Journal of Discrete Mathematical Sciences & Cryptography
ISSN 0972-0529 (Print), ISSN 2169-0065 (Online)
Vol. 28 (2025), No. 5-A, pp. 1835–1843
DOI : 10.47974/JDMSC-2183

An efficient image steganography using spider monkey optimization

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Abstract

Image steganography, which encodes secret information into digital photos, is crucial for covert communication. It's critical to strike a delicate balance between maintaining the altered image's visual quality (imperceptibility) and concealing just the right amount of information (embedding rate). This paper proposes image steganography using Spider Monkey Optimization (SMO) in conjunction with Least Significant Bit (LSB) embedding, applied on 4-Cover Image Set of Lena-Pepper-Baboon-Jet of pixel size 256 x 256 to optimize

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pixel selection and reduce distortion to enhance embedding efficiency and security. It finds the optimal solution using SMO algorithm and inserts the message using least significant bit that exhibits the superior performance in order to imperceptibility and payload capacity, compared to Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) along with existing methods. Experimental results depict SMO score 4-6 percent and 10-16 percent in Peak Signal-to-Noise Ratio (PSNR) and Mean Squared Error (MSE) over GA and PSO algorithms.

Subject Classification: *Primary 68M25, Secondary 68T01.*

Keywords: *Image steganography, Optimization, Spider monkey optimization, LSB, PSNR, MSE, Steganalysis.*

1. Introduction

Steganography is a widely used method in information security that guarantees security during data transmission. This method transmits a message that is encoded discretely in a carrier and that only the recipient can decipher. Many types of carriers can be used, including text, images, audio, and video.

The mode of steganography that we will be proposing is Image steganography. This work investigates the application of Spider Monkey Optimization (SMO) to enhance image steganography techniques. SMO is a powerful metaheuristic algorithm that may be used to optimize message content (Stego-Message Optimization), among other features. It was inspired by the social foraging behavior of spider monkeys. The quantity of data that can be embedded may be limited by typical steganographic techniques due to the constraints of maintaining image integrity.

This paper is compiled into five sections: the systematic literature review of more than a decade to discuss about the different optimization techniques applied for image steganography is given in Section 2. Section 3 comprises a proposed solution approach with an overview of all the algorithms used. Section 4 discusses experimental results and comparative analysis of GA, PSO and SMO optimization techniques. Section 5 presents the conclusion in terms of proposed research outcome of an efficient image steganography using spider monkey optimization and future scope.

2. Related Work

Image Steganography is categorized into three major classes: Spatial, Transfer and Hybrid Steganography domain. In spatial domain, information is exactly embedded in the pixel values of cover-images. It is most popular, straightforward and effective. Least Significant Bit Substitution and Pixel Value Differencing are two generally used techniques in spatial domain steganography.

Sutaone and Khandare [1] presented a technique for LSB substitution in which Random LSB insertion is utilized to distribute secret data across the cover-image. Authors [2] described a technique that combines steganography and cryptography. After encrypting the message using the Modified RSA technique. This technique increased information hiding's effectiveness, security, and imperceptibility. Considering the following spatial domain technique, the Octonary PVD methodology is proposed by Balasubramanian, Selvakumar, and Geetha [3] for secure image steganography. The suggested technique is safe against RS and LSB steganalysis and excels in embedding capacity and picture quality.

Optimization techniques in image steganography involve the use of various algorithms to enhance the resilience, imperceptibility, and payload capacity of the hidden data. Several articles have presented optimal pixel combination image steganography algorithms. The integration of Particle Swarm Optimization (PSO) within image steganography has been demonstrated as an effective approach for securely embedding secret data [7][8][4]. It chooses the best pixels in the host image for elevated embedding capacity and resilience to steganalysis attacks.

Radhakrishnan, and Asokan [6] uses Enhanced Chaotic Particle Swarm Optimization for choosing the optimum pixel location. This was proven to be robust to statistical threats. Collaborative efforts between PSO and steganography methods, such as SSOA, have been observed to enhance data security and privacy within IoT protocols, concurrently increasing payload capacity and improving image quality [9]. Consequently, the amalgamation of PSO with picture steganography techniques demonstrates a harmonious balance between efficiency, accuracy, and security, presenting advantages across multiple sectors.

Multiple works demonstrate a Genetic Algorithm (GA) based spatial steganography technique has been devised that maximizes pixel scanning and other operations to boost the capacity of LSB matching and embedding [5][10]. The security and quality of the photograph were greatly improved by this technique. Furthermore, GAs is used in conjunction with PSO and BWT proposed by Pramanik, Singh, and Ghosh [11] and Wang et al. [12].

Another meta-heuristic process used in cloud computing for resource placement is the SMO algorithm. It solves the issues of over and under provision resources in less time. The comparison analysis of SMO with

PSO in terms of execution time, fitness value, mean and standard deviation, where SMO outperforms than the PSO in all cases [13].

Besides, the extended research introduced the Parallel-Spider-Monkey-Optimization-Multi-Swarm (PSMO-MS) algorithm which was used for processing of big data sets. It is improved solution of SMO [14] and faster in context of time. Moreover, the SMO algorithm has also applied in job scheduling problems and the results is usually superior to the other algorithms given some circumstances.

3. Proposed Algorithm

The SMO algorithm is encouraged by the social foraging behavior of spider monkeys, which operate within a fission-fusion structure and where they split into smaller clusters or merge on the basis of the food availability. SMO algorithm for image steganography at the sender site is shown in Algorithm 3.1. Here pop is initialized randomly, then divided into groups and based on groups the solution pixel value is updated. After that message is embedded into solution using LSB and fitness function is computed. Spider Monkey Optimization algorithm for image steganography is defined in Algorithm 3.1.

Algorithm 3.1

```
Algorithm SMO_Steganography(image i, text t)
pop = 100, gll = 5, lll = 5, mg = 10,  pr = 0.2,  mi = 50, k=0
Convert image i and text t into binary format
Initialize population
While k < mi do
    For each solution in the population do
       For each pixel in the solution do
          If random() < (1 - pr) then
             Perturb the solution's pixel value based on the local leader's
             pixel value
    For each solution in the population do
       If random() < pr then
            Randomly select a pixel index
            Randomly select another solution
            Update the solution's based on global leader's and selected
            solution's
   For each solution in the population do
```

Insertion of t into s using LSB
Calculate fitness function using SSIM and PSNR (Eq.1)
Sort solutions based on fitness
Update global or local leader if necessary
If number of Populations > mg **then**
Divide populations among groups
Reallocate local leaders within groups
Else
Combine all solutions back into a single population Find the optimal solution and insert the text using LSB

$$fitness_{function} = -PSNR(cover, stegno) + (1 - SSIM(cover, stegno)) \tag{1}$$

In equation (1), cover image is original image and stego image is embedded with message. PSNR is defined in equation (2) and SSIM is defined in equation (4).

$$PSNR = 10 \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \tag{2}$$

Where MAX_i is maximum pixel value that is 255. MSE is defined in equation (3).

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{k=0}^{n-1}[I(i,j) - K(i,j)]^2 \tag{3}$$

MSE calculates the average squared difference of pixel values of the original cover and stego images, post-message embedding. Here *I(i, j)* and *K(i, j)* and is original and reconstructed image pixel value respectively. *1/mn* is normalized factor, m is row and n is column.

$$SSIM(x,y) = \frac{(2\mu_x\,\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)\,(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{4}$$

SSIM is computed using equation (4) where μ_x, μ_y are the mean of image x, y respectively; $\sigma_x \sigma_y$, the standard deviation of image x, y; $c_1 c_2$ are stabilize parameters.

To get the secret message at receiver site, the embedding process's steps must be reversed. Compare the LSB of stego-image and original image. If there is difference in bits combine them. Recode the binary sequence in ASCII characters.

4. Experimental Results and Discussion

Experiment is performed on MATLAB R2024a. Images were downloaded from the web and preprocessed (resized and enhanced) using the OpenCV library. We have taken four cover-images of lena, pepper, baboon and jet of pixel size 256 x 256.

Binary message of fixed size is embedded into the cover images. SMO is compared with GA and PSO. Performance parameters is considered as PSNR, MSE and histogram analysis in the proposed research.

Figure 1 depicts the PSNR value of cover-images of Lena-Pepper-Baboon-Jet. X-axis is taken for Lena-Pepper-Baboon-Jet images and applied optimization techniques of GA, PSO and SPO and Y-axis has PSNR value (in decibels). It can be observed in each case of Lena-Pepper-Baboon-Jet images, PSNR value is observed as maximum in SPO optimization technique. It is observed that in Lena-Pepper-Baboon-Jet images, the PSNR values in increasing order of GA, PSO and SPO respectively. Only in Baboon image, odd-one results depicting the PSNR values in increasing order of PSO, GA and SPO. It can be concluded (Figure 1) that in all images, SPO optimization is better than 4-5 percent than the PSO and GA.

Figure 2 shows the MSE of Lena-Pepper-Baboon-Jet images. X-axis is taken for Lena-Pepper-Baboon-Jet images and applied optimization techniques of GA, PSO and SPO and Y-axis has MSE values. It can be observed in each case of Lena-Pepper-Baboon-Jet images, MSE value is observed as minimum in SPO optimization technique. Average value in all cases is 0.38, 0.325, 0.225 of GA, PSO and SMO respectively of MSE.

Figure 3-4 shows the histogram analysis of Peppers and Lena images. This is utilized to compare the histograms for the cover-image and stego-image visually, indicating how much the image structure has been altered.

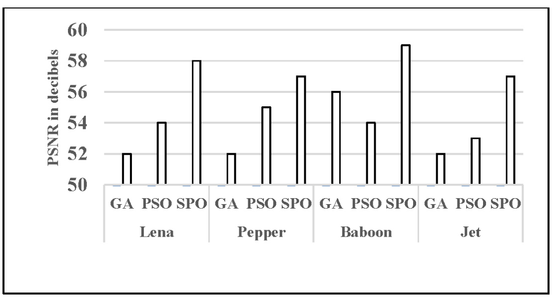

Figure 1

PSNR of different optimization algorithms and 4-cover image set

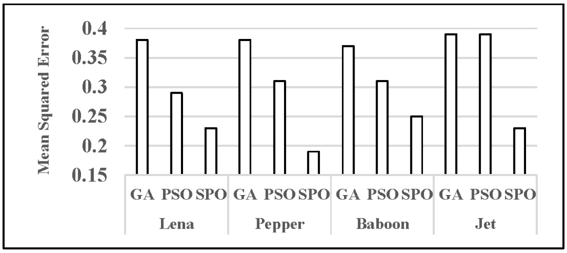

Figure 2

MSE of different optimization algorithms and 4-cover image set

It can be interpreted that cover and stego image have almost same frequency.

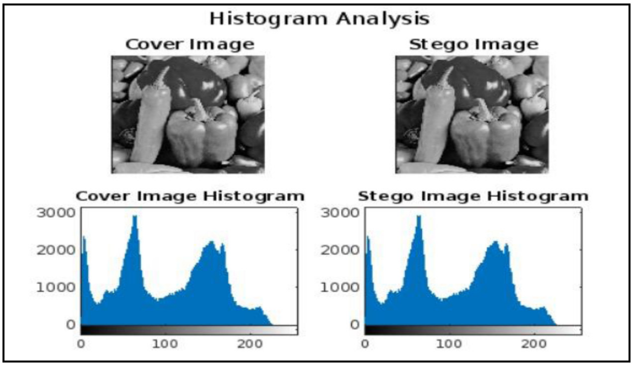

Figure 3

Histogram Analysis of Peppers

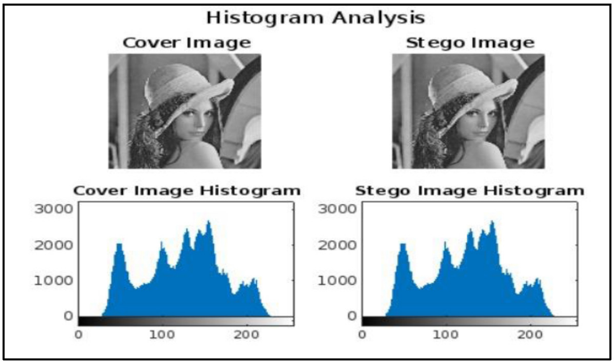

Figure 4

Histogram Analysis of Lena

5. Conclusion and Future Directions

This paper introduces a better security path of image steganography to enhance embedding efficiency and security using Spider Monkey Optimization algorithm. To optimize pixel selection and minimizing distortion with security of image is done in this work. The paper investigated the use of Spider Monkey Optimization with Least Significant Bit (LSB) embedding for the purpose of Image Steganography. The proposed SMO optimization technique scored 4-6 percent improvement in PSNR and 10-16 percent reduction in MSE in comparison with benchmark optimization techniques of GA and PSO.

Further stego images are high quality and the changes are imperceptible, as can be noted by their respective histograms. In future, more variation of SMO and integrating other nature inspired algorithms can be experimented to enhance security and robustness.

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Received November, 2024