

Bioinspired Optimization Algorithms of Steganography: A Review



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ABSTRACT

Hiding data inside images are a feasible alternative to cryptographic approaches for data security. Steganography algorithms protect the confidentiality of communications hidden behind cover images and provide clandestine communication channels. The main problem in the development of data hiding techniques is to achieve a balance between indicators of embedding quality, including imperceptibility, capacity, and robustness. A practical approach to solving this issue is the use of bioinspired optimization algorithms. This review presents how combining bioinspired algorithms with spatial domain techniques enhances the effectiveness of data embedding within digital images. It also reviews traditional methods, most of which utilize the least significant bit substitution method and their associated limitations in imperceptibility, payload capacity, and robustness. The review analyzes several bioinspired optimization approaches and their effectiveness in optimizing embedding positions to improve imperceptibility, security, and capacity. The paper highlights the benefits of bioinspired strategies for reducing the drawbacks of spatial domain steganography, namely for improving concealed data capacity while keeping visual quality better. The findings demonstrate that bioinspired techniques offer a practicable solution for enhancing both security and effectiveness of hidden systems by addressing limitations of traditional techniques and facilitating the development of more potent concealment of data solutions.

Index Terms: Bioinspired, Optimization Techniques, Payload Capacity, Steganography, Least Significant Bit, Spatial Domain, Data Hiding

1. INTRODUCTION

The technique of hiding secret information inside digital media, including images, audio, and video, in a way that conceals the presence of the covered message, is known as Steganography. The aim is imperceptibility – making the stego item physically or audibly indistinguishable from the original cover object – while guaranteeing enough payload capacity, resistance to signal processing or attacks, and security against steganalysis [1]. Fig. 1 illustrates a typical schematic of image steganography.

Spatial and transform domains are prioritized in contemporary image embedding algorithms [2]. The spatial domain is the primary method for embedding data into the least significant bit (LSB) of each pixel in the cover image. LSB-based embedding methods enable the rapid and effortless preparation and production of high-quality stego-images. Nevertheless, they are vulnerable to recurrent assaults on the stego-image. While frequency domain methods, confidential information is included in the modified coefficients after the transformation of the image into its frequency domain. In Chan and Cheng [3], the stego-image produced by the basic LSB replacement technique is enhanced by an optimal pixel modification function data concealing technique. A slight increase in processing complexity significantly improves the stego-image's image quality. A straightforward steganalytic method for LSB embedding was presented by Sakakura and

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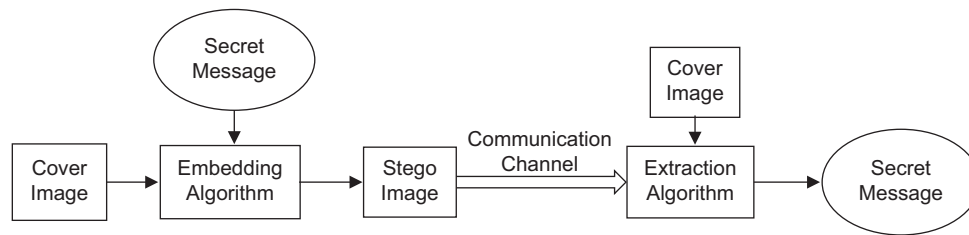


Fig. 1. Common block diagram image steganography.

Hayashi in [4]. By using the statistics of the image difference signal, the suggested method makes it possible to calculate the relative message length precisely through sample pair analysis. Each segment of the covered images is evaluated for inversion before embedding in a novel LSB-based technique known as the inverted pattern LSB, which is introduced in [5]. Using a bijective mapping function, Khodaei and Faez [6] attempted to turn a hidden image into an incoherent image.

Bioinspired algorithms have emerged as a key paradigm for solving complicated optimization problems, such as those in steganography, by taking inspiration from natural events, biological development, and collective behavior [7]. These techniques, which include particle swarm optimization (PSO), ant colony optimization (ACO), bee colony optimization, genetic algorithms (GA), and others, provide a means of maximizing hiding, maintaining good visual quality, and adaptively choosing embedding places.

The utility of bioinspired optimization algorithms as a tool is also necessary to improve steganography. In fact, Jackson *et al.* [8] provide a method for blind steganography detection that uses a computational immune system. The same authors propose an additional investigation examining a distinctive steganography detection technique for digital image applications that employs an artificial immune system [9]; the authors of [10] endeavor to leverage GA to get optimal data imperceptibility. Wu *et al.* [11] established two separate optimal replacement methodologies employing the evolutionary algorithm and LSB substitution. The [12] introduces an innovative steganographic technique utilizing JPEG and the PSO algorithm. The authors of [13] utilize the ACO algorithm to develop an optimal LSB replacement matrix. Brazil *et al.* in [14] presented a hybrid-heuristic that combines the route relinking metaheuristic with a GA to address this issue effectively. Rabevohitra and Sang [15] introduced a novel method for embedding a concealed message within a cover image through LSB substitution in the discrete cosine transformation (DCT) domain. Chang *et al.* [16] proposed an enhanced method for information concealment by embedding it within quantized DCT coefficients and modifying JPEG and quantization tables. Numerous geographical data

concealment approaches have failed to include resilience and distortion tolerance. In the spatial domain, Lin *et al.* [17] suggested contortion tolerance for concealing data. Effective data hiding strategies have also recently been put forward [18], [19]; however, they prioritize stego-image quality above distortion tolerance.

Image steganography has made progress, but balancing imperceptibility, payload capacity, resilience, and security remains a research problem. Traditional spatial-domain methods, such as LSB methods, are computationally efficient and easy to implement, but as embedding capacity increases, they become vulnerable to statistical steganalysis and image-processing operations. However, transform-domain methods are stronger. They are harder to calculate and transfer data less efficiently, making them unsuitable for real-time or resource-constrained scenarios.

Bioinspired optimization algorithms bio-inspired algorithms (BIAs) improve steganographic pixel selection, embedding sites, and distortion control, according to recent research. The literature on picture steganography uses numerous algorithms, such as PSO, GA, ACO, AIS, and DE, but it is primarily algorithm-centric and lacks a systematic and comparative technical study based on spatial-domain embedding. Many studies disregard benchmarks, modern steganalysis resistance, and coherent performance criteria when assessing performance under confined experimental settings. Therefore, a complete and systematic study is needed to determine how bioinspired optimization algorithms improve spatial-domain image steganography, identify research gaps, and explain their pros and downsides.

To improve the security of steganography, we need fast optimization algorithms. These must precisely find the best places to embed data in the search space while keeping the host image's visual quality good. Such algorithms try to balance invisibility and strength. They do this by limiting perceptual distortion and making statistical and learning-based steganalysis less likely to succeed. This has been a major focus of current research in image steganography.

Fig. 2 shows a conceptual framework for improving steganographic performance using bioinspired optimization techniques. The framework employs these algorithms to determine the ideal places to embed and keep track of distortion throughout the whole process. Steganography is seen as an optimization issue, and the algorithms try to find a balance between security, imperceptibility, payload, and resilience. As a consequence, the optimal embedding process creates stego-images that seem more realistic, hold more data, and are harder to analyze using both statistical and machine-learning methods.

This paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the research methodology. Section 4 presents the background of traditional image steganography techniques and bio-inspired optimization algorithms. Section 5 discusses the performance metrics used for evaluation, and Section 6 concludes the paper. Table 1 defines the abbreviations used in the paper.

2. RELATED WORKS

This section highlights bioinspired algorithms and significant contributions to steganographic hiding techniques. Steganography has grown in popularity among researchers as an important field in information security. Spatial-domain steganography is a common information hiding issue that is straightforward to implement but challenging to optimize. The goal of the challenge is to embed confidential information into the pixel values of a digital image in a manner that is both retrievable and undetected to the human eye. The difficulty is in determining the implantation positions that optimally balance payload capacity, visual

quality, robustness, and security. In order to resolve this issue, researchers have implemented bioinspired optimization algorithms that replicate natural processes, including immune adaptation, evolution, and swarm behavior, during the embedding process. Thus, spatial integration aims to identify the optimal pixel positions and configurations, as dictated by these algorithms, to enhance hiding effectiveness while reducing detectability. In [20], the authors proposed a steganography technique that maintains the quality of the resultant stego-image while determining optimal pixel placements in the cover image for concealing secret data using PSO and chaos theory. The host and secret images are divided into blocks, each of which has an appropriate number of secret bits, in order to increase the embedding capacity. Experimental findings indicate that the suggested strategy surpasses current methods for PSNR and SSIM metrics. The capacity-enhancing capabilities of the ACO with LSB in image steganography are demonstrated in this study [1]. The proposed method enhances the embedding capability defined by high-quality images and detection resilience by efficiently utilizing the cooperative and flexible features of ACO to embed data. It is now widely accepted experimentally that systems that use ACO are more capable than those that use conventional steganographic techniques. Compared to conventional techniques, specifically the LSB combined with ACO methodologies; our approach shows an average capacity gain of 34%. A maximum of 2.5 bits per pixel (BPP) was achieved in the study without appreciably lowering image quality. Under similar conditions, traditional methods typically

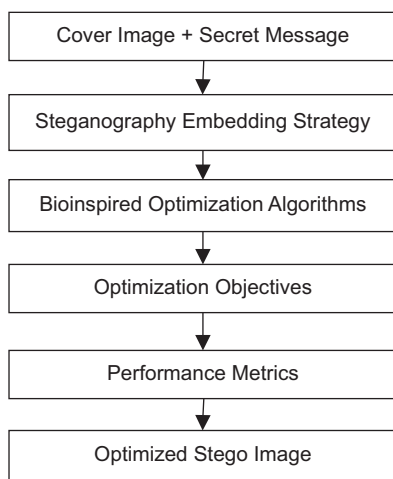


Fig. 2. Bioinspired framework for image steganography.

TABLE 1: Key acronyms and their meanings

| Key acronyms | Their meanings |
|--------------|-------------------------------------|
| ACO | Ant colony optimization |
| ABC | Artificial bee colony |
| AIS | Artificial immune system |
| CSO | Cat swarm optimization |
| CS | Cuckoo search optimization |
| FA | Firefly algorithm |
| GA | Genetic algorithm |
| LSB | Least significant Bit |
| PVD | Pixel value differencing |
| EBE | Edges-based data embedding |
| PSO | Particle swarm optimization |
| HHO | Harris Hawke optimization |
| DE | Differential evolution |
| MSE | Mean square error |
| PSNR | Peak signal-to-noise ratio |
| SSIM | Structural similarity index measure |
| DFT | Discrete Fourier transform |
| BIAs | Bioinspired algorithms |
| SSO | Shark smell optimization |

PSO: Particle swarm optimization, ACO: Ant colony optimization, BCO: Bee colony optimization, GA: Genetic algorithms, BIAs: Bio-inspired algorithms

obtain a maximum of about 2.0 BPP. Capacitance and imperceptibility measurements are compared with PSNR metrics of the PSO-LSB method to ensure high-quality implantation results. The method repeatedly refines and modifies the pheromone matrix to increase embedding capacity. Integrating ACO into image steganography significantly improves the effectiveness of data hiding. While in [21] presents a novel way to improve the LSB technique in picture steganography by identifying the most suitable pixels of the host image for embedding the secret image, using optimum block selection from the host image through the ABC algorithm. The authors conducted a comprehensive comparison of the suggested approach with other methods, including basic LSB, PSO, PRPSO, OQGA, and OLSGA, emphasizing their performance and the degree of distortion they could tolerate in the conducted experiments. The FA and PVD processes were successfully tested on four distinct cover images. The study found that firefly is an effective search tool. The FA finds the optimum concealing places, which are then distributed over the cover images. Firefly stego covers feature higher quality metrics [22]. In this [23] study utilizes the CSO method to obtain the most effective or nearly optimal solution for the stego-image quality problem. The CSO technique is developed through analysis of the feline behavior, demonstrating superior efficacy in identifying optimal global solutions. Analyzing this [24] issue as a search and optimization problem is the aim of this paper. High embedding capacity is made possible by the recommended LUDO scan technique's optimal utilization of the search domain. CS determines the ideal stego-key by using a Lévy flight to generate a new stego-key. In addition, a random key is used to generate a chaotic map, which is encrypted before inserting the secret message. The ample key space of the stego-key provides significant resistance to various cryptanalytic attacks. Results from evaluating the suggested steganography method using nine industry-standard test images are competitive. According to the findings, the suggested steganography system outperforms state-of-the-art high embedding steganography methods with respect to both payload capacity and visual degradation resistance. The article [25] presents a method for image steganography using LSB substitution and the Nature-Inspired HHO algorithm to effectively hide secret information inside a cover image, hence ensuring great secrecy. The HHO-based data encoding process employs the PSNR visual quality measure as its objective function. The best encoding vector for converting the secret message into its encoded format is chosen by the target function. The proposed approach maintains a significant embedding capacity while exceeding current state-of-the-art methods

for traditional visual quality metrics. When compared to current LSB or multi-directional PVD embedding methods, the suggested method shows that it offers better optimization and more embedding space while keeping the quality of the image. The proposed methodology also provides better protection against statistical Stego-Expose analysis, ALASKA2 deep learning steganalysis, and attacks on image processing. This [26] paper provides an improved LSB matching approach for image steganography that uses GA to optimize embedding placements. To improve data concealing, the approach combines operations such as pixel shifting, scanning direction control, secret image transposition, bit flipping, and XOR transformations. The GA effectively strikes a compromise between embedding capacity and imperceptibility by seeing steganography as an optimization problem. According to experimental results, the system outperforms traditional LSB and GA-based methods in terms of PSNR, statistical detection resistance, and visual undetectability. This [27] study presents an innovative watermarking approach that uses the DE optimization algorithm to conceal data effectively. The essential elements of any watermarking technique are imperceptibility and resilience. This research aims to achieve an ideal equilibrium between these two conflicting aspects by utilizing the optimization method of DE. This paper introduces a new approach that emphasizes two main aspects: (i) The use of DE to analyze the pixel intensities of the host image for identifying cognitively insignificant regions, and (ii) the careful selection of the DE scaling factor (SF). This SF, when applied during the watermark embedding process, ensures an optimal balance between imperceptibility and robustness. This work [28] presents an efficient solution for image steganography through the utilization of AIS and host image partitioning. The proposed method selects a portion of the host image and employs AIS to determine the most suitable template for embedding message bits within the pixels of the host image. This technique efficiently determines the appropriate embedding template, obviating the need to analyze the complete image for template identification. Our suggested approach provides enhanced embedding capability and necessitates less time compared to other methods. In [29] this study, the steganography is achieved using the LoG and SSO algorithm, where the original image is disintegrated into four parts. LoG is applied to each block to identify edge areas, where hiding the secret message in severe edges results in minimal distortion compared to the smooth regions. The SSO approach is used to ascertain the best pixel positions in the edge region for concealing critical information. The aim of using the LoG algorithm is to enhance payload capacity while preserving the quality of imperceptibility. Conversely,

the purpose of utilizing SSO and partitioning the cover image into four segments is to improve the quality of the stego media and enhance security, ensuring that the secret message cannot be extracted from the stego-image without knowledge of the employed algorithm and its parameters.

3. METHODOLOGY

We extensively researched the literature to find and assess publications on bioinspired optimization for picture steganography. Our technique made sure that everything was covered, relevant, and scientifically sound.

The study obtained research from credible scientific databases, including: IEEE Xplore, SpringerLink, ScienceDirect, Google Scholar, and ACM Digital Library.

These databases were selected because their material has been peer-reviewed and because they are included in the proceedings of well-known computer science and information security conferences.

A keyword search method was utilized, and the following terms were used together:

("Steganography" OR "data hiding" OR "information hiding") AND ("bioinspired" OR "nature-inspired" OR "evolutionary algorithm" OR "genetic algorithm" OR "particle swarm optimization" OR "ant colony" OR "bee colony" OR "artificial immune system") AND ("spatial domain" OR "LSB" OR "least significant bit") AND ("optimization" OR "pixel selection" OR "embedding strategy").

Researchers improved and combined the searches by employing Boolean operators, such as AND and OR, which assist to combine or leave out terms in database searches.

The chosen studies fulfilled the following criteria:

Criteria for inclusion:

- Articles from peer-reviewed journals and conference proceedings
- Books and articles published in English
- Studies on steganography and how to improve it
- Research conducted from 2000 until 2024.

Exclusion criteria:

- Publications that are the same
- Documents not written in English

- Articles that don't have anything to do with image-based steganography.

After gathering the first publications, titles, and abstracts were reviewed to exclude unrelated studies. Subsequently, a full-text screening was done to find the most important and relevant publications. After this step, we sorted the articles by their methods, the areas in which they were used, and their primary findings. The gathered information underwent qualitative analysis to identify trends, research gaps, issues, and potential future trajectories.

4. BACKGROUND

4.1. Traditional Steganography Methods

As mentioned above, steganography techniques are categorized into spatial and frequency domain methods:

4.2. Spatial Domain Methods

This approach involves the direct alteration of pixel values in the cover image to hide secret information. This indicates that a limited quantity of pixel values in the cover image is altered during encryption and data hiding. Numerous Spatial domain methodologies exist; however, a few of the most prevalent are included here:

- LSB
- Pixel value differencing
- Edges-based data embedding method.

a. LSB

LSB insertion is a prevalent and specific method for embedding information into a cover image. The LSB, or the 8th bit, of specific bytes inside an image is modified to encode a bit of the secret message.

In a 24-bit image, each pixel has 8 bits of data corresponding to the colors red, green, and blue. The last bit of each 8-bit data block may be used for the substitution of the secret data. This modification will be so slight that it will remain imperceptible to the mortal eye. The cover data are situated on the left side of the image if it is magnified by two pixels. Six bits of data are embedded inside the RGB data of two pixels, and the stego-data transformation of the cover data is shown in the image on the right. Typically, just half of the bits in an image required alteration to effectively obscure a concealed message while using the full cover capacity. Given that there are 256 potential intensities for each basic color, altering the LSB of a pixel induces minor variations in color intensity. The alterations are imperceptible to the human

eye, so ensuring the information remains well concealed. By choosing a suitable image, one may obscure the message among the least and second LSBs without perceiving any noticeable alteration. As a result, LSB steganography has been modified to accommodate various image formats.

LSB mainly utilizes BMP images because of their lossless compression characteristics. Regrettably, concealing a hidden message inside a BMP file necessitates a huge cover image. Currently, 800×600 pixel BMP images are hardly used on the internet and may raise suspicion. Consequently, LSB steganography has been adapted to work with many image file formats.

b. Pixel value differencing

The PVD-based technique and a simple LSBs scheme have been suggested to increase embedding capacity without presenting detectable visual artefacts into stego-images, taking into account that human vision is better able to detect small changes in smooth regions while being more tolerant of significant changes in edge regions. In PVD-based techniques, the difference between a pixel and its neighbor determines the number of embedded bits. More hidden bits can be embedded when the difference amount is larger. Compared to traditional LSB-based techniques with the same embedding capabilities, PVD-based techniques frequently yield more undetectable results.

c. Edges-based data embedding

EBE steganography is a technique that hides secret data inside the high-gradient edge regions of a cover image, keeping the original state of the smoother, non-edge portions. This method capitalizes on the principle that human visual perception is less responsive to changes in places of intense spatial activity, such as sharp edges, making inconspicuous adjustments more achievable in these locations than in uniform or smooth parts. To increase both visual and statistical security, the system leverages the enhanced LSB substitution algorithm, which reduces the amount of pixel value adjustments by optimizing bit replacement. Confidential data – irrespective of its nature, including but not limited to textual content – are inscribed inside the three LSBs of designated pixels. Embedding is confined only to pixels recognized as edges by an edge detection technique, therefore guaranteeing that data hiding takes place in perceptually resilient areas of the image. This selective embedding technique enhances steganographic security by reducing detectability during visual inspection and statistical analysis.

4.3. Evaluation Parameters

This study analyses methodologies in the spatial domain: LSB, PVD, and EBE. The three essential criteria for assessing image steganographic techniques are imperceptibility, capacity, and security. The fourth parameter is the difficulty or complexity of the operation. However, no researcher has used algorithmic complexity as an evaluative criterion in the literature.

4.3.1. Capacity

It indicates how many bits of data could be contained in the cover image. The objective is to conceal the most significant quantity of bits inside the cover image while preserving imperceptibility and security. The embedding rate, or BPP, is a term that signifies the entire amount of information relative to the overall number of pixels in the cover image.

4.3.2. Imperceptibility

When the confidential information is concealed, the resulting stego-image must not exhibit any indications that may arouse suspicion from human observers. Therefore, the objective is to minimize the extent of degradation. High imperceptibility correlates with poor capacity, and conversely. Therefore, a balance between these two principles is essential.

4.3.3. Security

Security is crucial for safeguarding information transmitted across insecure networks, such as the internet. It pertains to the capacity to discern concealed secret information within the cover image, as well as the proficiency in extracting it. The steganographic method must withstand the attacker's efforts to identify and retrieve the concealed information.

4.4. Bioinspired Algorithms

Optimization approaches provide a methodical approach to identify optimum or near-optimal solutions through repeated assessment. In picture steganography, these approaches are crucial for identifying appropriate embedding pixels that maintain the visual integrity of the stego-image while reducing distortion.

Various optimization techniques have been used for steganographic pixel selection, with BIAs garnering significant focus because to their flexibility and global search efficacy. Frequently used methodologies include GA, PSO, ABC, Fruit Fly Optimization, and ACO. This section examines the most significant BIAs used in steganographic optimization.

BIAs are classified into three types: Swarm intelligence algorithms, evolutionary algorithms, and ecology algorithms. Ecology algorithms pertain to interactions inside species (intraspecific)

and between species (interspecific). These algorithms often use approaches, such as symbiosis, biogeography, and colonization. The mechanism of evolutionary algorithms is based on biological evolution, including essential processes such as selection, mutation, reproduction, and recombination. Conversely, swarm intelligence algorithms use a collective of agents that interact with each other and their environment. The selected 12 algorithms are:

1. Swarm intelligence algorithms: PSO, ACO, ABC, FA, CSO, CS, HHO, and SSO
2. Evolutionary algorithms: GA and DE
3. Physiology-inspired algorithms: AIS.

4.5. Swarm Intelligence-Based Algorithms

4.5.1. Particle swarm optimization (PSO)

The PSO algorithm is designed to operate collaboratively and intelligently. Initiated in 1995, it has since seen several advancements across other fields, attributed to its close relationship with evolutionary algorithms and artificial life. It has several advantages, including the following: (a) It requires a small number of control settings, making it relatively easy to implement; (b) It can be easily accomplished by balanced computing, as it relates to particle aggregation. It mainly focuses on several random particles and aims to determine the optimal solution through iteration [30].

4.5.2. Ant colony optimization (ACO)

Established in 1991 [31], the ACO technique mimics ant behavior to discover optimal solutions. The ACO technique is predicated on the behavior of ant colonies, wherein worker ants are sent to forage for food randomly, leaving pheromone trails in their wake. Upon discovering food, worker ants return to the colony, therefore enhancing their pheromone trail. When presented with two routes to the meal, ants will initially select a path at random, but over time, the shorter route will get greater reinforcement. The colony will efficiently identify food sources and allocate a substantial workforce along the most optimal pathways, since an increased number of ants will be attracted to more potent pheromone trails [32].

Modifying parameters, such as ant quantity, pheromone evaporation rate, heuristic data, and termination criteria can enhance the ACO algorithm. These options may affect the quality of the solutions achieved and the pace of convergence. Therefore, to get the best performance, the parameters must be meticulously calibrated upon selection [7].

4.5.3. Artificial bee colony

In 2005, Karaboga introduced the ABC Optimization, inspired by the foraging behavior of honeybees [33]. This

population-centric optimization method employs swarm intelligence. This approach is extensively used to address non-linear, multimodal, and high-dimensional optimization issues due to its user-friendliness, robust heuristic capabilities, and reduced control parameters compared to other evolutionary algorithms, including GAs and PSO.

The ABC approach, employed bees and spectator bees equally share the colony's resources. A food source's location is represented by a collection of optimization parameters for each solution inside the search space. The abundance of food sources is directly proportional to the population of the active bees. In other words, each food source is associated with one specific foraging bee [21].

4.5.4. Firefly algorithm

The FA is an optimization approach that emulates characteristics and flashing conduct of fireflies. The regulations are encapsulated as follows: All fireflies are unisex, regardless of gender, and one firefly attracts other fireflies. Furthermore, among any two luminescent fireflies, the dimmer one will gravitate toward the brighter counterpart, since the allure is directly proportionate to their luminosity. The firefly moves erratically if no other entity is brighter than a certain firefly [22].

4.5.5. Cat swarm optimization

In 2007, Chu and Tsai proposed the CSO algorithm [23]. This optimizing strategy was developed by analyzing feline behavior. Two characteristics that distinguish cats are their exceptional hunting abilities and their acute fascination with moving things. The seeking and tracing modes for CSO represent two behavioral features of felines. The authors indicate that the cat represents the solution set. Every cat has a unique location defined by K dimensions, a velocity corresponding to each dimension, a fitness value reflecting cat's adaptation to the fitness function, and a flag indicating whether the cat is in seeking or tracing modes. The primary objective of CSO is to identify the cat with the optimal fitness value.

4.5.6. Cuckoo search algorithm

The CS algorithm is a bioinspired metaheuristic optimization technique created by Yang and Deb in 2009. It is depended on brood parasitic behavior shown by some species of cuckoos, which deposit their ova inside the nests of other bird species. The host bird should identify the foreign egg, the cuckoo chick thrives and is nurtured to the detriment of the host's progeny. This organic technique, when integrated with the notion of Lévy flights – a type of random walk that permits

sporadic, lengthy leaps – constitutes the foundation of the CS optimization methodology. Due to its robust global search capability, conceptual clarity, and few control parameters, the algorithm has been extensively used in addressing intricate engineering, image processing, and watermarking challenges [34].

4.5.7. Harris Hawk optimization

HHO is a metaheuristic algorithm developed in 2019. It is based on how Harris's hawks hunt in groups. It is based on nature and uses a population-based approach. The software uses prey-escape energy to model how exploration and exploitation change over time, enabling it to adjust its search. HHO uses a number of besiege tactics, such as gentle and strong encirclement and quick dives, to improve the search for possible solutions better. HHO excels at solving hard, non-linear, high-dimensional, and complex optimization problems because it doesn't require gradients. Experimental studies have shown that it works better than other metaheuristics in both benchmark and real-world problems. Due to this, HHO has been used a lot in machine learning, feature selection, and engineering optimization [25].

4.5.8. Shark smell optimization algorithm

The shark smell optimization method, developed in 2014, is considered one of the premier optimization tools [35]. It was designed to emulate the natural predatory behavior of sharks in the ocean. A shark is an apex predator possessing an acute olfactory sense that enables it to detect even minute traces of blood in the expansive ocean. The acute olfactory senses can swiftly discern the origin of the scent. Therefore, permit the shark to orient itself toward the potential prey's location. The shark's body possesses lateral lines that enable it to detect pulses or vibrations produced by its prey in the water. The capacity of sharks to perceive and seize their prey enables their survival in the ocean. Like PSO, SSO offers a simple formula that requires only the shark's updated position and velocity. The intensity of the injured prey's scent significantly influences the shark's movement. This signifies that the shark will advance and pivot to reach a region with a greater concentration of the scent [36].

4.6. Evolutionary-Based Algorithms

4.6.1. GA

GA is the most famous evolutionary-based algorithm with a long history, proposed in 1960, and has become popular since the 1990s. Inspired by Charles Darwin's theory of natural evolution, the individuals will be chosen and moved to the next generation for reproduction following the process of natural selection. Crossover and mutation are the two most

important genetic operators in GA. The basic strategy is to fine-tune the population size, crossover rate, and mutation rate for better optimal solutions [37].

4.6.2. Differential evolution

Storn and Price [27] were the forerunners in defining DE, an evolutionary method using metaheuristic population-based strategies. The primary aim is to devise an ideal solution by producing parameters for a trial vector. Every DE solution is classified as a genome or chromosome. Each genome must undergo a mutation followed by recombination, yielding trial vectors. After generating all trial vectors, the ideal solution is selected. The judicious selection of parent and trial vectors achieves the ideal solution. DE requires just a few control parameters for optimum performance: The crossover rate (C_r), SF, and population size (N_p), making the process simple to execute and robust.

4.7. Physiology-Inspired Algorithms

4.7.1. Artificial immune system

AIS are computer programs that can learn, adapt, and collaborate, just like the immune system. Stephanie Forrest and her team developed the first AIS models by studying how the immune system works, including clonal selection, negative selection, and immune memory. In line with the goals of optimization, AIS algorithms show possible solutions as antibodies and check how well they bind to antigens. Clonal selection lets you take advantage of high-affinity solutions by copying and changing them, while negative selection helps you find problems and keep diversity. People use AIS methods widely for optimization, pattern recognition, detecting anomalies, and cybersecurity because they are powerful, can run in parallel, and can adapt to new situations. Empirical studies validate that AIS methodologies exhibit superior performance relative to alternative evolutionary and swarm-based algorithms [28].

The following Table 2 provides a critical comparison of bioinspired optimization techniques used in steganography by evaluating convergence behavior, computational cost, robustness, and applicability.

5. PERFORMANCE METRICS

Different techniques have been developed to measure the efficacy of image steganographic approaches. The metrics include MSE, PSNR, SSIM, and Payload Capacity [38].

- 1) MSE measures the cover image error induced by the data embedding process. It is the average square of pixel-by-

TABLE 2: Comparative strengths and weaknesses of optimization algorithms in image steganography

| References no. | Algorithm | Strength | Weakness | Best application |
|----------------|-----------|--|--|---------------------------------|
| [20] | PSO | <ul style="list-style-type: none"> • Simplicity and ease of implementation • Fast convergence. • Good at handling continuous search spaces • Balance of exploration and exploitation | <ul style="list-style-type: none"> • Risk of pre-mature convergence • Parameter sensitivity • Lack of guarantee for the global optimum • Potential for slow convergence in complex landscapes | Local optimization |
| [1] | ACO | <ul style="list-style-type: none"> • Adaptive search capabilities • Probabilistic solution refinement • High robustness and flexibility • Superior performance in optimization | <ul style="list-style-type: none"> • High Computational Complexity • Potential for Slow Convergence • Dependence on Parameter Tuning • Susceptibility to Stagnation • Sensitivity to problem characteristics | Graph embedding |
| [21] | ABC | <ul style="list-style-type: none"> • Enhanced optimization performance • Robustness in image steganography • Enhanced security through permutation • Effective exploration and exploitation | <ul style="list-style-type: none"> • Designed for numerical optimization • Computational complexity for combinatorial problems • Limited hiding capacity | Image steganography enhancement |
| [22] | FA | <ul style="list-style-type: none"> • Effective in finding optimal embedding locations • Good imperceptibility | <ul style="list-style-type: none"> • Limited experimental validation • Security-focused evaluation | Region optimization |
| [23] | CSO | <ul style="list-style-type: none"> • Efficiency in high-dimensional search • Near-optimal solutions with good quality • Adaptability to the steganography problem | <ul style="list-style-type: none"> • Parameter sensitivity • No security or steganalysis evaluation | Pixel optimization |
| [24] | CS | <ul style="list-style-type: none"> • Global optimization capability • Fewer tuning parameters • Diversification and intensification balance • Suitable for high-dimensional problems • Effective in finding optimal Stego-Key | <ul style="list-style-type: none"> • Computational Complexity • Convergence Speed • Parameter Sensitivity • No Guarantee of Global Optimum • Application-Specific Adaptation Required | Global tuning |
| [25] | HHO | <ul style="list-style-type: none"> • Strong robustness • Effective exploration and exploitation balance • Fewer control parameters • Proven performance in real-world problems • Adaptability to steganography optimization • Soft switching between phases | <ul style="list-style-type: none"> • Computational Overhead • Parameter Sensitivity • Convergence Speed • No Guarantee of Global Optimum • Application-Specific Tuning Required • Limited Discussion on Computational Time | Secure embedding |
| [26] | GA | Global search | Slow convergence | Feature selection |
| [27] | DE | <ul style="list-style-type: none"> • High stability and accuracy • Fast convergence • Few control parameters • Efficient global search • Effective trade-off between imperceptibility and robustness • High imperceptibility results | <ul style="list-style-type: none"> • High computational time • Scalability issues with large images • Dependent on the scaling factor choice • Sensitivity to attack strength • Requires prior knowledge of image structure | Complex optimization |
| [28] | AIS | <ul style="list-style-type: none"> • Efficient optimization for steganography • Fast convergence compared to GA • Local search strategy improves speed • Flexible antibody representation • High embedding capacity with good quality • Vaccination mechanism for invalid solutions • Approximation guarantee | <ul style="list-style-type: none"> • Parameter sensitivity • Block size sensitivity • Limited to the spatial domain • No explicit robustness evaluation • Resizing of the secret image may lose information • Extraction requires antibody storage | Security modeling |

pixel difference between the original and stego-images. It's described by equation 1.

$$MSE = \frac{1}{mn} \sum_{i=1}^m \sum_{j=1}^n (x(i, j) - x'(i, j))^2 \quad (1)$$

W : Width of the image.

H : Height of the image.

x_{ij} : Pixel value at position (i, j) in the original image.

y_{ij} : Pixel value at position (i, j) in the distorted or reconstructed image.

2) PSNR is defined as the ratio of a signal's greatest achievable power to power of the corrupting noise. PSNR is commonly stated as logarithmic decibel scale. PSNR is given by equation 2.

$$PSNR (dB) = 20 \log_{10} \left(\frac{255}{MSE} \right) \quad (2)$$

3) SSIM is utilized for measuring the similarity among two images. It is defined by equation 3, where μ_x and μ_y indicates average of x and y , respectively. σ_x and σ_y

TABLE 3: Comparison of various steganography techniques reported in the literature

| References no. | Author (year) | Purpose of the study | Research methodology | Findings | PSNR (dB) | SSIM | MSE |
|----------------|---|---|---|--|------------|-------|--------|
| [20] | Mohsin <i>et al.</i> (2019) | High embedding capacity, high visual quality, and robustness against steganalytic attacks. | <ul style="list-style-type: none"> • Steganography • Spatial-domain LSB embedding • PSO | <ul style="list-style-type: none"> • A novel PSO-based scheme for selecting optimal pixel positions and scanning orders • Improved PSNR • Enhanced embedding capacity and security with minimal image distortion. | 57.65 dB | 0.999 | 0 |
| [1] | Jasim and Kurnaz (2024) | Enhance embedding capacity, quality, and security | <ul style="list-style-type: none"> • Steganography • Spatial-domain LSB embedding • ACO | +30% embedding capacity,,,,; +20% detection resistance; tested on 1000+grayscale images | 40.5 dB | 0.98. | 0 |
| [21] | Banhamsakun (2018) | To improve the quality, robustness, and security of LSB-based image steganography by optimizing block assignments using the Artificial Bee Colony algorithm. | <ul style="list-style-type: none"> • Steganography • Spatial-domain LSB embedding • ABC optimization with block assignment and permutation. | Proposed ABC-based scheme achieves higher image quality compared to PSO, GA, and other LSB methods, Demonstrates a lower bit error rate ($\approx 7.42\%$) under noise attacks, Offers strong robustness against steganalysis (e.g., VSL tool) and enhanced security due to block permutation. | 56.3987 dB | | 0 |
| [22] | Oluwaseun M. Alade <i>et al.</i> (2021) | To enhance embedding capacity and imperceptibility in image steganography by applying the FA to optimize the PVD technique. | <ul style="list-style-type: none"> • Steganography • PVD • FA for optimization of embedding positions | <ul style="list-style-type: none"> • The proposed FA-PVD scheme increases embedding capacity while maintaining high imperceptibility • Achieves improved PSNR and lower MSE compared to standard PVD methods • Demonstrates robustness against common image distortions and preserves the visual quality of stego-images | 48.83 dB | 0.98 | 1 |
| [23] | Wang <i>et al.</i> (2010) | To improve image quality and embedding efficiency in LSB-based steganography by reducing distortion and computation time compared to exhaustive LSB substitution. | <ul style="list-style-type: none"> • Steganography • LSB substitution • CSO with revised seeking and tracing modes. | <ul style="list-style-type: none"> • The proposed CSO-based scheme achieves near-optimal or optimal stego-image quality with significantly reduced computation time • Performs better than exhaustive LSB when embedding more than 3 bits per pixel • Maintains low MSE and high PSNR, ensuring high imperceptibility and robustness. | 44.63 dB | 0.97 | 2.2391 |
| [24] | Map <i>et al.</i> (2018) | To develop a secure and robust LSB-based image steganography method using a secret key, improving embedding security, imperceptibility, and resistance against attacks. | <ul style="list-style-type: none"> • Steganography • LSB substitution with stego-key direction • Security enhancement through key-based embedding positions. • CS | <ul style="list-style-type: none"> • The stego-key directed LSB method provides higher robustness against steganalysis and unauthorized extraction • Achieves better imperceptibility and embedding security compared to classical LSB methods • Ensures reliable recovery of hidden data with reduced vulnerability to brute-force or statistical attacks. | 44.09 dB | 0.97 | 2.5356 |
| [25] | Hameed <i>et al.</i> (2022) | Increase security, robustness, and capacity | <ul style="list-style-type: none"> • Steganography • LSB embedding • HHO | • Higher PSNR, lower BER versus classical LSB | 45.3950 dB | 0.996 | 1.8797 |

(Contd...)

TABLE 3: (Continued)

| References no. | Author (year) | Purpose of the study | Research methodology | Findings | PSNR (dB) | SSIM | MSE |
|----------------|----------------------------------|---|---|---|-----------|------|--------|
| [26] | Wang <i>et al.</i> (2019) | Improve hiding capacity and optimize LSB substitution | <ul style="list-style-type: none"> Steganography LSB substitution GA | <ul style="list-style-type: none"> improved resistance to steganalysis Adaptable to diverse images Randomized+optimal LSB substitution GA reduces computation, supports large payloads with high imperceptibility | 51.36 dB | | 0 |
| [27] | Basu <i>et al.</i> (2022) | Balance imperceptibility and robustness | <ul style="list-style-type: none"> Steganography/ Watermarking Spatial domain DE | <ul style="list-style-type: none"> High PSNR and transparency; watermark recognizable post-attack DE converges faster and is more stable than GA/PSO | 57.1 dB | 0.99 | 0 |
| [28] | Ahmadi and Sajedi (2017) | Efficient, high-capacity embedding with low complexity | <ul style="list-style-type: none"> Steganography LSB substitution+ partitioning AIS | <ul style="list-style-type: none"> AIS finds embedding templates faster, higher efficiency versus GA/PSO, maintains PSNR and imperceptibility | 54 dB | | 0 |
| [29] | Abdulhammed <i>et al.</i> (2022) | To propose a new steganography method combining edge detection (LoG) and Shark Smell Optimization (SSO) to enhance security, payload capacity, and imperceptibility in image steganography. | <ul style="list-style-type: none"> Edge detection using the Laplacian of Gaussian (LoG). Applying SSO to select optimal edge pixels. Embedding secret data with the least significant bit (LSB). - | <ul style="list-style-type: none"> Proposed method achieves high security and imperceptibility. Outperforms previous methods in PSNR and MSE. Histogram, entropy, and correlation analysis confirm strong robustness and secrecy. Secret message cannot be extracted without the algorithm details and parameters | 49 dB | | 0.8577 |

TABLE 4: Presents a comparative analysis of spatial domain techniques documented in the literature, evaluated according to several parameters

| References no. | Payload capacity | Visual quality | Robustness | Complexity | Security |
|----------------|------------------|------------------------------|---------------|------------|---------------|
| [20] | High | High | Medium | Medium | Low |
| [1] | High | High | Medium | Medium | High |
| [21] | Low | High | High | High | Low |
| [22] | High | High | Medium | Medium | High |
| [23] | Medium - high | High (2 LSB), medium (4 LSB) | Low | Low | High |
| [24] | High | High | High | High | High |
| [25] | High | High | High | Medium | High |
| [26] | High | Medium | Medium | Medium | Low |
| [27] | Medium | High | Medium | Medium | Medium |
| [28] | High | High | Low | Low | Medium - high |
| [29] | High | High | Medium - high | Medium | High |

indicates variance of x and y, respectively. σ_{xy} indicates the covariance of x and y, respectively. C1 and C2 are the constant values.

$$SSIM = \frac{(2 * \mu_x \mu_y + c1) + (2 * \sigma_{xy} + c2)}{(\mu_x^2 + \mu_y^2 + c1) + (\sigma_x^2 + \sigma_y^2 + c2)} \quad (3)$$

4) Payload capacity: The phrase “payload capacity” indicates the volume of data included within the cover image. In a steganographic system, this value is essential as the

maximum payload capacity dictates the communication overhead. BPP is the metric for assessing payload capacity. It is computed through the formula 4.

$$BPP = \frac{\text{Number of secret bits embedded}}{\text{Total number of pixels}} \quad (4)$$

5) Quality index (QI): The quality of the created images is measured using the universal image QI. QI represents the similarity between the original image and the produced image. It is calculated utilizing Equation 5.

$$QI = \frac{4\sigma_{xy}\bar{p}\bar{q}}{(\sigma_x^2 + \sigma_y^2)[(\bar{p})^2 + (\bar{q})^2]} \quad (5)$$

$$\bar{p} = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (p_{ij}) \quad (6)$$

$$\bar{q} = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (q_{ij}) \quad (7)$$

$$\sigma_x^2 = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (p_{ij} - \bar{p})^2 \quad (8)$$

$$\sigma_y^2 = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (q_{ij} - \bar{q})^2 \quad (9)$$

$$\sigma_{xy} = \frac{1}{m \times n} \sum_{i=1}^m \sum_{j=1}^n (p_{ij} - \bar{p})(q_{ij} - \bar{q}) \quad (10)$$

The ideal value for Q is 1. The ideal value can only be obtained if the original and produced images are entirely identical.

As illustrated in Table 3, bio-inspired optimization algorithms demonstrate improved performance in terms of embedding efficiency and imperceptibility in steganographic systems. Furthermore, Table 4 provides a comparative overview of these optimization techniques, outlining their computational trade-offs and security robustness.

6. CONCLUSION

This study analyses advanced techniques in image steganography that employ BIAs. Spatial domain methods were preferred because they entail lower computational overhead compared to transform domain methods. However, when more bits are added, the quality of the stego-image goes down, and it becomes more vulnerable to frequency-based attacks, such as filtering and compression. To hide secret data and improve payload capacity while keeping image quality, spatial domain methods, such as LSB were used. To enhance image quality, confidential data is concealed within optimal pixel coefficients identified through BIAs. Various optimization algorithms have been proposed in the literature, including GA, PSO, AISs, DE, and ACO. The performance measures for various techniques, including PSNR, SSIM, MES, and payload capacity, were also compared.

According to literature, combining nature-inspired algorithms with spatial domain steganography techniques achieves significant improvements in image quality (PSNR and SSIM)

and steganography capacity while maintaining a good level of security and attack resistance. Some studies have achieved PSNR values of approximately 57.74 dB and SSIM of up to 0.999, with steganography rates of up to 2.5 bits/pixel compared to conventional methods. However, spatial domain techniques remain less secure in principle, making reliance on transform domain methods more effective in terms of robustness. Meanwhile, bioinspired algorithms represent a pivotal improvement tool for enhancing the efficiency of both methods.

Recent studies on bioinspired optimization methods in image steganography have led to significant enhancements in both efficacy and security. Despite these advances, several challenges remain. For instance, the lack of standardized testing protocols and benchmark datasets hinders fair comparisons between studies. Most current research does not focus on modern deep learning-based steganalysis. High computational complexity still makes real-time use difficult for systems with limited resources. Also, robustness is often not tested enough, and hybrid optimization methods have not been fully studied.

We should build unified benchmarking frameworks, explore hybrid bioinspired optimization methodologies, and improve resistance to sophisticated steganalysis. Research should also focus on designing efficient real-time and IoT algorithms that are resilient to compression and noise. Future steganographic systems will be more practical by using multi-objective optimization models that balance imperceptibility, security, and capacity.

REFERENCES

- [1] Z. K. J. Jasim and S. Kurnaz. "An improved image steganography security and capacity using ant colony algorithm optimization". *Computers, Materials and Continua.*, vol. 80, no. 3, pp. 4643-4662, 2024.
- [2] A. Cheddad, J. Condell, K. Curran and P. Mc Kevitt. "Digital image steganography: Survey and analysis of current methods". *Signal Processing*, vol. 90, no. 3, pp. 727-752, 2010.
- [3] C. K. Chan and L. M. Cheng. "Hiding data in images by simple LSB substitution". *Pattern Recognition*, vol. 37, no. 3, pp. 469-474, 2004.
- [4] T. Sakakura and A. Hayashi. "A Simple Detection Scheme of LSB Steganography Based on Statistics of Image Difference Signal". *ISITA/ISSSTA 2010 - 2010 International Symposium on Information Theory and Its Applications*, pp. 320-325, 2010.
- [5] C. H. Yang. "Inverted pattern approach to improve image quality of information hiding by LSB substitution". *Pattern Recognition*, vol. 41, no. 8, pp. 2674-2683, 2008.
- [6] M. Khodaei and K. Faez. "Image hiding by using genetic algorithm and LSB substitution. In: "Lecture Notes in Computer Science

- (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)". vol. 6134. Springer Science+Business Media, Germany, pp. 404-411, 2010.
- [7] V. Gnanalakshmi and G. Indumathi. "A review on image steganographic techniques based on optimization algorithms for secret communication". *Multimedia Tools and Applications*, vol. 82, no. 28, pp. 44245-44258, 2023.
 - [8] J. T. Jackson, G. H. Gunsch, R. L. Claypoole and G. B. Lamont. "Blind steganography detection using a computational immune system: A work in progress". *International Journal of Digital Evidence*, vol. 4, no. 1, pp. 1-19, 2003.
 - [9] J. T. Jackson, G. H. Gunsch, R. L. Claypoole, and G. B. Lamont. "Novel Steganography Detection Using an Artificial Immune System Approach". In: *Proceedings of the IEEE Congress on Evolutionary Computation, CEC 2003*, vol. 1, pp. 139-145, 2003.
 - [10] S. P. Maity, M. K. Kundu and P. K. Nandi. "Genetic algorithm for optimal imperceptibility in image communication through noisy channel". In: *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 3316, pp. 700-705, 2004.
 - [11] M. N. Wu, M. H. Lin and C. C. Chang. "A LSB substitution oriented image hiding strategy using genetic algorithms". In: *Lecture Notes in Computer Science. (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 3309, pp. 219-229, 2004.
 - [12] X. Li and J. Wang. "A steganographic method based upon JPEG and particle swarm optimization algorithm". *Information Sciences Journal*, vol. 177, no. 15, pp. 3099-3109, 2007.
 - [13] C. S. Hsu and S. F. Tu. "Finding Optimal LSB Substitution using Ant Colony Optimization Algorithm". In: *2nd 18th International Conference on Communication Software and Networks, ICCSN 2010*, pp. 293-297, 2010.
 - [14] A. L. Brazil, A. Sanchez, A. Conci and N. Behlilovic. "Hybridizing Genetic Algorithms and Path Relinking for Steganography". In: *Proceedings Elmar - International Symposium Electronics in Marine*, pp. 285-288, 2011.
 - [15] F. H. Rabevohitra and J. Sang. "Using PSO Algorithm for Simple LSB Substitution Based Steganography Scheme in DCT Transformation Domain". In: *Lecture Notes in Computer Science. (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 6728, no. Part 1, pp. 212-220, 2011.
 - [16] C. C. Chang, T. S. Chen, and L. Z. Chung. "A steganographic method based upon JPEG and quantization table modification". *Information Sciences*, vol. 141, no. 1-2, pp. 123-138, 2002.
 - [17] I. C. Lin, Y. Bin Lin and C. M. Wang. "Hiding data in spatial domain images with distortion tolerance". *Computer Standards and Interfaces*, vol. 31, no. 2, pp. 458-464, 2009.
 - [18] Y. H. Huang, C. C. Chang and C. Y. Wu. "A DNA-based data hiding technique with low modification rates". *Multimedia Tools and Applications*, vol. 70, no. 3, pp. 1439-1451, 2014.
 - [19] P. Bedi, R. Bansal and P. Sehgal. "Using PSO in a spatial domain based image hiding scheme with distortion tolerance". *Computers and Electrical Engineering*, vol. 39, no. 2, pp. 640-654, 2013.
 - [20] A. H. Mohsin, A. A. Zaidan, B. B. Zaidan, O. S. Albahri, A. S. Albahri and M. A. Alsaalem. "New method of image steganography based on particle swarm optimization algorithm in spatial domain for high embedding capacity". *IEEE Access*, vol. 7, pp. 168994-169010, 2019.
 - [21] A. Banharsakun. "Artificial bee colony approach for enhancing LSB based image steganography". *Multimedia Tools and Applications*, vol. 77, no. 20, pp. 27491-27504, 2018.
 - [22] O. M. Alade, E. A. Amusan, O. T. Adedeji, and O. O. Alo. "Image steganography using pixel value differencing (PVD) technique based on firefly algorithm," *J. Sci. Res. Reports*, vol. 27, no. 7, pp. 80–86, 2021.
 - [23] Z. H. Wang, C. C. Chang and M. C. Li. "Optimizing least-significant-bit substitution using cat swarm optimization strategy". *Information Sciences*, 192, 98-108, 2012.
 - [24] C. Map, S. Makhija, K. Singh, K. Sharma, R. Stego-key, and C. Map, "Robust Stego-Key Directed LSB Substitution Scheme based upon Cuckoo Search and Chaotic Map," 2018.
 - [25] M. A. Hameed, O. A. Abdel-Aleem, and M. Hassaballah. "A secure data hiding approach based on least-significant-bit and nature-inspired optimization techniques". *Journal of Ambient Intelligence and Humanized Computing*, vol. 14, no. 5, pp. 4639-4657, 2023.
 - [26] R. Z. Wang, C. F. Lin and J. C. Lin. "Image hiding by optimal LSB substitution and genetic algorithm". *Pattern Recognition*, vol. 34, no. 3, pp. 671-683, 2001.
 - [27] S. Basu, A. Debnath, A. Basu and T. S. Das. "An image data hiding technique using differential evolution". *Multimedia Tools and Applications*, vol. 81, no. 28, pp. 39995-40012, 2022.
 - [28] S. D. Ahmadi and H. Sajedi. "Image Steganography with Artificial Immune System". In: *7th Artificial Intelligence and Robotics IRANOPEEN 2017*, pp. 45-50, 2017.
 - [29] O. Y. Abdulhammed, P. J. Karim, D. R. Arif, T. S. Ali, A. O. Abdalrahman and A. A. Saffer. "A secure image steganography using shark smell optimization and edge detection technique". *Kurdistan Journal of Applied Research*, vol. 7, no. 2, pp. 11-25, 2022.
 - [30] A. Jaradat, E. Taqieddin, and M. Mowafi. "A high-capacity image steganography method using chaotic particle swarm optimization". *Security and Communication Networks*, vol. 2021, p. 11, 2021.
 - [31] A. Coloni, M. Dorigo and V. Maniezzo. "Distributed Optimization by Ant Colonies". *Proceedings ECAL*. Elsevier Publishing, Amsterdam, pp. 134-142, 1991.
 - [32] M. Dorigo and T. Stützle. "*Ant Colony Optimization: Overview and Recent Advances*". Vol. 272. Université Libre de Bruxelles, Belgium, 2019.
 - [33] D. Karaboga. "*An Idea Based on Honey Bee Swarm For Numerical Optimization*". Technical Report - TR06, 2005.
 - [34] M. A. Al-Abaji. "A literature review of cuckoo search algorithm". *Journal of Education and Practice*, vol. 11, no. 8, pp. 1-8, 2020.
 - [35] B. T. Ahmed and O. Y. Abdulhameed. "Fingerprint authentication using shark smell optimization algorithm". *UHD Journal of Science and Technology*, vol. 4, no. 2, pp. 28-39, 2020.
 - [36] N. A. Kamarzaman, S. I. Sulaiman, and I. R. Ibrahim, "Adaptive Mechanism For Enhanced Performance Of Shark Smell Optimization," *J. Electr. Electron. Syst. Res.*, vol. 18, 2021.
 - [37] M. Soleimanpour and S. Talebi. "A novel technique for steganography method based on improved genetic algorithm optimization in spatial Domain". *Iranian Journal of Electrical and Electronic Engineering*, vol. 9, no. 2, pp. 67-75, 2013.
 - [38] S. Arivazhagan, W. S. L. Jebarani, S. Ananthi Roy and E. Amrutha. "Improving quality of stego images through dithering techniques for pixel pair matching steganographic schemes". *International Journal of Engineering and Advanced Technology*, vol. 8, no. 6, pp. 4923-4931, 2019.