Genetic algorithm for optimal imperceptibility in image communication through noisy channel

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Abstract. Data embedding in digital images involves a trade off relationship among imperceptibility, robustness, data security and embedding rate etc. Genetic Algorithms (GA) can be used to achieve optimal solution in this multidimensional nonlinear problem of conflicting nature. The use of the tool has been explored very little in this topic of research. The current paper attempts to use GA for finding out values of parameters, namely reference amplitude (A) and modulation index (μ) both with linear and non linear transformation functions, for achieving the optimal data imperceptibility. Results on security for the embedded data and robustness against linear, non linear filtering, noise addition, and lossy compression are reported here for some benchmark images.

1 Introduction

The properties of data hiding techniques in digital images such as perceptual transparency, higher capacity, statistical invisibility or security of the hidden data, and robustness to some types of attacks are related in a conflicting manner and the design tradeoff depends on the applications (see [1]and [2]). Genetic Algorithms (GAs) can be used to optimize the conflicting requirements of data hiding problem but the use of the tool has been explored very little in this topic of research although there are many problems in the area of pattern recognition and image processing [3] where GAs perform an efficient search in complex spaces in order to achieve an optimal solution.

In the present paper GA is used to find two parameter values, namely reference amplitude (A) and modulation index (μ) in linear and non linear transformation functions used to modulate the auxiliary message. The cover object (image) is chosen in which the message is well hidden unlike in watermarking applications where the message must be hidden in the cover work to which it refers and no other. Image regions with relatively low information content and having pixel values in the lower and upper portion of the dynamic range are used for data hiding as the characteristics of human visual system (HVS) are less sensitive to the change at these two ends.

The paper is organized as follows. Sections 2 describes transformation functions for message modulation and how to calculate the range of parameters. Genetic algorithm for data embedding is presented in section 3 with embedding and recovery process in section 4. Sections 5 and 6 present some results for highlighting the use of GA and conclusions respectively.

2 Modulation function and calculation of parameters

The cover and the auxiliary message are chosen as gray level images and the auxiliary message is modulated using suitable transformation functions to match the characteristics of the cover image regions. Distortions are then created over stego image to simulate the behavior of a noisy channel.

The power-law function $X^{'} = A(X + \varepsilon)^{\mu}$ which is widely used for image enhancement operation is considered as modulation function. Here X denotes the pixel value in auxiliary message and transformation function modulates X to $X^{'}$, the pixel value of the cover image selected for embedding. Two other transformation functions, One is linear transformation function of the form $X^{'} = A(1 + \mu X)$ and other one is parabolic function of the form $X^{'} = A(1 + \mu\sqrt{X})$, are compared for their suitability on imperceptibility, security and robustness issues of data embedding. The following sub sections describe how to calculate the range of parameter values.

2.1 Calculation of *A*

The modulation function is as follows:

$X^{'} = A(X + \varepsilon)^{\mu}$ (1)

Differentiating $X^{'}$ with respect to X, we get

$dX^{'}/dX = A\mu(X+\varepsilon)^{\mu-1}$ (2)

Here $dX^{'}/dX$ is positive provided $A > 0$, $\mu > 0$ and $(X + \varepsilon) > 0$, which implies $X^{'}$ increases monotonically with X. The upper ($U^{'}$) and lower ($L^{'}$) bound of the modulated pixel values are

$U^{'} = X^{'}_{max} = A(X_{max} + \varepsilon)^{\mu}$ (3)

$L^{'} = X^{'}_{min} = A(X_{min} + \varepsilon)^{\mu}$ (4)

The range (Ψ) of the modulated pixel values is given as follows:

$\Psi = U^{'} - L^{'} = A[(X_{max} + \varepsilon)^{\mu} - (X_{min} + \varepsilon)^{\mu}]$(5)

The relation shows that for large A value, the span of the modulated pixel values (Ψ) will be large leading to smaller probability of matching between the modulated message and embedding regions. This in turn suggests to select lower value of A for better imperceptibility. The small span (Ψ) is also possible for large A value provided very small value is selected for μ. But it is shown in the detection process that small value of μ will make the auxiliary message vulnerable to elimination in noisy transmission media. Similar argument also holds good for the value of A. The value of A depends on selection of the auxiliary message as well as regions selected for embedding. As rule of thumb A is selected as

$A = X^{'}_{mode}/(X_{mode} + \varepsilon)^{\mu}$ (6)

where $X^{'}_{mode}$ and X_{mode} respectively denote the mode of the gray values for the embedding regions and the auxiliary messgaes.

2.2 Calculation of μ

Power-law transformation suggests if μ value is taken small ($\mu < 1.0$) keeping A constant, auxiliary message is mapped into a narrow range of gray values. This fact is also supported by equation (5). Confinement of gray values inside a narrow range increases the probability of matching between the modulated message and the data embedding region. But very small value of μ makes the detection of message impossible even after a very small image distortion. The upper and lower value of μ are calculated as follows:
It is found that $X^{'}$ is a monotonically increasing function of X. The value of ε, acts as offset value in image display, is set to (~ 0.01). From equation (1), we write $X^{'}_{max} = A(255 + 0.01)^{\mu} = A(255.01)^{\mu}$
The maximum X value is taken 255 for monochrome gray level image. The corresponding μ value is designated as μ_{max} and is related with X_{max} and A as follows: $\mu_{max} \simeq \frac{\log X^{'}_{max} - \log A}{\log 255}$
Similarly, μ_{min} value can be written as follows:
$\mu_{min} \simeq \frac{\log X^{'}_{min} - \log A}{\log 0.01} = \frac{\log A - \log X^{'}_{min}}{2.0}$
The value of μ will be positive if A lies between X_{max} and X_{min} where the later values represent the maximum and minimum gray values of the embedding regions respectively.

3 GA for data hiding

Let us analyze the use of GA in data hiding problem (any problem) and the main steps are as follows [4]:
(1) Chromosomal representation of the parameter values, namely the reference amplitude (A) and modulation index (μ) associated with the problem.
(2) Creation of an initial population of chromosomes for possible solutions by using random binary strings of length pq where p represents the number of parameters and q are the bits assigned for each parameter.
(3) To quantify the closeness measure among pixel values over sub image or image, average Euclidean distance is considered here as fitness function. The value of pay-off function can be expressed mathematically as follows:

$$F(A, \mu)=\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}[S_{ij} - e_{ij}(A,\mu)]}{N^2} \quad (7)$$

where S_{ij} is the gray value of (i, j)-th pixel of the embedding region, $e_{ij}(A, \mu) = A(X_{ij} + c)^{\mu}$, is the gray value of (i, j)-th pixel of the message after modulation and N^2 is the total number of pixels in the embedding regions as well as in the auxiliary message.
(4) According to De Jong's elitist model [5], the best fit string obtained is included in the new population to preserve the best structure in the population.
(5) Although the high mutation probability leads to exhaustive search which

may results in better imperceptibility at higher computation cost. Here moderate value of mutation probability is chosen in order to achieve imperceptibility at comparatively lower cost.
Size of the population is 20, Number of generations are 800, Probability of crossover per generation is 0.95, probability of mutation is 0.005.

4 Message hiding and recovery

The particular cover image can be selected from its histogram on the basis of higher frequency of occurrence in pixel values in either end and the auxiliary message is modulated using the transformation functions. The message modulated by transformation function using GA replaces the selected regions of the cover image.

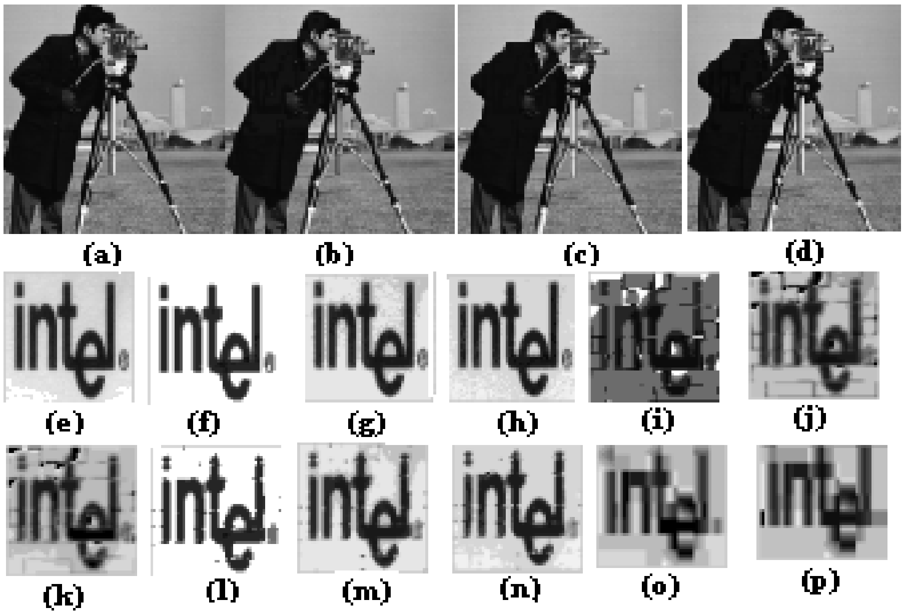

Fig. 1. (a) Cover image; (b), (c), (d) Stego images using power-law (PSNR=41.77 dB), parabolic function (PSNR=51.58 dB), linear function (PSNR= 47. 45 dB) respectively; (e) Auxiliary message; (f), (g), (h) Extracted messages from (b), (c), (d) respectively; (i), (j), (k) Extracted messages from mean filtered stego images when power law, parabolic, linear functions are used respectively; (l), (m), (n) Extracted messages from median filtered stego images when power law, parabolic, linear functions are used respectively; (o), (p) Extracted messages from compressed (JPEG) stego images (PSNR=31.06 dB) and (PSNR=31.88 dB) using power law and linear function respectively.

Data recovery process uses inverse transformation function that maps X' into X and thus message is recovered. If power-law, linear and parabolic functions are used for message modulation, extracted message can be represented respectively as follows:

$X=(X^{'}/A)^{1/\mu} - \varepsilon$ (8)

$X=(1/\mu A)(X^{'} - A)$ (9)

$X=1/(\mu A)^{2}(X^{'} - A)^{2}$ (10)

Differentiating equations (8),(9) and (10) with respect to $X^{'}$ the following equations are obtained respectively,

$dX/dX^{'} = (1/\mu)(1/A)^{1/\mu}(X^{'})^{1/\mu-1}$ (11)

$dX/dX^{'} = 1/\mu A$ (12)

$dX/dX^{'} = 2(X^{'} - A)/(\mu A)^{2}$ (13)

$dX/dX^{'}$ denotes the change of X with respect to the change of $X^{'}$ i.e. a measure of noise immunity in the detection process. The large values of A and μ are preferable for reliable decoding whereas small values of the same are desirable for better imperceptibility. Lower value of $dX/dX^{'}$ indicates better reliability in detection process.

5 Results and discussions

The efficiency of the proposed algorithm is tested by embedding different messages in several cover images like Cameraman (results reported), Black bear, Bandron [6] etc. and the messages are extracted from various noisy version of the stego images. Peak signal to Noise Ratio (PSNR), relative entropy distance (Kulback Leibler distance)[7], and mutual information [8] are used as representative objective measures of data imperceptibility, security and robustness respectively. Table 1 shows the robustness results where 1, 2, and 3 used in the objective measures indicate the results for power-law, linear and parabolic functions respectively.

Robustness efficiency against mean, median filtering and lossy compression are shown in respective figures. Poor robustness in the case of power law function is supported by eqn. (11) where small values of A and μ causes change in $X^{'}$ manifold even for the small change in X. Linear transformation function offers better imperceptibility as large range of message gray values can be mapped to smaller range by choosing the small slope i.e. the product of A and μ. At the same time better resiliency is achieved since $dX/dX^{'}$ (equation 12) is no way dependent on $X^{'}$ although very small values of A and μ will affect the detection process. Best data imperceptibility and security result is possible in case of parabolic function, as small values of A and μ map wide range of message gray values to the narrow region in the lower range of pixel values of the cover image. Detection reliability in such case is also satisfactory since $dX/dX^{'}$ does not contain $X^{'}$ with power term of A and μ like power law transformation function, although small values of the parameters affect detection process little more compared to linear transformation function.

Table 1. Performance results of different modulation functions

Generation number	PSNR $(\mathrm{dB})_1$	ε value (1)	$I(X;Y)$ value(1)	PSNR $(\mathrm{dB})_2$	ε value (2)	$I(X;Y)$ value(2)	PSNR $(\mathrm{dB})_3$	ε value (3)	$I(X;Y)$ value(3)
50	40.56	0.046	0.28	43.49	0.037	0.48	45.42	0.037	0.38
150	40.79	0.045	0.21	44.36	0.040	0.44	46.74	0.037	0.39
400	40.90	0.041	0.20	47.90	0.036	0.42	48.73	0.036	0.34
600	41.50	0.039	0.19	48.36	0.030	0.39	50.37	0.025	0.35
800	41.77	0.038	0.15	47.45	0.034	0.40	51.53	0.023	0.32

6 Conclusions

The paper proposes an invisible image-in-image communication through noisy channel where linear, power-law and parabolic functions are used to modulate the auxiliary messages. GA is used to find the optimal parameter values, viz. reference amplitude (A) and modulation index (μ) for data imperceptibility. Experimental results show that parabolic function offers higher visual and statistical invisibility and reasonably good robustness, whereas, linear function offers higher robustness with reasonably good invisibility. Power-law function neither provides good resiliency nor imperceptibility. Future work can be directed to develop better form of modulation functions in order to improve the robustness performance against various types of distortions in stego images along with higher embedding rate.

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