A reversible image watermarking scheme based on a new modulation mode of DCT coefficients

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Abstract. Watermarking reversibility is one of the main requirements for medical and some other applications. In these fields even a slight change in the original image can lead to significant mistakes in the decision making process. In addition, the watermarking scheme should allow to embed a large amount of hidden data into the original image. This paper proposes a blind, fully reversible, high capacity scheme that utilizes an Even-Odd Modulation technique to modify the cosine coefficients while embedding the watermark bits. In multi-layer mode the scheme is capable to embed 3145728 watermark bits into the image of size 512x512 with the following indicators: the values of Peak Signal Noise Ratio of the watermarked images are about 70 dB, the Mean Structural Similarity Index Measure between the embedded and extracted watermarks in all cases is equal to one and the scheme allows to restore the original image with 100\% accuracy. The validity and superiority of the proposed scheme is verified through extensive simulations.

1. Introduction

The watermarking process usually introduces irreversible degradation of the original media, such, for instance, as a digital image. The degradation introduced by embedding the watermarks is often constrained so that the original and the watermarked images are perceptually equivalent. However, in some applications, especially in the medical and legal domains, even the imperceptible distortion is unacceptable [1, 2].

While classical watermarking introduces permanent distortions, reversible watermarking not only extracts the embedded data, but also recovers the original image without any distortion.

The reversible watermarking can be realized mainly in two domains: frequency [1-5] and spatial domains [6-10]. At present, most robust watermarking approaches are based on transform domain.

In order to achieve an effective copyright protection, the watermarking scheme should meet three basic requirements: robustness, imperceptibility, capacity. Robustness means that the watermarking scheme is able to withstand with some intentional or unintentional manipulations to remove or damage the watermark. Imperceptibility represents the invisibility to human eyes. Determining the capacity of watermark means how much data can be hidden in an image without perceptible distortion, while maintaining watermark robustness against usual signal processing manipulations and attacks. All these requirements are often contradictory with each other and it is needed to make a trade-off among them.
The purpose of this work was to develop an image watermarking scheme that meets the listed conflicting requirements. To this end, it was proposed to use a new Even-Odd Modulation (EOM) technique [6]. According to this technique the procedure of the watermark embedding into the original image is carried out in a frequency domain. The watermark bits are embedded into frequency coefficients obtained with help of a discrete cosine transform (DCT). In addition, the process of embedding secret data into an image was proposed to carry out in a multi-layer mode, which led to a considerable increase of the scheme capacity [7, 10, 11, 12, 13].

In this work a blind, multi-layer watermarking scheme is presented which is capable to restore the original image completely. In connection with that note that in most publications devoted to this problem, the proposed schemes are considered as reversible schemes although, as a rule, they are often characterized by relatively low value of the Peak Signal to Noise Ratio (PSNR) and PSNR values for recovered images are not given at all.

2. Embedding, extraction and restoration procedures

In the proposed scheme a watermark is embedded into coefficients of global cosine transform by changing a parity of some chosen digits [7]. Suppose we have obtained a spectrum of the original gray-level image $I$ of size $M \times N$ presented by matrix $A$. In general case any coefficient $a(m, n)$ of this matrix may be written as follows:

$$a(m, n) = a(m, n)_{P-1}10^{P-1} + a(m, n)_{P-2}10^{P-2} + \cdots + a(m, n)_{k}10^{k} + \cdots + a(m, n)_{1}10^{1} + a(m, n)_{0}10^{0} + a(m, n)_{-1}10^{-1} + a(m, n)_{-2}10^{-2} + \cdots + a(m, n)_{-T}10^{-T},$$

where $T = P - 1, T + 1, \ldots, -1, 0, 1, \ldots, P - 2, P - 1$, $(T > 0, P > 0)$.

Naturally, any digit $a(m, n)_{k}$ of the coefficient $a(m, n)$ can be even or odd. Let the digital watermark $W$ be a binary matrix of size $G \times H$ formed by a pseudo-random generator. Denote the values of coefficients within the area $Q$ by $q(g, h)$.

It is obviously that

$$q(g, h) = a(m' - 1 + g, n' - 1 + h), \quad g = \overline{1, G}, \quad h = \overline{1, H},$$

where $m'$ and $n'$ are coordinates of the upper left corner of the area $Q$ as shown in figure 1.

Figure 1. Matrix $A$ of size $M \times N$.

In this paper the watermark bits are embedded into coefficients on base of EOM technique. The principle of EOM is that in some sequence consisting, for example, of even numbers, the watermark is embedded by changing the parity of some numbers. Suppose that the $k$-th digits of coefficients $q(g, h)$ were chosen for embedding of the watermark bits. Denote them by $q(g, h)_{k}$.

It is obvious that the numbers written in the $k$-th digits may be even or odd. In accordance with the EOM technique, we convert all odd numbers into even numbers by subtracting ones from them. To be able to restore the odd values, it is needed to remember the locations of all transformed numbers. This can be done by using labels recorded in the neighboring digits. In order to clear spaces for these labels, it is proposed to shift to the right by one position all numbers starting from the $(k - 1)$-th digit and writing zeros into $q(g, h)_{k-1}$ digits.

Suppose, for example, that the coefficient $q(g, h) = 3493.629$ and note that a number of digits after the decimal point is limited by three. Admit that a bit of the watermark must be embedded into the first
digit $q(g, h)_1 = 9$. By dividing that odd number with “2” we receive a floating point number “8.5”. Then the integer part (the number “8”) is placed in the $q(g, h)_1$ digit and any random number other than zero is inserted into the digit $q(g, h)_0$. Suppose this number was generated using a pseudo-random number generator and it turned out to be the number "7". As a result we have $q(g, h) = 3487.362$. Then the embedding procedure may be described as follows:

- if $w(g, h) = 1$ then $q(g, h)_k$ is increased by one, that is this digit turns into odd number,
- if $w(g, h) = 0$ then $q(g, h)_k$ remains unchanged.

Note that in our example $w(g, h) = 1$, the number “8” is incremented by one and the coefficient $q(g, h)$ takes the value “3497.362”. It means that the digit $q(g, h)_{k-1}$ is lost.

Similarly, all coefficients within the area $\tilde{Q}$ are modified. Upon completion of the modification the inverse DCT is performed and as a result the watermarked image $\tilde{I}$ is obtained.

The purpose of the watermark extraction procedure is to form a matrix $\hat{W}$, which ideally should be identical to the matrix $W$. With this connection the direct DCT is first performed over the image $\tilde{I}$ and a matrix of frequency coefficients $\hat{A}$ is formed. Then by known coordinates $m'$ and $n'$ the upper left corner of the area $Q$ is found. It is obvious that at the stage of extracting the area $\tilde{Q}$ corresponds to the area $\tilde{Q}$. Therefore, in the area $\tilde{Q}$ the $k$-th digits of the extracted coefficients are analyzed to form elements $\hat{w}(g, h)$ of the matrix $\hat{W}$.

It follows that

$$q(g, h) = \hat{w}(m' - 1 + g, n' - 1 + h),$$

where $g = \frac{1}{M}, h = \frac{1}{N}$.

In this instance

- if $\hat{q}(g, h)_k$ is odd then $\hat{w}(g, h) = 1$, otherwise $\hat{w}(g, h) = 0$,
- where $\hat{q}(g, h)_k$ is the $k$-th digit of the extracted coefficient $\hat{q}(g, h)$.

So as a result the matrix $\tilde{W}$ is formed, which represents the extracted watermark.

Restoration of the original image is carried out in two stages. At the first stage, the parity of the numbers written in the $\hat{q}(g, h)_k$ digits is determined. Then, all odd numbers written in $\hat{q}(g, h)_k$ digits are converted to even numbers by subtracting ones from them, which is equivalent to removing the bits of the embedded watermark from $\hat{q}(g, h)_k$ digits. Upon completion of this procedure, all numbers written in $k$-th digits become even.

At the second stage, the initial values of the numbers written in the $k$-th digits are first restored. To do this, ones are added to the numbers written in $k$-th digits of coefficients $\hat{q}(g, h)$, if $\hat{q}(g, h)_{k-1} > 0$.

Finally, these labels are erased and all numbers of the $\hat{q}(g, h)$ coefficients are shifted to the left by one position starting from the $(k - 2)$-th digits.

For example, if the extracted coefficient is equal to “3497.362”, then one is subtracted from the content of the digit $\hat{q}(g, h)_1$. Since the digit $\hat{q}(g, h)_{k-1} > 0$ then one is added to the content of the digit $\hat{q}(g, h)_1$. At last, the number “7” is erased and all numbers starting with the digit $\hat{q}(g, h)_{-1}$ are shifted to the left and the coefficient $\hat{q}(g, h)$ takes the value “3493.620”.

In a similar way all the other extracted coefficients are transformed and so we obtain a copy of the matrix $\hat{A}$. Finally, the inverse cosine transform is performed, as a result of which the original image is restored. Note that the coefficients $\hat{q}(g, h)$ are restored with some error but as it was shown by experimental studies these errors are insignificant and to eliminate their influence it is necessary to embed watermark bits into the older bits of the cosine coefficients.

To increase the capacity of the watermarking scheme we propose to embed watermarks using a multi-layer mode. The proposed multi-layer embedding goes as follows. Assume that it is needed to embed into an original image $\tilde{N}$ watermarks. Since, according to the proposed scheme, the embedding of watermarks is carried out in the frequency domain, first of all, the transition to this domain is done by means of a cosine transform. Then the bits of the first watermark are embedded into the frequency coefficients and thus there is a formation of the first layer of embedding. Upon completion of formation
of the first layer, the second layer is formed and so the process continues until the last watermark is embedded into the same coefficients.

The watermark extraction process is performed in reverse order, that is, first of all the \(N\)-th watermark is extracted. Then the values of the frequency coefficients in the \(N\)-th layer are converted to the values they had before the watermark embedding the into them and the penultimate watermark \(N-1\) is extracted from the layer \(N-1\). Thus the process of watermarks extraction will continue in a loop until the last watermark is extracted from the first layer and until the original image is fully restored.

3. Simulation and results

The proposed scheme is implemented in the MATLAB software. For measuring the quality of watermarked images we used PSNR. For calculating the degree of similarity between the original and extracted watermarks we used the same metrics as in [7, 10, 11-13]: Mean Structural Similarity Index Measure (MSSIM).

To compare with the results presented in other publications, the test images of size 512×512 pixels were chosen (“Lena”, “Baboon”, “airplane”, “boat” and “Barbara”).

The binary watermarks of size 512×512 pixels were generated by a pseudo-noise generator.

Figure 2 shows the image quality in cases of multiple embedding the watermarks by using different reversible schemes. From figure 2 it is seen that the values of PSNR for our scheme and in [11] is slightly fluctuating around a certain average value. This means that the process of multi-layer embedding of watermarks into the same images does not lead to increasing of their distortion when compared with schemes [7] and [13]. It follows that, judging only by this indicator, the proposed scheme does not impose restrictions on a number of watermark embeddings in contrast with [7] and [13] schemes.

![Figure 2](image.png)

**Figure 2.** Image quality in PSNR depending on the embedding level for different reversible schemes.

The table 1 shows the values of such indicators as:

| Embedding level | PSNR (dB) |
|-----------------|-----------|
| 2               | 50        |
| 4               | 45        |
| 6               | 40        |
| 8               | 35        |
| 10              | 30        |
| 12              | 25        |

- the drawback of the schemes [7, 13] is that the values of PSNR are strongly dependent on the number of watermark embeddings;
- the advantage of our scheme and the scheme presented in work [11] is that they practically do not depend on the number of watermark embeddings;
- another advantage of our scheme is that PSNR obtained with its help exceed sharply the values presented in [7, 11, 13].

The proposed scheme does not encounter the overflow/underflow problem so there is no need to create a location map, which decreases the value of bpp indicator.

The table 1 shows the values of such indicators as:
- PSNR1, which is calculated for watermarked images;
- PSNR2, which is calculated for the case when the original image and the recovered image are represented by integer and real numbers, respectively;
- PSNR3, which is calculated for the case when both original and restored images are represented by integers (that is the real values representing the restored image have been turned into integers before calculating PSNR3). The table also shows the values that determine the capacities of the various embedding schemes and the values of MSSIM.

The table 1 presents experimental data obtained as a result of four embeddings of watermarks into images “Lena”, “Baboon” and “Barbara” using different schemes [7, 10, 11, 13]. In order to have an opportunity to compare our scheme with some previous schemes like [7], [12], [10] and [11] we made a program in MATLAB in such a way that during one iteration two watermark bits were embedded into the same coefficient. The data reflected in Table 1 shows the capacities of different reversible schemes in cases of multiple embedding. From the presented graphs it is clear seen that the proposed scheme has the best performance in terms of PSNR and bpp.

| Cover image | Indicator | [7]  | [12] | [10] | [11] | Our scheme |
|-------------|-----------|------|------|------|------|------------|
| Lena        | PSNR1     | 40.06| 51.15| 53.72| 51.63| 69.87      |
|             | PSNR2     | -    | -    | -    | -    | 151.68     |
|             | PSNR3     | -    | -    | -    | -    | +∞         |
|             | Capacity  | 0.3856| 5.0974| 7.6534| 7.8707| 8.0        |
|             | MSSIM     | 0.9235| 0.9918| 0.9876| 0.9932| 1.0        |
|             | PSNR1     | - | 51.15| 53.65| 51.62| 69.86      |
|             | PSNR2     | - | - | - | - | 151.68     |
| Baboon      | PSNR3     | -    | -    | -    | -    | +∞         |
|             | Capacity  | 5.0995| 7.6534| 7.8620| 8.0  |
|             | MSSIM     | 0.9921| 0.9875| 0.9938| 1.0  |
|             | PSNR1     | - | 51.15| 47.13| 51.59| 69.88      |
|             | PSNR2     | - | - | - | - | 151.67     |
| Barbara     | PSNR3     | -    | -    | -    | -    | +∞         |
|             | Capacity  | 5.0992| 7.8379| 7.8677| 8.0  |
|             | MSSIM     | 0.9923| 0.9879| 0.9933| 1.0  |

Analyzing the values of PSNR1, capacity and MSSIM obtained with a help of different schemes for various test images we can conclude that these values do not depend on the structure of image.

As presented in tables 1 the indicator bpp of our scheme is the highest in comparison with other schemes and the values of PSNR3 and MSSIM even after four embeddings tends to infinity and equal to 1, respectively. It means that the watermarks have been extracted without any distortions and the original images have been restored completely. In the same time for all schemes given in the tables, such an important indicator as MSSIM in all cases is less than one.

It follows that the watermarks are extracted with certain distortions. During experiments with a help of our scheme the different watermarks have been embedded into original images a lot of times.

It is established that with further increase in number of watermark embeddings the proposed scheme is able to maintain the key indicators PSNR3 and MSSIM unchanged for six iterations. The amount of secret data that is embedded in the original image during these six iterations is a record number: \((512 \times 512) \times 6 \times 2 = 3 \times 145728\) bits. The finiteness of iterations at which PSNR3 tends to infinity and MSSIM = 1 can be explained as follows. After the first iteration, the value of PSNR2 is about 273 dB.
Then the values of PSNR2 are being decreased with each step subsequent of the original image restoration. It means that there takes place accumulation of errors first in the fractional parts of the numbers representing pixels of the image and then in the integer parts. Therefore, as soon as the changes start to occur in integer parts, the values of PSNR3 decrease sharply. It indicates that the original image is not fully restored. The accumulation of errors can be explained by a finite number of digits representing the DCT coefficients in MATLAB. As it is known, by default, the MATLAB stores all variables as double-precision floating-point values of 64 bits.

The less digits are allocated to represent DCT coefficients, the faster the accumulation of this error occurs. To verify this assumption, we described these coefficients using the function “single” as 32 bits variables. In the result, the number of iterations at which the watermarked image was restored by 100% decreased from 6 to 2 (after 2 iterations the value of PSNR2 fell to 63.6983 dB, after 6 iterations to 29.1538 dB). Thus, we have concluded: the more digits are allocated for the DCT coefficients, the more hidden data can be extracted from the watermarked image with PSNR3 tends to infinity.

4. Conclusions
In this paper, we have presented a fully reversible, multi-layer watermarking scheme which is capable to embed into the image of size 512x512 a record number 3 145728 bits of hidden data with the following indicators: the values of PSNR of the watermarked images are about 70 dB, MSSIM between the embedded and extracted watermarks is equal to one and after performing the restoration procedure, the values of PSNR between the original and restored images tend to infinity.

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