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ABSTRACT

This paper presents data an Ant colony optimization (ACO) based data hiding technique. ACO is used to detect complex region of cover image and afterward, least significant bits (LSB) substitution is used to hide secret information in the detected complex regions' pixels. ACO is an algorithm developed inspired by the inborn manners of ant species. The ant leaves pheromone on the ground for searching food and provisions. The proposed ACO-based data hiding in complex region establishes an array of pheromone, also called pheromone matrix, which represents the complex region in sequence at each pixel position of the cover image. The pheromone matrix is developed according to the movements of ants, determined by local differences of the image element's intensity. The least significant bits of complex region pixels are substituted with message bits, to hide secret information. The experimental results, provided, show the significance of the performance of the proposed method.

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1. INTRODUCTION

Image steganography is information hiding technique that use digital image as cover media. Along with secret exchange of information, it has various other applications e.g. copyright, data integrity and authentication [1], [2]. Digital audio, video and text can also be used as a cover, but image is adopted most widely for this purpose due its high redundancy.

Data hiding techniques are explored by many researchers and proposed various good hiding techniques to insure security of hidden information. Honsinger et al.'s and Fridrich et al.'s proposed steganography methods in spatial domain by hiding secret information directly in image pixels [3], [4]. Sahib et al. proposed variable least significant bits (VLSB) steganography and presented techniques, like modular distance technique (MDT) [5], decreasing distance decreasing bits algorithm (DDDBA) [6], varying index varying bits substitution (VIVBS) algorithm [7]. Sahib et al., inspired from chipper block chaining (CBC) encryption, proposed new techniques of stego block chaining (SBC) and enhanced stego block chaining (ESBC) to hide information in digital images [8].

The aim of all data hiding techniques is to make the presence of hidden information undetectable and this attracted the attention of researcher to make use of HVS limitation. HVS can very easily detect the variations made in smooth area of cover image as compared to the changes in complex region. Due to this characteristic of the HVS, complex region of cover image is subjected to hiding and smooth region is not modified [9], [10]. In some techniques, complex region is subjected to more to data hiding than smooth region. This approach results in high quality of the stego-image, which means increase in the security of hidden information. Various techniques, including LSB methods [11], PVD methods, and side-match methods [12], [13], have been proposed to hide information in complex area of cover; a detail can be found in [14], [15]. But, these techniques present a low hiding capacity and don't comply completely with the rules that the complex region can bear more changes than smooth region [12], [13]. To increase data hiding capacity Jung et al. [16] presented a new technique that hides data in smooth areas along with edges, but results in more distortion. However, the methods adopted by these data hiding techniques for detection of complex region are more vulnerable to noise.

The proposed technique is one such effort towards data hiding in complex region of cover image. The hiding information in cover media does not attract the human attention and the presence of hidden information is not perceivable to HVS. This technique made use of ACO, a nature-inspired optimization algorithm [17-19] for detection of complex region [20], and secret information are embedded in LSB of the complex region pixels [21], [22]. The forthcoming contents of the paper are organized as follow. Section 2, presents the ACO based data hiding in complex, the experimental results are presented in Section 3 and at end papers is concluded with Section 4.

2. PROPOSED TECHNIQUE

The detection of complex region in cover image is the key step in hiding of information in complex region. There various methods to detect complex region in images. These methods include canny edge detection, deriche, differential, sobel, prewitt, Roberts cross and other methods. These methods are very efficient to detect complex region in digital images but, these methods don't comply completely with the rules that the complex region and hide data in complex region previous methods hide data in the complex region of cover image as most of these methods detect weak and disconnected edge pixels and consider that as true complex region. But, these techniques also hide data in those pixels that doesn't belong to edges and are more vulnerable to noise. In this paper an ACO based technique has been used to detect complex region in cover image [23], [24] and then to target this region for data hiding using LSB steganography.

ACO-based image edge detection approach, construct a pheromone matrix, utilizing many ants to move on a 2-D image. The movement of the ants is guided by the local differences of the image pixel's intensity values. The entries of the pheromone matrix represent the edge information at each pixel location of the cover image. The ACO based technique is initialized first and run for N iterations to build pheromone matrix. The process performs both construction and update steps iteratively. At the end decision process is used to determine the pixels belong to complex region. The whole process is explained here in detail as follow.

2.1. Initialization

A digital image is an array of pixels with intensity level I. Let consider a grayscale image of size $M_1 \times M_2$, as cover medium. A total of K ants are randomly assigned on an image C. Each pixel of the cover image is considered as a node. To initialize the complex region detection, process the initial value of each pheromone matrix's component $\tau^{(0)}$ is set to a constant $\tau_{initial}$.

2.2. Construction

The construction process is composed various steps, at the nth construction-step, one ant, from a total of K ant, is randomly selected. The selected ant can move over the cover image for N_{mov} movement steps. The movement of the ant from initial node (x, y) to its neighbor node (i, j) is done according to the transition probability $\mathrm{p}^{(\mathrm{n})}_{(\mathrm{x,y}),(\mathrm{i,j})}$ as given by Equation (1)

$$\mathrm{p}^{(\mathrm{n})}_{(\mathrm{x,y}),(\mathrm{i,j})} = \frac{\left(\tau_{i,j}^{(n-1)}\right)^{\alpha} (\eta_{i,j})^{\beta}}{\sum_{(i,j)\in\Omega_{(x,y)}} \left(\tau_{i,j}^{(n-1)}\right)^{\alpha} (\eta_{i,j})^{\beta}} \quad (1)$$

Where

$\tau_{i,j}^{(n-1)}$: Pheromone value at node (i, j)

$\Omega_{(x,y)}$: Neighborhood (4 or 8-connected) node of the node (x, y)

$\eta_{i,j}$:Heuristic information at node (i, j)

α : Influence of pheromone matrix

β : Influence of heuristic matrix

The heuristic information at any node (i, j) is calculated using Equation (2).

$$\eta_{i,j} = \frac{V_c(C_{i,j})}{Z} \quad (2)$$

Where Z is the normalization factor and given by Equation (3).

$$Z = \sum_{i=1:M_1} \sum_{J=1:M_2} V_c(C_{i,j}) \quad (3)$$

Where

$C_{i,j}$: The intensity level pixel (i, j) of image C

The $V_c(C_{i,j})$ depends on the variation in gray levels of strength of pixels in the clique c is represented as by Equation (4)

$$V_c(C_{i,j}) = f(|C_{i-2,j-1} - C_{i+2,j+1}| + |C_{i-2,j+1} - C_{i+2,j-1}| + |C_{i-1,j-2} - C_{i+1,j+2}| + |C_{i-1,j-1} - C_{i+1,j+1}| + |C_{i-1,j} - C_{i+1,j}| + |C_{i-1,j+1} - C_{i-1,j-1}| + |C_{i-1,j+2} - C_{i-1,j-2}| + |C_{i,j-1} - C_{i,j+1}|) \quad (4)$$

To calculate f (.) there are four different function Flat, Gaussian, Sine and Wave and each of them is considered in this paper and are given here in Equation (5) to Equation (8).

$$f(x) = \lambda x \; for \; x \geq 0 \quad (5)$$

$$f(x) = \lambda x^2 \; for \; x \geq 0 \quad (6)$$

$$f(x) = \begin{cases} \sin\left(\frac{\pi x}{2\lambda}\right) \; 0 \leq x \leq \lambda \\ 0 \; else \end{cases} \quad (7)$$

$$f(x) = \begin{cases} \frac{\pi x \sin\left(\frac{\pi x}{\lambda}\right)}{\lambda} \; 0 \leq x \leq \lambda \\ 0 \; else \end{cases} \quad (8)$$

Where

λ : The shape control parameter for functions.

2.3. Updating Stage

The pheromone matrix is updated in two steps. The first updating is performed, in each construction step, after the movement of each ant, according to Equation (9)

$$\tau_{i,j}^{(n-1)} = \begin{cases} (1-\rho).\tau_{i,j}^{(n-1)} + \rho.\Delta_{i,j}^{(k)}, if \; (i,j) is \; visited \; by \; K \; ant \\ \tau_{i,j}^{(n-1)} \; otherwise \end{cases} \quad (9)$$

Where

ρ: The evaporation rates

$\Delta_{i,j}^{(k)}$: Determined by heuristic matrix is equal to $\eta_{i,j}$

When the entire ant completes their movement in each construction step, the second updating process is performed using Equation (10).

$$\tau^{(n)} = (1-\psi).\tau^{(n-1)} + \psi.\tau^{(0)} \quad (10)$$

Where

ψ:The pheromone decay coefficient

2.4. Decision Stage

The decision process is the final is binary decision-making process to decide whether the pixel belong to complex region or smooth region. In this a threshold is applied on the final pheromone matrix τ^N. The threshold is computed according to the technique presented in [20].

The mean of value of pheromone matrix is selected as initial threshold $T^{(0)}$. Then all the pheromone matrix entries are divided in two groups. One group contains all the value smaller than the initial threshold $T^{(0)}$ and other possess the value greater than the initail threshold $T^{(0)}$. Means values of each of the group is calculated and new threshold is defined as the average of both means. The process of for calculation of threshold is repeated till the threshold value reaches to a stable value in term of user define tolerance ε.

Final decision for each pixel at (i, j) is made on the bases of the pheromone vale $\tau_{i,j}^{(N)}$at postion (i, j) compared with the final threshold value $T^{(l)}$ as given by Equation (11).

$$E_{i,j} = \begin{cases} 0 \; if \; \tau_{i,j}^{(N)} \geq T^{(l)} \\ 1 \; otherwise \end{cases} \quad (11)$$

Where

E: The baniary image

If the pheromone value at current position (i, j) is greater than threshold it is, consider as a part of complex region and other its treated as smooth region pixel.

2.5. Data Hiding Process

The data hiding step is the LSB substitution process. This stage hides secret information in the LSBs of the cover image on the bases of the complex region detected. In this process whole cover image C is considered and is processed pixel by pixel. Each pixel $C_{i,j}$ is check whether it belongs to complex region or smooth region. If the pixel corresponds to smooth region it is left unaffected and another pixel is considered. And if the pixel belongs to complex region then its LSB bits are substitued with the secret information. This process continues until the whole cover image is explored. The hiding process is accomplished in following manner.

A pixel $C_{i,j}$ is cosider as complex region pixel if its correspding $E_{i,j}$=0 and is consider smooth region componant if $E_{i,j=}1$. Lets cosider a secret messahe m to be hidden in complex region and S is final stego image obtained after information hiding. The stego image S is given by Equation (12).

$$S_{i,j} = \begin{cases} C_{\,i,j} * m \; if \; E_{i,j} = 0 \\ C_{\,i,j} \; if \; E_{i,j} = 1 \end{cases} \quad (12)$$

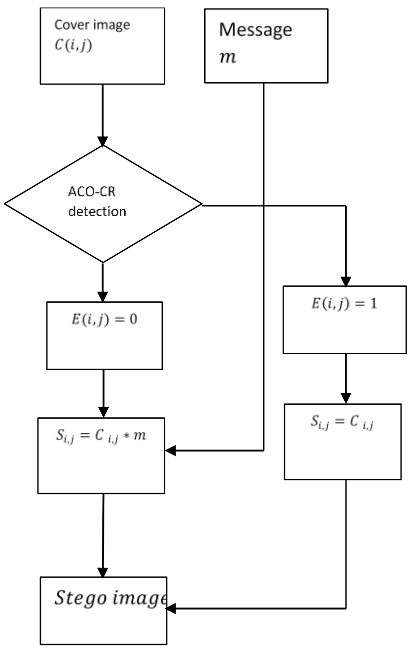

Figure 1. ACO-based data hiding in complex region

3. IMPLEMENTATION, EXPERIMENTAL RESULTS AND ANALYSIS

To hide secret data in complex region of cover image using ACO algorithm and get experimental results, many different cover images are used. These cover images include, Cameraman, Lena, House, Jelly beans, Mandrill, Pepper, Tiffany and Tree as presented in Figures 2(a), 2(b), 2(c), 2(d), 2(e), 2(f), 2(g) and 2(h), respectively. All these cover images are taken from image used are of the same size of 128×128. Each of the cover is subjected to data hiding using the proposed technique. As discusses earlier ACO can be used for complex region detection using four different functions i.e. Flat, Gaussian, Sine and Wave as given by Equation (5) to Equation (8), respectively. After the complex region and smooth region's pixel classification, an LSB substitution technique is used for data hiding in the complex region's pixels only.

ACO approach is dependent on a very large number of parameters. The parameters set for the experimentation are given as:

The shape control parameter λ= 10
The influence of pheromone matrix α = 1
The influence of heuristic matrix β = 0.1
The evaporation rate ρ = 0.1
The pheromone decay coefficient ψ = 0.05

To analyze the proposed technique quantitatively, the data hiding capacity the *MSE* and *PSNR* are calculated as given by Equation (13) to Equation (15), respectively [20].

$$\mathrm{HC} = \frac{\text{No.bits hidden}}{\text{Total bits of Cover image}} \times 100 = \frac{\mathrm{m}}{\mathrm{r}*\mathrm{c}*8} \times 100 \qquad (13)$$

$$\mathrm{MSE} = \frac{\sum_{i=1}^{r}\sum_{j=1}^{c}(\mathrm{Cover}(i,j)-\mathrm{Stego}(i,j))^2}{\mathrm{r}*\mathrm{c}} \qquad (14)$$

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2}{\mathrm{MSE}} \qquad (15)$$

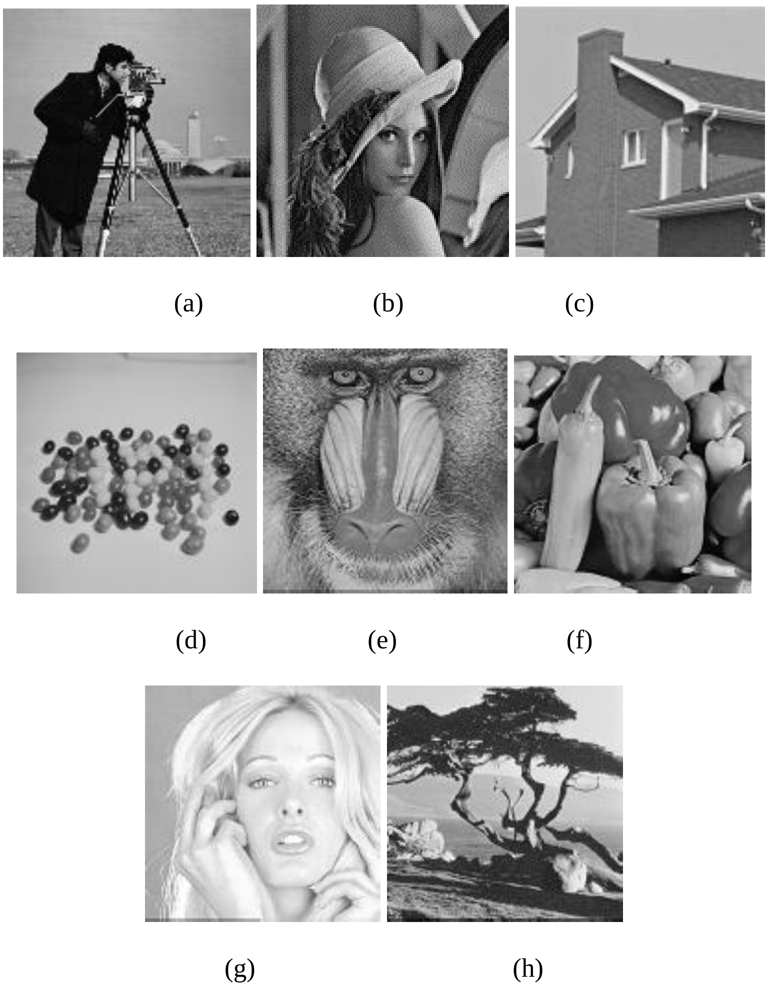

Figure 2. Cover Images (a) Cameraman, (b) Lena, (c) House, (d) Jelly Beans, (e) Mandrill, (f) Pepper, (g) Tiffany, and (h) Tree

Firstly, the proposed technique is applied on all the cover images shown in Figure 2. Flat function as given by Equation (5) has been used in ACO based complex region detection. The stego images obtained are shown in Figure (3). The hiding capacity, MSE and PSNR calculated for each cover image is listed in Table 1.

(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 3. Stego Images obtained using Flat function given in Equation (5) (a) Cameraman, (b) Lena, (c) House, (d) Jelly Beans, (e) Mandrill, (f) Pepper, (g) Tiffany, and (h) Tree

Table 1. Hiding Capacity, PSNR and MSE using Flat Function

Cover Image	PSNR (dB)	MSE	Hiding Capacity (%)
Cameraman	45.74131	1.7336	4.1229
Lena	50.27679	0.6101	4.5105
House	46.43288	1.4784	4.0344
Jelly Beans	46.71787	1.3845	4.0558
Mandrill	45.95596	1.6500	5.5817
Pepper	47.14022	1.2562	4.5776
Tiffany	45.84321	1.6934	4.5837
Tree	45.77451	1.7204	5.2399

Secondly, ACO based data hiding in complex region techniques is implemented the same cover images shown in Figure 2, but using Gaussian function, as given by Equation (6). The resulted stego images are displayed here Figure 4. The hiding capacity, MSE and PSNR calculated, using each cover image for information hiding, is listed in Table 2.

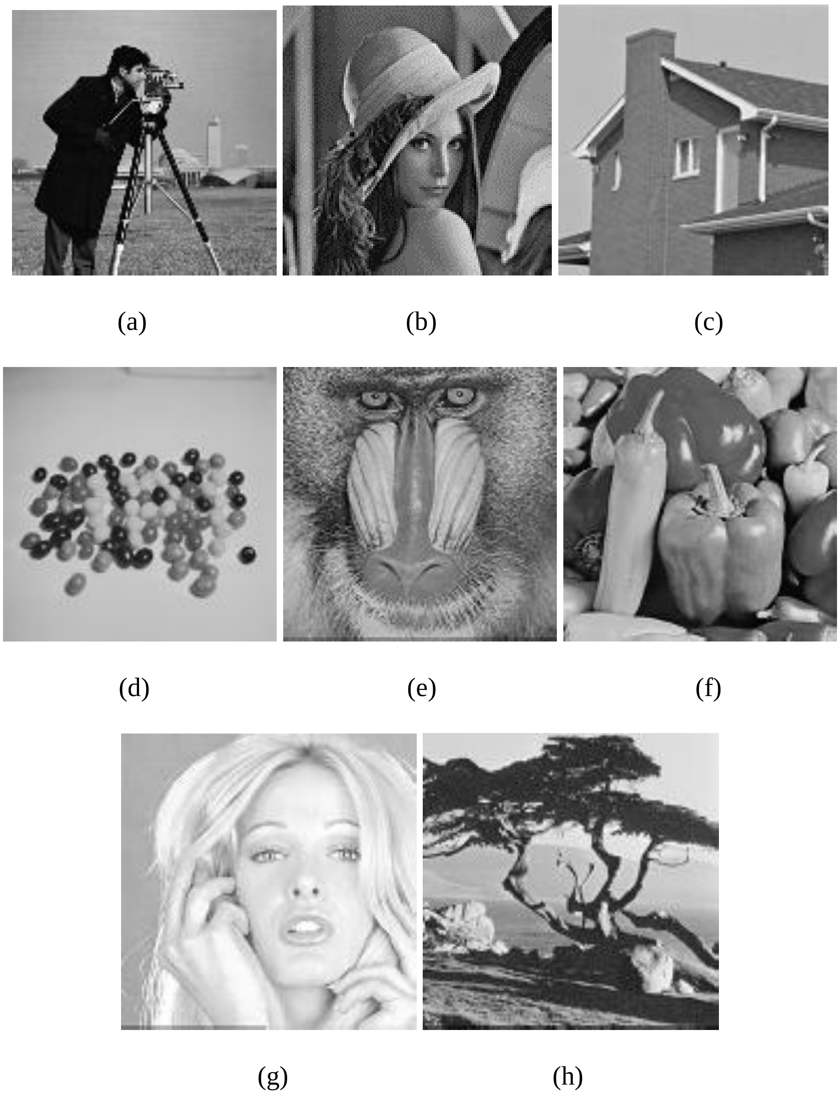

Figure 4. Stego Images obtained using Gaussian function given in Equation (6) (a) Cameraman, (b) Lena, (c) House, (d) Jelly Beans, (e) Mandrill, (f) Pepper, (g) Tiffany, and (h) Tree

Table 2. Hiding Capacity, PSNR and MSE using GaussianFunction

Cover Image	PSNR (dB)	MSE	Hiding Capacity (%)
Cameraman	46.23899	1.5459	3.1647
Lena	52.68888	0.3501	2.1667
House	48.79289	0.8586	1.8951
Jelly Beans	48.3673	0.9470	2.4780
Mandrill	50.35944	0.5986	2.6489
Pepper	48.23987	0.9752	2.9724
Tiffany	49.16224	0.7886	2.0294
Tree	47.12503	1.2606	4.3274

Similarly, in third step all the cover images given in Figure 2 are subjected to data hiding using the proposed technique. Moreover, this time Sine function given in Equation (7) is used in ACO complex region detection. The obtained stego images, with hidden information inside it, are shown here Figure (5). The Table 3 contains the calculated hiding capacity, MSE and PSNR for all cover images.

Figure 5. Stego Images obtained using Sine function given in Equation (7) (a) Cameraman, (b) Lena, (c) House, (d) Jelly Beans, (e) Mandrill, (f) Pepper, (g) Tiffany, and (h) Tree

Table 3. Hiding Capacity, PSNR and MSE using Sine Function

Cover Image	PSNR (dB)	MSE	Hiding Capacity (%)
Cameraman	45.23581	1.9476	4.4312
Lena	50.54471	0.5736	4.3854
House	46.63738	1.4104	3.7842
Jelly Beans	45.67469	1.7604	4.1870
Mandrill	46.5508	1.4388	5.8777
Pepper	46.12038	1.5887	4.5044
Tiffany	46.13627	1.5829	4.4250
Tree	45.81178	1.7057	5.5786

Lastly, Wave function, mathematically given by Equation (8), is used by ACO algorithm to classify, the complex and smooth region's pixels and the cover images obtained after data hiding in complex region are shown in Figure 6. The values of hiding capacity, MSE and PSNR are listed in Table 4.

The results show that all the ACO based data hiding in complex region results in significantly high quality stego images. However, Flat function in Equation (5) and Sine function in Equation (7), are very efficient both in term of hiding capacity and stego image quality.

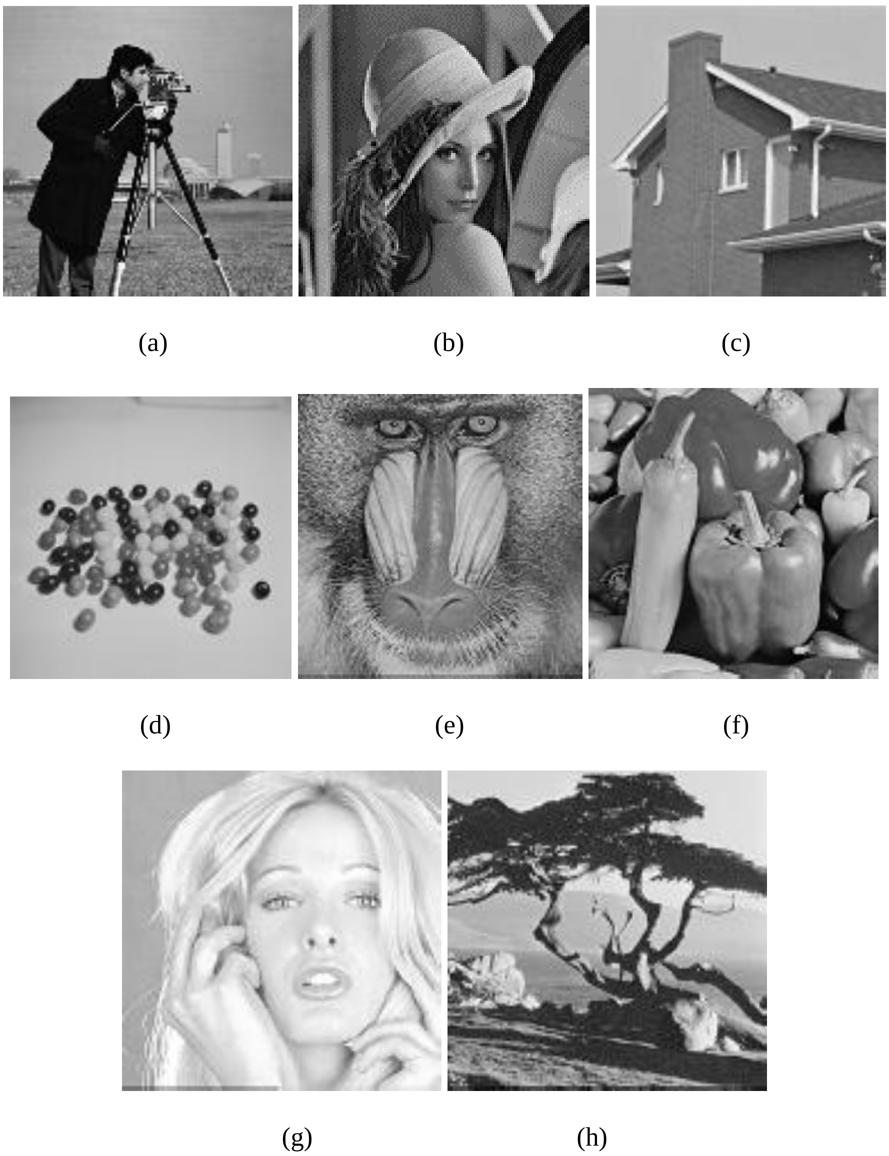

Figure 6. Stego Images obtained using Wave function given in Equation (8) (a) Cameraman, (b) Lena, (c) House, (d) Jelly Beans, (e) Mandrill, (f) Pepper, (g) Tiffany, and (h) Tree

Table 4. Hiding Capacity, PSNR and MSE using Wave Function

Cover Image	PSNR (dB)	MSE	Hiding Capacity (%)
Cameraman	46.90996	1.3246	2.9755
Lena	52.65306	0.3530	2.4200
House	48.5624	0.9054	2.0874
Jelly Beans	47.54692	1.1439	2.8076
Mandrill	48.88336	0.8409	2.8473
Pepper	47.8757	1.0605	2.8661
Tiffany	49.45377	0.7374	2.1210
Tree	46.90079	1.3274	4.1229

4. COMPARISON WITH OTHER TECHNIQUES

As discussed in Section 3, the proposed method results in a very high quality stego images with PSNR greater than 100dB for all images using all four functions mentioned in Section 2. Here, this represents the comparison of the proposed method with different previous techniques. As the proposed technique is data hiding method that hides secret information in complex region of cover images. Therefore, a comparison of the proposed technique is made only with the data hiding techniques that uses edges or complex region of cover images. The comparison is made with Fridrich et al. [3], Honsinger et al. [4], Khan et al. [24], Goljan et al. [25], Macq and Dewey [26], and Vleeschouwer et al. [27], in term of PSNR and hiding capacity. The comparison made using Lena and Mandrill as cover images. The resulted values of hiding capacity and PNSR are listed in Table 5.

The Honsinger et al. and Fridrich et al. techniques results in a hiding capacity of less than 0.0156 bpp and 0.0156 bpp, respectively. Vleeschourwer et al. achieve a hiding capacity of 0.156 bpp, with significantly stego image quality of 30dB in term of PSNR. Macq and Deweyand proposed technique, increases the data hiding capacity and results in a hiding capacity more than Honsinger et al., Fridrich et al. and Vleeschourwer et al. techniques. A hiding capacity of less than 0.03125 is recorded, but the visual quality of the stego image is affected very much. Goljan et al. and Khan et al. presented techniques claim hiding capacity of 0.36bpp and 0.33bpp, with PSNR of 39.00dB and 46.23dB respectively. The proposed technique resulted in a hiding capacity of 0.36 and 0.44 with PNSR greater than 50dB and 45dB for Lena and Mandrill cover images, correspondingly.

The Table 5 shows that the PSNR of the proposed technique is significantly higher than the PSNR values of all the other techniques. While, the hiding capacity of the proposed technique is also higher than all techniques except that of Goljan et al. and Khan et al. techniques. ACO based data hiding in complex region has equal data hiding capacity as that of Goljan et al. but, the quality of the stego images is significantly better than the Goljan et al.

Table 5. Comparison of proposed method with other methods

Technique	Lena		Lena	
	Hiding Capacity (bpp)	PSNR (dB)	Hiding Capacity (bpp)	PSNR (dB)
Honsinger et al.	<0.0156	-	<0.0156	-
Fridrich et al.	0.0156	-	0.0156	-
Vleeschouwer et al.	0.0156	30.00	0.0156	29.00
Macq and Deweyand	<0.03125	-	<0.03125	-
Goljan et al.	0.36	39.00	0.44	39.00
Khan et al.	0.33	46.23	0.669	44.12
Porposed technique	0.36	>50	0.44	>45

5. CONCLUSION

ACO based data hiding in complex region of digital images is an efficient data hiding technique that successfully exploits the HVS limitation of less sensitivity to the changes in complex regions. This technique results in high data hiding capacity with significantly good quality stego image. The beauty of the proposed technique lies in the fact that hiding capacity can be controlled by changing the function in ACO classification stage and the hiding capacity can be increased significantly with affecting the PSNR by choosing either Flat function in Equation (5) or Sine function in Equation (7), instead of Gaussian and Wave functions in Equation (6) and Equation (8), respectively. The hiding capacity and *PSNR* of the proposed work is higher than or comparable to other methods. The PSNR of the proposed method remain above 100 dB for all images as discussed in Section IV. In short, the ACO based data hiding in complex region technique is an efficient and secure data hiding method, resulting in a high quality stego-image, significantly high PSNR and reasonable data hiding capacity.

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