Journal of Computer Engineering
ISSN 10003428

Original Research Article
Vol 8, Issue 7, 2019 | ISSN: 1000-3428

An Integrated Mamdani Fuzzy Inference System and Local Uncertainty Descriptor for Digital Image Watermarking

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Abstract

The goal of this paper is to introduce a combination between the Fuzzy inference system (FIS) Mamdani kind and the linear algebra decomposition LU. The proposed method for hiding the watermark into the original image is built depending on the FIS and LUD without using any other factors like transformation or logistic map. The reason for relying on FIS and LUD is to exploit the advantages of FIS and the decomposition method. The experiments show that the proposed algorithm is worked in high accuracy and the watermark can be extracted correctly as the standard measurements NC and PSNR shows. This is due to the advantages of the FIS and LUD that help to control the imperceptibility and the robustness.

Indexed keywords: Computer Engineering, Advanced Computing, Technology, Open Access

Article History: Received: 13 May 2019 | Accepted: 30 June 2019 | Published: 25 July 2019

Key words: Mamdani fuzzy Inference System, LU decomposition; watermarked image, the Peak Signal to Noise Ratio (PSNR), normalized correlation (NC).

1. INTRODUCTION

Fuzzy Digital watermarking technique 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. Fuzzy theory has become the cornerstone of many important sciences today. 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 is the first kind of mechanisms to better the impartiality and reliability of digital data. Digital image watermarking is information known as the watermark that hiding into the digital data. In other words, to affirm the originality of the data; the embedded secret image can be specified or extracted later. Lately, authentication is one of the major watermarking requirements in image processing applications [2].

On the other hand, 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. Furthermore, linear algebra plays an important role in image processing, particularly in watermarking.

Imran and Harvey proposed in [3] a blind adaptive color image watermarking technique depending on 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.

Typically the goodness of the watermarked image is handled in [4] 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

How to cite: Amal A. Hashim and Huda M. Al-Mosawi (2019). An Integrated Mamdani Fuzzy Inference System and Local Uncertainty Descriptor for Digital Image Watermarking. Journal of Computer Engineering, 8(7), 28–33. DOI: https://doi.org/10.5281/zenodo.19340555

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.

A novel robust watermarking scheme is implemented 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 [5].

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The essential difficulty for creating a new watermarking scheme is typically the stalemate between impressionability plus robustness. Lalani and Doye [6] 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 3^{rd} level of DWT to obtain the modified component.

Authors in [7] used the DWT and then develops a DWT-SVD path using the band LL obtained from the 2-level DWT. 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.

In the proposed work in [8], an authentication technique has been developed in the wavelet domain of a medical image. 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.

Firstly in [9] Fan and Wu 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. Motivated by the above, this paper focus on a digital watermarking algorithm depends primarily on LUD factorization which is taken into consideration for the first time in the watermarking techniques common side by side with the Fuzzy Inference System (FIS). This work investigates the robustness and the imperceptibility in the frequency domain of LUD. Moreover, in this paper, various attacks are adopted to explain the advantages of the given digital image watermarking.

This paper partitioned into five sections, in Section 2 basic important information of LUD and FIS is 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. PRELIMINARIES

This section presents several known pieces of information and definitions required in the rest of the work.

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 [10] 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, its LU decomposition can be presented as:

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

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

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:

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

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

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 [11, 12].

Mamdani 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 combine 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 [13].

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 [14].

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

Rules of Inference and Logic Operator

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 [13].

3. METHODOLOGY

In this section, we propose a protection scheme for improving watermarking relies on FIS and LU Matrix Decomposition method. The proposed watermarking scheme can be characterized as follows:

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 64×64pixels.
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 Mamdani Fuzzy Inference System (FIS) built on 9 fuzzy rules to generate the weight factor α.
6. Implement the LU matrix decomposition method to 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 αrepresents 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:

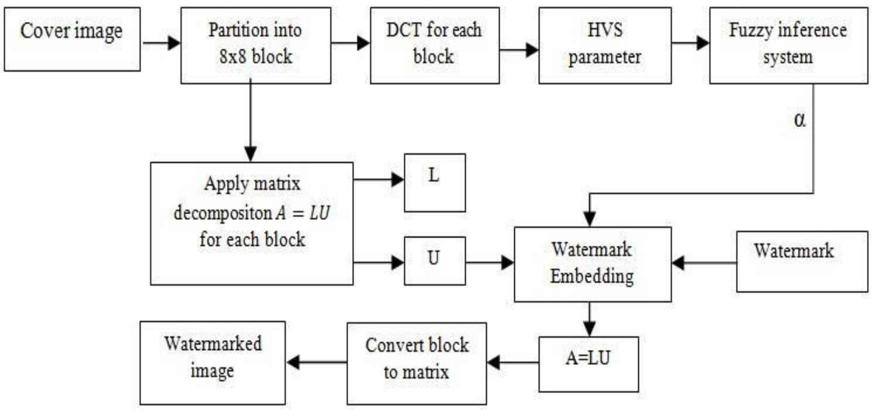


Fig. 1 Block Diagram of the Embedding Algorithm

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:

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

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

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

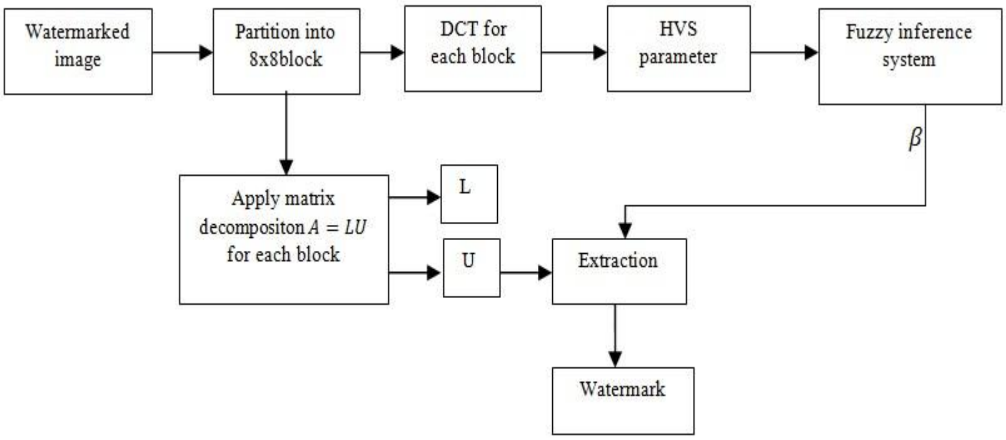
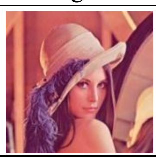


Fig. 2 Block Diagram of Extraction Algorithm

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:

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

where

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

and MAX is the maximum grey scale value which here is equal to 256.

The matching between the extracted watermark W′ and the authentic watermark W is computed based on NC (a normalized correlation) between W and W′.

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

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			
	Image 1	Image 2	Image 3	Image 4
No attacks	39.4487	40.4437	40.0941	39.3643
Salt and Pepper %1	26.9148	26.2126	27.0967	26.8277
JPEG Compression	59.4723	59.5809	58.9448	59.3819
Gaussian noise	37.679	37.658	37.689	37.672
Winer	38.1769	41.3513	39.3788	39.7002
Speckle noise	39.4487	40.4437	40.0941	39.3643

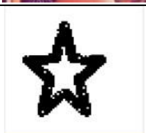
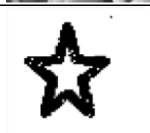
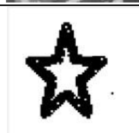
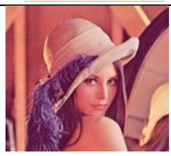
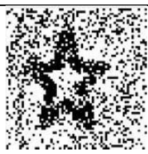
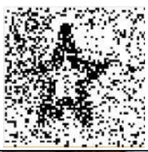
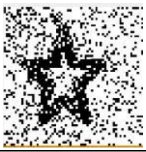
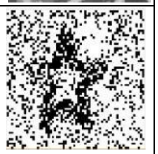
In Table3, results of the NC values are shown against different attacks. High NC values show the robustness of this method against Salt and Pepper, JPEG Compression. Our method does not perform well under the Speckle noise attack. **Table -3 The NC Values for Different Attacks Applied to Test Images**

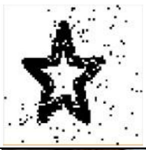
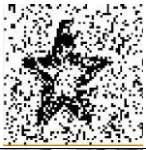
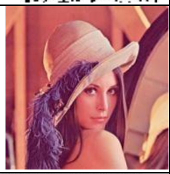
Types of attacks	NC values for watermarked images			
	Image 1	**Image 2**	**Image 3**	**Image 4**
No attack	1	1	1	1
Salt and Pepper %1	0.99737	0.9967	0.9966	0.9972
JPEG Compression	1	1	1	1
Gaussian noise	0.84182	0.8421	0.8751	0.8426
Winer	0.84099	0.9763	0.8679	0.8674
Specklenoise	0.70419	0.9539	0.7196	0.6810

Our method used Mamdani -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

This paper uses one of the important trends in mathematics. Linear algebra and Fuzzy logic are common in image processing and in particular in watermarking. In order to achieve the determined goal, HVS, FIS, and LUD are used together. It is concluded that the embedding and extraction of the proposed algorithm are well optimized. 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. 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. 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 robustness is achieved using LUD depending on the properties of the R matrix. The aim of the proposed algorithm is to introduce a combination of the linear algebra decomposition method LUD and the Fuzzy inference system (FIS).

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