Study of robustness of information embedding into digital images DWT domain using QIM method against destructive effects and steganalysis

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Abstract. Steganography is one of effective solutions to ensure information confidentiality. For this purpose, secret information is embedded into a cover object, for example, a digital image. However, embedded data can be detected using steganalysis techniques. As a result, an attacker can apply destructive effects to the stego-image and destroy the embedded data to prevent their hidden transmission. Therefore, this paper presents a study of robustness of information embedding into digital images DWT domain using QIM method against destructive effects (JPEG compression, brightness change, etc.) and statistical steganalysis at the same time. The results will help to increase the efficiency of information embedding into DWT domain of digital images.

1. Introduction

In the modern world, the task of data confidentiality protection is of significant importance. A possible solution of the given task is the application of digital steganography methods – the study of hidden transmission and storage of the information so that the fact of its existence is secret for the malefactor. At the same time, the confidential information is embedded into some digital objects such as multimedia data (images, audio and video files), executable files of programs, sensor data and many others. In particular, the most common containers for the additional information are digital images, because the exchange of various pictures, photos and other graphical objects is now widespread and is a common thing. However, the popularity of data hiding in digital images simultaneously leads to the development of methods of steganalysis – the study of detection of steganographic embedded data. Even if a malefactor has only a suspicion about the presence of the embedded information in one or another image, he or she can apply some destructive action to the stego-image, for example, to compress or crop it to destroy potential embedding. And if the presence of embedded data is revealed through steganalysis, the probability of its substitution or destruction by the malefactor essentially increases. Therefore, the task of current importance is to study the robustness of steganographic
embedded data both against the steganalysis and the destructive actions in order to further develop new algorithms and to update existing ones in such a way that to minimize the probability of detection and destruction of the message transmitted along a hidden channel. The purpose of the present paper is to research of robustness of information embedding into the area of discrete wavelet transformation (DWT) of digital images by means of popular steganographic QIM method against destructive actions on images and against steganalysis.

2. Discrete wavelet transformation
Frequency transformation of a digital signal is a transformation which breaks down an initial signal according to a certain basis with the possibility to select significant and insignificant components in the transformed signal. Such transformations, for example, can be used for image compression with losses and their subsequent restoring with a comprehensible degree of quality. Frequency transformations are widely used in digital steganography to form the space of hiding: bits of a confidential message, in this case, are embedded into the frequency coefficients. The most popular methods for digital steganography have become the discrete cosine transformation (DCT), the discrete Fourier transformation and discrete wavelet transformation (DWT).

In the present paper, the attention is focused on DWT which is, as a matter of fact, a whole set of frequency transformations.

For example, Haar transformation is a most simple wavelet-transformation in which for one-dimensional transformation the initial vector is divided into blocks with 2 values each, and for each of the values, there is a half-sum \( a \) and a half-difference \( b \). In the result, a vector is obtained, where even values correspond to low frequencies and odd ones correspond to high frequencies. Reverse transformation is carried out as follows: the first value in the pair is calculated as the sum of \( a \) and \( b \), and the second one as the reminder. The matrix of some readouts of a signal, for example, of a digital image, is subject to two-dimensional transformation.

Daubechies transformation 9/7, unlike Haar transformation, calculates each pair of frequency coefficients not based on pair adjacent readouts of a digital signal (pixels) but on the basis of 7 and 9 neighbours for low-frequency and high-frequency coefficients accordingly. In the given transformation, correlations of input data are considered; therefore, in the case of data lost in the spectrum, the initial data are restored better than with the use of Haar transformation.

These and other variants of wavelet-transformations are often used by the development of methods and algorithms of steganographic information hiding into digital images. Let us note the examples of such research of the last years. For example, in the article [1], the embedding area is the quadrant of mid-frequency values LH2 received after two iterations of DWT. Embedding consists of the change of energy of the block coefficients by means of matrix operations. In the paper [2] the method of information embedding of in the DWT area is offered; this method considers the features of the model of the human visual system. The embedding operation is adapting of operation of the least significant bit replacement for real numbers. The paper [3] describes the method in which information embedding is carried out with the usage of combination DCT and DWT as well as singular expansion. The paper [4] considers reversible embedding when the image-container is reversed to the initial state at the extraction of a confidential message. Embedding is carried out in the DWT area and is combined with the method of image encoding. In the paper [5] the embedding is carried out into the coefficients of integer wavelet-transformation of the digital image. Thus, it is possible to conclude that the information embedding into DWT area of digital images is widespread enough, which confirms the urgency of the research on its robustness against destructive effect and the steganalysis.

3. Information embedding into DWT coefficients using the QIM method
The algorithm of information embedding applied during experiments is based on the QIM method (Quantization Index Modulation). It is applicable for both embedding in unitary ratios and for embedding in blocks of coefficients. The key parameter of the given method is the quantization step [6]. Embedding is carried out according to the formula:
\[ K_2 = F(K_1) + \frac{\Delta}{2} b \]

where \( K_1 \) is the value of a unitary ratio before embedding or the sum of element values of the block, \( K_2 \) is the value of a unitary ratio or the sum of coefficient values after embedding, \( \Delta \) is the quantization step, \( F \) is the function which returns the number the closest, as much as possible, to the value of the argument which is divided by the quantization step without remainder, \( b \) is a secret message bit.

Information embedding was realised for four possible variants of combinations of the wavelet-transformation and the way of embedding:

- Haar transformation and embedding into unitary ratios;
- Daubechies transformation and embedding into unitary ratios;
- Haar transformation and block embedding;
- Daubechies transformation and block embedding.

In all cases, the message volume was 10000 bits. For embedding in unitary ratios, the quantization step \( \Delta = 10 \) was selected. For block embedding, the block size was \( 3 \times 3 \) coefficient, and the quantization step \( \Delta = 25 \) was selected since, at equal values of a quantization step, the capacity of block embedding is essentially less. And, the greater quantization step allows ensuring the embedding of the necessary number of bits.

In order to conduct the experiments, the collection of 30 images with the size of \( 512 \times 512 \) was used; the images were taken out of the base [7] and presented in gradation of grey.

4. Research on robustness against destructive actions effects on a stego-image

In order to analyse what effect is rendered on the embedded message by various destructive actions, some typical operations on a digital image were considered, such as noise masking, JPEG-compression, Gaussian blur, brightness and contrast change. In practice, similar destructive actions can be applied to an image with embedded information both incidentally (for example, on ignorance), and purposefully, with the aim of the destruction of the embedded information. Parameters of destructive actions varied as follows:

- Amplitude of noise: 0, 5, 10, 25;
- Quality of JPEG-compression: 70, 80, 90, 100;
- Gauss filter radius: 0.1, 0.5, 1.2;
- Brightness increasing: 10, 15, 20, 25;
- Coefficient of contrast change: 0.5, 1.5, 2.

In order to make an estimation of the effect of destructive actions on the embedded information in each experiment, the coefficient of restoring was calculated, i.e. the ratio of correctly extracted bits to the total number of the embedded bits. We will note that in the absence of any destructive actions, the coefficient of restoring for the studied algorithm is equal on the average to 0.95. Some part of errors at the extraction arises because of round-off of the real values of DWT-factors to obtain the integer values of pixels, which is characteristic for embedding in the frequency area of digital images [8].

The volume of the present article does not allow displaying the results of all experiments; however, for illustrative purposes, the results of one of the experiments are presented in Table 1. The given table shows the values of the restoring coefficient after the destructive actions on a stego-image. The values were obtained for the case of embedding into unitary ratios of the Haar transformation. To estimate the degree of the destructive action, the value of PSNR metrics calculated for the stego-image before application of destructive action is shown.

The analysis of the results of the conducted experiments has shown the following:

- with the increase in amplitude of noise, the coefficient of restoring worsens, but under small amplitude of noise (equal 5) the extractions of the information with the coefficient of restoring 0.85 on the average of all images is possible;
• the coefficient of restoring is the higher the higher the quality of JPEG-compression, and besides, the compression with the maximum quality allows extracting the information with the coefficient of restoring 0.9 on the average for all images;
• the coefficient of restoring sharply decreases with the increase of the radius of Gauss filter higher than 1 for embedding into unitary ratios, and it is more than 0.5 for block embedding; therefore, the studied algorithm is not robust against similar effect;
• the increase of brightness poorly influences the coefficient of restoring, which tells about the robustness against the given effect;
• the algorithm is not robust against contrast change; already at the coefficient of contrast 1.5 the coefficient of restoring is equal to 0.71 on the average for all images;
• embedding into unitary ratios is more robust to brightness and contrast change, than block embedding.

| Destructive effect | Changeable parameter and its value | PSNR, dB | Coefficient of restoring |
|--------------------|-----------------------------------|----------|--------------------------|
| Noise imposing     | The amplitude of noise is equal 5 | 45.243   | 0.867                    |
| Noise imposing     | The amplitude of noise is equal 10| 38.314   | 0.612                    |
| Noise imposing     | The amplitude of noise is equal 25| 31.195   | 0.507                    |
| JPEG-compression   | Quality of compression is equal 70| 35.082   | 0.500                    |
| JPEG-compression   | Quality of compression is equal 80| 36.730   | 0.499                    |
| JPEG-compression   | Quality of compression is equal 90| 40.064   | 0.531                    |
| JPEG-compression   | Quality of compression is equal 100| 58.830   | 0.933                    |
| Gauss filter       | The filter radius is equal 0.1    | 47.210   | 0.951                    |
| Gauss filter       | The filter radius is equal 0.5    | 37.740   | 0.747                    |
| Gauss filter       | The filter radius is equal 1      | 29.390   | 0.500                    |
| Gauss filter       | The filter radius is equal 2      | 25.430   | 0.501                    |
| Contrast change    | Contrast coefficient is equal 0.5 | 22.176   | 0.591                    |
| Contrast change    | Contrast coefficient is equal 1.5 | 24.552   | 0.786                    |
| Contrast change    | Contrast coefficient is equal 2   | 19.888   | 0.619                    |
| Brightness increase| Brightness increase for 10        | 28.465   | 0.912                    |
| Brightness increase| Brightness increase for 15        | 24.965   | 0.909                    |
| Brightness increase| Brightness increase for 20        | 22.487   | 0.906                    |
| Brightness increase| Brightness increase for 25        | 20.568   | 0.901                    |

Let us note that any essential difference in respect of robustness between Haar transformation and that of Daubechies is not found. As a whole, embedding in unitary ratios has higher robustness against destructive effects, than block embedding.

A conclusion can be drawn that the studied algorithm is robust generally against weak destructive actions, and embedding in the unitary ratios is more preferable as it shows higher robustness.

5. Research of robustness to the steganalysis
The main objective of the steganalysis is to determine the fact, whether some digital object contains steganographic embedded data or not. In the present paper, we study the robustness of the algorithm based on the QIM method and operating with DWT coefficients against the statistical steganalysis. It consists in the study of the natural model of a digital image in the frequency area for distortions of
statistical characteristics of the image. The steganalitic attack implemented in the present research is based on the fact that during the information embedding according to QIM method, the change of frequency coefficients concerning the reference values depends only on the quantization step and if one gathers the statistics of the distribution of coefficients, then one can restore the value of the quantization step.

To find the characteristics of the presence of embedded data, difference histograms of values of DWT-coefficients before and after embedding were constructed. The following scheme of experiments was used:

- DWT was applied to image pixels;
- the histogram of the obtained values of DWT coefficients was built;
- embedding of the information and formation of a stego-image was fulfilled;
- DWT was applied to the pixels of the stego-image;
- the histogram of values of DWT coefficients of the stego-image was built;
- the difference histogram was built.

During embedding in unitary ratios, the number of certain values of DWT coefficients increases to the maximum in the area of zero and after the period equal to half of the quantization step. It allows unambiguously defining the presence of the embedded data and the quantization step using which the information was recorded. On the example represented in figure 1, peaks alternate through 5; therefore, the quantization step is equal to 10.

![Figure 1](image1.png)

**Figure 1.** Difference histogram for the case of embedding in unitary ratios.

When embedding in blocks of coefficients, the difference histogram has other forms (Figure 2) which also reveals the fact of the presence of steganographic embedded data. However, the values of DWT coefficients at block embedding vary more smoothly and without strongly pronounced peaks since the coefficients increase or decrease for values in the range from 0 to the quantization step, which that does not allow defining the quantization step using the difference histogram.
Figure 2. Difference histogram for the case of embedding in blocks of coefficients.

The results of experiments showed that, as a whole, the studied algorithm does not show greater robustness to the statistical steganalysis. However, block embedding makes a smaller impact on the values of DWT coefficients and does not allow defining the quantization step according to the difference histogram. Therefore, this method of embedding is more robust against statistical attack. At the same time, there has not been found an essential difference between Haar transformation and that of Daubechies 9/7.

6. Conclusion
The given paper presents the study on the robustness of information embedding into DWT frequency area of digital images by means of QIM method against destructive actions on images and against the steganalysis. According to the obtained results, a conclusion could be drawn that at present the studied algorithm shows a low level of robustness. The further work will be directed on the increase of efficiency of the algorithm regarding the robustness against various effects on a stego-image and against stego-analytical attacks.

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