Genetic Algorithm for improvement in detection of hidden data in digital images

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The paper proposes a data hiding scheme in digital images to serve the purpose of authentication and covert communication. The algorithm is implemented in three stages. In the first stage, a region for data embedding is selected in such a way so that maximum number pixel values of the cover image differ from the message pixel values by less than a predefined threshold and a difference signal (D) is formed. The difference signal modulated by proper embedding strength is then added to the cover to achieve stego image. In the second stage, Genetic Algorithm (GA) is used to achieve a set of parameter values (used as Key) to represent optimally this difference signal. In the third stage, the parameter values at the decoder end form an approximate version of the difference signal using linear interpolation scheme and subsequently the embedded data is decoded. The novelty of the proposed scheme lies in higher payload capacity without compromising much for visual and statistical invisibility of the hidden data. The later property is verified as the proposed embedding process, unlike many other reported algorithms, causes very small change in the higher-order statistics of the wavelet coefficients for the stego data. Experiment results also show that the algorithm is robust to non-malicious operations like mean and median filtering, additive noise and moderate image compression.

Keywords: Digital data hiding; Difference signal; GA; Statistical invisibility.

1. Introduction

Data hiding is the art of invisible communication that embeds a secret message into innocuous-looking cover objects such as simple text, images, audio or video recordings. After embedding, the cover object becomes known as the Stego-object. The essential requirements of image data hiding are visual imperceptibility of the hidden data, security against statistical analysis and robustness to non-malicious operations that a communication channel is to face. A data hiding method will be called secure if the stego-objects do not contain any detectable artifacts due to message embedding. In other words, the set of stego-objects should have the same statistical properties as the set of cover-objects. If there exists an algorithm that can guess whether or not a given object contains a secret message with a success rate better than random guessing, the data hiding system is considered broken [1].

Payload becomes an important requirement when information hiding is used for covert communication. However, higher embedding capacity obviously affects visual and statistical invisibility of the hidden information along with robustness performance. These requirements form a multidimensional nonlinear problem of conflicting nature. Genetic algorithm (GA), like an efficient search for optimal solutions in many image processing and pattern recognition problems, can also be used in this topic of research but in reality the usage of the tool has been explored very little. Maity et al [2] propose an algorithm for data hiding in digital images where GA is used to find out parameter values, namely reference amplitude and modulation index. The performance of the algorithm is compared for linear, parabolic and power law functions used for modulating the auxiliary message.

In this work, Genetic Algorithm is used to achieve a set of parameter values (used as Key) to represent optimally the difference signal (D) that is obtained by subtracting the pixel values of the auxiliary images (messages) from that of the pixel values of the cover image. The difference signal with its proper embedding strength is added to the respective cover data. The parameter values at the decoder end are used to form difference signal using Linear Interpolation method. Message is recovered by doing inverse operation using this difference signal. Experiment results show that the hidden data is secured against statistical analysis and robust to various non-malicious operations.

The rest of the paper is organized as follows: Section 2 presents problem definition and scope of the work. Section 3 briefly describes steganalysis method based on higher order statistics and section 4 presents proposed data embedding method. Section 5 describes performance evaluation while conclusions are drawn in section 6.

2. Problem definition & scope of the work

In additive embedding process, data hiding is accomplished by adding to the host data a scaled version of the auxiliary message. Image fidelity is degraded with the increase in payload capacity and embedding strength. The higher value of embedding strength, at the cost of greater visual distortion, increases reliability of decoding.

One possible solution to cope up this trade-off like problem is to map the auxiliary message signal to a difference signal. This is formed by selecting the embedding region within the cover signal so that auxiliary message forms a lower distance difference signal. Now the difference signal can then be added with higher embedding strength so that visual distortion of the cover can be set to an acceptable value. Decoding of message needs the regeneration of difference signal and inverse process will extract the message signal. The reliability of the decoding process depends on how faithfully the difference signal is regenerated. The best decoding is possible if complete knowledge of the difference signal is available at decoder end which may be treated as an overhead problem. To reiterate the problem, the higher the payload capacity, the more number of signal points are needed for regeneration of the difference signal. Thus important point arises how to select those N-signal points that regenerate the M-point difference signal faithfully where $N \ll M$. This can be thought as an optimization problem and GA finds application to yield optimal solutions.

3. Steganalysis based on higher order statistics

Farid proposed a universal blind steganalytic detection method [3] based on higher order statistics of natural images. We briefly describe two steps as follows:

Formation of feature vectors

The feature vector, for a certain image, is formed using the first four normalized moments namely Mean, Variance, Skewness and Kurtosis of the wavelet coefficients of vertical ($v_i[x,y]$), horizontal ($h_i[x,y]$), and diagonal ($d_i[x,y]$) subbands at scales $i = 1,2,3....n$. Thus we have total 4.3. (n-1) elements of the feature vector f for the test image.

The remaining elements of f are derived from the Error Statistics of an Optimal Linear Predictor. The prediction for a specific subband coefficient is performed considering the 4 neighboring coefficients, the corresponding in the courser scale of the same orientation and coefficients of subbands of other orientations (and scales).

The predicted value for the vertical subband $v_i[x,y)]$ is given by

$$v_i^{'} = w_1 v_i[x-1,y] + w_2 v_i[x+1,y] + w_3 v_i[x,y-1] + w_4 v_i[x,y+1] + w_5 v_{i+1}[x/2+y/2] + w_6 d_i[x,y] + w_7 d_{i+1}[x/2,y/2] \quad (1)$$

where w_k denotes the predictor coefficients. The other two subbands $h[x,y)]$ and $d[x,y)]$ can be predicted in the same way. The optimal predictor coefficients $w_{k,opt}$ are determined for each subband so that the mean squared error within each is minimised. The log error in the linear predictor is then given by:

$$e_{v_i}{}^{log}[x,y] = \log_2(v_i[x,y]) - log_2(v_i^{'}[x,y]) \quad (2)$$

where $v_i[x,y]$ is obtained by inserting $\mathbf{w_{k,opt}}$ into Eq. (1), yields the Log Error. The mean, variance, skewness, and kurtosis of the Log Error of each subband form the remaining 4.3.(n-1) elements of f.

Classification Algorithm

The classification algorithm called the Fisher Linear Discriminant Analysis is used to classify a new image by means of its feature vector. The FLD algorithm is first trained with feature vectors from untouched and stego-images. The algorithm determines a projection axis by means of this training set to project the 24.(n-1)-dimensional space of feature vectors into a one dimensional subspace. The projected feature vector $\mathbf{f}$ is referred to as the Detection Variable $\mathbf{d}$. New feature vectors obtained from new images are classified by thresholding $\mathbf{d}$. If d is greater than a certain value, the image is classified as stego, if not, it is classified as untouched.

4. Proposed method

The total process of data embedding and decoding consists of three stages. These are Stage 1: Selection of data embedding regions and formation of difference matrix followed by data embedding, Stage 2: Generation of set of points using GA to optimally represent the difference matrix, Stage 3: Message retrieval.

A. Stage 1

The choice of cover images is important and influences the security in a major way. Images with a low number of colors, computer art, images with a unique semantic content, such as fonts, should be avoided. Some data hiding experts recommend grayscale images as the best cover-images. We consider gray scale image as cover and the similar type image like text information as message signal since it can preserve contextual information even after various signal processing operations. Steps for the selection of embedding region are as follows.
Step 1 : Input gray scale images as cover and message signal.
Step 2: Setting of an appreciable Percentage for matching criteria (82 percent)
Step 3 : Selection of a region from the Cover equal in the size to that of message signal.
Step 4 : Comparison of variation of the pixel values between the cover and message signal.
Step 5 : Repetition of the above process by dynamically selecting windows all over the cover image.
Step 6 : Once the Percentage matching criteria is satisfied, the process terminates, otherwise, it is continued till the end of the cover image.
Step 7 : Output: (1) If percentage matching criteria is satisfied, then returns the Difference Matrix to ensure a smooth image with little variations. (2) If no matching region is found, returns a null matrix denoting failure of finding the specified percentage matching region.

The difference matrix (D) is then multiplied by proper embedding strength (K), and added to the respective pixel values of the cover image (C). The stego image can be obtained as follows:

$$S = C + K.D \tag{3}$$

B. Stage 2

The main objective is to find an optimal set of points using GA [4] so that an approximate version of difference signal can be generated.
1. Initialization of population: Chromosomal representation of the parameter values. The initial population is formed by taking almost equi-spaced x-y data points with small perturbations.
2. Select Mates: Objective : To select, most of the times, the best fitted pair of individuals for crossover.
Step 1 : Input : Population
Step 2 : Best fitted pair of Individuals are chosen by Roulette-wheel selection process by adding up fitness values of the individuals to get *Sumfitness*
Step 3 : Then randomly select Individuals to cross 50% of the *Sumfitness* value in a cumulative way
Step 4 : The particular Individual which crosses the 50% criteria in the Cumulative process, is chosen to be one of the mating pool pair.
Step 5 : This process is again carried on to find another Individual of the mating pool
Step 6 : Output : Pair of Individuals or mating pool
3. Crossover: Objective: To find the Crossover site and to perform crossover between the Mating pool pair to get new pair of more fitted Individuals.
Step 1 : Input: Mating pool pair
Step 2 : Finding the crossover site in a random manner
Step 3 : Exchange the portions lying on one side of crossover site of those mating pool pair
Step 4 : Output: New pair of Individuals
4. Mutation: Objective: To mutate or change a particular bit or allele in a Chromosome with a very small probability.
Step 1 : Choose a very small mutation probability
Step 2 : Depending upon that probability value, change a bit from '1' to '0' or '0' to '1'
Step 3 : The bit position selected for mutation is the Crossover site
5. Objective function: Objective : To estimate the fitness value of an Individual
Step 1 : Input: Population
Step 2 : On each Individual of the Population apply 2-D interpolation technique to approximate the original matrix
Step 3 : The absolute mean error is evaluated by subtracting the interpolated matrix from the original matrix

Step 4 : The inverse of that absolute mean error is considered to be the fitness value of that particular Individual

C. Stage 3

The final stage of the algorithm is the retrieval process of the message. An approximate version (D_{app}) of difference signal (D) is obtained using Linear Interpolation technique among the N points grayscale values calculated by Genetic Algorithm. The approximate cover image matrix C_{app} is then calculated using the Stego-image S and D_{app} as follows:

$$C_{app} = S - K.D_{app} \tag{4}$$

The message can be retrieved from the following relation:

$$L = C_{app} - D_{app} \tag{5}$$

where $D_{app} = K.D$.

5. Performance evaluation

The efficiency of the proposed algorithm is tested by embedding difference signal in several cover images. PSNR value for the watermarked image shown in Fig. 1(a) is 39.33 dB. As the number of generations are increased from 1000, 2000 to 4000, observation of Figs. (c), (d) and (e) reveals the fact that the retrieved watermark images are becoming more and more close to the original images. This is borne out by the property of Genetic Algorithm which produces better solutions as the number of generations are increased. The number of parameter values considered here are (20×20).

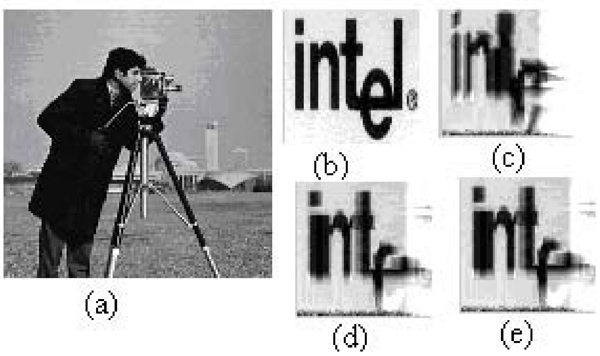

Fig. 1. (a) Watermarked image; (b) watermark image; (c)-(e) retrieved messages after 1000, 2000 and 4000 iterations respectively

Fig. 2 shows the retrieved watermark messages from the median filtered version of the watermarked images. Figs. show how the quality of retrieved messages are improved with number of iterations although the number of parameters value remain same.

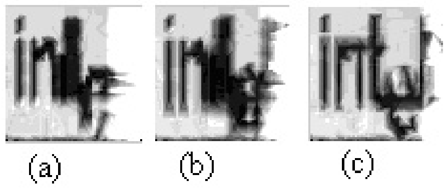

Fig. 2. Robustness performance of median filtering; (a),(b) and (c) indicate retrieved watermark messages after 1000, 2000 and 4000 iterations respectively

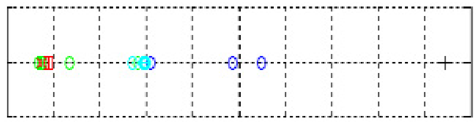

Fig. 3. Stego-test; Black cross–stego test image using proposed algorithm; (b)Colour circles–Sample stego images after various operations; (c)red square–untouched image

Fig. 3 shows the stego-test results. As we observe, this stego-test does not place the test image within the cluster for sample stego-images. Therefore, the test cannot decide with certainty that the test image is actually a stego-image. This establishes the security of the proposed algorithm against Farid's steganalytic technique involving higher-order statistics.

6. Conclusions

A data hiding algorithm with improved payload capacity is proposed for digital images. GA is used to achieve a set of parameter values so that faithful decoding of message is possible. The algorithm is proven to be secured against stego-test based on higher order statistics.

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