Conference Paper

Wavelet Methods in Steganography

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Abstract

This paper is devoted to graphic information protection by means of computer steganography using wavelet techniques. The methods of the image processing using digital watermarking are classified. Some research of the structure of the digital image is investigated. In the first solution the steganographic system, which uses a discrete wavelet transform for embedding of grayscale watermark into wavelet coefficients of grayscale container is modeled and realized. Stego image is achieved by the inverse discrete wavelet transform. Binarization using halftoning algorithm is considered as a kind of powerful attack to stego image. After binarization attack the extracted watermark was found to have acceptable visual quality. The degradation of the embedded digital watermark after binarization is estimated using human visual system. Corresponding conclusions on steganographic system stability are drawn. In the second solution we propose the steganographic scheme which uses the proposed wavelet basis images.

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1. Introduction

The modern steganography, which studies embedding digital data of one object into digital data of another, has wide application for protection of media information, especially for saving author's rights. The properties of the digital image that are defined by its structure allow creating different applied tasks, which also include digital watermarking. Watermarking techniques have a number of applications including protection of digital media, the Color to Gray and Back problem and others.

Following [1], digital steganography is a "science on invisible and foolproof hiding one bit sequences into another one, having analog nature".

Among general problems of watermark embedding the problem of stability of stego image to transformations, which can lead to the embedded data distortion, is emphasized especially.

Digital watermarks can be obtained in different ways and have various graphic representation. There are different well-known ways of watermarking, such as variants of Least Significant Bit (LSB), blocking and additive embedding, where bit presentation is used, embedding into Gray planes and others. An example of the steganographic system using Gray planes of grayscale digital image, which are based on the Gray codes, is described in [2]. There we applied modern halftoning algorithms for obtaining digital binarized image, applicable as a digital watermark. The stego containers are subjected to JPEG compression, and then accomplished the watermarks extracting with estimation of their degradation.

We use orthogonal transform of the digital grayscale image, formulated in terms of basis matrices, and transform called Color to Gray and Back. Orthogonal transforms are widely used in the image processing problems, particularly at lossy compression where discrete cosine and discrete wavelet transform (DWT) are used.

The works [3-6] rely to embedding digital watermarks into digital grayscale images using DWT. As in papers [3, 4] we will embed grayscale watermark with preliminary data pre-processing. In our case, the digital watermark presented in the matrix form is divided by number, which is calculated experimentally. This operation intended for darkening of the watermark in the purpose of its small showing through stego image. An approach with using DWT together with artificial neural network is cited in the paper [5]. In the work [6] some demands are made to digital watermark, then it transforms into pseudo-random binary sequence.

The standard DWT technique refers to the frequency domain and digital data are usually embedded in the wavelet coefficients. For embedding digital watermarks into digital image at Print-Scan transform several techniques are known, for example Color to Gray and Back Reversible Transformation (CGRT) [7, 8]. The idea consists of the following. The information about color of initial image is embedded into its grayscale version using steganography, then for example after printing the color is extracted from black and white print and original is recovered.

We adapted this procedure of embedding for adding grayscale watermark to grayscale original and following binarization with analysis of the results.

There are several literature sources on embedding digital watermark using standard DWT with decomposition into coefficients. They are different in having secret key,

embedding techniques, preliminary digital watermark and container processing. However the ways of the digital watermark embedding with a help of DWT with decomposition into basis matrices in literature resources are not represented. In the next section we will describe classification of the methods of the watermarks embedding, orthogonal DWT techniques for decomposition of the digital images and propose two steganographic systems on watermarks embedding distinguishable from each other in the ways of the decomposition of the digital images.

Embedding of the digital watermarks is possible to divide into two groups: embedding into primary image domain or spatial domain and embedding into transform domain or frequency domain. Examples of the existing watermarks embedding methods into digital images are shown in Figure 1.
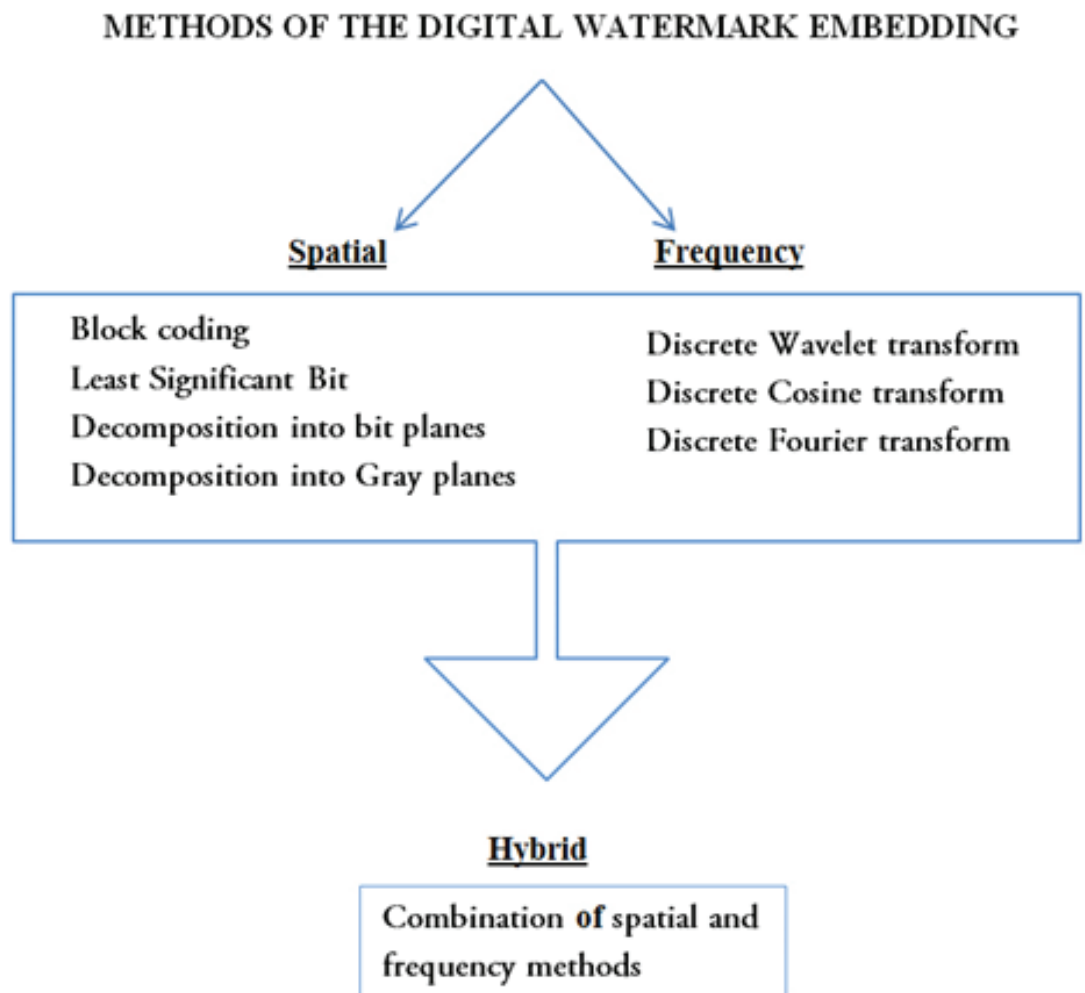
METHODS OF THE DIGITAL WATERMARK EMBEDDING

Spatial

Block coding
Least Significant Bit
Decomposition into bit planes
Decomposition into Gray planes

Frequency

Discrete Wavelet transform
Discrete Cosine transform
Discrete Fourier transform

Hybrid

Combination of spatial and frequency methods

Figure 1: Methods of the digital watermarks embedding.

Embedding into spatial domain operates separate elements of the image – pixels or block of the pixels. Embedding into frequency domain consists in preliminary transformation of the image, for example, discrete Cosine transform and DWT. This methods are often more stable to the distortions, but have several features. In particular, embedding into frequency domain is much more exigent to the resources. Besides that, these methods are much more complicated in the realization and need to take into consideration many peculiarities.

In our work we consider frequency methods of embedding with possibility of the modification for solving practical tasks of the information protection.

2. Wavelet transform for decomposition of the digital images

2.1. Purposes of the orthogonal transforms

Let us describe initial digital image in spatial domain as $F = \{F[x, y]\}$ is given in the spatial domain; especially it is point out that we deal with sensible picture. Due to orthogonal transforms image from spatial domain converts to frequency domain. To divide these domains in (9) we use lower indexes. In the frequency domain the matrix $G = \{G[k, p]\}$ is uniquely defined by the initial one. In spite of the fact that in frequency domain an image received inappropriate view, it can demonstrate its useful properties.

One of these properties, which have a big interest for the practice, is redundancy. It can be extracted by means of orthogonal transforms, which concentrate the energy, square of brightness of pixel. In a result image in a frequency domain will collect pixels in a small neighborhood, containing almost all image energy. Setting the threshold the pixels with a small energy can be ignored and the image comes back into spatial domain without visible loss of quality. This scheme is a background of the lossy compression. In other case the pixels with small energy may be not deleted, but modified, with inserting into the for example the digital watermarks.

2.2. Standard one level DWT

Usual DWT belongs to the frequency embedding methods, and digital data are usually embedded into wavelet coefficients. For the decomposition of the digital grayscale image presented as two-dimensional signal, we use separable basis, consisted of product of two one-dimensional wavelets.

First level transform is described by the matrix U_1 with size $n \times n$, consisted of low frequency and high frequency blocks

$$U_1 = cat(\ 1,\ L_n,\ H_n\ ) = \begin{bmatrix} L_n \\ H_n \end{bmatrix}, \tag{1}$$

where *cat* is operation of concatenation.

Let's choose square grayscale image S with size $n \times n$. Its orthogonal transformation has the form

$$C' = U_1 S U_1^T, \tag{2}$$

After matrix multiplication the representation C consists of four blocks with size $n/2 \times n/2$

$$C' = \begin{bmatrix} cA & cH \\ cV & cD \end{bmatrix}, \tag{3}$$

where the matrices cA, cH, cV и cD are approximation coefficients, coefficients of horizontal, vertical and diagonal details respectively. They have following form

$$cA = L_n S L_n^T,$$
$$cH = L_n S H_n^T,$$
$$cV = H_n S L_n^T, \tag{4}$$
$$cD = H_n S H_n^T.$$

In the matrices of the horizontal and vertical details cH and cV horizontal and vertical details of the digital image are highlighted, and in the matrix cD diagonal details

dominate. This feature is used for image analysis tasks, where it is necessary to select or find the contours of the interested objects. Initial image S is recovered from the given matrices cA, cH, cV and cD by inverse transform represented by four matrices, describing approximation and details

$$S = U_1^T C U_1 = A + H + V + D, \tag{5}$$

where

$$A = L_n^T cA L_n,$$

$$H = L_n^T cH H_n,$$

$$V = H_n^T cV L_n, \tag{6}$$

$$D = H_n^T CD H_n.$$

Due to the analysis process approximation coefficients cA and details cH, cV и cD could be modified. For the signal reconstruction, it is possible to use formulas (6), but recovered signal will not coincide with initial one.

2.3. One level DWT based on the basis matrices

Orthogonal transform can be presented as decomposition by vector or matrices, which constitute the basis. For decomposition of the matrices or images, it is needed to take two sets of the basis vectors. There could be vector columns of the two orthogonal matrices U and V with a size $M \times M$ and $N \times N$ accordingly.

$$u_k = (U[1, k], U[2, k], ..., U[M, k]),$$

$$v_p = (V[1, p], V[2, p], ..., V[N, p]). \tag{7}$$

Using these resources, we define basis images as a tensor product of these vectors.

$$E_{(kp)} = u_k \otimes u_p. \tag{8}$$

Here we enumerate matrices by the lower subscript kp. It is in brackets to avoid confusing with symbol of the matrix element. From the definition it follows that the matrix elements $E_{(kp)}$ are all possible products of components of the vectors u_k and v_p or product of elements of the matrices U and V

$$E_{(kp)}[x, y] = U[x, k]V[y, p]. \tag{9}$$

In general, it will be *MN* basis images; each of them is a real matrix with size *M×N*. They will be orthonormal in terms of

$$\left(E_{(kp)} E_{(ab)} \right) = \delta_{ka} \delta_{pb}. \tag{10}$$

where scalar product of the matrices is a sum of the products of their elements with a same name.

In a result, we obtain a decomposition of the matrix F into basis images

$$F = \sum_{kp} G[k, p] E_{(kp)}, \tag{11}$$

$$G[k, p] = \left(F, E_{(kp)} \right),$$

where coefficients *G[k,p]* are possible to consider as a "coordinates" of an image *F*.

Obtained representation is a form of notation of orthogonal matrix transform. Indeed, let's use matrix notation of the equation $F = UGV^T$ and found

$$F[x, y] = \sum_{kp} U[x, k] G[k, p] V[y, p]$$

$$= \sum_{kp} G[k, p] E_{kp}[x, y] \tag{12}$$

$$= G[1, 1] \cdot E_{(11)}[x, y] + G[1, 2] \cdot E_{(12)}[x, y] + G[1, 2] \cdot E_{(21)}[x, y] + ...$$

From this it follows that element *F[x, y]* of the matrix *F* is represented as a linear combination of the matrix elements of the matrices *E*(11), *E*(12), *E*(21), …

3. Steganographic system based on standard DWT transform

The Color to Gray and Back transformation is one of the examples that shows how steganographic technique works for image processing applications. We will briefly discuss it following Queiroz and Braun [7].

The solution is based on DWT. A RGB image is transformed into the YCbCr color space, where Y is luminosity and two chrominance components Cb and Cr keep the color information. One level DWT of luminosity DWT(Y) has four blocks; the size of each block is a quarter of Y. Two blocks are replaced by two quarters of coefficients from Cr and Cr and a new luminosity Y' appears. Then an inverse transform of Y' results in a grayscale version Yc = IDWT(Y') with color embedded. To recover the color we need to reverse the mentioned above steps. According to this approach, a quarter of all color information is exploited. That means that the initial and retrieved color images are not equal however they are visually undistinguishable.

We adapted this approach for constructing our stego system with digital watermark embedding by means of replacing one of the obtained coefficient blocks with digital watermark. In our research we use digital grayscale image as a cover works and watermarks. We embed grayscale watermark into wavelet coefficients of the grayscale image.

One of the examples graphic of models of the steganographic system is shown on Figure 2. The grayscale image C is converted into matrix of the grayscale image C' using DWT, which consists of four blocks of coefficients; each of the blocks is equal to quarter of initial image. Then one block of this matrix is replaced with grayscale watermark M. After inverse DWT we get the watermarked image S with embedded watermark, which is binarized. Then DWT is applied to the binarized image Sb, and the binarized watermark Mb is extracted from the obtained matrix.
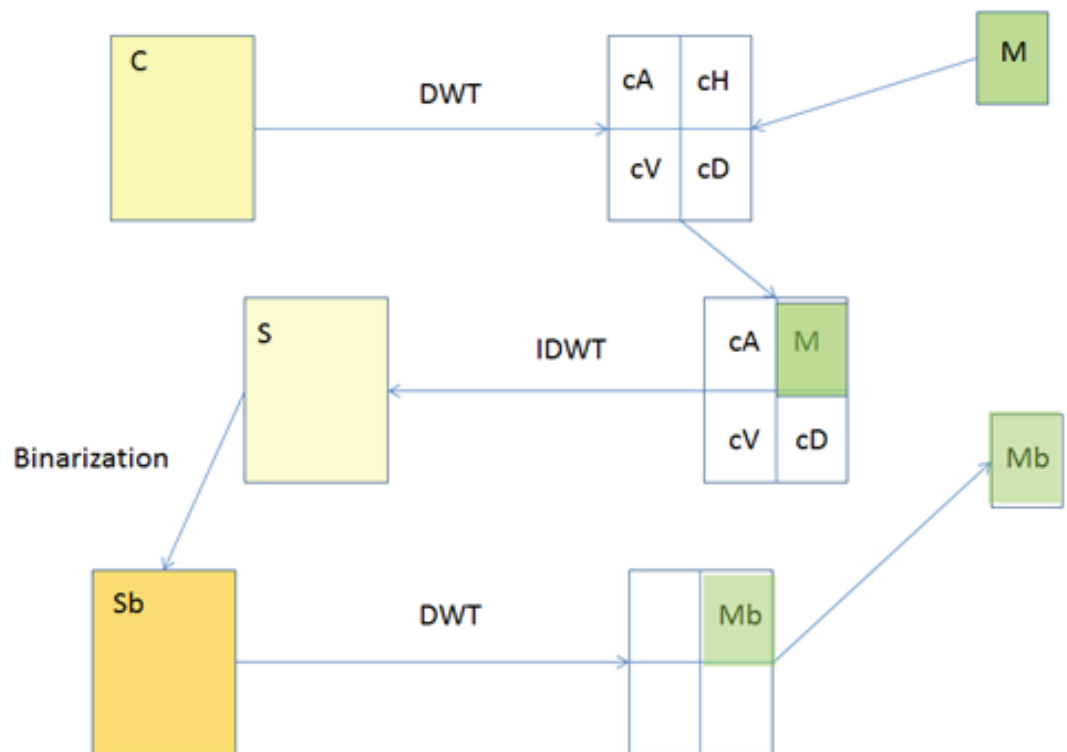
Figure 2: The model of the steganographic system for embedding and extracting of the watermark.

On the base of the scheme presented on Figure 2 the experiment was carried out on watermark embedding, halftoning of the stego container and subsequent extracting and detection of the watermark.

The work of this algorithm is shown on Figure 3. The grayscale image M (Figure 3, b) is embedded into the grayscale image C (Figure 3, a). For the embedding, the

coefficients of the diagonal details of the image obtained by DWT transform of the initial image are chosen.
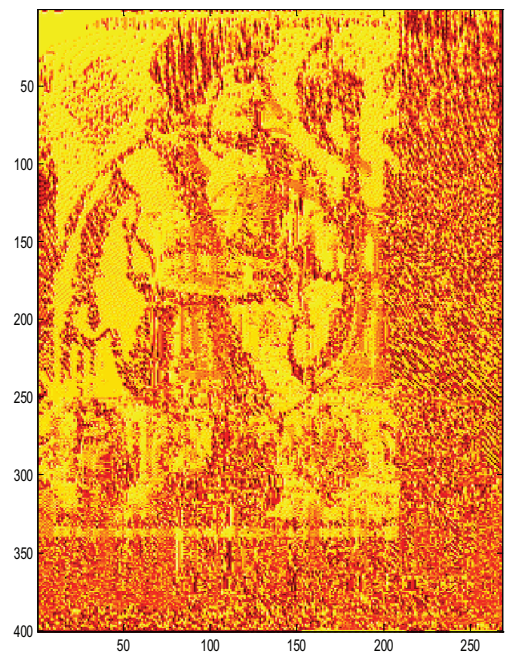

a

b

c

d

Figure 3: Embedding of the grayscale image into grayscale. a) grayscale container, b) grayscale watermark, c) stego container with watermark, d) watermark after binarization.

Halftoning of the stego container with embedded digital watermark (Figure 3, c) negatively affects visual quality of the watermark because of loss at brightness transforms. At the same time, on Figure 3, d, it is possible to detect the watermark visually that provides stability of the suggested steganographic system to halftoning. Obtained value of the PSNR is equal to 3.3998 dB. It is known from literature, that PSNR from 20 dB and higher shows the satisfied visual image quality [8]. At the same time, it is well known that PSNR is not always in accordance with visual perception. In our case, the obtained PSNR is small and two points may be made about it. First, binarization introduces a very large distortion. Second, the extracted watermark does not look bad and we have an example of objective measure PSNR that is not in accordance with visual perception.

4. Steganographic system based on DWT using the basis matrices

Here we describe the steganographic system for embedding digital watermarks using orthogonal DWT based on basis matrices. For our system first it needs to generate a set of bases wavelet matrices, that can be achieved in according with equation (8). An example of the one-level decomposition of the orthogonal wavelet type *db6* Daubechies [10, 11] into basis images is presented in Figure 4. The basis matrix has a block of $N \times N$ matrices with size $N \times N$, where $N = 6$.

Let $A = \{a_1, a_k, ..., a_n\}$ be a set of bases wavelet images. The main idea is to consider data embedding as a modification of a basis image $a_k \in A$. Let $N = 4$, then $A = \{a_1, a_2, a_3, a_4\}$. Let's define data embedding into basis vector as a modification

$$a_3 \rightarrow a_3^* = x_1 a_1 + x_2 a_2 + x_3 a_3 + x_4 a_4. \tag{13}$$

A simple example of this embedding can be replacing of vector a_3 with another one. For this purposes instead of the vector a_3^* we introduce standardized vector

$$a_3^* \rightarrow a_{3M} = \frac{a_3^*}{\sqrt{x_3^2 + x_4^2}} = \eta_1 a_1 + \eta_2 a_2 + \eta_3 a_3 + \eta_4 a_4, \tag{14}$$

where $\eta_k = x_k / \sqrt{x_3^2 + x_4^2}$ and $\eta_3^2 + \eta_4^2 = 1$. Then we will consider the vector a_{3M} as an embedded message. In contrast to a_3^* it is not arbitrary because of condition $\eta_3^2 + \eta_4^2 = 1$. However, at the visualization process this limitation will not be significant, because in the MATLAB package both vectors a_3^* and a_{3M} will look the same.

After the modification there appears a new set of vectors $\{a_1, a_2, a_{3M}, a_4\}$ from which after orthogonalization by Gram–Schmidt process it is possible to build a new basis $B = \{e_1, e_2, e_3, e_4\}$, where $e_1 = a_1$, $e_2 = a_2$.
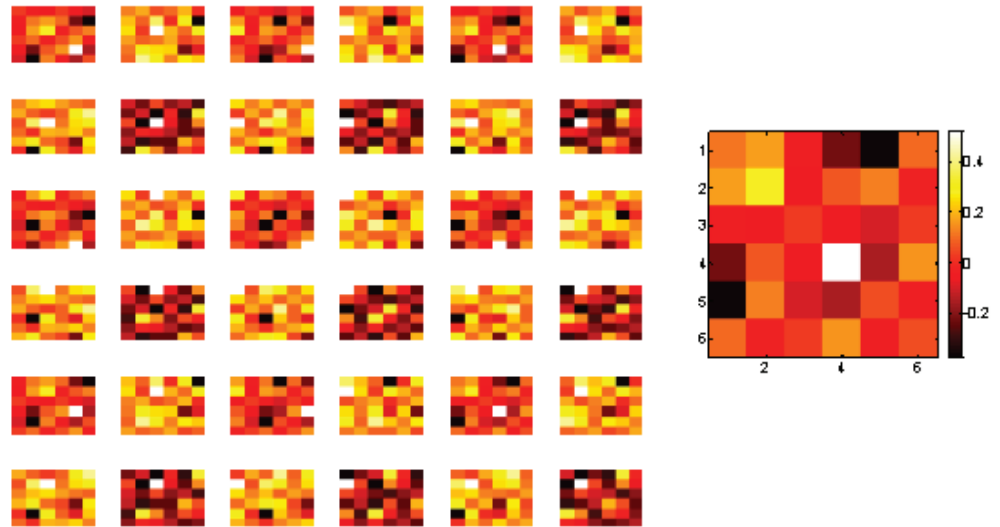
Figure 4: 36 basis matrices with a size 6×6 of the wavelet db6.

5. Conclusions

DWT allows us to transform image into frequency domain that can be useful to hide digital data. We consider single level DWT and introduce a sample technique for embedding data into wavelet coefficients. The system is robust to very powerful attack caused by binarization of the stego image. The extracted watermark has small degradation, however, its visual quality is good. It may be useful for some applications particularly for the problem of protection of hardcopies.

Together with frequency embedding, we discuss a scheme based on wavelet basis images. The scheme has features of frequency and spatial embedding techniques and differs from them. The scheme may be useful for protection of the digital images and its properties will be a subject of the future investigations.

Acknowledgments

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