ORIGINAL ARTICLE

Image watermark detection techniques using quadtrees

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Abstract   The quadtree, a hierarchical data structure for the representation of spatial information based on the principle of recursive decomposition, is widely used in digital image processing and computer graphics. This paper demonstrates the detection of invisible watermarked images generated by popular watermarking techniques, including CDMA, DCT, DWT, and Least Significant Bit (LSB) using quadtree. Results corresponding to typical (512×512) pixel images show differences among these methods when they are used. Each time we use the same image, the original images and invisible watermarked image to test the four methods in conjunction with quadtree decomposition. In addition to the subjective method represented by quadtree, many objective evaluations such as Pearson correlation, mean square error (MSE), Structural SIMilarity Index (SSIM) and false positive and false negative were used to give the comparison criteria between original and watermarked images. In results, the quadtree decomposition considered a promise subjective method to recognize among these watermark techniques.

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

1. Introduction

Digital image watermarking has attracted the attention of many researchers over the past decade. The motivation behind this work is the achievement of information security, information concealment, authentication, and fingerprinting. Several approaches to digital image watermarking have been proposed, one of which is the discrete wavelet transform (DWT). The DWT has become highly popular in the field of watermarking due to its ability to decompose available images into sub-bands in which watermarks can be embedded selectively. There are many published studies on this approach and its combination with other approaches, such as quadtrees, DCT, and CDMA approaches. A semi-blind algorithm proposed [4] that embeds a binary sequence watermark into significant wavelet coefficients using quadtree decomposition. A random location table is used to identify the coefficient in which the watermark bit is embedded. In [12], an algorithm for digital watermarking based on the discrete cosine transform (DCT) and the discrete wavelet transform (DWT) was presented. Mistry [13] provides a comparison (in terms of spatial and frequency domains) of digital watermarking methods including the LSB, the DCT, and the DWT. Copyright protection is an important issue in the field of watermarking. In Satyanarayana Murty and Rajesh Kumar [17], the authors presented a hybrid watermark scheme using DWT, DCT, and SVD. In Gunjal [7], a comprehensive overview of digital image watermarking was provided through performance evaluation metrics such as PSNR and correlation factors. Abdallah et al. [1] applied blind image watermarking using wavelets that required neither the original image nor any additional information for watermark recovery. In the medical field [3] combined reversible watermarking with CDMADWT and CDMA-sp, in a study of three security properties (integrity, authenticity and confidentiality) of medical data and patient information. Khalili [9] proposed a secure and robust cryptographic CDMA watermark algorithm with DWT, YIQ color space, and the Arnold transform against JPEG compression and various noise attacks. Digital media content protection and copyright protection were discussed in Sharma and Prashar [18] with regard to DWT.

Many papers deal with the direction of objective metrics, few of them concentrated on the subjective metric especially for invisible watermark.

The most accurate tests of accuracy and quality are subjective tests involving the human observers. Those tests have been developed by psychophysics, scientific disciplines, which aim to identify the relationship between the physical world and people's subjective experience of this world. An accepted measure for evaluation of the level of distortion is a Just Noticeable Difference (JND), and it represents a level of distortion that can be perceived in 50% of experimental trials. One JND thus represents a minimum distortion that is generally perceptible [15]. Survey of watermarking techniques and applications was given in Muharemagic and Furht [15]. Marini et al. [11] proposed to use a Double Stimulus Impairment Scale (DSIS) protocol. In this protocol, the original and the watermarked images are

presented explicitly to the observer. The observer is asked to rate the impairments on a scale of five categories: imperceptible corresponding to score 5, perceptible but not annoying/score 4, slightly annoying/score 3, annoying/score 2 and very annoying/score 1.

These subjective tests can provide very accurate measure of perceptibility of an embedded watermark. However, they can be very expensive to administer, they are not easily repeatable, and they cannot be automated.

The quadtrees have many applications such as image segmentation, data smoothing, edge enhancement and image compression [19,20,10,8,2].

Quadtree decomposition is used in this paper as an analytical technique to subdivide an image into blocks that are more homogeneous than the image itself. This technique reveals information about the structure of the image. We use this data structure to examine differences among watermarking methods such as DWT, DCT, LSB, and CDMA in relation to watermark insertion.

This paper is organized as follows: Section 2 provides an overview of related theories. Section 3 presents the subjective and objective performance evaluation. Section 4 depicts the proposed system. In Section 5, we present experimental results and a discussion of the proposed system. Finally, Section 6 concludes the paper.

2. Related theories

2.1. Code division multiple access (CDMA)

CDMA is an application of a direct sequence spread spectrum. Its purpose is to combine multiple signals that, despite overlapping in both time and frequency, remain separable. This separability is achieved by projecting individual messages onto near-orthogonal PN sequences prior to carrier modulation. The number of simultaneous users in the system dictates the choice of a particular sequence. Maximal length, Kasami, and Gold sequences have been widely used for many reasons.

For example, m-sequences provide the longest period but do not offer as many orthogonal choices as the other two do [14].

Spread spectrum (SS) watermarking is accomplished by embedding every watermark bit over many samples of the cover image using a modulated pseudo-random spreading sequence. SS watermark embedding is analyzed mathematically as follows:

2.1.1. Watermark insertion

Let B denote the string of binary-valued watermark bits as a sequence of N bits.

$$B = \{b_1, b_2, b_3, \ldots, b_i\}, \quad b_i \in \{1, 0\}. \tag{1}$$

If I denotes the image block of length L (i.e., image transformation coefficients of length L), a binary-valued code pattern of length M is used to spread each watermark bit. Therefore, a set P of N code patterns, each of length M, is generated to form watermark sequence W through the following operation.

$$[W_M] = \sum_{i=1}^{N} b_i [P_M]_i \tag{2}$$

The watermarked image I_w is obtained by embedding watermark information W into image block I. The data embedding operation can be mathematically expressed as follows:

$$[(I_W)_M] = [I_M] + \alpha \cdot [W_M] \tag{3}$$

Here, α is the modulation index, and its proper choice will optimize the maximum amount of allowed distortion and minimum necessary watermark energy for reliable detection. α may or may not be a function of image coefficients. Accordingly, SS watermarking schemes can be categorized as signal adaptive or non-adaptive [5].

2.2. Discrete wavelet transform

The fundamental idea of the discrete wavelet transform (DWT) in image processing is to decompose the image into sub-images of different spatial domains and independent frequency districts. Next, the coefficient of the sub-image is transformed. After the original image has been DWT-transformed, it is decomposed into four frequency districts: one low-frequency district (LL) and three high-frequency districts (LH, HL, and HH). If information from the low-frequency district is DWT-transformed, information about the sub-level frequency district can be obtained. A two-dimensional image after three iterations of DWT decomposition is shown in Fig. 1, where L represents the low-pass filter and H represents the high-pass filter [18,21].

An original image can be decomposed into frequency districts HL1, LH1, and HH1. The information from the low-frequency district also can be decomposed

LL3	HL3	HL2	HL1
LH3	HH3		
LH2		HH2	
LH1			HH1

Figure 1   Image after DWT decomposition.

into sub-level frequency districts LL2, HL2, LH2, and HH2. Thus, the original image can be decomposed for *n* level wavelet transformation.

2.2.1. Watermark insertion

The original image and the watermark are first decomposed using the wavelet pyramid structure. Next, the wavelet coefficients (W_W) of the low-resolution representation of the watermark (W) are embedded in the largest wavelet coefficients (I_W) of the low-resolution representation of the original image (I), with μ as a scaling parameter, as follows:

$$I'_W = I_W(1 + \mu W_W) \tag{4}$$

2.3. Discrete cosine transform

Resembling the discrete Fourier transform (DFT) in character, the discrete cosine transform (DCT) turns over the edge of the image to transform the image into the form of an even function. The DCT is one of the most commonly used linear transformations in digital signal process technology [12]. The two-dimensional discrete cosine transform (2D-DCT) is defined as follows:

$$C(u, v) = a(u)a(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos\left[\frac{(2x+1)u\pi}{2N}\right] \cos\left[\frac{(2y+1)v\pi}{2N}\right] \tag{5}$$

The corresponding inverse transformation (2D-IDCT) is defined as follows:

$$f(x, y) = \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} a(u)a(v)C(u, v) \cos\left[\frac{(2x+1)u\pi}{2N}\right] \cos\left[\frac{(2y+1)v\pi}{2N}\right] \tag{6}$$

Here, C is the DC-transformed block, f is the inverse DCT block, and $u = 0, 1, 2, \ldots, K - 1$, $v = 0, 1, 2, \ldots, L - 1$; K and L are the length and breadth of the image; $a(u)$ and $a(v)$ are defined in the following equation.

$$a(u) = \begin{cases} \frac{1}{\sqrt{K}}, & u = 0 \\ \sqrt{\frac{2}{K}}, & 1 \leqslant u \leqslant K - 1 \end{cases}, \quad a(v) = \begin{cases} \frac{1}{\sqrt{L}}, & v = 0 \\ \sqrt{\frac{2}{L}}, & 1 \leqslant v \leqslant L - 1 \end{cases}$$

Not only can the 2D-DCT concentrate the information contained in the original image into the smallest low-frequency coefficient, it can also minimize the image blocking effect to achieve a good compromise between the demands of centralizing information and computing complications. Thus, the 2D-DCT is widely applied in compression coding.

2.3.1. Watermark insertion

The embedding process is implemented in the following three steps:

Step 1: The original image is transformed into the DCT domain to calculate DCT components using (5):

Step 2: The watermark is embedded in n higher-magnitude coefficients in the transform matrix, excluding the DC component. This step ensures that the watermark is embedded in the most significant perceptual components of the image. A watermark embedded in the less significant components may be destroyed by compression or other attacks. When the watermark $X(n)$ is embedded into DCT components $C(u, v)$ to obtain new watermarked DCT coefficients $C^*(u, v)$, we specify a scaling parameter α that determines the extent to which $X(n)$ alters $C(u, v)$, as shown in the following equation:

$$C(u, v)^* = C(u, v)[1 + \alpha X(n)] \tag{7}$$

Step 3: n modified DCT components $C^*(u, v)$ are reinserted, and the inverse DCT transform is taken to obtain the watermarked image $I^*(u, v)$ [6].

2.4. Least Significant Bit (LSB)

LSB coding is one of the earliest used methods in watermarking and steganography. It can be applied to any form of watermarking. In this method, the LSB of the carrier signal is substituted with the watermark. The bits are embedded in a sequence that acts as the key. To retrieve the signal, this sequence must be known. The watermark encoder first selects a subset of pixel values in which the watermark must be embedded. Then, the watermark information is embedded on the LSBs of the pixels from this subset. While LSB coding is a very simple technique, the robustness of the watermark tends to be insufficient. When using LSB coding, it is usually impossible to retrieve the watermark without noise [13].

2.4.1. Watermark insertion

Procedure for Invisible Watermarking (Least Significant Bit Watermarking). A raw bitmap image 'A' is selected from the set of standard test images. Let this be the base image onto which the watermark will be added.

(1) A raw bitmap image 'B' is selected from the set of standard test images. This is the watermark image to be added to the base image.
(2) The most significant bit (MSB) of the watermark image 'B' is read and written onto the Least Significant Bit (LSB) of the base image 'A'.

Thus, 'A' is watermarked with 'B', resulting in a combined image 'C'. Thus, 'C' now contains an image 'A' that has its LSBs replaced with the MSBs of 'B'. The

LSB is a form of the spatial domain technique. This technique is used to add an invisible or visible watermark to an image.

3. Performance evaluation

This section demonstrates the subjective and objective performance evaluation.

3.1. Quadtree for the detection of watermarking techniques (QT)

A natural gray-level image usually can be divided into differently sized regions with variable amounts of details and information. Such segmentation of the image is useful for the efficient coding of image data. QT decomposition is a powerful technique that divides the image into 2-D homogeneous regions, thereby producing the segmentation.

The decomposition builds a tree. Each tree node has four children and is associated with a uniquely defined region of the image. The root of the tree is associated with the entire image [19].

A quadtree representing a picture is a tree in which successively deeper levels represent successively finer subdivisions of picture areas. Each node represents the quadrant of its parent. The tree is filled through the process of recursively subdividing an image matrix into four quadrants until a quadrant is one solid color. A quadtree is a tree with nodes that are either leaves or have four children. The children are ordered: 1, 2, 3, and 4.

3.1.1. Quadtree types

Quadtrees may be classified based on the type of data they represent, including areas, points, lines and curves. Quadtrees may also be classified by whether the shape of the tree is independent of the order in which the data are processed. Some common types of quadtrees are:

(1) The region quadtree: The region quadtree represents a partition of space into two dimensions that decomposes a region into four equal quadrants, subquadrants, and so on. Each leaf node contains data corresponding to a specific subregion. Each node in the tree has either exactly four children or no children (a leaf node).

The region quadtree is not strictly a 'tree' (more precisely, 'trees') because the positions of subdivisions are independent of the data. A region quadtree with a depth of n may be used to represent an image of $2^n \times 2^n$ pixels, with each pixel valued 0 or 1. The root node represents the entire image region. If the pixels in any region are not entirely 0 s or 1 s, that region is subdivided.

In this application, each leaf node represents a block of pixels that are all 0 s or all 1 s. A region quadtree may also be used as a variable resolution representation of a data field. In this paper, the region quadtree is assumed.

(2) Point quadtree: The point quadtree is an adaptation of a binary tree used to represent two-dimensional point data. It shares the features of all quadtrees but is a true tree because the center of a subdivision is always on a point. The shape of the tree depends on the order in which the data are processed. The point quadtree is typically very efficient at comparing two-dimensional ordered data points, usually operating in $O(\log n)$ time.

Therefore, a node contains the following information:

• Four pointers: quad ['NW'], quad ['NE'], quad ['SW'], and quad ['SE'].
• A point that, in turn, contains:
  – A key, usually expressed as x and y coordinates.
  – A value, e.g., a name.

(1) Edge quadtree: Edge quadtrees are specifically used to store lines rather than points. Curves are approximated by subdividing cells until a very fine resolution is reached. This procedure can result in extremely unbalanced trees, which may defeat the purpose of indexing. Fig. 2 demonstrates the decomposition of an image [20,10].

The sparse matrix is used to save the data of quadtree decomposition. If S is a sparse matrix, $S(m, n)$ has the value of the block size at the location (m, n) such that only non-zero elements are given as $\{(mn), \text{value}\}$.

3.2. Objective performance evaluation

3.2.1. Pearson correlation coefficient

Pearson's correlation coefficient, r, is widely used in statistical analysis, pattern recognition, and image processing. Applications include comparing two images for the purposes of image registration, object recognition, and disparity measurement. For monochrome digital images, the Pearson correlation coefficient is defined as [16]:
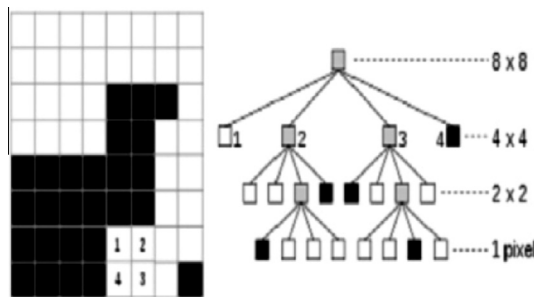

Figure 2   Image and its quadtree.

$$r = \frac{\sum_i (x_i - x_m)(y_i - y_m)}{\sqrt{\sum_i (x_i - x_m)^2}\sqrt{\sum_i (y_i - y_m)^2}} \tag{8}$$

where x_i is the intensity of the ith pixel in image 1, y_i is the intensity of the ith pixel in image 2, x_m is the mean intensity of image 1, and y_m is the mean intensity of image 2.

The correlation coefficient has the value $r = 1$ if the two images are absolutely identical, $r = 0$ if they are completely uncorrelated, and $r = -1$ if they are completely anti-correlated, for example, if one image is the negative of the other.

3.2.2. The Structural SIMilarity Index (SSIM)

SSIM index is a method for measuring the similarity between two images. Structural information is the idea that the pixels have strong inter-dependencies especially when they are spatially close. These dependencies carry important information about the structure of the objects in the visual scene. The SSIM metric is calculated on various windows of an image. The measure between two windows x and y of common size $N \times N$ is [22]:

$$\text{SSIM}(x, y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{9}$$

where μ_x and μ_y are the average of x and y, respectively, σ_x^2 and σ_y^2 are the variance of x and y respectively, and σ_{xy} is the covariance of x and y. $c_1 = (k_1 L)^2$ and $c_2 = (k_2 L)^2$ are two variables to stabilize the division with weak denominator, L is the dynamic range of the pixel-values (typically this is $2^{\#\text{bits per pixel}} - 1$), and $k_1 = 0.01$ and $k_2 = 0.03$. The resultant SSIM index is a decimal value between -1 and 1, and value 1 is only reachable in the case of two identical sets of data.

3.2.3. Mean square error (MSE)

The MSE is the expected value of the squared error

$$\text{MSE} = \frac{1}{MN} \sum_{y=1}^{M} \sum_{x=1}^{N} [I(x, y) - I'(x, y)]^2 \tag{10}$$

where $I(x, y)$ is the original image, $I'(x, y)$ is the approximated version and (M, N) are the dimensions of the images. A lower value for MSE means less error.

3.2.4. Confusion matrix

This matrix provides a quantitative performance representation for each classifier in terms of class recognition or detection. Values along the main diagonal give the total number of correct classifications for each class. Values other than those on the main diagonal represent classification errors.

4. Proposed system for detection of watermarking techniques

The proposed system was implemented on a Dell Laptop (Windows 7, Processor Core 2 Duo and 2.00 GB RAM) using MATLAB. In this section, we describe a detection system using a quadtree. Fig. 3 is a conceptual diagram of the proposed system.

The system operates on the basis of the steps below:

1. Read a gray BMP-type image S.
2. Read a black and white image for use as the watermark w (the watermark image, 50×20).
3. Embed the image using CDMA, DWT, DCT, and LSB techniques.
4. Performance Evaluation which is divided into two criteria, subjective and objective.
4.1. Run a quadtree for each technique individually as subjective criterion.
    4.1.1. The quadtree divides a square image into four equal-sized square blocks.
    4.1.2. Each block is tested against a specified criterion of homogeneity (the quadtree is based on the successive subdivision of a bound image array into four equal-size quadrants. If the array does not consist entirely of 1 s (black) or entirely of 0 s (white), then it is subdivided into quadrants, subquadrants, and so on, until blocks are obtained that consists entirely of 1 s or entirely of 0 s; that is, each block is entirely contained in the region or entirely disjoint from it).
    4.1.3. If a block meets the criterion.
- It is not further divided.
- If it does not meet the criterion, it is further subdivided into four blocks; go to 4.1.3.
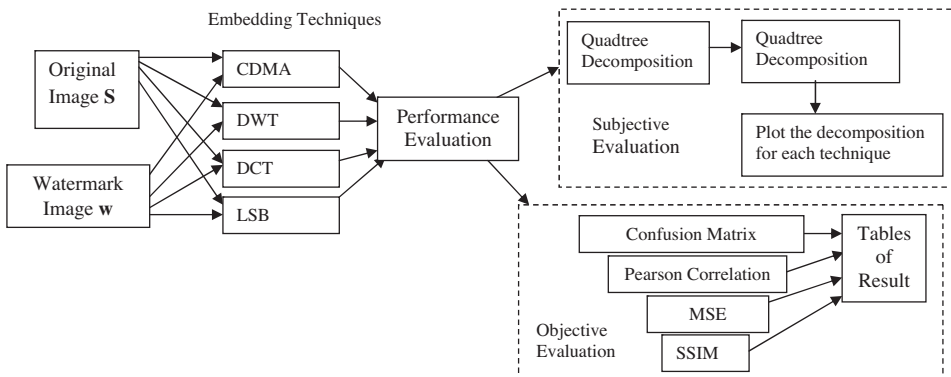

Figure 3 The proposed system.

4.2. Plot the quadtree decomposition for each watermarking technique.

4.3. Plot the quadtree decomposition for the original image.

4.4. Compare the results of the two plots.

5. Objective Evaluation.

5.1. Pearson correlation.

5.2. MSE.

5.3. SSIM.

5.4. Confusion matrix.

5. Experimental results

This section presents the results of the implementation of different watermark techniques. Fig. 4 shows the original images (512×512 in size) used in the experiment and the black and white watermark image (50×20 in size).

In experimental results, we want to show the difference between the common original image (like Lena) and if this image was watermarked with another image using four distinct watermark techniques CDMA, DWT, DCT, and LSB. Quadtree decomposition is a subjective method to reveal the difference between the original and the watermark images using the histogram.

The quadtree decomposition of distinct images was illustrated using original images like Lena, Alaine, Boat and House (see Supplementary Figs. S1–S4).

We examine the quadtree decomposition as subjective metrics with compare with originals images which show the difference between the histogram for distinct watermark techniques: CDMA, DWT, DCT, and LSB (see Supplementary Figs. S1–S4).

In accordance with the histograms of subjective evaluation using quadtree, the metric should provide a quantitative evaluation of watermark image techniques that conform to subjective assessment which are given in Tables 1–4.

Table 1 presents the results for SSIM between original and watermarked images. The result shows that the compare between original images are identical. It also is observed from the comparison of the original image with watermarked images that there fluctuate depending on methods that used to image watermark-
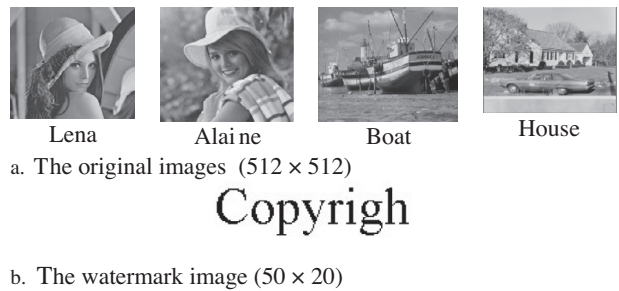

Lena   Alaine   Boat   House

a. The original images (512×512)

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b. The watermark image (50×20)

Figure 4   Original and watermark image.

Table 1   Structural SIMilarity index (SSIM) between original and watermarked images.

	Original image	DCT	DWT	CDMA	LSB
Lena (original image)	1	0.86	0.66	0.77	0.99
Alaine (original image)	1	0.86	0.66	0.77	0.99
Boat (original image)	1	0.86	0.66	0.77	0.99
House (original image)	1	0.86	0.66	0.77	0.99

Table 2   Correlation between original and watermarked images.

	Original image	DCT	DWT	CDMA	LSB
Lena (original image)	1	0.993	0.976	0.987	0.999
Alaine (original image)	1	0.993	0.976	0.987	0.999
Boat (original image)	1	0.993	0.976	0.987	0.999
House (original image)	1	0.993	0.976	0.988	0.999

Table 3   Mean square error (MSE) between original and watermarked images.

	Original image	DCT	DWT	CDMA	LSB
Lena (original image)	0	27.4	105.2	52.4	0.4
Alaine (original image)	0	27.2	105.1	52.4	0.4
Boat (original image)	0	27.8	104.2	52.4	0.4
House (original image)	0	27.1	105.1	52.4	0.4

ing with nearly equal to the values resulting from each method, suggesting a way to differentiate from other. Table 2 gives the resultant of the correlation between the original images and the watermarked images. The results seen for the same images show that the output correlation is equal to 1, which means that the two images are identical. As mentioned earlier in SSIM index, there is variation in the results of each method of image watermarking. Table 3 shows MSE results, which indicate no error between the same images. A lower value for MSE means less error as noted in the LSB method.

Depending on the results of these assessments, another comparison between the original images and watermarked images achieved in Table 4 through the confusion matrix and the Supplementary Fig. S5 using the false positive and false negative. The confusion matrix is given in Table 4; numbers shown in bold font are correct classifications.

Results were evaluated from the confusion matrices to calculate percentage accuracy measurements for each classification.

All tested images used watermarked images. Note that the results reported in Supplementary Fig. S5 show that the false negative decreases as false positive increases. Fortunately, this action reduces the chance of false negative conditions which occurs when a watermark detector fails to detect a watermark.

Table 4 Confusion matrix for Lena original image and watermark embedding methods.

Class	1	2	3	4	Row Total
1	**449**	0	0	0	449
2	0	**11**	0	0	11
3	0	0	**8**	0	8
4	0	0	0	**1**	1
Column Total	449	11	8	1	469
Correct 469/ 469= 1%					

Original Image

Class	1	2	3	4	Row Total
1	**444**	4	0	1	449
2	2	**4**	4	1	11
3	5	2	**0**	1	8
4	1	0	0	**0**	1
Column Total	452	10	4	3	469
Correct 448/469= 95.52%					

CDMA

Class	1	2	3	4	Row Total
1	**405**	31	9	2	447
2	8	**2**	0	0	10
3	2	3	**2**	1	8
4	0	1	0	**0**	1
Column Total	415	37	11	3	466
Correct 409/ 466= 87.77%					

DCT

Class	1	2	3	4	Row Total
1	**437**	9	2	0	448
2	5	**5**	0	1	11
3	2	5	**0**	0	7
4	0	0	1	**0**	1
Column Total	444	19	3	1	467
Correct 442/467= 94.65%					

DWT

Class	1	2	3	4	Row Total
1	**52**	382	11	3	448
2	5	**3**	2	1	11
3	5	2	**1**	0	8
4	0	0	1	**0**	1
Column Total	62	387	15	4	468
Correct 56/468= 11.97%					

LSB

6. Conclusion

In this work, we have presented quadtree decomposition as a subjective metric and objective metrics based on SSIM, MSE, Pearson correlation and false positive and false negative. We tested its performance in the context of four distinct watermark techniques: CDMA, DWT, DCT, and LSB. Quadtree is usually used in segmentation process; in this paper, we benefit of quadtree decomposition to recognize the method of image watermark. The results reveal differences between the watermarked image and the original image across the four techniques; this was confirmed by the results of the quantitative evaluation. This research demonstrates the effectiveness of the quadtree as a detector of watermarked images and shows the differences in the performance of various techniques.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aci.2014.07.003.

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