Fast BCH Coding for Optimal Robust Image Watermarking in DCT Domain

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Abstract—This paper investigates a novel approach of digital image watermarking based on BCH error correction code in Discrete Cosine Transformation (DCT) domain. In the proposed technique, the watermark is encoded through BCH error correction code before embedding process, then it is embedded into the Discrete Cosine Transformation (DCT) coefficients of cover image. The proposed algorithm also employs lookup table method to find the best positions in the frequency domains for watermark insertion. The significant feature of this method is the reduction of time required in the process embedding of information, security and ability to correct the error caused by different attacks. Experimental results show the superiority of the proposed approach against the existing approaches.

Keywords—Digital Watermarking, Discrete Cosine Transformation, Error Correction Codes, BCH code, Look Up Table

I. INTRODUCTION

Due to the rapid advancement of the internet and computer networks, as well as easy access to information, saving, copying, modifying, and even illegally diffusing unauthorized copies of copyrighted digital contents without altering their quality have become more convenient than before. Thus, the security of information has become an indispensable factor in information transmission. One of the most effective solutions to mitigate this problem is digital watermarking. Watermarking is a technique for hiding data in a medium coverage so that its presence is not detectable by a human visual system and is recoverable only by the authorized recipient. According to the working domain, the watermarking techniques can be divided into two types: a) spatial domain watermarking techniques b) frequency domain watermarking techniques. In spatial domain techniques, the watermark embedding is done on image pixels while in frequency domain watermarking technique the embedding is done after transformation of taking image [12].

In recent years, error detecting and correcting codes have played a significant role in the robustness, security and, transparency of digital image watermarking. The theory of error detecting and correcting codes is a branch of engineering and mathematics which deals with the reliable transmission and storage of data [18]. Regarding this concept, recently error correction codes have been used considerably to achieve the imperceptibility, robustness and security of digital image watermarking and various codes including Hamming code [4], BCH code [2, 6, 13, 15, 20], Reed Solomon code [3, 23], convolutional code [11], LDPC code [12] and turbo code [19] have been studied to achieve these objectives. Several types of research have been proposed in digital watermarking process using error correction code in the literature. For example, Marvel [10] has considered the protection of the steganographic payload in images by using Reed-Solomon codes, turbo codes and, special codes developed by Retter2 in both hard decision and soft-decision decoding contexts. The scheme consists of an interleaver that disperses long error bursts followed by the coder unit, achieves a Bit Error Rate (BER) of about $10^{-2}$ at a high embedding density of 0.16 bit/pixel.

Alattar et al. [1] suggested a watermarking algorithm for electronic documentation which uses the spread spectrum method. They used BCH coding to obtain the watermark more successfully after the print and scan process of the electronic documentation. Findik et al. [12] proposed a digital color image watermarking technique based on artificial neural networks (ANN) and BCH coding together.

Crandall [14] has considered the Matrix Embedding (ME) scheme to reduce the number of required changes of the cover by carefully selecting the positions used for embedding. Fridrich et al. [8, 9] suggested an embedding algorithm based on syndrome coding using random codes, called Wet Paper codes. This embedding scenario does not require the sender to share any knowledge about the constraints with the recipient and does not even sacrifice embedding capacity, however, this can lead to an increased embedding complexity.

Westfeld [2] suggested using a matrix encoding technique for hiding data to DCT coefficients. His scheme hides more than one bit by changing at most one coefficient in a block. The matrix encoding technique is based on the Hamming code. The $(n, m, t)$ matrix encoding technique can hide $n$ bits of data into $m = 2n − 1$ coefficients by flipping $t$ coefficients.

Schonfeld and Winkler [6] found a way to hide data using a more powerful error correction code (ECC). They used
structured BCH code for data embedding. They showed two ways for computing position of the coefficients in the block to be modified. The first way is based on a structured encoding matrix and the second way uses the generator polynomial \( g(x) \).

In this paper, a digital watermarking technique based on BCH error correction code in Discrete Cosine Transformation (DCT) domain is proposed. The time complexity is one of the disadvantages of the BCH coding, regarding this challenge, this paper is also proposed lookup table method to decrease complexity of computation and speed up the process of finding the proper position to insert a watermark signal. Watermarked image robustness has been investigated against different kinds of attacks and the simulation results indicate that the proposed algorithm outperforms the existing methods in terms of imperceptibility, robustness and security.

The rest of this paper is organized as follows. Section II introduces a basic definition of \( t \)-error-correction BCH coding scheme, BCH encoder and decoder. Lookup table method is introduced in Section III. In section IV, the proposed embedded and extraction algorithm is presented. Section V reports the experiments that are conducted for evaluating the proposed technique and presents the results. Finally, in section VI, the conclusion is drawn.

I. BCH CODE

BCH code is a family of cyclic codes, with an algebraic structure that is useful in simplifying its encoding and decoding procedures. While operating under \( GF(2^m) \), it has error correcting capability of \( t \). The main parameters of BCH codes are summarized as following parameters \([18, 22]\):

- Block length: \( n = 2^m - 1 \)
- Message length: \( k \)
- Maximum correctable error bits: \( t \)
- Number of information bits: \( k \geq n - m \cdot t \)
- Minimum distance: \( d_{\text{min}} \geq 2t + 1 \)

Obviously, this code is capable of correcting any combination of \( r \) or fewer errors in a block of \( n = 2^m - 1 \) digits. For a given codeword length \( n \), only specific message length \( k \) is valid for a BCH code. This code is called a \( t \)-error-correcting BCH code. If a coding scheme generates a codeword of length \( n \) from a message of length \( k \), the coding rate is \( R = k/n \), \( k \leq n \). A BCH code is generated by the polynomial \( g(x) \), the generator polynomial of BCH code is constructed by using minimal polynomials in \( GF(2^m) \) which is explained in [11]. Let \( \alpha \) be a primitive element in \( GF(2^m) \). For any specified \( m \) and \( d \) the code generated by \( g(X) \) is a BCH code, if \( g(x) \) is the polynomial of the lowest degree over \( GF(2^m) \) for which \( \alpha^i, \alpha^{i+1}, \ldots, \alpha^{i+m-2} \) are roots. Let \( \phi_i(x) \) be the minimal polynomials of \( \alpha^i \) then generator polynomial of BCH code is computed as the least common multiple (LCM) among \( 2t \) minimal polynomials \( \phi_i(x) \):

\[
g(x) = \text{LCM}\{\phi_1(x), \phi_2(x), \ldots, \phi_{2t}(x)\}
\]

An \((n, k)\) binary BCH code encodes \( k \)-bit messages into \( n \)-bit codewords. The \( k \)-bit message is the input of encoder and the BCH encoder generates \((n-k)\)-bit parity. After encoding, the \((n-k)\)-bit parity together with \( k \)-bit message generate a codeword as follow:

\[
v(x) = c(x)x^{n-k} + \text{Re} \{v(x)x^{n-k} \} g(x)
\]

If the channel is noisy, the received vector \( r \) can be expressed as follow:

\[
r(x) = v(x) + e(x)
\]

Upon receiving \( r \), decoder must first determine whether there are transmission errors in \( r \). If there is no error in the received data, the syndrome should be all zero and the decoding procedure is finished. Otherwise, the syndrome should be sent to error-location block to generate the error-locating polynomial. Then, the Chien search block is used to find out which bits are erroneous. Finally, the corrected message is extracted. Generally, the decoding of BCH code has three main steps that are expressed as follows:

I. Computing the syndromes from the received codeword as follow:

\[
S_i = r(\alpha^i) = c(\alpha^i) + e(\alpha^i) = e(\alpha^i)
\]

II. Key equation solver, which determines the error locator polynomial \( \sigma(X) \) through the BM (Berlekamp-Massey) algorithm as follow:

\[
\sigma(X) = \sigma_0 + \sigma_1 X + \sigma_2 X^2 + \ldots + \sigma_v X^v
\]

III. Determining the error locating numbers by finding the roots of error locating polynomial (identifying the position of erroneous bit).

The block diagram of decoding process for a \( t \)-error correcting BCH code has been illustrated in figure 1. For further information on BCH codes, we orientate readers towards references [18, 22].
The aim of coding theory is different from the data hiding method even though both methods use the error correction codes [16]. In coding theory, the syndrome equation \( S = H \cdot r^T \) in the first stage of decoder block is used to detect and correct the error which is not expected in advance at the encoder block, while in data hiding, the syndrome is used to select proper coefficients to insert a watermark signal and decline distortion. In the embedding process, by choosing proper \( e(x) \), some of the host image bits are modified intentionally.

Let \( r(x) \) and \( v(x) \) denote watermarked image and host image respectively. \( r(x) \) and \( v(x) \) can be represented as the polynomial \( r(x) = r_1x + r_2x^2 + ... + r_nx^n \) and \( v(x) = v_1x + v_2x^2 + ... + v_nx^n \) over \( GF(2^m) \). Then, watermark image \( I \) is obtained as follow:

\[
I = r \cdot H^T
\]  

(6)

Where \( H \) is the parity-check matrix that its entries are constructed by the primitive element in \( GF(2^m) \) as follow:

\[
H = \begin{bmatrix}
1 & \alpha & \alpha^2 & \cdots & \alpha^{n-1} \\
1 & (\alpha)^2 & (\alpha^2)^2 & \cdots & (\alpha^2)^{n-1} \\
\vdots & \vdots & \ddots & \vdots & \vdots \\
1 & (\alpha^{2t}) & (\alpha^{2t})^2 & \cdots & (\alpha^{2t})^{n-1}
\end{bmatrix}
\]  

(7)

Suppose that \( v(x) = v_1x + v_2x^2 + ... + v_nx^n \) is host image and modifying in the host image bits after inserting watermark image results in the following watermarked image:

\[
r(x) = r_1x + r_2x^2 + ... + r_nx^n + e_n x^{n-1}
\]  

(8)

Let \( e(x) \) be flip pattern. Then

\[
r(x) = e(x) + v(x)
\]  

(9)

The first step of the watermarking process is to compute the syndrome from the \( r(x) \). The syndrome is a \( 2t \)-tuple,

\[
S = (S_1, S_2, ..., S_{2t}) = r \cdot H^T
\]  

(10)

From (6) and (9) the following equation is obtained:

\[
I = [v(x) + e(x)] \cdot H^T 
\]  

(11)

\[
I - v \cdot H^T = e \cdot H^T
\]  

(12)

From (10) and (11) the relationship between the syndrome and the flip pattern can be described as follow, for further details, refer to reference [18].

Suppose that the flip pattern \( e(x) \) has \( v \) flip at locations \( X^1 + X^2 + ... + X^v \), that is,

\[
e(X) = X^j_1 + X^j_2 + ... + X^j_v
\]  

(13)

The power \( j_1, j_2, ..., j_v \) tell us the location of host image bits that are modified to insert a watermark image. Letting \( B_k \) denotes \( a^k \), combining (12) and (13), the syndrome is obtained as follow:

\[
S_1 = e_1 + e_2 \cdot \beta_1 + e_3 \cdot \beta_2 + ... + e_v \cdot \beta_v \\
S_2 = e_1 \cdot \beta_1^2 + e_2 \cdot \beta_1 \cdot \beta_2 + ... + e_v \cdot \beta_v^2 \\
\vdots \\
S_{2t} = e_1 \cdot \beta_1^{2t} + e_2 \cdot \beta_1^{2t-1} \cdot \beta_2 + ... + e_v \cdot \beta_v^{2t}
\]  

(14)

Notice that for binary codes, \( e_k = 1 \) (\( k = 1, 2, ..., k \)). Equation (14) can be simplified further as follow:

\[
S_1 = \beta_1 + \beta_2 + \beta_3 + ... + \beta_v \\
S_2 = \beta_1^2 + \beta_2 \cdot \beta_1 + \beta_3 + ... + \beta_v^2 \\
S_3 = \beta_1^3 + \beta_2^2 \cdot \beta_1 + \beta_3 + ... + \beta_v^3
\]  

(15)

The embedding process in watermarking is done to find \( B_k \)'s. Once all \( B_k \)'s are known, the location of host image bits for inserting watermark is also known. Equation (15) is a set of nonlinear function which solving it seems to be difficult. However, a polynomial \( \sigma(x) \) whose roots are the reciprocals of \( B_k \)'s can be used as follow:

\[
\sigma(X) = (1 + \beta_1 X)(1 + \beta_2 X) ...(1 + \beta_v X)
\]  

\[
= \sigma_0 + \sigma_1 X + \sigma_2 X^2 + ... + \sigma_v X^v
\]  

(16)

The next step is to find the roots of error location polynomial. The effective method is using Chien search algorithm. Any root of \( \sigma(x) \) must be one of the elements in Galois field. The Chien search algorithm examines if \( 3^a \) is a root of \( \sigma(x) \) for \( 1 \leq i \leq n \) by substituting \( 3^a \) into \( X \) of error location polynomial [18, 22].

Finding roots of error locator polynomial using Chien search algorithm leads to increasing latency in decoding process. In this paper, an improved algorithm based on the lookup table method for finding roots of polynomials over finite fields is utilized that is proposed by Zhao et al [24]. The complexity of root finding can be significantly reduced by using lookup table method, it does not require an exhaustive search. So, this makes a fast embedded process to insert watermark signal using BCH codes. In the next section, a construction method of lookup table for quadratic and cubic polynomials is introduced based on the five lemmas proposed by Zhao et al [24].
II. LOOKUP TABLE METHOD

Consider two polynomials of degree 2 over finite field $GF(2^m)$ as follow:

$$f(x) = x^2 + \sigma x + \sigma^2$$

$$f(y) = y^2 + y + \sigma^2$$

(17)

The method of Zhao states four lemmas as follows [24]:

**Lemma 1:** If $y_0$ is a root of $f(y)$, then $y_0 + 1$ is another root of $f(y)$.

**Lemma 2:** If $y_0$ is a root of $f(y)$, then $x_0 = \sigma y_0$ is another root of $f(x)$.

**Lemma 3:** If $y_0$ is a root of $f(y)$, then $x_0 = \sigma y_0 + \sigma^2$ is another root of $f(x)$.

Lookup table $q$ with size $n \times 1$ keeps the roots of any $y_0$ of the family of quadratic polynomials $f(y) = y^2 + y + i$, where $i \in [1; 2^m - 1]$ in $GF(2^m)$. Thus, the size of the lookup table $q$ is $(2^m - 1) \times 1$. The roots of polynomial $f(x)$ can be found in the lookup table $q$ in position $\sigma^2 / \sigma^2 _1$. If there are no roots for some corresponding positions in the table are marked as -1 [7, 25]. For a cubic polynomial

$$f(x) = x^3 + \sigma x^2 + \sigma x + \sigma$$

in $GF(2^m)$, there are two parameters such as $a = \sigma^2 + \sigma_2$ and $b = \sigma_1$. $\sigma_2 + \sigma_3$. If the polynomial $f(y) = y^3 + y + \frac{b}{a^{3/2}}$ is pair of $f(x)$, the relationship between roots of $f(x)$ and $f(y)$ can be described using following lemma:

**Lemma 4:** If $y_j (j = 1, 2, 3)$ is a root of $f(y)$, then $x_j = a^{1/2} y_j + \sigma_1$ is another root of $f(x)$.

The proof of these lemmas can be found in reference [24]. Similar to the quadratic polynomial, a lookup table $c$ with size $n \times 3$ keeps roots $y_j$ ($j = 1, 2, 3$) of the family of cubic polynomials $f(y) = y^3 + y + i$; If there are not three roots for some $f(y)$, the $i$th row of the table is marked as -1. The roots of the $f(x) = x^3 + \sigma x^2 + \sigma_2 x + \sigma_3$ can be found in the lookup table $c$ in position $b/a^{3/2}$. For further calculations, the indexes of the rows which have 3 roots have to be stored in a special table $k$. The size of the special table $k = D \times 1$, where $D$ is the number of rows that have 3 roots [20, 24].

III. PROPOSED WATERMARKING ALGORITHM

This section describes the process of the data watermarking in digital image by using BCH coding. At the first step of the watermarking process, host image $v$ is divided into blocks $B$ of dimensions $8 \times 8$ pixels. Each block $B$ is transformed into frequency domain by DCT. The watermark bits are inserted in host image by using the proposed image watermarking algorithm. The proposed image watermarking scheme is based on $BCH(n, k, t)$ where $n = 2^k - 1$, $m=1, 2, 3, \ldots, t = 2$ and able to insert $t.m$ bit watermark signal in the $n$ bit of host image. So the proposed algorithm to insert watermark image $I$ ($|I| = t.m$) in host image $v$ ($|v| = n$) is designed as follow:

**Input:** watermark image $I$, blocks of host image, distortion maximum allowed $i = 2, 3$.

**Output:** image watermarked $r$.

**Step 1:** Compute syndrome using equation (10).

**Step 2:** If $S_1 = S_2 = 0$ there is not any $e$ in order to satisfy equation(12), omit current block, otherwise go to step 3.

**Step 3:** If $S_2 + S_1^3 = 0$, watermark signal can be inserted to a block of host image by modifying just one coefficient. So degree of polynomial $\sigma(x)$ is 1 such as $\sigma(X) = X + \sigma_1$ and its root is $\beta = \sigma_1$. The position of the coefficient to be modified is $j = \log(\beta) _1$, otherwise go to step 4.

**Step 4:** If inserting a watermark signal is possible by modifying at most two coefficients, The degree of polynomial $\sigma(x)$ is 2 such as $\sigma(x) = X^2 + \sigma_1 X + \sigma_2$. At the first, parameter $u = \sigma_2^3 / \sigma_1^3$ is calculated. The parameter $u$ is the index value in the lookup table $q$. The basic root $y_i = q(u)$ can be obtained from the lookup table $q$ in row $u$. If $y_j \neq -1$, the roots of polynomial $\sigma(x)$ are computed such as $\beta_1 = S_1.y_1$, $\beta_2 = S_1 + S_1.1$, and the positions of the coefficient to be modified are $j = \log(\beta), i = 1, 2$, otherwise go to step 5.

**Step 5:** If inserting a watermark signal is possible by modifying at most three coefficients, The degree of polynomial $\sigma(x)$ is 3 such as $\sigma(x) = X^3 + \sigma_1 X^2 + \sigma_2 X + \sigma_3$. At the first, parameter $o = \frac{b}{a^{3/2}}$ is calculated. The parameter $o$ is the index value in the lookup table $c$. The three basics roots $y_i = c(o, i), i = 1, 2, 3$, can be obtained from the lookup table $q$. The roots of polynomial $\sigma(x)$ are computed such as $\beta_i = \rho \cdot y_i + S_1, i = 1, 2, 3$ where $\rho = \frac{s_{1}^{3} + s_{2}^{3}}{o}$ and the positions of the coefficient to be modified are $j = \log(\beta), i = 1, 2, 3$.
**Step 6:** modifying the host image bits \( v \) after inserting a watermark image results in the watermarked image as \( r(x) = v(x) + e(x) \) and to embedding a watermark signal, the proposed algorithm is repeated for each block.

In the extraction process, distorted bits are retrieved by using BCH coding. Decoding process as explained in section II is applied to obtain a secured watermark from each block. The BCH decoder can correct up to a certain number of errors. Thus, watermark image can be exactly extracted with no bit errors by this method.

### IV. SIMULATION RESULTS

This section discusses the results of several experiments conducted using the proposed algorithm. Simulations are carried out in MATLAB to test the proposed algorithm’s efficiency. It is notable to mention that Communications System Toolbox in MATLAB provides essential algorithms and functions for the implementation BCH code.

In these experiments, a secret image is concealed into the different amount of host images using the proposed BCH-based watermarking scheme. The peak signal to noise ratio (PSNR) metric is measured in order to evaluate imperceptibility between original and attacked watermarked image. Its value can be defined as follows:

\[
PSNR = 10 \log_{10} \frac{255^2}{MSE}
\]

(18)

Here MSE is called the mean squared error between the original and distorted image which is defined:

\[
MSE = \frac{1}{MN} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} [x(i, j) - \hat{x}(i, j)]^2
\]

(19)

The watermarked image with the best quality, will have the higher the PSNR value. It should also be noted that, according to formula (18), the higher the PSNR value means the lower MSE value. Therefore, the watermarked image with better quality, will have the lower the MSE value. In formula (18), \( M \) and \( N \) denote the length of the image, \( x \) is the pixel value of the original image, and \( \hat{x} \) is the pixel value of the watermarked image in the position of \((i, j)\). As pointed earlier, robustness is the resistance of an embedded watermark against different kinds of attacks, so the normalized correlation coefficient (NCC) is used to evaluate the degree between the embedded watermark and extracted watermark from the attacked image which can be defined as follow:

\[
NCC = \frac{\sum_{i=0}^{i-1} \sum_{j=0}^{j-1} W_{ij} \hat{W}_{ij}}{\sqrt{\sum_{i=0}^{i-1} \sum_{j=0}^{j-1} W_{ij}^2 \hat{W}_{ij}^2}}
\]

(20)

Where \( i, j \) define the size of the embedded watermark and \( W \) and \( \hat{W} \) define the original and extracted watermark bits, respectively. The value of NCC is between 0 and 1. And the bigger value is, the better the watermark robustness is. Figure 2 shows five test images that have been used in our experiments, namely barbara, watch, man, yacht, lena, and the size of each test image is 512x512. The cameraman image of size 256x256 has been used as a watermark image. In the first experiment, we transformed each block of size 8x8 pixels of original image into DCT domain. Watermarked image imperceptibility, robustness, security and effectiveness BCH code have been investigated against different kinds of attacks namely wiener filter, gaussian filter, rotation \( 2^\circ \), JPEG compression and resize. Due to the limitation of paper space, only extracted watermark for Lena image has been illustrated in figure 3.
Fig. 3. Attacked image of watermarked Lena, and Corresponding extracted (d) Rotation 2 watermark after (a) 3x3 Median Filtering (b) Gauss noise (c) JPEG Compression (e) Resize 256→128→256

BCH coding parameters that are applied in this study including ECC rate k/n, maximum percent error correction capability of the ECC t/n, and PSNR value per codeword are given in Table 1. The relationship between PSNR of the watermarked image and the ECC rate is also shown in Table 1. It is observed that (31, 26), (31, 21) and (31, 16) BCH coding achieved the best results compared to (15, 11), (15, 7) and (15, 5) BCH coding which correct 1, 2 and 3 bits respectively. There is a dependency between ECC rate and the quality of the watermarked image. If ECC rate increases, redundancy is smaller, this means that distortion of the original image concerning to embed watermark signal decreases, so watermarked image would be imperceptible. On the other hand, if ECC rate is low the quality of the image is low and this is mainly because the payload to insert is bigger. Generally, ECC rates close to 1 have less redundancy and the payload is smaller, so the imperceptibility of the watermarked image (PSNR) is high. According to Table 1, if ECC rate is equal to 0.837, PSNR value is 42 dB and the watermarked image is imperceptible. For ECC rates lower than 0.516, the PSNR value and imperceptibility of the watermarked image reduce.

| n  | k  | t  | R  = k/n | t/n | PSNR  |
|----|----|----|---------|-----|-------|
| 15 | 11 | 1  | 0.733   | 0.066| 41.7 dB|
| 15 | 7  | 2  | 0.466   | 0.133| 36.7 dB|
| 15 | 5  | 3  | 0.333   | 0.2  | 34.5 dB|
| 31 | 26 | 1  | 0.837   | 0.032| 42.0 dB|
| 31 | 21 | 2  | 0.677   | 0.095| 40.8 dB|
| 31 | 16 | 3  | 0.516   | 0.187| 39.6 dB|

The parameters used in this study are the watermark strength $\alpha = 0.2$, The encoded message length $n = 31$, message length $k = 16$ and error correction capability of the implemented BCH coding $t = 3$ over $GF(2^5)$. For all attacks cases, PSNR and NCC values are given in Table 2 and Table 3 respectively. It can be seen that the proposed algorithm is robust against most attacks. The values of $PSNR$s are between 35 and 42 dBs, and NCC values are close to 1 which confirm the desired robustness of the proposed watermarking algorithm against different attacks. In this experiments, two methods have been also evaluated: the first one is only based on the BCH-based watermarking scheme which uses Chien search method for finding a position to insert watermark signal, and the second one is BCH-based watermarking scheme with the proposed lookup table (LUT) method after applying different attacks on “Lena”. Table 4 shows the obtained results using both methods. The proposed method achieves high $PSNR$ and $NCC$ compared to the classical method based on Chien search. It is evident that Normalized Correlation Coefficient (NCC) values are greater than 0.90 and the minimum $PSNR$ is 38.68.
Table 2. Results of PSNR Values for The Proposed Algorithm

| Attack            | Name of Image | Lena | Yacht | Man   | Watch |
|-------------------|---------------|------|-------|-------|-------|
| 3x3 Wiener filter | Barbara       | 41.50| 40.62 | 41.72 | 40.89 | 41.69 |
| Gaussian filter   | Barbara       | 40.52| 40.52 | 40.63 | 39.14 | 40.59 |
| (Var=0.01)        |               |      |       |       |       |       |
| Rotation 2°       | Barbara       | 39.82| 39.69 | 39.56 | 37.63 | 39.43 |
| JPEG Compression  | Barbara       | 40.81| 39.50 | 39.45 | 39.49 | 39.68 |
| Resize 256⇒128⇒256| Barbara       | 38.81| 37.50 | 37.89 | 38.49 | 38.68 |

Table 3. Results of Normalized Correlation Coefficient (NCC) Values for the proposed algorithm

| Attack            | Name of Image | Lena | Yacht | Man   | Watch |
|-------------------|---------------|------|-------|-------|-------|
| 3x3 Wiener filter | Barbara       | 0.97 | 0.95  | 0.97  | 0.96  | 0.98  |
| Gaussian filter   | Barbara       | 0.93 | 0.94  | 0.95  | 0.93  | 0.95  |
| (Var=0.01)        |               |      |       |       |       |       |
| Rotation 2°       | Barbara       | 0.90 | 0.89  | 0.91  | 0.91  | 0.92  |
| JPEG Compression  | Barbara       | 0.95 | 0.94  | 0.94  | 0.95  | 0.96  |
| Resize 256⇒128⇒256| Barbara       | 0.96 | 0.96  | 0.95  | 0.96  | 0.95  |

Table 4. Comparison of proposed Algorithm with classical ones

| Attack            | DCT_BCH Based LUT method | DCT_BCH Based Chien search method |
|-------------------|--------------------------|----------------------------------|
|                   | NCC  | PSNR | NCC  | PSNR |
| 3x3 Wiener filter | 0.98 | 41.69| 0.76 | 27.05|
| Gaussian filter   | 0.95 | 40.59| 0.61 | 20.05|
| (Var=0.01)        |      |      |      |      |
| Rotation 2°       | 0.92 | 39.43| 0.74 | 17.69|
| JPEG Compression  | 0.96 | 39.68| 0.73 | 29.69|
| Resize 256⇒128⇒256| 0.95 | 38.68| 28.49| 32.68|

Figure 4 shows the comparison of the visual quality concerning to the number of modified pixels between three algorithms: DCT-BCH-LUT, DCT-BCH-Chien search and DCT without BCH. This figure demonstrates two objectives. The first objective is to show image quality degradation with number of modified pixels to embed. The second objective is to show the proposed methods’ excellent visual quality versus other methods’ results. The main reason that why the proposed method has a better visual quality than other methods is that the proposed watermarking algorithm based on BCH-LUT can find all possible positions to be modified and choose the best position for inserting watermark signal, which leads to less distortion. Experimental results show the proposed algorithm is superior compared to classical ones and accurately detects where the image has been modified, and it can resist against large modifications.

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