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The Effectiveness of LUD on Digital Image Watermarking Based on Sugeno Fuzzy Inference System

Areej M. Abduldaim[1], Raghad I. Sabri[2]
[1](Department of Applied Sciences/ University of Technology, Baghdad, Iraq)
[2](Department of Applied Sciences/ University of Technology, Baghdad, Iraq)

Abstract: The usage of LUD with Fuzzy Inference System is not very familiar, especially with the Sugeno type. In this paper, the Sugeno Fuzzy Inference System (SFIS) is adopted with the linear algebra method named LU decomposition (LUD) to establish a watermarking algorithm for digital images. The proposed algorithm starts with computing the controller parameter resulted from the SFIS this parameter controls the rate of the visibility of the watermarked image compared with the host image and then use this parameter to modify the D matrix resulted after applying the LUD to the processed original image in order to embed the watermark within the original image. After that, some attacks are shed for testing the robustness and the imperceptibility of the proposed technique.

Keywords: Sugeno fuzzy Inference System; Image Watermark; LU decomposition; the Peak Signal to Noise Ratio (PSNR); normalized correlation (NC).

1. INTRODUCTION

Linear algebra is a division of mathematics that is broadly utilized through engineering and science. A perfect understanding of linear algebra is substantial for comprehending and dealing with numerous algorithms, in particular, image processing algorithms. Further, linear algebra is a subfield of mathematics interested with matrices, vectors, and linear transforms. It is a fundamental key to the field of image processing, from symbols used to describe the approach of algorithms to the enforcement of algorithms in code. On the other hand, linear algebra plays an important role in image processing, particularly in watermarking.

In parallel, Fuzzy Logic starts with the notion of fuzzy theory. The fundamental of fuzzy logic is analogous to human attitude. It is based on the linguistic variables concerning the human language. Moreover, these variables are specified by some tentative experiments. With the gradual transition of science into the digital world, fuzzy logic has become one of the most important influences in the development of the rest of science, including image processing. Digital watermarking techniques depends on many factors to insert the information of the watermark into the cover image. Fuzzy Inference System (FIS) [1] is one of these factors that used to control the decision of how to embed bits of the watermark depending on the goal to be achieved. Digital watermarking is the first kind of mechanisms to better the impartiality and reliability of digital data. Lately, authentication is one of the major watermarking requirements in image processing applications [2]

There are two known types of FIS named Mamdani and Sugeno. Sakr et al. [3] exploited Sugeno type of the FIS along with DWT in order to propose a nonblind digital image watermarking technique. The embedding process uses the result of applying DWT to the original image first to generate the watermark weighting function using FIS and second to embed the watermark (which consists of a binary pseudo-random sequence) into the lowest level subbands of the DWT. In [4] Imran and Harvey proposed a blind adaptive color image watermarking technique depending on the two algebraic methods PCA, SVD, and HVS. To improve the perceptual quality of the watermarked image PCA is used to decorrelate the three color channels of the cover image. While the HVS and FIS worked to further improve both robustness and imperceptibility by choosing a suitable running scale, for this reason, regions more susceptible to noise can be added with additional information as compared to fewer susceptible regions. The goodness of the watermarked image is typically handled in [5] by locating the adaptable running factor for every demarcation pixel intensity. The HVS (texture masking) and FIS were used in order to set the adaptable scaling factor. To enhance the security grade and robustness DWT has been used. This improvement is owing to the irregular apportionment of the watermark within the image through the transform converse. The algorithm of using (SVD) in order to decompose LH; and HL sub-bands is given. Kumar and Rao in [6] implemented a novel robust watermarking scheme relying on DWT and SVD using Fuzzy Logic and Genetic Algorithm. Fuzzy logic system is used to find the strength of watermark that has to be added to the original image while embedding. Lalani and Doye [7] proposed a technique tries to solve this problem by designing a fuzzy inference system (FIS) based on just-noticeable distortion (JND) that takes into consideration the image characteristics for deciding the transparency of the cover signal. apply a worthy tool in numerical linear algebra named SVD to the HL band obtained from the 3rd level of DWT to obtain the modified component. The DWT is used and then develops a DWT-SVD path using the band LL obtained from the 2-level DWT in [8]. Even if DWT has a broad scope of implementation but when combined both SVD and DWT it will boost the robustness of the extracted watermark. An authentication technique has been developed in the wavelet domain of a medical image by Jayanthi and Sridevi in [9]. The authentication message is embedded in the singular values of Region of Non-Interest (RONI) pixels. The watermark strength of the pixels in the RONI portion is predicted using fuzzy inference rules, Singular Value Decomposition (SVD)is applied to the HL details of the RONI. Fan and Wu in [10] decompose the cover image using the complex wavelet transform. Secondly, the selection of the singular value of the low-frequency coefficients is made as an embedded factor, which hides the watermark perfectly. Ultimately, as a fuzzy clustering feature vectors, image high frequency texture features and low frequency background, that are regarding human visual masking, are utilized in order to set the different embedding strength.

In this paper, a Sugeno FIS is adopted along with LU factorization which is taken into consideration for the first time in the watermarking techniques to introduce a digital watermarking algorithm. This work investigates the robustness and the imperceptibility in the frequency domain of LU. Moreover, in this paper, various attacks are given to explain the advantages of the proposed digital image watermarking.

The remainder of this paper is organized as follows. In Section 2 basic important information of LU and FIS are covered concisely. Section 3 devoted to present the proposed algorithm. Section 4 of this paper particularized to explain the experimental results and discussion. Finally, the conclusion is documented in Section 5.

2. BACKGROUND

In this section, some needed information is given that will be used in the next sections.

2.1 LU Decomposition

In linear algebra and numerical analysis, lower–upper decomposition (LU) (or LU factorization) operators a matrix A as the product of a lower triangular matrix (L) and an upper triangular matrix(U), as well as sometimes the product includes a permutation matrix. In 1948 [11]Turing gives LU decomposition which is the basic modified way of Gaussian elimination. LU decomposition is often adopted in solving square systems of linear equations. It is a necessary process when calculating the determinant of a matrix or inverting a matrix. For example, for a 3×3 matrix A, LU decomposition can be presented as:

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} = LU = \begin{pmatrix} 1 & 0 & 0 \\ l_{21} & 1 & 0 \\ l_{31} & l_{32} & 1 \end{pmatrix} \begin{pmatrix} u_{11} & u_{12} & u_{13} \\ 0 & u_{22} & u_{23} \\ 0 & 0 & u_{33} \end{pmatrix}$$

$$= \begin{pmatrix} u_{11} & u_{12} & u_{13} \\ l_{21}u_{11} & l_{21}u_{12} + u_{22} & l_{21}u_{13} + u_{23} \\ l_{31}u_{11} & l_{31}u_{12} + l_{32}u_{22} & l_{31}u_{13} + l_{32}u_{23} + u_{33} \end{pmatrix}$$

2.2 Discrete Cosine Transform

DCT represents a technique for converting the signal from time-domain representation to frequency band form. For a given image A of size $n \times n$, in digital image processing, the two-dimensional DCT is given as:

$$C_{nm} = \alpha n\, \alpha m \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} Z_{ij} \left(\frac{\cos{(2\pi i+1)n}}{2I}\right)\left(\frac{\cos{(2\pi j+1)m}}{2J}\right), \text{ for } 0 \le n \le I-1 \text{and } 0 \le m \le J-1 \quad (1)$$

$$\alpha n = \begin{cases} \frac{1}{\sqrt{J}}, & n = 0 \\ \frac{2}{\sqrt{J}}, & 1 \le n \le J-1 \end{cases}, \quad \alpha m = \begin{cases} \frac{1}{\sqrt{I}}, & m = 0 \\ \frac{2}{\sqrt{I}}, & 1 \le m \le I-1 \end{cases}$$

Dct is characterized by the property that most of the important optical functions are concentrated around the image in a few DCT parameters and therefore we observe the use of DCT frequently in image compression applications[12, 13].

2.3 Sugeno Fuzzy Inference System

Fuzzy inference system illustrates the procedure of deriving the mapping from a specific stimulus to a suitable result utilizing fuzzy logic. Two kinds of these systems are familiar: Mamdani-type and Sugeno-type which can be implemented through fuzzy logic Toolbox. Mamdani's method represents among the first control systems built using fuzzy set theory which is the most common method used. The procedure of fuzzy inference includes Fuzzy variables and corresponding membership functions, logic operators and if-then rules. Fuzzy inference system is also called the rule base, which consists of the fuzzy rules. These rules combine one or more fuzzy set utilizing the fuzzy operators AND, OR, and NOT. The valuation of fuzzy rules is executed by the inference system to employ the aggregate function. These operation combines a weight parameter of the resultant part of all relevant rules in a fuzzy set to obtain the output. On output, the fuzzy inference system can not supply fuzzy values that can only operate, so it is needful to provide precise values. This stage is done using membership functions. Many values will be obtained from the degrees of membership functions. To determine the accurate value to use, one of the four methods can be applied which is: Centroid, Max, Sum, and Probor. Using one of these methods, one output value will be obtained from the total output values. In this method, we use the Centroid concept to find the weighing parameter [14].

2.4 Fuzzy Variables and Membership Functions:

One of the steps or stages of implementing a fuzzy inference system is processed the given information and classify the grade of results to which they belong utilizing membership functions. One of the mathematical functions used in the FIS is a membership function which takes the given information to a grade of membership between [0,1]. There are several shapes of membership functions, they are not limited to triangular and trapezoidal functions. Any form for membership functions can be adopted mathematically defined according to the demands of the case. The input variables used in our system are Edge sensitivity and contrast sensitivity while the membership functions used are triangular functions[15].

$$\mu_A(x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{m-a}, & a < x \le m \\ \dfrac{b-x}{b-m}, & b < x < m \\ 0, & x \ge b \end{cases}$$

2.5 Rules of Inference and Logic Operators

Rules of inference represent all fuzzy rules aggregating the various variables of a fuzzy inference system. These rules take the following form:

- If (condition 1) and / or condition (N) then (action on the outputs)

Inference rules are crafted using a fuzzy logical operator such as AND or OR. After we apply the rules using the "AND" or "OR" operator, the output value is obtained with the minimum or maximum input values respectively[14].

3. METHODOLOGY

In this section, we propose a protection scheme for improving watermarking relies on FIS(Sugeno-type) and QR Matrix Decomposition. The proposed watermarking scheme can be characterized as follows:

3.1 Embedding Algorithm

The process of embedding the watermark into the cover image based on FIS and LUD is illustrated by Fig. 1, and the detailed steps are listed as follows.

1. Input the cover image which is a grayscale image of size 512×512 pixels and the watermark image is a binary image of size 64×64 pixels.
2. Partition the cover image into 8×8 blocks.
3. Implement the DCT to each block.
4. Find the edge sensitivity and contrast sensitivity of each block resulted from the DCT.
5. Input the edge and contrast sensitivity parameters to the Sugeno Fuzzy Inference System (FIS) built on 9 fuzzy rules to generate the weight factor α.
6. Implement the LU matrix decomposition methodto each 8 × 8 blocks obtain in step 2 of the cover image.
7. Embedding binary watermark bits in U submatrix

$$U\{i,j\}(1,1) = U\{i,j\}(1,1) - mod(U\{i,j\}(1,1), \alpha) + T1 \quad if \;\; w(i,j) = 1$$
$$U\{i,j\}(1,1) = U\{i,j\}(1,1) - mod(U\{i,j\}(1,1), \alpha) + T2 \quad if \;\; w(i,j) = 0$$

where α represents the weight factor gained from the designed fuzzy inference system (FIS) and $T1 = 0.75 * \alpha$, $T2 = 0.25 * \alpha$ and mod (.) is the modulo operation.

8- Convert block to the matrix and obtain Watermarked image

The following figure illustrates the above steps:

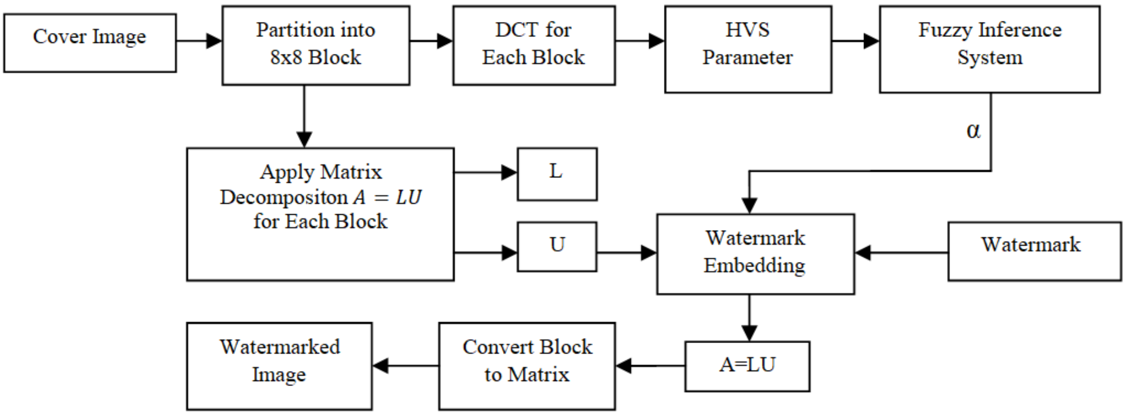


Fig. 1: Block Diagram of The Embedding Algorithm

3.2 Extraction Algorithm

The process of extracting the watermark of the proposed method is illustrated in Fig. 2. As can be seen, the cover image is unrequired in the extracted process of the watermark. The detailed extraction steps are given as follows.

1.Input the watermarked image with size 512×512 and convert this image to grayscale image.
2. Partition the watermarked image into 8 × 8 blocks.
3. Implement the DCT to each block.
4. Find the edge sensitivity and contrast sensitivity of each block resulted from the DCT.
5. Input the edge and contrast sensitivity parameters to the Fuzzy Inference System (FIS) to generate the weight factor β.
6. Implement the LU matrix decomposition method to each 8 × 8 blocks obtain in step 2 of the cover image.
7. The watermark bit is extracted as follows:

$$w(i,j) = 0 \quad if \quad mod(U1\{i,j\}(1,1),\beta) < ave$$
$$w(i,j) = 1 \quad if \quad mod(U1\{i,j\}(1,1),\beta) > ave$$

whereβ represents the weight factor gained from the designed fuzzy inference system (Sugeno-type) and $ave \; = (T1 + T2)/2$ represents the average

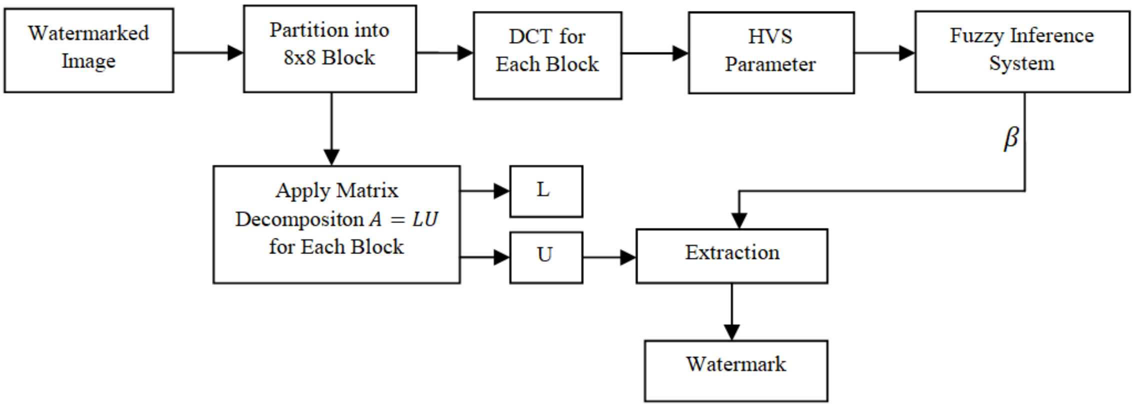
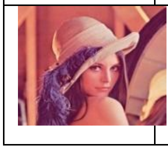


Fig. 2: Block Diagram of Extraction Algorithm

4. EXPERIMENTAL RESULTS

In this section, some experiments are performed to assess the imperceptibility and robustness of the proposed watermarking algorithm. The proposed image watermarking technique is examined with different grayscale cover images of size 512×512. A binary image of size 64×64 is utilized as a watermark image. Table 1 shows the watermark and the images used to test the proposed algorithm.

Table 1: The Watermark and the Images used to Test the Proposed Algorithm

Image 1	Image 2	Image 3	Image 4	Watermark Image
				

To evidence the soundness of the proposed watermarking algorithm, some results are clarified. Five sorts of attacks were utilized to test the robustness of the proposed watermarking algorithm.
In general, the performances of image watermarking techniques are measured by the robustness, invisibility, computation complexity, etc.
PSNR as a good tester for the watermark visibility assess and it is given by the following equation:

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{\mathrm{MAX}^2}{\mathrm{MSE}}\right). \qquad (2)$$

where

$$\mathrm{MES} = \frac{1}{pq}\sum_{i=0}^{p-1}\sum_{j=0}^{q-1}[I(i,j) - K(i,j)]^2. \qquad (3)$$

AndMAX is the maximum greyscale value which here is equal to 256.
The matching between the extracted watermark W' and the authentic watermark Wis computed based on NC (a normalized correlation) between W and W' .

$$\mathrm{NC} = \frac{\sum_i\sum_j w(i,j).w'(i,j)}{\sqrt{\sum_i\sum_j w(i,j)}\sqrt{\sum_i\sum_j w'(i,j)}}. \qquad (4)$$

To show the robustness of the proposed mechanism, diverse attacks are implemented on the watermarked image to assess the robustness of the proposed mechanism as shown in Table 2, Table 3 respectively. In salt and pepper noise attack, noise is added to the watermarked image at 1 % density. Another important attack is JPEG compression attack. It is one of the common attacks that our proposed method has a good performance against it.

Table 2: PSNR Values for Different Attacks Applied to Test Images

Types of attacks	**PSNR values for watermarked images**			
	Image1	Image2	Image3	Image4
No attacks	35.776	38.4311	36.3713	36.3311
Salt and Pepper %1	26.9117	26.2168	26.7758	26.9921
JPEG Compression	59.4134	59.5191	59.2105	59.0253
Gaussian noise	37.679	37.6582	37.6894	37.6718
Winer	37.647	40.8622	37.8177	39.4084
Specklenoise	35.6025	40.9621	35.6836	34.6573

In Table3, results of the NC values are shown against different attacks. High NC values show the robustness of this method against Salt and Pepper, JPEG Compression, Gaussian and Winer attack while our method gives fewer NC values against the Specklenoise attack.

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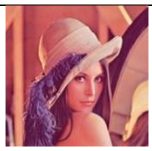
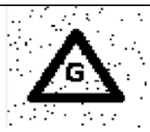
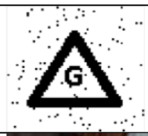
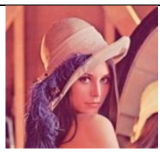
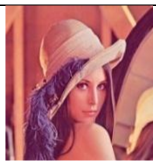
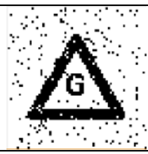
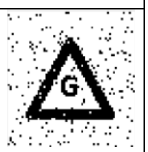
Table 3: The NC Values for Different Attacks Applied to Test Images

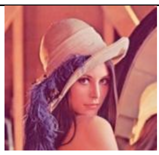
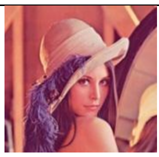
Types of attacks	**NC values for watermarked images**			
	Image1	Image2	Image3	Image4
No attack	1	1	1	1
Salt and Pepper %1	0.9854	0.9871	0.9848	0.9887
JPEG Compression	1	1	1	1
Gaussian noise	0.9649	0.9645	0.9702	0.9708
Winer	0.9695	0.9976	0.9437	0.9864
Specklenoise	0.8837	0.9871	0.9038	0.8635

Our method used Sugeno-fuzzy inference system to generate the weighting factor for embedding the watermark in order to control balance achieved between robustness and imperceptibility and that the values of the robustness and imperceptibility vary by the value of weighting factor.

The following are the watermarked images and the extracted watermark image from each one respectively after attacks implementation:

Table 4: Test Original Images and Watermarked Images after Attacks

Attack / **Extracted watermark**	**Image1**	**Image2**	**Image3**	**Image4**
Salt and Pepper %1				
Extracted watermark				
JPEG Compression				
Extracted watermark				
Gaussian noise				
Extracted watermark				

Winer				
Extracted watermark				
Specklenoise				
Extracted watermark				

5. CONCLUSION

In order to achieve the determined goal, HVS, FIS, and LUD are used together. The aim of the proposed algorithm is to introduce a combination of the linear algebra decomposition method LUD and the Fuzzy inference system (FIS). The watermarking technique given in this paper involves two basic parameters of the HVS model namely Edge and Contrast Sensitivity computed using block threshold value and block variance. These HVS parameters are modeled using fuzzy inference system to implement the watermarking algorithm using four different gray-scale images. So, imperceptibility is then enhanced and can be seen from the results that the imperceptibility of the proposed scheme is good or acceptable comparing with existing methods. The perceptible quality is good as indicated by the PSNR values and the watermark extraction is also found to be good as indicated by good values of the NC between the embedded and the extracted watermark. It is concluded that the embedding and extraction of the proposed algorithm are well optimized. The robustness is achieved using LUD depending on the properties of the R matrix.

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