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A robust image watermarking technique using SVD and differential evolution in DCT domain

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ABSTRACT

In this paper we applied differential evolution (DE) algorithm to balance the tradeoff between robustness and imperceptibility by exploring multiple scaling factors in image watermarking. First of all, the original image is partitioned into blocks and the blocks are transformed into Discrete Cosine Transform (DCT) domain. The DC coefficients from each block are collected to construct a low-resolution approximation image and apply Singular Value Decomposition (SVD) on this approximation image. After that watermark is embedded by modifying singular values with the singular values of the watermark. The role of DE algorithm is to identify the best multiple scaling factors for embedding process in order to achieve the best performance in terms of robustness without compromising with the quality of the image. To enhance the security, watermark is scrambled by Arnold transform before embedding. Experimental results show that the proposed scheme maintains a satisfactory image quality and watermark can still be identified from a seriously distorted image.

1. Introduction

In the recent past, application and popularization of multimedia technologies and computer networks have made duplication and distribution much easier of multimedia contents such as audio, video or images. From a copyright point of view and also from the security viewpoint, protection of such data has become an important and challenging task. This anxiety has raised the interest of the researchers toward the development of multimedia protection schemes. Digital watermarking [1–3], is the most popular and efficient scheme for multimedia protection. In a digital image watermarking algorithm a watermark structure is embedded within the cover image to protect it from illegal usage. The watermark structure may be in the form of a visible or an invisible pattern that is embedded in the host data permanently. However, it is the main concern of the watermarking schemes that the embedded watermark should not degrade the quality of the host image and the inserted watermark must be as much invisible as possible. The first property (efficiency with which we are embedding the watermark) is called robustness while the latter (visibility of watermark) is called imperceptibility.

Watermarking techniques can be classified into two groups based on the domain in which the watermark is inserted; spatial domain techniques and frequency domain techniques. In spatial domain techniques, the watermark is directly inserted into the cover image by altering the pixel values [4,5]. The simplest technique in this category is to modify the least significant bits (LSB) of the host image pixels by watermark image pixels [3]. The spatial domain methods have the advantages of easy implementation and low cost of operation but are generally not robust to geometrical and image processing attacks.

In contrast, frequency domain methods transform the representation of spatial domain into the frequency domain and then modify its frequency coefficients to embed the watermark. There are many transform domain watermarking techniques such as discrete cosine transforms (DCT) [6–11], singular value decomposition (SVD) [2,12,13], discrete Fourier transforms (DFT) [14,15], and discrete wavelet transforms (DWT) [16,17]. These techniques are more robust against many signal and image processing attacks in comparison to the spatial domain techniques but generally require higher computational cost.

SVD, a mathematical technique, is used to extract geometric features from an image. Due to its high robustness, high energy compaction and low computation cost, DCT is often used as the basis of digital watermarking. The performance of watermarking methods further improved by combining two or more transformations [18–27]. The idea was based on the reality that combined effect with the transforms would be more effective than the sum of their individual effects.

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Imperceptibility and robustness are important issues that a watermarking algorithm needs to address. Most existing watermarking schemes take scaling factor as a single value that needs the proper fine tuning. However, the use of multiple scaling factors is suggested in the literature [1] pointing the problem with the single scaling factor. A single scaling factor may not be suitable in case of SVD watermarking as each singular value has a different tolerance limit. The tradeoff between transparency and robustness in watermarking problem can be viewed as an optimization problem. Therefore, it can be solved by taking advantage of artificial intelligence techniques such as, genetic algorithms (GA), particle swarm optimization (PSO) and differential evolution (DE). Existing literature shows the benefits of these methods of improving the performance of existing watermarking schemes and obtaining a high quality resulting image. Examples include application of GA [28–33], PSO [34–37] and DE [38].

This paper describes a digital image watermarking algorithm based on a combination of two transforms; DCT and SVD; and finding multiple scaling factors by DE. The proposed technique named as DCT + SVD + DE. Watermarking is done by altering the DC coefficients of the 8×8 sub-blocks of the original image in SVD domain carefully employing the multiple scaling factors obtained by DE. The scaling factors are in the form of diagonal matrix that lies between zero and one. DE has already been employed for finding an optimized solution for watermarking in SVD domain [38]. In this paper we provide another scope by employing DE to adaptively select the strength of the watermark in the combined domain of DCT and SVD. To enhance security and robustness of the embedded watermark an additional protection level, before the embedding process the watermark data is randomized, is done using a chaotic permutation called Arnold transform [39].

The rest of the paper is structured as follows. The preliminaries of this research are briefly described in Section 2. The proposed technique is explained in Section 3. The experimental results are discussed in Section 4. Finally, Section 5 draws the conclusions based on this research.

2. Preliminary

2.1. Discrete cosine transform (DCT)

Discrete cosine transform (DCT) [40] is one of the most fascinating transformation methods that transforms the data from the spatial domain to frequency domain. Having the property of energy compaction it has been widely applied to the problems of signal and image processing. Most of the energy is concentrated in the lower frequencies and the higher frequency coefficients may be thrown away from its frequency components without too much data quality degradation. The mathematical equations of 2D discrete cosine transform and its inverse transform are

$$C(u,v) = \frac{2}{\sqrt{mn}}\alpha(u)\alpha(v)\sum_{x=0}^{m-1}\sum_{y=0}^{n-1}f(x,y) \times \cos\frac{(2x+1)u\pi}{2m} \times \cos\frac{(2y+1)v\pi}{2n} \tag{1}$$

$$f(x,y) = \frac{2}{\sqrt{mn}}\sum_{u=0}^{m-1}\sum_{v=0}^{n-1}\alpha(u)\alpha(v)f(x,y) \times \cos\frac{(2x+1)u\pi}{2m} \times \cos\frac{(2y+1)v\pi}{2n} \tag{2}$$

where $f(x, y)$ is the pixel value in the spatial domain, $C(u, v)$ is the DCT coefficient, m and n represent the block size and

$$\alpha(u), \alpha(v) = \begin{cases} 1/\sqrt{2} & \text{if } u, v = 0 \\ 1 & \text{else} \end{cases} \tag{3}$$

The DC coefficient, which is the average value of the sample data, is obtained by putting $u = v = 0$ in Eq. (1) and all other coefficients are called the AC coefficients.

2.2. Singular value decomposition (SVD)

The singular value decomposition, or SVD, is related to the theory of diagonalizing a symmetric matrix in linear algebra. It decomposes a rectangular matrix A into three matrices U, S and the transpose of V; U and V are orthogonal square matrices whose columns are called left and right singular vectors respectively, S is a rectangular diagonal matrix with diagonal entries in descending order that are called singular values. It may be considered as a method of transforming correlated data set into uncorrelated one that better explain the various relationships among the original data. SVD finds its significance in image processing as a digital image can be viewed as a matrix of nonnegative scalar entries. Let A be a square matrix of order n, then according to SVD it can be represented mathematically as:

$$A = USV^T \tag{4}$$

where $UU^T = I_n$ and $VV^T = I_n$; the columns of U are orthonormal eigenvectors of AA^T, the columns of V are orthonormal vectors of A^TA and S is a diagonal matrix containing the square roots of the eigenvalues from U or V in descending order. If r ($r \le n$) is the rank of the matrix A then the elements of the diagonal matrix S satisfy the relation (5) and the matrix A can be written as (6):

$$\sigma_1 \ge \sigma_2 \ge \ldots \ge \sigma_r > \sigma_{r+1} = \sigma_{r+2} \ldots = \sigma_n = 0 \tag{5}$$

$$A = \sum_{i=1}^{r} \sigma_i u_i v_i^T \tag{6}$$

where u_i and v_i are the ith eigenvector of U and V and σ_i is the ith singular value.

2.3. Arnold transform

To enhance the security of the watermarking scheme watermark should be randomized before embedding into cover image. There are many ways for scrambling, but here we will discuss the only Arnold transform [39] that is an iterative process to move the pixel position. The generalized two dimension (2D) Arnold transform is defined as:

$$\begin{bmatrix} x_k \\ y_k \end{bmatrix} = \begin{bmatrix} 1 & a \\ b & ab+1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ y_{k-1} \end{bmatrix} \bmod (n) \tag{7}$$

where x_k and y_k are transformed coordinates corresponding to coordinates x_{k-1} and y_{k-1} after k iterations; n is the height or width of the square image processed; a and b are positive integers. It is an iterative process, if the location (x,y) is transformed several times then it returns to its original position after T iterations. This T is called the period of the transformation and depends on parameters a, b and k. These parameters can be used as secret keys.

To get back the original image, periodicity is required. Suppose the scrambling is done performing k iterations, so one can get back the original image by performing $(T - k)$ iterations.

2.4. Differential evolution (DE)

A simple, fast and robust evolutionary algorithm (EA) named DE was introduced by Storn and Price [41] in 1995. It starts with an initial population of *NP* individuals $X_{i,G}$, $i = 1,\ldots, NP$, each of dimension *D*, where the index *i* denotes the *i*th solution of the population at generation *G*. There are three main operations of DE that are briefly described below.

Mutation: Corresponding to each target individual $X_{i,G}$ to produce the perturbed individual $V_{i,G}$, the mutation process is begin by randomly selecting three distinct individuals $\{X_{r1}, X_{r2}, X_{r3}\}$ from the current population that must also be different the target individual $X_{i,G}$ (i.e., $r1 \neq r2 \neq r3 \neq i$). It applies the vector difference between the existing population individuals in determining both the degree and direction of the perturbation. The difference between two individuals after scaling by a scaling factor $F \in [0,1]$, is added to the third individual. Mathematically it is given as:

$$V_{i,G} = X_{r1,G} + F \times (X_{r2,G} - X_{r3,G}) \tag{8}$$

where, *i* ranges over the number of individuals.

Crossover: Crossover operation is performed between perturbed individual $V_{i,G}$ and target individual $X_{i,G}$ to generate the trial individual, $T_{i,G}$. This operation depends on a crossover probability $Cr \in [0,1]$ that decides the components of trial individual. It also promises depending on $k \in \{1,\ldots, D\}$ that trial individual will be different in at least one component. Mathematical equation of trial individual generation is as:

$$t_{j,i.G} = \begin{cases} v_{j,i.G} & \text{if } \; rand_j \leq C_r \quad \vee \; j = k \\ x_{j,i.G} & \text{otherwise} \end{cases} \tag{9}$$

where, *j* ranges over the dimension of the problem.

Selection: After reproduction of the trial individual, evaluate the fitness and compare it to its corresponding target individual. It is done by the selection operation that selects the best individual from the target and trial individuals. Mathematically it is defined by the following equation:

$$X_{i.G+1} = \begin{cases} T_{i.G} & \text{if } \; f(T_{i.G}) \leq \; f(X_{i.G}) \\ X_{i.G} & \text{otherwise} \end{cases} \tag{10}$$

If the trial individual is better than target individual then it replaces target individual in the next generation otherwise it will continue target individual. Thus, each individual of the temporary (trial) population is compared with its counterpart in the current population.

3. Proposed technique

This section describes the proposed watermarking scheme. It has three components, finding optimal scaling factors, embedding and extraction. These are explained below. Watermark embedding and extraction procedures are also illustrated with the help of block diagrams in Figs. 1 and 2.

3.1. Embedding process

(1) Divide the cover image *I* into 8 × 8 square blocks, apply the DCT on each block and collect the DC value from each DCT coefficient matrix $C(m, n)$ to construct the matrix *A*. That is called the low-resolution approximation image.

(2) Perform SVD operation on matrix *A* to partition it into three matrices *U, V* and *S* such that.

$$A = USV^T \tag{11}$$

(3) Apply the Arnold transforms to watermark image to scramble watermark *W* and then inserted into the diagonal matrix *S* by employing *scaling factor* λ (*in the form of diagonal matrix*) *obtained by the use of a differential evolution algorithm.*

$$S_1 = S + \lambda W \tag{12}$$

(4) SVD operation is applied on matrix S_1 to obtain three matrices U_W, S_W and V_W such that

$$S_1 = U_w S_w V_w \tag{13}$$

(5) Find the matrix A_W with modified DC values by multiplying the matrices *U*, S_W, and V^T

$$A_w = US_w V^T \tag{14}$$

(6) Put back these modified DC values to the corresponding blocks and perform inverse DCT (IDCT) and merge the blocks to get the watermarked image I_W.

3.2. Extraction process

The extraction process of our scheme is divided into four steps. If U_W, *S*, V_W, and λ are provided by the owner and I_W^* is the possibly corrupted watermarked image, then a possibly distorted watermark W^* can be extracted by doing the reverse process. The computational steps of extraction process are given by:

(1) Apply the *step* 1 of embedding process on corrupted watermarked image I_W^* to get A_W^* and then *step* 2 on A_W^* to partition it into three matrices.

$$A_w^* = U^* S_w^* V^{*T} \tag{15}$$

(2) Compute possibly corrupted S_1^*

$$S_1^* = U_w S_w^* V_w^T \tag{16}$$

(3) Extract the possibly corrupted scrambled watermark W^*

$$W^* = \frac{S_1^* - S}{\lambda} \tag{17}$$

(4) Apply Arnold transforms $(T - k)$ times on W^* to get the watermark.

3.3. DE implementation detail

Watermark strength is a key point in image watermarking and can be visualized as an optimization problem. When the watermarking is done in SVD domain, single scaling factor does not make sense because each singular value has a different tolerance limit. Furthermore, we do not have any idea about the sensitivity of the image to a particular scaling factor, so a powerful algorithm is required to obtain the suitable scaling factors that could improve the robustness with minimum loss in quality. We consider the application of DE, an efficient optimizer, in finding the optimum scaling factors to achieve a better performance.

To apply the DE on the watermarking problem in hand, the individual structure is properly encoded and fitness function. The multiple scaling factors together make a single individual in DE. The procedure is started by initializing the population generated by a random number generator.

Using these solutions we modify the singular values (SVs) of the low-resolution approximation image in the embedding process. Then the watermarked image is examined for several attacks, and from these corrupted watermarked images the watermarks are extracted using the extraction process. The fitness (22) is computed for each individual and then the individuals with smaller fitness values are selected for the next generation. Now, we start

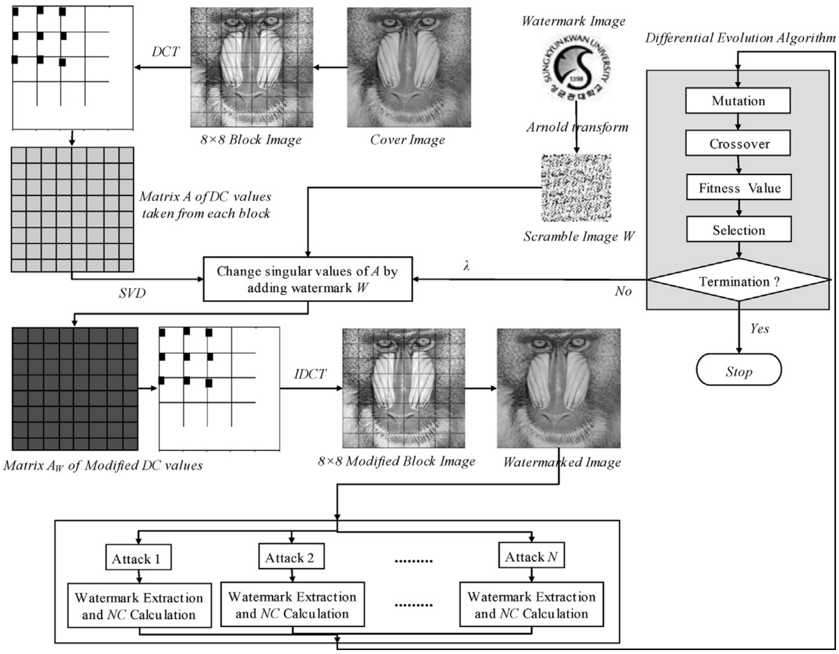

Fig. 1. Embedding process.

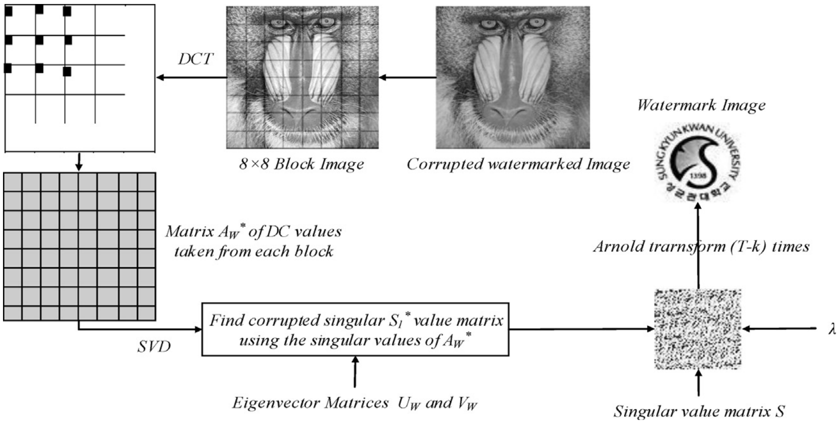

Fig. 2. Extraction process.

the main loop of DE; perform mutation and crossover operations on each individual and compute the fitness. The process is repeated till the termination criterion not satisfied. The individual with the minimum fitness of the final generation is used for watermark embedding.

Peak Signal to Noise Ratio (PSNR) and two dimensional Normalized Correlation (NC) given in (20) and (21) are used as perceptual imperceptibility and similarity measures respectively that has application in fitness evaluation.

$$\text{Imperceptibility} = NC(I, I_W) \tag{18}$$

$$\text{Robustness} = \frac{N}{\sum_{i=1}^{N} NC(WmW_i^*)} \tag{19}$$

$$\text{PSNR} = 10\log_{10}\left(\frac{(X_{MAX})^2}{1/(n \times n)\sum_i\sum_j(X(i,j) - \hat{X}(i,j))^2}\right) \tag{20}$$

$$NC(X, \hat{X}) = \frac{\sum_i\sum_j X(i,J)\hat{X}(i,J)}{\sqrt{\sum_i\sum_j X(i,j)^2}\sqrt{\sum_i\sum_j \hat{X}(i,j)^2}} \tag{21}$$


(a) (b) (c) (d) (e)

Fig. 3. (a) Cover image Airplane, (b) cover image Baboon, (c) watermark image, (d) watermarked Airplane image with PSNR (NC) 36.3848 (0.9998) value and (e) watermarked Baboon image with PSNR (NC) 32.4527 (0.9989) value.

Table 1
DE parameters.

Population size *NP*	10
Scaling factor *F*	0.5
Crossover rate *Cr*	0.5
Maximum generation	200

$$\text{Minimize} \quad f = \frac{N}{\sum_{i=1}^{N} NC(W, W_i^*)} - NC(I, I_W) \qquad (22)$$

where I and I_W stand for the cover image and the image after embedding the watermark, respectively; NC indicates the 2D normalized correlation value; W and W^* point toward the original watermark and the extracted watermark images, respectively; X and $\widehat{X}$ represent the original and the processed images; X_{MAX} is the maximum possible value of the image X, for an 8-bit per pixel representation X_{MAX} is 255; N represents the number of attacking methods; and n is the height or width of the square image.

4. Results and discussions

This section validates the performance of the proposed watermarking scheme for the numerous experiments. Watermarked image is distorted taken various attacks, like (1) average filtering (AF) using 3 × 3 pixel's neighborhood, (2) rotation (RO) with 30° anticlockwise, (3) gamma correction (GC) with 0.6, (4) cropping (CR) one fourth from left side, (5) translation (TR) with 20 × 20 pixels (6) histogram equalization (HE), (7) Gaussian noise (GN) with zero mean and 0.01 variance, (8) JPEG compression with quality factor 50, (9) rescaling (RS) 512 → 256 → 512 and (10) median filtering (MF) using 3 × 3 pixel's neighborhood. All the algorithms are implemented in MATLAB environment on a PC with 4 GB RAM and Core 2 Duo processor.

Two well-known images named "Airplane" and "Baboon" of size 512 × 512 from the image database of USC-SIPI [42] are taken as cover image and a gray scale logo of size 64 × 64 as the watermark image. PSNR (peak signal-to-noise ratio) (20) is used to analyze the visual quality and normalized correlation coefficient defined in (21) is used as a similarity measure between the original image and processed image.

Taking the advantage of micro DE [43] the parameters of DE are given in Table 1. Parameter values of Arnold transform are taken as $k = 10$, $a = 1$ and $b = 1$. The results of the proposed watermarking algorithm are compared to the results of DCT and SVD based watermarking algorithm by Liu and Liu [23] with scaling factor 0.1 and we named it DCT + SVD + cont.

The PSNR (*NC*) values of the watermarked images in the proposed scheme are about 36.3848 (0.9998) and 32.4527 (0.9989) for the Airplane and Baboon images respectively. Fig. 3 shows the quality of the watermarked images with PSNR and *NC* values. It can be seen that there is no degradation in visual quality.

Average filtering is a noise removal method that takes the average of its neighbor's pixels to replace the current pixel value and simply smoothes local variations in an image. Experimental results applying the average filter are shown in Fig. 4(a) and comparisons with DCT + SVD + cont are shown in Figs. 5 and 6 that clearly indicates better performance of the proposed technique.

Rotation attack is among the most popular kinds of geometrical attack on digital images. This operation is applied to destroy the watermark by breaking the synchronization of the spatial relationships between the original and watermarked images. The rotation attack with 30° has been shown in Fig. 4(b) with its extracted watermarks and performance measures and it is found that the proposed scheme provides better results.

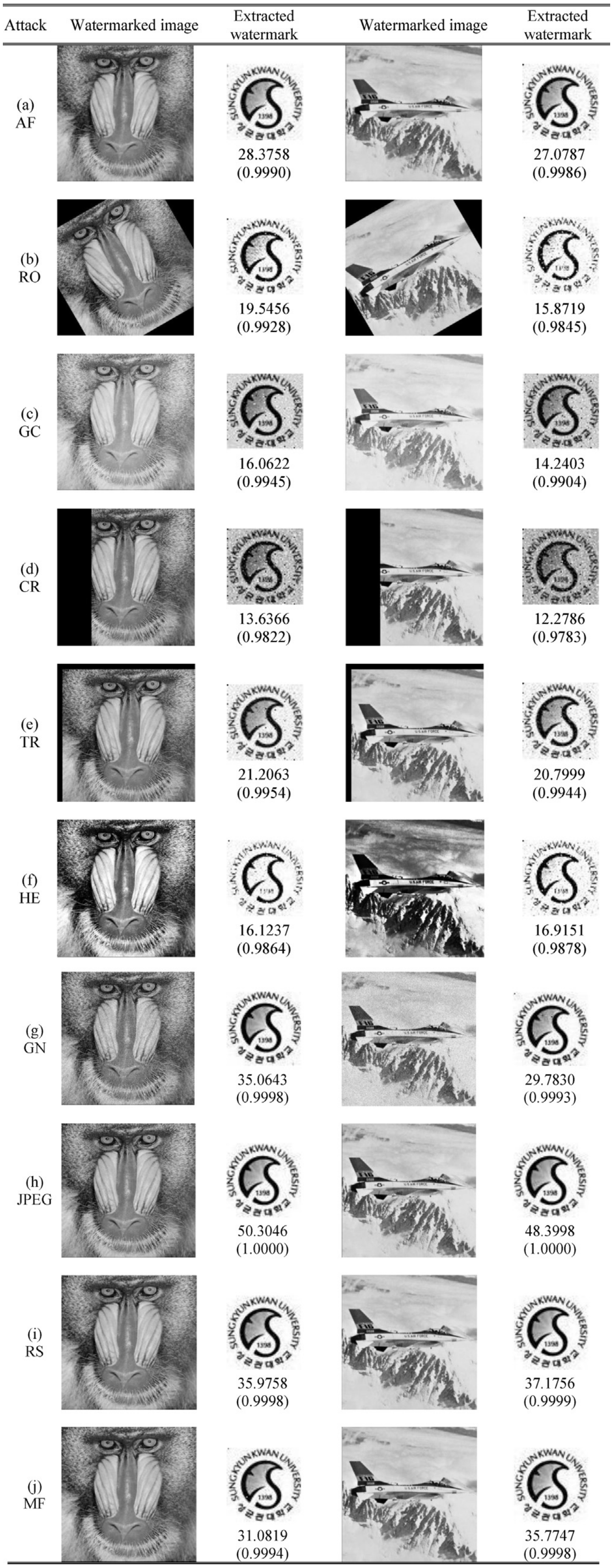

Fig. 4. Distorted watermarked images Baboon, Airplane and their corresponding extracted watermarks after attacks indicating the PSNR (*NC*) value (a) average filtering, (b) rotation, (c) addition of Gaussian noise, (d) cropping, (e) translation, (f) histogram equalization, (g) Gaussian noise, (h) JPEG compression, (i) rescaling and (j) median filtering.

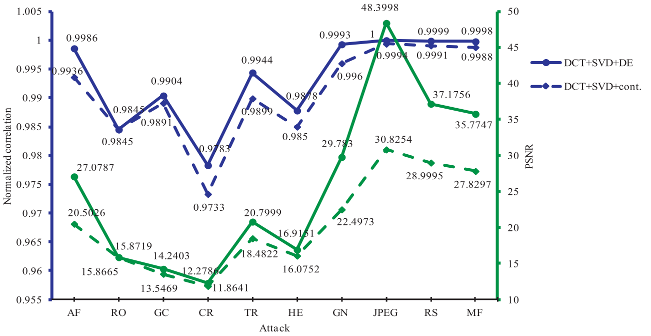

Fig. 5. Comparison of algorithms in term of NC and PSNR values of Airplane image. NC values are plotted on the primary axis and PSNR on the secondary axis.

Gamma correction, another image processing attack, transformed the image using gamma correction factor 0.6. Nonlinearity encountered during image capturing, printing and displaying can be corrected using gamma correction. Results of gamma correction are shown in Fig. 4(c).

To fit some specific purpose of application usually some part of the image is cropped. One fourth of the images are cropped and extracted results and cropped images are shown in Fig. 4(d). The extracted watermarks are still robust with the acceptable PSNR (*NC*) values.

Translation of the watermarked image cause the watermark to go undetected or destroyed. Fig. 4(e) illustrates the detection responses of the watermarks after translating the watermarked image by 20 × 20 pixels. We note that our watermarking scheme resists this attack.

In image processing, histogram equalization method is used for contrast adjustment using the image's histogram. The effect of histogram equalization and extracted watermark are shown in Fig. 4(f). The quality of extracted watermark is not good enough, however it is better than the DCT + SVD + cont algorithm which is clear from Figs. 5 and 6. Robustness against Gaussian additive noise with zero mean and variance 0.01 demonstrates that the proposed algorithm is robust to the additive noise that is supported by Fig. 4(g).

JPEG compression is the most common image compression technology in digital image processing. Robustness is checked against this attack with quality index 50 and compressed images and extracted watermarks logo are shown in Fig. 4(h). PSNR and NC values obtained by our algorithm of extracted watermarks from Airplane and from Baboon images are better than the DCT + SVD + cont scheme (Figs. 5 and 6).

An image is usually enlarged or reduced to fit it into the desired size for a specific purpose that results in information loss including embedded watermark. We first reduced the size of the image from 512 × 512 to 256 × 256 pixels and then enlarged the size of the image again to the original size. Fig. 4(i) shows the detected feature points from the scaled version of the watermarked image with good quality measures.

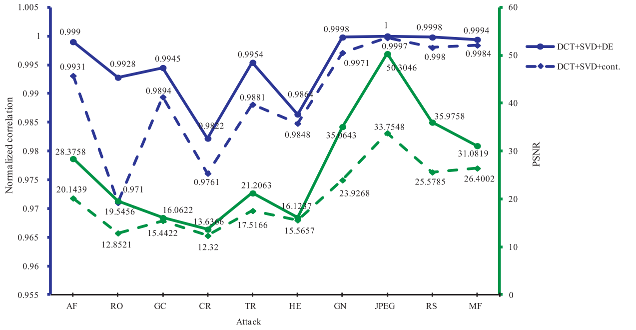

Fig. 6. Comparison of algorithms in term of NC and PSNR values of Baboon image. NC values are plotted on the primary axis and PSNR on the secondary axis.

To remove the noise and smoothen the data median filtering technique is adapted globally. Our experimental results show that the extracted watermark by proposed technique has great robustness against median filtering attack in comparison to the DCT + SVD + cont scheme. From Figs. 5 and 6, we can see that the proposed method is obviously better than another one.

Additionally, the proposed watermarking technique is much more robust in comparison to the other algorithm in most of the cases. It can also be observed from Figs. 5 and 6 that the proposed method provides better results in all the cases in comparison to the DCT + SVD + cont algorithm. However, the proposed scheme does not fare well under histogram equalization, cropping, gamma correction and rotation attacks in term of visual quality of extracted watermark and need some improvement in this direction.

5. Conclusions

In the proposed technique the singular values of low-resolution approximation image formed by DC values of blocks of the cover image are changed with the singular values of watermark image. The major contribution of the proposed method is the application of the DE algorithm for finding suitable multiple scaling factors and application of Arnold transform for randomizing the watermark. Extensive experimental results show that the proposed watermarking technique yields strong robustness to the geometrical and image processing attacks and imperceptibility of the watermarked image is also promising. The watermarks can be extracted from the distorted image after most of the common image processing attack with high normalized correlation values. The advantage of the proposed technique is that it automatically chooses the appropriate multiple scaling factors, while the ordinary methods embed watermark using single scaling factor. Our method could achieve balance between transparency and robustness. Therefore, DE algorithm offers an effective alternative for optimizing the watermarking algorithms. We have also compared its performance with a single scaling factor 0.1 watermarking scheme [23], and shown that the proposed scheme outperforms single scaling factor watermarking scheme under various image processing attacks. However, the proposed scheme is not much robust against histogram equalization, cropping, gamma correction and rotation attacks where the PSNR values are less in comparison to other cases and need further improvement in these directions.

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