, FLV, BL (0.3), BL (0.5), BL (1), MB (15, 45), SH (0.3), SH (0.5), SH (1), JPEG (5), JPEG (20), JPEG (80), JPEG (90), GN (0, 0.001), GN (0, 0.1), GN (0, 0.3), SN (0.001), SN (0.3) and SP (0.3) attacks.

The test results also show that the CRC robustness parameter of the proposed method improved on all images compared to the tested methods after AF 3x3, AF 5x5, GP 3x3, GP 5x5, MF 3x3, MF 5x5, RO (5), FLH, FLV, BL (0.3), BL (0.5), BL (1), MB (15, 45), SH (0.3), SH (0.5), SH (1), JPEG (5), JPEG (20), JPEG (80), JPEG (90), GN (0, 0.001), GN (0, 0.1), GN (0, 0.3), SN (0.001), SN (0.3) and SP (0.001) attacks.

For instance, Lena's watermarking image and the extracted watermark can be seen after applying different image processing attacks in Figure 6.

![Figure 4. Images used for the host](image-url)

![Figure 5. Image used for watermarking](image-url)

**TABLE 1.** Comparison of transparency and robustness of the proposed method with the traditional one

| Attacks | NSWT | NSCT | DWT SVD | DST BSVD | NSST WOA | Alpha | NSWT | NSCT | DWT SVD | DST BSVD | NSST WOA |
|---------|------|------|---------|----------|----------|-------|------|------|---------|----------|----------|
| No Attack | 27.5352 | 27.5422 | 21.9887 | 27.6045 | 27.6082 | 0.0495 | 27.5642 | 27.5374 | 22.1424 | 27.6045 | 27.6722 |
| CR | 0.9976 | 0.9976 | 0.9912 | 0.9976 | 0.9976 | 0.0975 | 0.9976 | 0.9976 | 0.9915 | 0.9976 | 0.9976 |
| AF 3x3 | -0.0193 | 20.7062 | 5.0495 | 24.4168 | 24.4186 | 0.0499 | 1.3383 | 21.1577 | 6.1167 | 25.9312 | 25.9561 |
| CR | 0.5612 | 0.9882 | 0.7822 | 0.9949 | 0.9949 | 0.617 | 0.9893 | 0.8162 | 0.9964 | 0.9964 |
| AF 5x5 | -6.1806 | 14.0629 | -0.188 | 20.7052 | 20.728 | 0.0506 | -5.105 | 14.5596 | 0.7797 | 23.4313 | 23.4325 |
| CR | 0.3434 | 0.9493 | 0.6046 | 0.9881 | 0.9881 | 0.3774 | 0.9545 | 0.6436 | 0.9936 | 0.9936 |
| GP 3x3 | 9.0892 | 26.2659 | 14.7156 | 27.2263 | 27.2838 | 0.0496 | 10.4572 | 26.4244 | 15.9669 | 27.4432 | 27.5103 |
| CR | 0.871 | 0.9967 | 0.9595 | 0.9974 | 0.9974 | 0.9002 | 0.9968 | 0.9691 | 0.9975 | 0.9975 |
|        |        |        |        |        |        |
|--------|--------|--------|--------|--------|--------|
|        | PSNR   | PSNR   | PSNR   | PSNR   | PSNR   |
| GP 5x5 | 9.034  | 9.067  | 0.959  | 0.974  | 0.974  |
|        | 0.967  | 0.959  | 0.974  | 0.974  | 0.974  |
|        | 0.959  | 0.974  | 0.974  | 0.974  | 0.974  |
| MF 3x3 | 6.585  | 4.239  | 11.387 | 27.273 | 27.340 |
|        | 0.949  | 0.9234 | 0.9974 | 0.974  | 0.974  |
|        | 0.9234 | 0.9974 | 0.974  | 0.974  | 0.974  |
| MF 5x5 | 0.927  | 21.894 | 5.5602 | 26.674 | 26.705 |
|        | 0.5098 | 0.9909 | 0.7991 | 0.977  | 0.977  |
|        | 0.9909 | 0.7991 | 0.977  | 0.977  | 0.977  |
| CR (50,50) | -1.4583 | 13.7274 | 2.6289 | 15.693 | 15.909 |
|        | 0.4235 | 0.9428 | 0.6073 | 0.9634 | 0.9634 |
|        | 0.4235 | 0.9428 | 0.6073 | 0.9634 | 0.9634 |
| RO (5) | -8.7343 | 9.8694 | -0.3362 | 5.7629 | 8.1631 |
|        | 0.2305 | 0.8877 | 0.5076 | 0.7566 | 0.7566 |
|        | 0.2305 | 0.8877 | 0.5076 | 0.7566 | 0.7566 |
| RO (45) | -11.1896 | 7.3059 | -2.7841 | 3.3138 | 6.948  |
|        | 0.1379 | 0.8072 | 0.2731 | 0.9669 | 0.9667 |
|        | 0.1379 | 0.8072 | 0.2731 | 0.9669 | 0.9667 |
| RO (110) | -10.7669 | 6.2575 | -5.1083 | 10.8244 | 11.6408 |
|        | 0.1191 | 0.7586 | 0.2509 | 0.8997 | 0.8989 |
|        | 0.1191 | 0.7586 | 0.2509 | 0.8997 | 0.8989 |
| TR (5,10) | -8.7343 | 9.8694 | -0.3362 | 5.7629 | 8.1631 |
|        | 0.2305 | 0.8877 | 0.5076 | 0.7566 | 0.7566 |
|        | 0.2305 | 0.8877 | 0.5076 | 0.7566 | 0.7566 |
| TR (10,10) | -11.1896 | 7.3059 | -2.7841 | 3.3138 | 6.948  |
|        | 0.1379 | 0.8072 | 0.2731 | 0.9669 | 0.9667 |
|        | 0.1379 | 0.8072 | 0.2731 | 0.9669 | 0.9667 |
| TR (10,15) | -13.0371 | 5.364  | -4.8295 | 1.7165 | 6.3338 |
|        | 0.1513 | 0.7431 | 0.348  | 0.5930 | 0.5901 |
|        | 0.1513 | 0.7431 | 0.348  | 0.5930 | 0.5901 |
| FLH    | 27.5532 | 27.5422 | 21.9887 | 27.6045 | 27.68  |
|        | 0.9976 | 0.9976 | 0.9912 | 0.9976 | 0.9976 |
|        | 0.9976 | 0.9976 | 0.9912 | 0.9976 | 0.9976 |
| FLY    | 27.5532 | 27.5422 | 21.9887 | 27.6045 | 27.6799 |
|        | 0.9976 | 0.9976 | 0.9912 | 0.9976 | 0.9976 |
|        | 0.9976 | 0.9976 | 0.9912 | 0.9976 | 0.9976 |
| BL (0.3) | 27.2721 | 27.5422 | 22.6795 | 27.6085 | 27.684  |
|        | 0.9974 | 0.9976 | 0.9925 | 0.9976 | 0.9976 |
|        | 0.9974 | 0.9976 | 0.9925 | 0.9976 | 0.9976 |
| BL (0.5) | 9.034  | 26.2477 | 14.6593 | 27.2223 | 27.2796 |
|        | 0.8697 | 0.9667 | 0.959  | 0.974  | 0.974  |
|        | 0.8697 | 0.9667 | 0.959  | 0.974  | 0.974  |
| BL (1) | -1.5598 | 19.1654 | 3.7335 | 24.0507 | 24.0507 |
|        | 0.5009 | 0.9833 | 0.7407 | 0.9945 | 0.9945 |
|        | 0.5009 | 0.9833 | 0.7407 | 0.9945 | 0.9945 |
| MB (15,45) | -10.3849 | 8.3785 | -2.8112 | 13.9633 | 14.3528 |
|        | 0.2275 | 0.8457 | 0.4851 | 0.9472 | 0.9472 |
|        | 0.2275 | 0.8457 | 0.4851 | 0.9472 | 0.9472 |
| SH (0.3) | 27.2895 | 27.5427 | 21.548 | 27.6041 | 27.6795 |
|        | 0.9974 | 0.9976 | 0.9902 | 0.9976 | 0.9976 |
|        | 0.9974 | 0.9976 | 0.9902 | 0.9976 | 0.9976 |
| SH (0.5) | 12.7994 | 26.7514 | 12.9629 | 27.5937 | 27.6692 |
|        | 0.9282 | 0.9971 | 0.9284 | 0.9976 | 0.9976 |
|        | 0.9282 | 0.9971 | 0.9284 | 0.9976 | 0.9976 |
| SH (1) | 2.8272 | 22.4063 | 5.302  | 27.5768 | 27.6522 |
|        | 0.5622 | 0.9919 | 0.6786 | 0.9976 | 0.9976 |
|        | 0.5622 | 0.9919 | 0.6786 | 0.9976 | 0.9976 |
| JPEG (5) | 0.1168 | 17.1102 | 7.6878 | 24.2946 | 24.2964 |
|        | 0.5055 | 0.9728 | 0.8157 | 0.9948 | 0.9948 |
|        | 0.5055 | 0.9728 | 0.8157 | 0.9948 | 0.9948 |
| JPEG (20) | 5.2688 | 21.2887 | 12.0118 | 27.1215 | 27.1803 |
|        | 0.7219 | 0.9895 | 0.9151 | 0.9973 | 0.9973 |
|        | 0.7219 | 0.9895 | 0.9151 | 0.9973 | 0.9973 |
| Method                         | PSNR  | CRC   | PSNR  | CRC   | PSNR  | CRC   | PSNR  | CRC   | PSNR  | CRC   |
|-------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| JPEG (80)                     | 11.4999 | 0.9079 | 25.4888 | 0.9961 | 16.0991 | 0.9632 | 27.5979 | 0.9976 | 27.6697 | 0.9976 |
| JPEG (90)                     | 14.0842 | 0.9466 | 26.4018 | 0.9974 | 17.9799 | 0.9976 | 27.6153 | 0.9976 | 27.6431 | 0.9976 |
| GN (0,0.001)                  | 21.6183 | 0.9004 | 27.3805 | 0.9975 | 19.4741 | 0.9842 | 27.6103 | 0.9976 | 27.6748 | 0.9976 |
| GN (0,0.1)                    | -9.893 | 0.1248 | 9.4688 | 0.1813 | -4.5191 | 0.9109 | 11.4189 | 0.9181 | 12.4969 | 0.9181 |
| SN (0,0.3)                    | -15.8199 | 0.9944 | 3.3436 | 0.987 | -2.5212 | 0.9976 | 4.6152 | 0.9976 | 7.711 | 0.9976 |
| SN (0.1)                      | -6.8981 | 0.2014 | 12.5193 | 0.3052 | -1.6489 | 0.9564 | 14.8625 | 0.9969 | 15.2098 | 0.9969 |
| SN (0.3)                      | -14.2862 | 0.0709 | 4.1495 | 0.0951 | -8.331 | 0.7127 | 5.0541 | 0.7248 | 7.9473 | 0.7248 |
| SP (0,0.001)                  | 23.9428 | 0.9944 | 27.4682 | 0.987 | 20.3124 | 0.9976 | 27.5969 | 0.9976 | 27.6488 | 0.9976 |
| SP (0.1)                      | -5.0013 | 0.2575 | 14.1647 | 0.3706 | -0.3985 | 0.9664 | 16.0549 | 0.9862 | 16.4447 | 0.9862 |
| SP (0.3)                      | -13.8007 | 0.0729 | 4.9173 | 0.1057 | -7.5212 | 0.7902 | 6.7054 | 0.7881 | 8.69 | 0.7881 |

Figure 6. Results of watermarking images (Lena image) and extracted watermark image (Peugeot logo)

We can see the PSNR and the CRC results obtained from the methods tested on different images in Figures 7, 8, 9, and 10, respectively. After various attacks, the result of experiments in the proposed method indicated that we have improved and increased the transparency parameters of PSNR and the CRC robustness parameter over the tested methods. The execution time of the studied algorithms is shown in Table 2.
In this paper, a new watermarking method using the Shearlet Transform domain coupled with the SVD transform and Whale optimization algorithm is presented with higher transparency and robustness than the comparison methods. Shearlet Transform has more transparency than traditional converts. The SVD transform also increases the robustness of watermarking operations. The whale optimization algorithm is also used to recover the watermark with the least damage in the watermark extraction step. An optimal combination of these methods has resulted in good transparency and resistivity watermarking. The results are extensible in future work and can be tested using other optimization transformations and algorithms.

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چکیده

نهان نگاری برای پنهان کردن یا اضافه کردن اطلاعات مهمی در فایل دیگر، به طوری که فقط افراد آگاه با ابزار لازم بتوانند به آن دست یابند و همچنین یکی از راههای حفاظت از دادههای حساسی به داخل روبات و تردد غیرقانونی آنها است. در روش های قابل توجه نگاری تصویر دیجیتال بینش از روی های مانند تبدیلات فوریه و تبدیلات موجک و روش های ریاضی و آماری دیگر استفاده می‌کند. تبدیل فیچر که نوع خاص و نسبتاً جدیدی می‌باشد، می‌تواند برای نگاری در تصاویر دیجیتال مورد استفاده قرار گیرد. این روش به دلیل ویژگی‌های خاص خود می‌تواند بعث افزایش اثر و بهره وری در کاربردهای مانند نگاری تصاویر موجود مورد استفاده قرار گیرد. در این مقاله بر خلاف روش‌های قدیمی برای افزایش شفافیت و مقاومت تصویر نهان نگاری در بهبود توانایی پرکاری باند فرکانس پاسخگذاری می‌باشد.

Persian Abstract

چکیده

نهان نگاری برای پنهان کردن یا اضافه کردن اطلاعات مهمی در فایل دیگر، به طوری که فقط افراد آگاه با ابزار لازم بتوانند به آن دست یابند و همچنین یکی از راههای حفاظت از دادههای حساسی به داخل روبات و تردد غیرقانونی آنها است. در روش های قابل توجه نگاری تصویر دیجیتال بینش از روی های مانند تبدیلات فوریه و تبدیلات موجک و روش های ریاضی و آماری دیگر استفاده می‌کند. تبدیل فیچر که نوع خاص و نسبتاً جدیدی می‌باشد، می‌تواند برای نگاری در تصاویر دیجیتال مورد استفاده قرار گیرد. این روش به دلیل ویژگی‌های خاص خود می‌تواند بعث افزایش اثر و بهره وری در کاربردهای مانند نگاری تصاویر موجود مورد استفاده قرار گیرد. در این مقاله بر خلاف روش‌های قدیمی برای افزایش شفافیت و مقاومت تصویر نهان نگاری در بهبود توانایی پرکاری باند فرکانس پاسخگذاری می‌باشد.