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PATTERN METHOD EFFECTIVNESS IMPROVEMENT FOR HIDING DATA IN IMAGES

The paper suggests the method of embedding data into images, which are subject to further JPEG-algorithm processing. There had been considered the special features of embedding that determine secrecy and stability of confidential data. With the objective to develop an efficient steganographic method there had been synthesized a criterion that has been applied as the target function for embedding. The procedure of data hiding is hereby realized by means of solving the optimization problem.

***Keywords**: steganography, pattern-based embedding, secrecy, robustness, JPEG algorithm, wavelet-transform.*

Introduction

Image steganography is a branch of science that has been rapidly progressing during the past decade. One can define its objective as a confidential and deformation-stable hiding of data.The practical tasks within its boundaries concern some aspects of confidentiality and robustness to a greater or lesser extent [1, 2].

Since confidentiality corruption can result in the full message loss it's the stated quality that sets the main requirements in developing a stegosystem. The relative nature of this value determines the presence of a large number of criteria, efficiency of which being different for various embedding methods.

The other important aspect is the robustness requirement. As the patterns of channel coding are widely-spread, the problem of robustness can be easily solved, the effectiveness of the result being determined by reliability of the recovered data [3].

Development of any stegosystem can therefore be considered as a conditional optimization task, the purpose-oriented function of which associates robustness with some confidentiality degree, whereas limitations determine the domain of criterion adequacy. Such a universal approach provides high level of adaptability to the conditions of direct stegosystem functioning.

The scheme of blind embedding is particularly widespread in image steganography, where only stegocontainer is transmitted. This defines the special features of steganalysis, the task of which consists in binary classification of images based on the properties undergoing the most serious transformations in the process of embedding. Particularly promising are the criteria based on support vector machines (SVM) [4], their major advantage being the effectiveness of point-characteristic classification in the feature space.

Compression techniques are extremely popular as a method of image processing. One can get the maximum compression factor by means of lossy compression methods [5]. The JPEG (Joint Photography Expert Group) compression standard is still widely used in spite of the fact that more effective wavelet-transform standards (take, for example, JPEG2000) has been introduced. Such situation is apparently due to the inertness of the software developments concepts in this sphere, which, in its turn, supposes the significant conversion duration.

Thus, JPEG processing is considered as the main factor of effect upon the stegocontainer. On the other hand, steganographic application of wavelet-transform suggests the obscurity of the changes made. The integral interconnection of confidentiality and robustness of the specified usage in the wavelet-transform region has been suggested for research by means of the developed criterion.

The factors have been agreed upon to modify according to the widely-used approach of vector quantization. Its modification is the scheme of pattern embedding, for which the value of piece of confidential data varies depending upon the factor set to some benchmark value ratio [6]. The main advantage of the pattern-based embedding is the possibility of multivariable presentation of piece of confidential data, which increases its stability.

While developing modern methods of hiding, one of characteristics of confidentiality or robustness is optimized. Usage of the criterion combining the specified characteristics is intended for increasing of stegaprotection efficiency. The relevancy aspect is not limited by this criterion only: an adaptation method for its enhancement has been proposed. The characteristics of every object of steganographic manipulation having elementary part of confidential data are taken into account.

The special features of the approach proposed are expected to ensure the high level of stegomethod efficiency on its basis and the development of this method is the objective of this research.

Steganographic efficiency criterion

The complex estimation of the stegomethod efficiency is recommended for use together with independent indices of confidentiality and robustness. Robustness is determined as a part of saved elementary pieces of confidential data after processing of stego image. As a secrecy criterion a steganalytical criterion suggested in [4] has been agreed upon. This applies SVM for image classification. To do this each image is described by the vector of constant length, the value of which is obtained by means of comparing the adjacent pixels.

For most steganalytical criterion the connection between PSNR (the Peak Signal to Noise Ratio) and detection entropy $e^{\det} = -p\log p - \overline{p}\log\overline{p}$ is thus direct, where $\overline{p} = 1 - p$, p – are the probability of correct classification. A high level correlation has been experimentally established for this connection. This connection is therefore considered later by default.

Estimation of embedding efficiency calls for taking into account the typical effects of the third party. When applying JPEG-compression, the outcome depends on compression variables, specified by the user. Quantization of Discrete Cosine Transform (DCT) is described by

$$dct_{i,j}^{jpeg} = \frac{Q_{i,j}}{q}\,\mathrm{round}\left(\frac{dct_{i,j}}{Q_{i,j}}q\right), \quad (1)$$

where $Q_{i,j}$ – is a corresponding element of Quantization matrix (Q-matrix) Q, $i, j = 1\ldots8$, and q – is the variable specified by the user and determining the quality and size of the compressed image file [5]. It is usually impossible to anticipate the value of q in each case, but applying statistic distribution f_q makes reasonable estimation possible. Fig. 1 demonstrates the typical distribution of f_q.

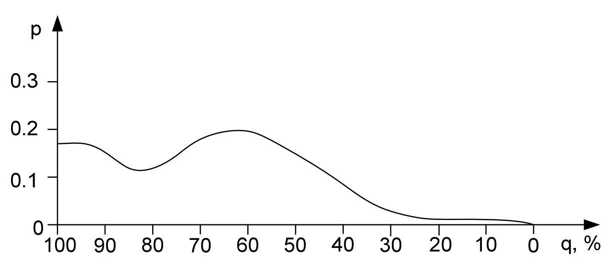

Fig. 1. Typical distribution of q

Since the result of JPEG-algorithm processing (quantization) is dependent on the DCT coefficients values the stability of embedded data for various image blocks is different. The same is true when concerning the quantitative degree of embedding distortions. In JPEG-compression image blocks 8×8 are processed independently. Therefore, if embedding into these blocks is independent, one can get a stegosystem adaptable to the requirements of confidentiality and robustness.

The criterion of embedding efficiency is to be integral since instead of variable q only distribution f_q is known. Therefore, probability f_{q_i} and the integral characteristic of the system efficiency z_i conform to the i – condition of quantization being fully determined by q_i. If z_i is determined as the product of the steganalythical detection entropy $e_i^{\det}$ and the robustness variable $r_i = 1 - \mathrm{BER}_i$ where BER (Bit Error Rate) is the value of bit errors, the criterion of general embedding efficiency can be represented by the expression:

$$E = \sum_i z_i f_{q_i} = \sum_i e_i^{\det} r_i f_{q_i} . \tag{2}$$

Taking into consideration that variables $e_i^{\det}$ and r_i depend on the embedding energy $d = \left\| I^{org} - I^{stg} \right\|^2$ (distortion of the stegoimage I^{stg} if compared to the original I^{org}), the preceding expression becomes

$$E(d) = \sum_i e_{i,d}^{\det} r_{i,d} f_{q_i} . \tag{3}$$

In the case of uninterrupted alteration of quantization conditions we get:

$$E(d) = \int e^{\det}(q,d) r(q,d) f(q) dq . \tag{4}$$

But the suggested adaptation approach about z_i calls for additional estimation of the embedding efficiency criterion. According to the abovementioned assumption $e^{\det}(q,d)$ is a single-valued function. This is also true for the robustness variable $r(q,d)$ of the majority of the popular stegomethods. In the case of adaptable embedding independent variables (q,d) are insufficient for adequate representing of robustness level, since each object of steganographic manipulation may undergo many-valued effects. Therefore the key maximization moment $E(d)$ is the retrieval of $r(q,d,\Omega)$, where $\Omega = \{\Omega_j\}$, $j = 1 \ldots m$, Ω_j – is the state vector of j-object. The final task of stegomethod development is formalized:

$$\max_d \left(\max_\Omega \int e^{\det}(q,d) r(q,d,\Omega) f(q) dq \right). \tag{5}$$

Obviously, the embedding efficiency is defined by not only the optimization methods when solving the problem specified above. In the first place the embedding method (pattern-based in given case) sets constraints and has profound effect on the result [2]. In spite of the fact that the suggested approach can be combined with any scheme, a pattern one has been agreed upon for further use. This choice is due to the high freedom level for definition of Ω.

Model of pattern-based data embedding into wavelet-coefficients

The pattern scheme being the base of a stegomethod is a set of conditions that are simply interpreted when some confidential data being extracted. But in embedding one can define similar data by different conditions. Thus the correspondence "one-to-many" is valid. The set of conditions of the selected pattern scheme describes the relationship among four scalar variables and a single threshold constant TH when embedding two bits of confidential data (tab. 1). Every condition is described by four bits corresponding to the logic result of the inequality $a_l^j \geq TH$, $l = 1 \ldots 4$, $j = 1 \ldots m$, where a_l^j - is the l-element of the j-object of manipulating [6].

Table 1

Logic conditions of data embedding according to pattern scheme

Confidential data	0 0	0 1	1 0	1 1
Condition	0 0 0 1	0 1 1 1	0 0 0 0	1 1 1 1
	0 0 1 0	1 0 1 1	0 0 1 1	1 0 0 1
	0 1 0 0	1 1 0 1	0 1 0 1	1 0 1 0
	1 0 0 0	1 1 1 0	0 1 1 0	1 1 0 0

The advantages of this scheme are flexibility and possibility of high level robustness. On the other hand this results in redundancy and, consequently, in more serious distortions since two bits are embedded into four elements. However, the choice of this scheme is connected with the possibility of employing the property of flexibility in order to ensure the optimal ratio “distortions/robustness”.

Determination of the transformation method of getting elements that are used by the pattern scheme will have a profound effect on the general efficiency [7]. The main feature of the wavelet-transform is the scaling reflection of the signal x:

$$\varphi_{j,n}(x) = \sqrt{2^j}\varphi(2^j x - n),\ \psi_{j,n}(x) = \sqrt{2^j}\psi(2^j x - n), \tag{6}$$

where $\varphi_{j,n}(x)$, $\psi_{j,n}(x)$ – is the scaling-function and the wavelet-function, respectively, j – is the level of factorization, n – the shift [8, 9]. For instance, by means of the ortonormal Daubechies basis

$$\mathbf{D} = \begin{bmatrix} h_0 & h_1 & h_2 & h_3 & \underbrace{0 \ \dots \ 0}_{n-4} \\ 0 & 0 & h_0 & h_1 & h_2 & h_3 & \dots \\ & & & \vdots_{n/2-3} \vdots & & & \\ h_2 & h_3 & 0 & \dots & 0 & h_0 & h_1 \\ g_0 & g_1 & g_2 & g_3 & 0 & \dots & 0 \\ 0 & 0 & g_0 & g_1 & g_2 & g_3 & \dots \\ & & & \vdots & & & \\ g_2 & g_3 & 0 & \dots & 0 & g_0 & g_1 \end{bmatrix} \tag{7}$$

the transformation of the signal $\mathbf{S} = [s_1 \ \dots \ s_i \ \dots \ s_n]$ can be represented in the matrix form:

$$\mathbf{W} = \mathbf{D} \times \mathbf{S}^T, \tag{8}$$

where $\mathbf{W}^T = [\underbrace{w_1 \ \dots \ w_{n/2}}_{low} \ \underbrace{w_{n/2+1} \ \dots \ w_n}_{high}]$. By means of further factorization the components low get the system of scaled reflections of the signal $\mathbf{S}$. For images a two-dimensional wavelet-transform is used:

$$\begin{aligned} \varphi_{j,k,n}(x,y) &= 2^j\varphi(2^j x - k)\varphi(2^j y - n), & \psi^H_{j,k,n}(x,y) &= 2^j\varphi(2^j x - k)\psi(2^j y - n), \\ \psi^V_{j,k,n}(x,y) &= 2^j\psi(2^j x - k)\varphi(2^j y - n), & \psi^D_{j,k,n}(x,y) &= 2^j\psi(2^j x - k)\psi(2^j y - n). \end{aligned} \tag{10}$$

Wavelet-based scaling enables the choice of the optimal level of reflection according to the criterion E.

Since, while being compressed, the JPEG-factors of DCT are quantized unequally, one can distinguish the part of the DCT-basis with less distortion of quantization. Respectively, the reflecting completeness of manipulation region in this part of the basis is more preferable for ensuring robustness. The choice of the wavelet-reflection level for embedding is directly connected with this priority. One can demonstrate this by comparing the values of the vector projections of the wavelet basis on the significant part of DCT basis. The notion of the significant part is rather conventional but, for the most part, JPEG-compression variables suppose the non-zero value of the part of DCT-coefficients, which are separated by the boundary on fig. 2,a.

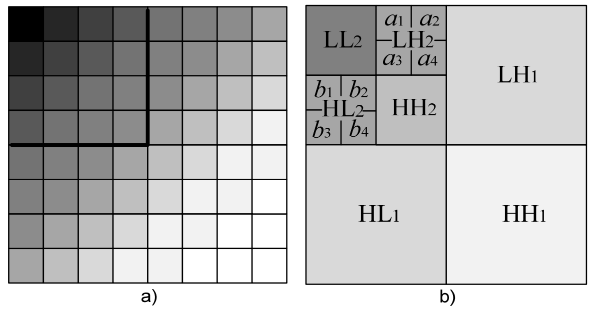

Fig. 2. a) Significance degree of DCT- coefficients; b) Coefficients significance of different wavelet-transform levels

The DCT- coefficients are given by the expression:

$$y(k) = \varpi(k)\sum_{n=1}^{N} x(n)\cos\tfrac{\pi(2n-1)(k-1)}{2N}, \quad k = 1,\ldots,N\ , \tag{11}$$

where $\varpi(k) = \begin{cases} 1/\sqrt{N}, & k = 1 \\ \sqrt{2/N}, & 2 \le k \le N \end{cases}$, $x(n)$ – is the signal, and N – is the number of DCT-coefficients [5].

The two-dimensional DCT is therefore determined as:

$$B_{pq} = \alpha_p \alpha_p \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} A_{mn}\cos\tfrac{\pi(2m+1)p}{2M}\cos\tfrac{\pi(2n+1)q}{2N}, \qquad \begin{matrix} 0 \le p \le M-1; \\ 0 \le q \le N-1; \end{matrix}$$
$$\alpha_p = \begin{cases} 1/M, & p = 0; \\ \sqrt{2/M}, & 1 \le p \le M-1; \end{cases} \qquad \alpha_q = \begin{cases} 1/N, & q = 0; \\ \sqrt{2/N}, & 1 \le q \le N-1. \end{cases} \tag{12}$$

Let the significant part of DCT basis for transformation of 8×8 image be indicated as $\mathbf{C}_{16}^{pr}$. In this case the projections $T_i, i = 1\ldots16$ of the wavelet-basis part $\mathbf{H}_{16}^{pr}$, defining the upper left quarter of the factors in fig. 2,b, are calculated as follows $T_i = \sum_j (v_{i,j})^2$, $\mathbf{V} = \mathbf{H}_{16}^{pr}\left(\mathbf{C}_{16}^{pr}\right)^T$, $v_{i,j} \subset \mathbf{V}$ (since both bases are ortonormal) [8, 9]. The bar charts of projection indices for Haar and Daubechies wavelets are given in fig. 3,a and 3,b respectively.

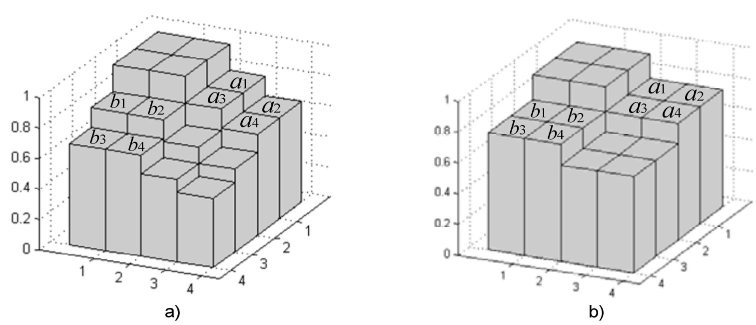

Fig. 3. Indices of the vector projections of the wavelet basis on the "main" part of DCT basis: a) Daubechies basis; b) Haar basis

The established by means of projections relationship between the bases enables the choice of the elements in order to form the objects of steganographic manipulation. The choice of the sets of elements $\{a_1, a_2, a_3, a_4\}$ and $\{b_1, b_2, b_3, b_4\}$ is conditioned by the possible effects of their replacement by the images (distortions) on the one hand and sensitivity of reflection of such changes under the condition of JPEG-compression (robustness) on the other hand.

The efficiency of pattern-based embedding is essentially influenced by the choice of the variable TH. Under the condition of manipulating on $LH2$ and $HL2$ levels of wavelet-coefficients, their indices vary around zero-point. So, such choice enables the increase of the number of embedded two-bit pieces of confidential data provided the distortion constraints are constant (fig. 4).

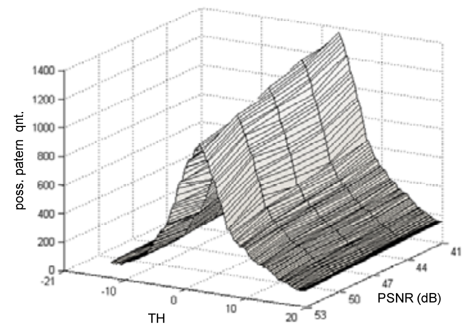

Fig. 4. Dependence of the number of embedded patterns on the variable TH and the reasonable PSNR level

When recalling the problem solution

$$\max_d \left(\max_\Omega \int e^{\det}(q,d) r(q,d,\Omega) f(q) dq \right) \quad (13)$$

as to the suggested scheme and the object of steganographic manipulation, one needs to define the special features of forming Ω. The interpretation of Ω in the image region is evidently to be single-valued. On the other hand, Ω is the only argument of the first stage of optimization but its formation is gradual by means of Ω_j, $j = 1 \ldots m$. Here arises the necessity of correspondence of optimal relationship "robustness/distortions" to every possible Ω_j. As a result, under the condition of the beforehand determined (tabulated) values of q_i, for any j-object one must define and solve the problem of distortion minimization.

However, the special features of constraints do not allow the methods of classic optimization for solution of the specified problem [10]. This, firstly, is due to the need for the integer value result (indices of pixels – are integer numbers), secondly, upon the DCT and corresponding q_i quantization the schematic interpretation of the wavelet-coefficients should agree with the piece of embedded data:

$$\left\| P^{org} - P^{stg} \right\|^2 \to \min, \quad (14)$$

under the condition of constraints

$$\begin{cases} p_{i,j}^{stg} \in Z, \quad i, j = 1 \ldots 8; \\ \mathbf{M}^{emb} \times (\mathbf{D} \times \mathbf{C} \times Q_i(\mathbf{C} \times \overline{P}^{stg}) - \mathbf{TH}) \le \mathbf{0}, \end{cases} \quad (15)$$

where $\overline{P}^{stg}$ – is the column representing the pixels P^{stg}; $Q_i(\bullet)$ – is the quantization operator according to the i-condition; $\mathbf{M}^{emb}$ – is the mask interpreting the piece of data for embedding; $\mathbf{TH}$ and $\mathbf{0}$ – are the columns containing only variables TH and 0 respectively.

Steganographic model optimization stages

In the chapter the method for ensuring the suboptimality of decision for every possible value of Ω_j, $j = 1\ldots m$ is suggested, afterwards the method of optimal forming of Ω is discussed.

The nonlinearity of operator $Q_i(\bullet)$ is the only obstacle in solving the problem specified above by means of least-squares algorithm (lsq optimization) with linear constraints. This explains the need of the iterative approach in employing this method under the condition of approximation to optimum [11].

The evolutionary algorithm has been proposed, consisting in the following. The genotype is the vector G_i, the length of which being 64 and the elements of which taking on values from $\{0,1\}$. Every generation p is made up of the population $\mathbf{G}^p = \{G_i^p\}, \quad i = 1\ldots g$. To form $\mathbf{G}^{p+1}$:

1) a choice c among the best carriers $\dot{G}_i^p$ of the genotype with the least values is made

$$A_i = \sum_{j=1}^{64} (G_{i,j}^p - \dot{G}_{i,j}^p), \tag{16}$$

$$\dot{G}_{i,j}^p = \begin{cases} 0, G_{i,j}^p = 0; \\ 1, Q_i^i(\mathbf{C} \times \overline{P}^{stg^p}) \neq Q_i^i(\mathbf{C} \times \overline{P}^{stg^{p-1}}); \\ -1, Q_i^i(\mathbf{C} \times \overline{P}^{stg^p}) = Q_i^i(\mathbf{C} \times \overline{P}^{stg^{p-1}}), \end{cases} \tag{17}$$

where $\overline{P}^{stg^p}$ is obtained as the result of solving the problem

$$\left\| P^{org} - P^{stg^p} \right\|^2 \to \min, \tag{18}$$

under the condition of constraints

$$\begin{cases} p_{i,j}^{stg^p} \in Z, \quad i, j = 1\ldots 8; \\ \mathbf{M}^{emb} \times (\mathbf{D} \times \mathbf{C} \times (\widehat{\mathbf{C}}^{G_i^p} \times \overline{P}^{mid^p} + \breve{\mathbf{C}}^{G_i^p} \times \overline{P}^{stg^{p-1}}) - \mathbf{TH}) \leq -\Delta^p; \end{cases} \tag{19}$$

in this case the intermediate stegoimage on the iteration p provides:

$$\overline{P}^{stg^p} = \mathbf{C} \times (\widehat{\mathbf{C}}^{G_i^p} \times \overline{P}^{mid^p} + \breve{\mathbf{C}}^{G_i^p} \times \overline{P}^{stg^{p-1}}), \tag{20}$$

where $\widehat{c}_{l,m}^{G_i^p} = G_{i,l}^p \cdot c_{l,m}$; $\breve{c}_{l,m}^{G_i^p} = (1 - G_{i,l}^p) \cdot c_{l,m}$; $\widehat{c}_{l,m}^{G_i^p} \subset \widehat{\mathbf{C}}^{G_i^p}, \breve{c}_{l,m}^{G_i^p} \subset \breve{\mathbf{C}}^{G_i^p}$; $\overline{P}^{mid^p}$ – is the column of intermediate values of pixels, Δ^p – is the column of Δ^p elements, which is positive and depends on $\mathbf{G}^p$ and Δ^{p-1};

2) $g = C_c^2$ combinations of crossed sequences $\ddot{G}_i^p$ is obtained by forming one break point for two $\dot{G}_l^p$ and $\dot{G}_m^p$, $l \neq m$, and by means of their by-pair combining.

3) the substitution with random result (mutation) is realized for every value of -1, as a result we obtain $\mathbf{G}^{p+1}$: $\mathbf{G}^{p+1} \Leftarrow \ddot{\mathbf{G}}^p$,

$$\forall i, j\ G_{i,j}^{p+1}(-1) = \begin{cases} 1,\ p^{mut}(1) = y; \\ 0,\ p^{mut}(0) = 1 - y, \end{cases} \tag{21}$$

where y – is some constant. The evolution lasts until the condition (15) is met, or Δ^p exceeds some determined threshold $T\Delta$.

Thus, the main special feature of this method is the iterative generation of embedding directions, which ensures the highest sensitivity quantization with the variable q_i. But the convergence to the conditions (15) can't be proven so, for the sake of to saving computer power the $T\Delta$ is specified [10, 11].

The following stage calls for the determining of Ω. For simplification, when specifying and solving the problem, only distortion indices d_i^j are used, which correspond to saving the piece of confidential data in the j-fragment of the image under the i-condition of DCT quantization in the process of JPEG-compressing. If the ratio d_i^j to q_i is particularly advantageous this is represented by 1 in the i-position of the vector Ω_j, the rest of the positions being equal to 0. To determine such relationships one should consider all m objects and the general distortion constraint Td. The main feature used is the possible determination of the effect on the value of the goal function and the distortion under the condition of choice of Ω_j, regardless of the rest of the objects.

If the stegokey and the confidential data are known and constant every piece of data correlates with some definite fragment of the image. Let the quantization condition corresponding to embedding of j piece of data with minimal distortion $d_{\min}^j$ be $q_{\min}^j$. Then the lower boundary of general distortions of the image is $Td_{\min} = \sum_j d_{\min}^j$. When defining Td one should abide by $Td \geq Td_{\min}$. Therefore, in robust embedding of data into the *j*-fragment with the variable $q_i^j \neq q_{\min}^j$ we obtain the improvement (increase) of the E criterion by ΔE_i^j and the corresponding increase of distortions by Δd_i^j. Under the condition of the fixed set of data $q_i, i = 1 \ldots r$ the number of the variants of optimization E according to the j-fragment only doesn't exceed $r-1$. Let us assume that as a result of every iteration of the optimization algorithm the confirmation or rejection of the conversion from $q_{\min}^j$ to q_i^j for all m fragments is obtained, where the i-variable of quantization independent of the other ones can be established for every j-fragment. Even if for the j-fragment the possibility of conversion is rejected, in the succeeding iterations the variable q_i isn't considered as a variant of conversion. If the conversion is confirmed the following iteration tests the possibility of this very conversion variant. The optimization process is completed if every possible conversion for all rejections is exhausted or m confirmations are received. Consequently, in the case that the process of solving is the slowest, only one conversion out of m being rejected, not more than $m(r-1)$ iterations are necessary for convergence [11].

The very last argument of optimization is Td, being determined as the result of the problem solution without restrictions.

Experiment

The objective of the experiment is the comparison of efficiency of concealing the data developed by means of the methods, being widely practically used. For comparing the following methods have been chosen: the Least Significant Bit (LSB) method [12], the pattern method on the basis of integer wavelet transform (IWT) [6] and the method operating in the DCT region [13]. Some confidential data has been embedded into the images selected, when using the same stegokey. The efficiency of the methods was defined according to the two dependences (1) the secrecy of stegomanipulations and (2) the robustness of the embedded data on the value of q, determining the degree of compression. Since the development of proposed method was being made on the basis of the suggested criterion of embedding efficiency, the comparison with the other methods according to this criterion and the abovementioned dependences could state the adequacy of the criterion.

According to the special features of the stegomethod development to define and solve the task of embedding optimization one should pre-define the distribution $f(q)$ as well as the function of steganalythical entropy $e^{\det}(q,d)$. The dependence $f(q)$ has been determined by means of the expert recognition of the popular and widely-used 256×256 grey scale images, which have been processed by the JPEG-algorithm with various q indices depending on the examined web-pages. The training and testing samples have been modeled while determining $e^{\det}(q,d)$ for every q_i (which ranging from 1 to 0.65 with the step of 0.05). The first one has been applied in SVM training, according to the suggested in [4] characteristic vector, the second one being used for determining the average probability of reliable detecting depending on the distortion variable d. The images in the training and testing samples don't match. Every sample is in half consists of the original images (400 in quantity) as well as of the stegoimages extracted from the original ones by means of the described pattern-based embedding model. Fig. 5 demonstrates the diagram of the detecting probability function $p^{\det}(q,d)$.

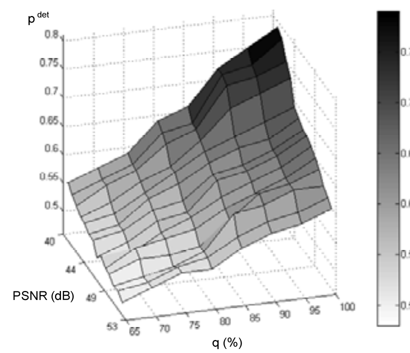

Fig.5. Dependence of the detecting probability $p^{\det}$ on the variable q and the distortion level (PSNR)

As a result of the above described optimization stages of embedding 2000 bits of confidential data into the Haar wavelet-coefficients according to the E criterion, the quantitative efficiency index, being the average for 20 images, makes 0.63. For the method described in [6] in terms of the integer wavelet-base the criterion index equals 0.48, the efficiency of embedding into the DCT region [13] is 0.42, the steganographic efficiency of the method [12] on the basis of LSB constitutes 0.28.

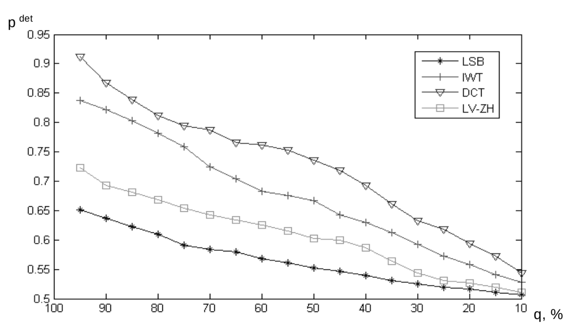

Fig.6. Dependence of the detecting probability $p^{\det}$ on the value of JPEG-compression quality q

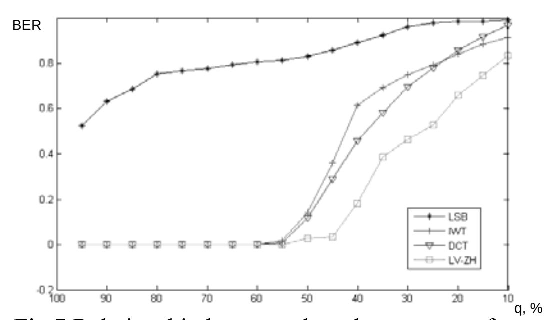

Fig.7 Relationship between the robustness r of embedded data and the value of q

On purpose to present the adequacy of the criterion and the developed method two diagrams of the dependence of detecting probability $p^{\det}$ on the value of q (fig. 6) and the embedding robustness r on q (fig. 7). They clearly explain the advantages and disadvantages of every method evaluated above.

Conclusions

The steganographic method has been developed, applying the principle of pattern-based embedding in the wavelet-transform region. The special feature of the method is the conformity with the requirements of secrecy and robustness of the JPEG-conversion, which is realized by means of combining them with the aid of the suggested criterion. The problem has therefore been specified as the task of optimization with constraints and has been solved stage-by-stage.

The suggested approach enables the increase of the general efficiency of data embedding, this having been verified experimentally as compared with the popular stegomethods. The disadvantage of this method is its complexity stipulated by the differential (by-block) nature of embedding and, as a result, by the necessity of iterative solution of computational optimization tasks.

However, the applied optimization approaches allow the search for compromises between the computational complexity and the efficiency of the solution, which is the objective of the consequent studies. Yet another perspective direction of study is the application of the suggested approach to embedding with the different conversions of the image processing (not JPEG only).

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