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Algebraic Hessenberg Decomposition Method Optimized by Genetic Algorithm for Zero Watermarking Technique

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Abstract

Mathematics and in particular linear algebra play an important role in most scientific fields. Image processing has had the largest share of the use of linear algebra, especially image watermarking techniques. This paper aims to use the Hessenberg decomposition method (HDM) as an algebraic transform to construct a zero watermarking technique and to optimize this technique using the genetic algorithm (GA) in the YCbCr space. After several preprocesses on the Y component, the feature matrix bits are extracted from the features matrices after applying HDM to obtain the final zero-secret. The optimized zero-secret is generated by applying GA on zero-secret to optimize the zero watermarking technique. The experimental outcomes display that the technique has worked successfully and it is robust and resistant against the various attacks depending on the test of the normalized correlation (NC) values.

1 Introduction

The algebraic analysis of matrices are considered as one of the most important tools in linear algebra that have proven their distinctive role in developing

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several areas, the most important of which are digital images [1]. In recent years, there has been interest in using watermarks to protect property rights from tampering. There are two ways to embed the watermark, either in the cover image directly (watermarking) or in the features extracted from the cover image itself (zero watermarking). The zero watermarking technique has become more common than the watermarking technique because zero watermarking depends on the features extracted from the cover image and consequently remains conservative to the original image without any change. Thus, the zero watermarking technique has more robustness and imperceptibility than the watermarking technique in which the image distortion is mandatory, even if by a small percentage [2]. The genetic algorithm is one of the most important of many optimization algorithms that have been used in order to improve many watermarking techniques and increase their efficiency in terms of robustness and imperceptibility [3].

The Hessenberg decomposition method (HDM) is used in different ways in many papers to construct watermarking techniques. The Arnold transform is used with the HDM to propose a technique for embedding the color watermark in the colored cover image in the RGB space [4]. In 2018, Abodena [5] presented a blueprint for watermarking blind color images using HDM and employing two levels of the Discrete Wavelet Transform (DWT) with fast Walsh Hadamard transform (FWHT) In 2019, a watermarking technique [6] was given using HDM and multi-level DWT with the singular value decomposition (SVD) on both the original image and the watermark image to complete the embedding procedure. In 2020, HDM was used with DWT on the original image to construct a watermarking technique [7].

Along the same trend, many other algebraic decomposition methods were used in both watermarking and zero watermarking techniques. The LU algebraic decomposition method was combined with the Mamdani fuzzy inference system (FIS) and lifting wavelet transform (LWT) to construct a watermarking technique [8]. Pandey et al. [9] proposed a non-blind watermarking technique depending on Arnold scrambling using the YCbCr color space with SVD and SWT. In [10], a zero watermarking technique was suggested to extract the features matrix from a color image using SVD and DWT in the YCbCr space. In [11], a robust color image zero watermarking scheme depends on SVD and visual cryptography was proposed.

On the other hand, the genetic algorithm was used in [12] to propose a digital image watermarking technique in YCbCr space and Discrete cosine transform (DCT) domain using Arnold transform to scramble the Y component. In [13], a zero watermark technique was built depending on the optimization algorithm Shuffled Frog Leaping (SFL) and SVD to extract the features of a digital image in YCbCr space. In [14], the DC values resulted from using the DCT on the original images was utilized to find the secret shares for the watermark image and then optimizing these secret shares using the GA in order to determine the ideal locations for extracting the features. It is worth mentioning that, as far as we know, there is no zero watermarking technique that uses the HDM.

In this paper, a technique for zero watermarking is proposed depending on the algebraic Hessenberg decomposition method (HDM) and considered as an algebraic transformation utilizing genetic algorithm (GA) to improve a zero-secret that represents the best positions of the features extracted after each iteration of the genetic algorithm.

The organization of this paper is as follows: In section 2, the definitions of HDM, YCbCr color space and GA are restated. The proposed optimized zero watermarking technique using HDM to embed and extract the watermark image is introduced in section 3 and the effect of the genetic algorithm in improving this technique is demonstrated. In section 4, the results of experiments carried out for the grayscale cover images and the measurements of the robustness and imperceptibility are computed to assess the zero watermarking algorithm. Section 5 is devoted to compare the proposed optimized zero watermarking technique with some existing techniques. Finally, the conclusion is given in section 6.

2 Backround

In this section, needed basic information is given to structure the technique proposed in this work.

Definition 2.1. *Following [15], the YCbCr color space is one of the color spaces that transform the digital image from the color space RGB into three channels: The first channel "Y" denotes the luminance, while the second and third channels "Cb and Cr" denote the blue and red channels, respectively. The transformation process from RGB space to the YCbCr space is presented in the following equations:*

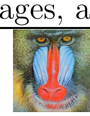
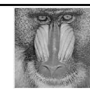
$$Y = 0.299R + 0.587G + 0.114B \tag{2.1}$$

$$Cb = -0.1687R - 0.3313G + 0.5B + 12 \tag{2.2}$$

$$Cr = 0.5R - 0.4187G - 0.0813B + 128 \tag{2.3}$$

Table 1 shows the original color images and the outcome images using YCbCr space, and the Y component images.

Table 1: The original color images,YCbCr images, and Y grayscale images

Y Image				
YCbCr Image				
Y Image				

Definition 2.2. *Following [16], the algebraic Hessenberg decomposition method (HDM) is a type of matrix decompositions that is utilized to decompose the a square matrix. An $n \times n$ square matrix C can be decomposed by HDM as follows:*

$$PHP^T = HDM(C) \tag{2.4}$$

The two matrices outcome from the HDM are the matrix P representing an orthogonal matrix and the matrix H representing the upper matrix; that is, $h_{ij} = 0$ where $i > j + 1$. The HDM is typically computed by the Householder matrix B which is an orthogonal matrix expressed as:

$$B = (I_n - vv^T)/v^T v, \tag{2.5}$$

where v is a non-zero vector in R^n, and I_n is the $n \times n$ identity matrix. There are $n - 2$ steps in the overall procedure. Therefore, HDM is calculated as follows:

$$P = (B_1 B_2 ... B_{n-2})^T C (B_1 B_2 ... B_{n-2}) \tag{2.6}$$

$$H = P^T C P \tag{2.7}$$

$$C = PHP^T \tag{2.8}$$

Definition 2.3. *A Genetic algorithm (GA) is a stochastic searching algorithm based on the mechanisms of natural selection and genetics and is very efficient in searching for global optimum solutions [17]. The genetic algorithm goes through five stages, namely*

1- Initial Population: The process begins with a group of individuals called the population. Each individual is a solution to a problem and it is characterized by a set of variants known as genes that form a chromosome. 2- Fitness *function: It is a function that awards a fitness score to each individual. 3- Selection: This is the stage of selecting individuals (parents) who have a high degree of fitness for reproduction. 4- Crossover: This is the stage of choosing a random crossing point from within the genes of parents to be mated to create the offspring. 5- Mutation: This stage cover the possibility that some of the genes of the new offspring are exposed to mutations of low random probability. The algorithm terminates if the population has converged and we say that the genetic algorithm has provided a set of solutions to our problem. A simple GA in its simplified form is shown in Figure 1.*

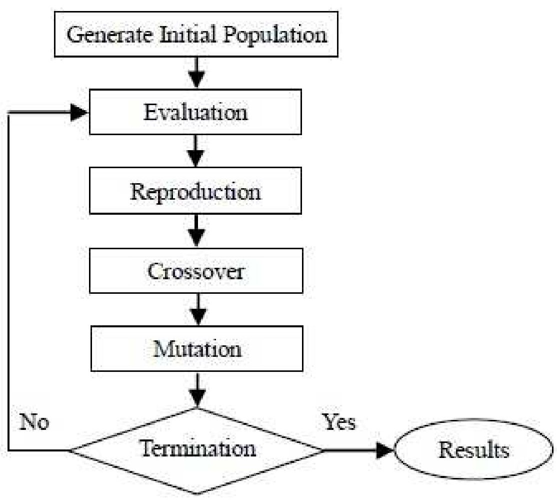


Figure 1: A simple GA.

3 The Proposed Algebraic HDM Optimized by GA for Zero Watermarking Technique

In this section, details of the proposed zero watermarking technique are explained. The HDM is used in this technique to extract the features of the original image in the YCbCr space using the Y component that represents the grayscale channel. The GA is applied to determine the best position of the features extracted to embed the watermark image.

3.1 Embedding Procedure

In this Procedure, the 512×512 RGB host image converted to the YCbCr space and the Y component is chosen to be divided into 8×8 non-overlapping blocks. The HDM is applied to each block as an algebraic transform to extract the features of the original image and then generate the master share (feature matrix bits). Secondly, the GA is implemented on the zero-secret obtained from XORing the master share with the 32×32 watermark image. Next, GA is performed on the zero-secret to obtain the zero-secret sequence which represents the best position features that are exploited to optimize the fitness function which is the sum of the NC values calculated after applying the three attacks adopted in this work to test robustness. The NC is used for measuring the robustness of the suggested technique. The optimal value of the NC is equal to 1:

$$NC(W, W') = \Sigma_{n=1}\Sigma_{m=1} W \times W' / \sqrt{\Sigma_{n=1}\Sigma_{m=1} W^2} \times \sqrt{\Sigma_{n=1}\Sigma_{m=1} W'^2}. \quad (3.9)$$

The embedding process of the watermark into the best features extracted from a grayscale image is shown in Figure 2.

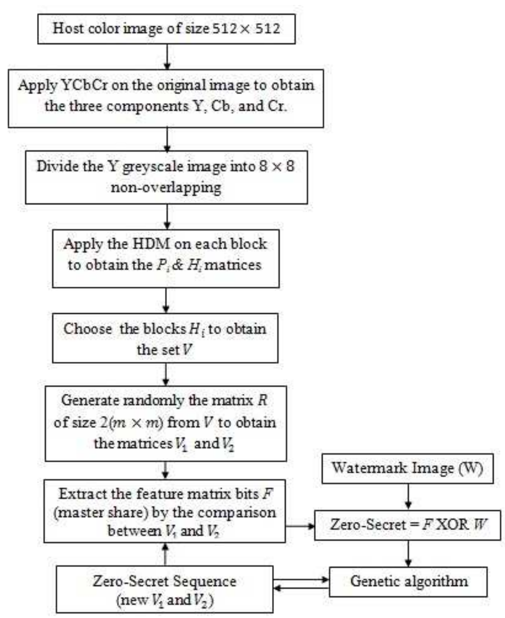


Figure 2: Embedding Procedure

Step 1: Input the original color image of size $n \times n$ (in our case 512×512) and input the binary watermark image W

Step 2: Apply YCbCr on the original image to obtain the three components Y, Cb, and Cr.

Step 3: Select the Y component.

Step 4: To extract the feature bits matrix, divide the Y greyscale image into 8×8 non-overlapping blocks to obtain 64×64 blocks.

step 5: Apply HDM to each block in step 4 to obtain the two matrices P_i and H_i. Choose the blocks H_i to obtain $T = \{H_1, H_2, ..., H_i\}$, where $i = 4096$ represents the overall number of blocks.

Step 6: Choose all the values in the position $H_i(2, 2)$ to create the vector V of 4096 elements.

Step 7: Generate a random matrix R of dimension $2(m \times m)$, $R = \{R_1, R_2, ..., R_{2(n \times n)}\}$, where R_j is chosen randomly from the elements of V such that j lies in between 1 and i. This is because the number of the bits of the watermark is less compared to the overall number of blocks i. Thus the number of blocks that need to be selected from V is $2(m \times m)$.

Step 8: Choose two new matrices V_1 and V_2 randomly from the random matrix R of which one of them is of size $m \times m$. Now, compare each element in V_1 with the corresponding element in V_2 to obtain the feature matrix F according to the following equation:

$$F(i, j) = \begin{Bmatrix} 1 & \text{if} \;\; V_1(i, j) \geq V_2(i, j) \\ 0 & \text{Otherwise} \end{Bmatrix}$$

where $F(i, j) \in \{0, 1\}, 1 \leq (i, j) \leq n$.

Step 9: Perform XOR logical operation between the master share F and the W to get the zero-secret.

Step 10: Apply the genetic algorithm on zero-secret to obtain a zero-secret sequence which represents the best position features extracted after each life cycle of the genetic algorithm. Figure 3 shows how the (GA) work.

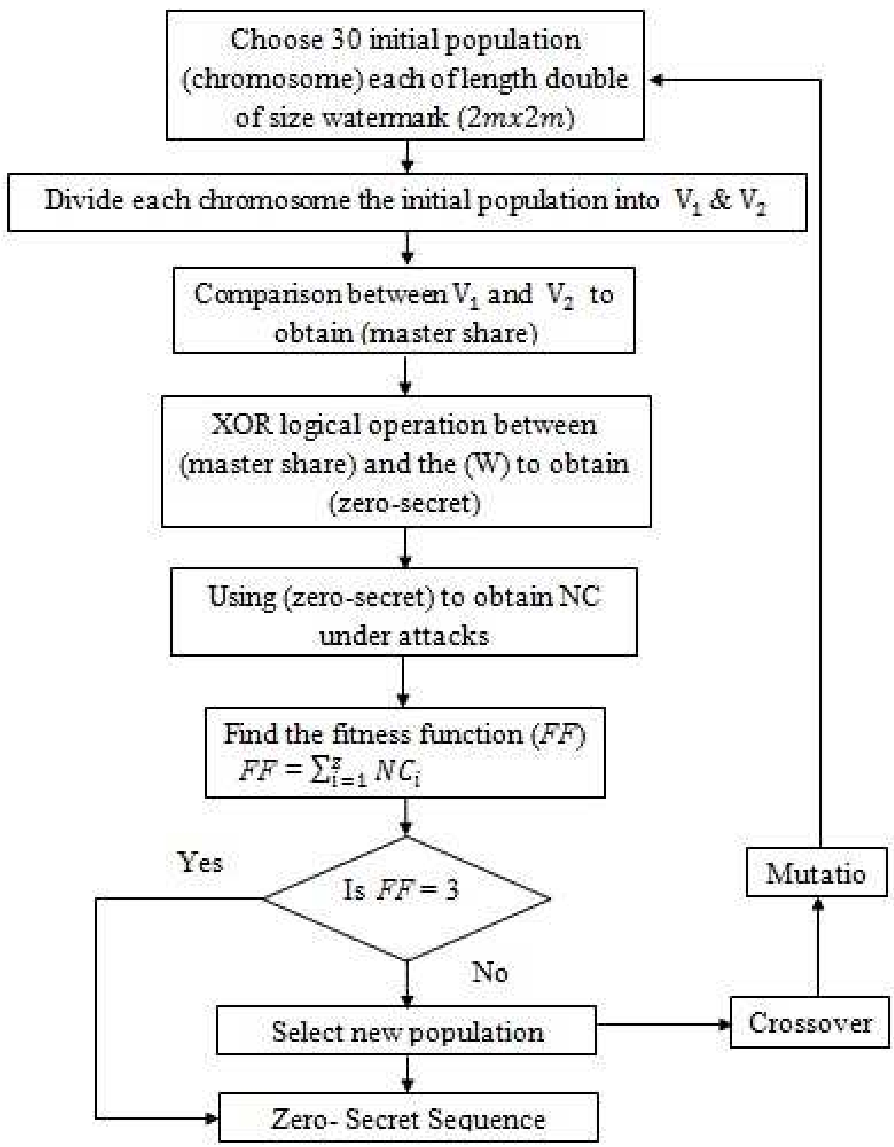


Figure 3: How the GA works

3.2 Optimal Zero-Secret Selection Based on Genetic Algorithm (GA)

To select the best positions to construct a robust feature bits matrix, GA is utilized in the proposed technique to find these locations. The steps of GA is given as follows:

1 - Initial Population: An initial group is randomly generated by 30 elements called chromosomes, and this group is considered the default set of solutions. The chromosome length is assumed to equal to double the size of the watermark ($2m \times 2m$). For the 30 chromosomes, divide each of them into two sets V_1 and V_2 with the number of generations repeated 100 times. The best gene in a chromosome is taken into consideration to be the site of extraction of the best-extracted features. This is done by comparing V_1 and V_2 obtaining the master share.

2 - After XORing the obtained master share with the watermark W, there are three types of image attacks: Intensity Adjustment ([0 0.8], [0 1]), with a window of size 2×2, Gaussian low pass filtering of the image is done and Gamma Correction 1.5.

3 - The robustness function for z types of attacks known as the fitness function FF is performed on the proposed zero watermarking technique as follows:

$$FF = \Sigma_{i=1}^{z} NC_i \tag{3.10}$$

The main goal is to make the fitness function as large as possible to attain optimum robustness of the proposed zero watermarking technique (in our case, the maximum of $FF = 3$).

4 - Crossover and Mutation: To generate the new population crossover and mutation (single in our case) are performed on the selected population. The crossover probability is set at 0.95 and the rate of the mutation is 0.5. To perform the process of crossover and mutation on the chromosomes, random values are generated and compared with the values of the probabilities imposed for the process of crossover and the mutation. If these random values are less than the values imposed, ten the crossover process and the mutation are carried out on the chromosome. When imposing several values of probabilities and observing the results, we found that the mentioned values are the best values that gave the best results.

5 - The GA iterations are terminated when the number of rounds is complete. The optimal positions are selected with the highest values of fitness in the last generation of the population.

3.3 Extraction Procedure

In this procedure, after applying the YCbCr space on the original color images of size 512×512, the watermark is extracted before and after the images are attacked. The Y component is chosen and divided into 8×8 non-overlapping blocks. Then the algebraic HDM is applied to each block to extract the master share (feature bits matrix). First, perform the XOR operation between the zero-secret and master share to get the watermark image from the Y component before the images are attacked. Secondly, apply the GA on the zero-secret to obtain the zero-secret sequences that represent the optimal zero-secret. Afterwards, perform the XOR operation between the optimal zero-secret and master share to get the watermark image from the grayscale images after it is attacked. Figure 4 shows the steps of this procedure:

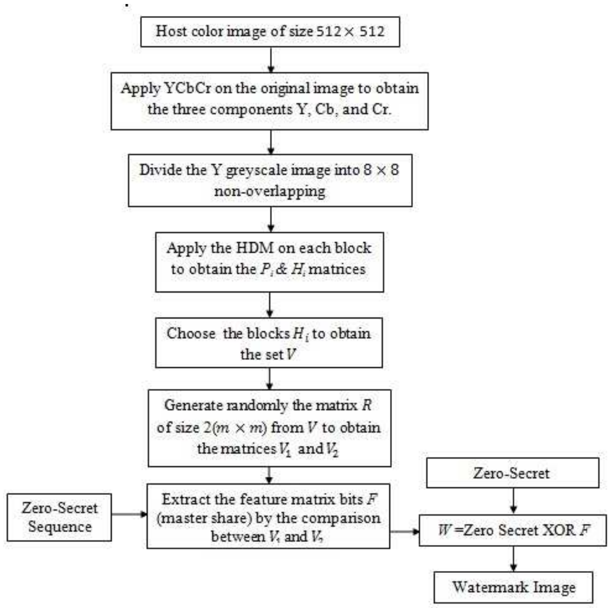


Figure 4: Extraction Procedure

Step 1: Input the original color image of size $n \times n$ (in our case 512×512)

Step 2: Apply YCbCr on the original image to obtain the three components Y, Cb, and Cr.

Step 3: Select the Y component.

Step 4: To extract the feature bits matrix, divide the Y greyscale image into 8×8 non-overlapping blocks to obtain 64×64 blocks.

step 5: Apply HDM to each block in step 4 to obtain the two matrices P_i and H_i. Choose the blocks H_i to obtain $T = \{H_1, H_2, ..., H_i\}$, where $i = 4096$ represents the overall number of blocks.

Step 6: Choose all the values in the position $H_i(2, 2)$ to create the vector V of 4096 elements.

Step 7: Generate a random matrix R of dimension $2(m \times m)$, $R = \{R_1, R_2, ..., R_{2(n\times n)}\}$, where R_j is chosen randomly from the elements of V such that j lies in between 1 and i. This is because the number of the bits of the watermark is less compared to the overall number of blocks i. Thus the number of blocks that need to be selected from V is $2(m \times m)$.

Step 8: Choose new two matrices V_1 and V_2 randomly from the random matrix R of which one of them is of size $m \times m$. Now, compare each element in V_1 with the corresponding element in V_2 to obtain the feature matrix F according to the following equation:

$$F(i,j) = \begin{Bmatrix} 1 & \text{if} \quad V_1(i,j) \geq V_2(i,j) \\ 0 & \text{Otherwise} \end{Bmatrix},$$

where $F(i, j) \in \{0, 1\}, 1 \leq (i, j) \leq n$.

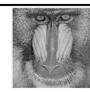
Step 9: Input zero-secret.

Step 10: Perform the XOR logical operation between zero-secret and master share F to obtain W.

4 The Experimental Results

In this section, the proposed zero watermarking technique is examined to assess the robustness and imperceptibility using the Y component image that results from applying YCbCr space on some popular original color images as shown in Table 2.

Table 2: The Y component image and the watermark utilized for the suggested algorithm

Lena	Girl	Mandrill	Peppers	Watermark
				

4.1 The Accuracy of the Proposed Technique

The 512×512 Y grayscale image is decomposed into 8×8 non-overlapping blocks to get 64×64 blocks. employ HDM to transform algebraically each 8×8 block to the frequency domain that factorizes each block into two matrices P_i and H_i. Mathematically, the outcomes display that the algebraic transformation HDM is worked successfully in general. Moreover, the standard measurement, normalized correlation (NC), shows that the proposed zero watermarking technique worked correctly to give logical and precise results such that NC=1 as in Table 3.

Table 3: The NC Values without Attacks

images	Lena	Girl	Mandrill	Peppers
NC	1	1	1	1

4.2 The Impact and Significance of HDM and GA

The most interesting thing about the suggested algorithm is not to employ any of the popular transformations in image processing in general and watermarking techniques in particular. Instead, the HDM itself taking the venue of the transformation to extract the features of the Y component that represent the grayscale image from the original color image after applying the YCbCr color space on the original color image. Divide the Y component into 8×8 non-overlapping blocks to obtain 64×64 blocks. Afterwards,transform algebraically to the frequency domain utilizing HDM that split every block into two matrices P_i and H_i. The values in the site $H_i(2, 2)$ are selected from the matrices H_i to create the matrix of feature F these values are the optimal choices to improve the zero-watermark. The paramount features of the image matrix are transformed algebraically by HDM into a few coefficients whose values are centered in the (2,2) position of each block. This is because HDM is appropriate for any kind of local statistics of the image matrix according to its stability. Moreover, employing the GA will improve the zero-secret meaning improving the extracted binary watermark image from the images that were attacked. The NC value will be improved progressively relying on the fitness function after sufficiency iterations.

4.3 Results of the Suggested Technique

In this section, the results of the proposed scheme based on HDM and GA are obtained using MATLAB and explained in detail. To show the robustness of the proposed zero watermarking technique, three common attacks in image processing are performed on the Y grayscale images: Gamma Correction 1.5, Gaussian low pass filtering, and Intensity Adjustment ([0 0.8], [0 1]). To test the robustness and imperceptibility of the zero watermarking technique without using GA, table 4 shows that the best recovery of the watermark after the attack the images without GA are with the Intensity Adjustment. However, table 5 shows that all the outcomes are improved with NC=1 after using GA. Table 6 shows the images that were attacked and the extracted watermarks after attacks without and with GA. On the other hand, to test the imperceptibility of the zero watermarking technique, Table 7 shows the PSNR values of the reconstructed watermark under the three types of attacks. The strength of the proposed technique for the zero watermarking is shown through the values of NC that show the amount of congruence between the original watermark image and the watermark extracted from the image after three attacks were carried out.

Table 4: NC Values from The Suggested non Optimized Zero Watermarking Techniques

Attacks	NC Values without GA			
	Lena	Girl	Mandrill	Peppers
Gaussian low pass filtering	0.9894	0.9911	0.9759	0.9911
Intensity Adjustment	0.9770	0.9994	1.0000	0.9928
Gamma Correction	0.9961	0.9983	0.9950	0.9961

We note that the exact value of maximum fitness for the test images is 3.0000 for each image: Lena, Girl, Mandrill, and Peppers.

Table 5: NC Values from The Suggested Optimized Zero Watermarking Techniques

Attacks	NC Values with GA				
	gen	Lena	Girl	Mandrill	Peppers
Gaussian low pass filtering	10	1.0000	1.0000	1.0000	1.0000
	25	1.0000	1.0000	1.0000	1.0000
	50	1.0000	1.0000	1.0000	1.0000
	75	1.0000	1.0000	1.0000	1.0000
	100	1.0000	1.0000	1.0000	1.0000
Intensity Adjustment	10	1.0000	1.0000	1.0000	1.0000
	25	1.0000	1.0000	1.0000	1.0000
	50	1.0000	1.0000	1.0000	1.0000
	75	1.0000	1.0000	1.0000	1.0000
	100	1.0000	1.0000	1.0000	1.0000
Gamma Correction	10	1.0000	1.0000	1.0000	1.0000
	25	1.0000	1.0000	1.0000	1.0000
	50	1.0000	1.0000	1.0000	1.0000
	75	1.0000	1.0000	1.0000	1.0000
	100	1.0000	1.0000	1.0000	1.0000

5 Comparison

In this work, the HDM is used to algebraically transform the image into a frequency domain with and without performing GA. It is shown that all the results are improved with GA to the optimal NC after the images attacked. First, the results show that using GA improves the robustness of the technique compared to using GA. Since, as far as we know, there is no zero watermarking technique that uses the HDM, several papers using different algebraic decomposition methods and various tools are considered for comparison. Tables 8,9 and 10 explain the comparison.

6 Conclusion

In this paper, an optimal zero watermarking technique based on Hessenberg decomposition method (HDM) only (i.e. without using any other transformation) was presented to achieve the highest possible robustness without losing watermark transparency, genetic algorithm (GA) optimization is used. A 100 iteration in GA is adopted to find the best master share (feature bits ma-

Table 6: NC Values from The Suggested Optimized Zero Watermarking Techniques

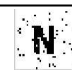
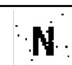
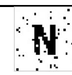
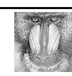
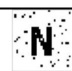
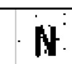
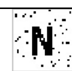
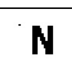
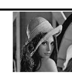
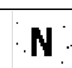
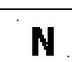
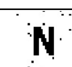
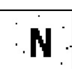
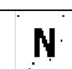
Attacks / Extracted watermark without and with GA	Lena	Girl	Mandrill	Peppers
Gaussian low pass filtering				
Extracted watermark without GA				
Extracted watermark with GA				
Intensity Adjustment				
Extracted watermark without GA				
Extracted watermark with GA				
Gamma Correction				
Extracted watermark without GA				
Extracted watermark with GA				

Table 7: The VALUE of PSNR Between the Y grayscale image and the Attack image

Attacks	PSNR Values			
	Lena	Girl	Mandrill	Peppers
Gaussian low pass filtering	31.0947	35.1266	23.4195	30.4147
Intensity Adjustment	17.871	20.1716	17.5122	17.8921
Gamma Correction	17.7535	17.6981	17.565	18.0396

Table 8: NC comparison with that in [4]

Image	Attack	Su [4]	Proposed Technique
Peppers	Gaussian Low Pass Filtering	0.8232	1

trix). The proposed technique generates a master share (feature bits matrix) from the Y grayscale image through the embedding phase, this master share

Table 9: NC comparison with that in [6].

Image	Attack	Liu et al [6]	Proposed Technique
Lena	Gaussian Low Pass Filtering	0.9794	1

Table 10: NC comparison with that in [13]

Attacks	Waleed et al [13]			Proposed Technique		
	Lena	Mandrill	Peppers	Lena	Mandrill	Peppers
Gaussian Low Pass Filtering	0.991	0.9887	0.9877	1	1	1
Intensity Adjustment	1	0.9994	1	1	1	1

is generated using the featuers that extracted after applying the HDM, that considered as an algebraic transformation, on each 8×8 block of the host image. The master share feature bits matrix is used to generate the zero-secret. According to the values of the NC, the proposed zero watermarking technique seems to have excellent flexibility against the three adopted attacks: intensity adjustment, Gaussian low pass filtering, and gamma correction.

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