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Digital Watermarking Using Hybrid Grasshopper Optimization Algorithm and Genetic Algorithm (HGOAGA)

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Abstract: The advancement of computer technology has raised significant issues with digital content piracy and copyright law. A popular method of protecting copyright and related uses is digital watermarking. Various algorithms have been developed to address the need for invisible performance and robustness in digital watermarking schemes. Here, we proposed a novel evolutionary algorithm, the hybrid Grass Hopper Optimization algorithm, and the Genetic algorithm (HGOAGA) for optimizing multiple scaling factors in the digital watermarking scheme in the frequency domain of hybrid Discrete Wavelet Transformation (DWT) and Singular Value Decomposition (SVD) method (hybrid DWT-SVD). The subcomponents of the image are determined by calculating the DWT of the cover image. The problem is determining the best scaling factor for watermarking after converting the subcomponent to the frequency domain using SVD. In HGOAGA, an optimal solution of multiple scaling factors is found after several iterations, starting with a set of randomly generated solutions. The advantages of GOA and GA are combined in the HGOAGA to balance exploration and exploitation functionalities. Furthermore, HGOAGA can converge quickly and escape local optima well. Some standard images were used in the MATLAB environment to test the proposed algorithm. The evaluation of the experiment was carried out using various metrics such as the Structural Similarity Index (SSIM), the Normalized Cross-Correlation (NCC), and the Peak Signal-to-Noise Ratio (PSNR). The experimental results of the tests showed a PSNR value of 51db for the proposed method compared to existing methods, and they are best suited to solving conflict problems between robustness and quality.

Introduction

Multimedia content became widespread at the end of the 20th century with the advent of the digital age. Due to the rise of digital technology, there is a concern that the unauthorized distribution and modification of multimedia files can occur. The use of a watermarking technique addresses this issue. This method involves concealing information in the content. Several techniques, such as steganography (Cox et al., 2007) cryptography (Louet al., 2007) and digital watermarking (Baluja, 2020; Evsutin et al., 2020) have recently been developed to protect the information in documents. It hasn't proven easy to distribute digital data while maintaining copyright and ownership of the content, even with the robust security provided by cryptography. By using data hiding techniques, such as watermarking, the original owner can ensure that their digital information is not available for unauthorized distribution or copying. One of the most common reasons researchers use digital watermarking is to protect the content of files online or offline. Due to the increasing number and variety of shared digital images, the development of new communication tools and signal-processing techniques has been increasing.

Different techniques can be used to embed labels or images in a document, categorized into frequency, visibility, permanency, and spatial. The earliest known

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method for embedding labels or logos is through the spatial domain. It involves changing the pixels' values. For watermarking, the spread spectrum and the lesser bit are commonly used. Although this technique has various advantages, it is not ideal for tackling attacks. The host image can be transformed using various frequency transformations, such as the Discrete Cosine Transform (DCT) (Mohanarathinam et al., 2019; Begum et al., 2020), the Discrete Wavelet Transform (DWT) (Tang et al., 2022; Begum et al., 2024) the Discrete Fourier Transform (DFT) (Cedillo-Hernandez, 2021; Ying et al., 2019), etc. After the coefficients have been modified, a unique image is obtained by implementing a watermark.

Embedding a copy-protected image can degrade its visual quality. In addition, the image should resist damage caused by signal processing operations attacks, such as unintentional or intentional attacks. The concept of robustness denotes that extracting a protected object from a hostile environment is required after it has been attacked. Significant changes to the host image can improve its robustness in most cases. However, these modifications cannot satisfy the requirement for imperceptibility since they are distinguishable. The embedding strength, such as the scaling factors of the cover image, determines how well the two are balanced. The imperceptibility of watermarking techniques is usually expected to be high. This can be achieved by using SSIM and PSNR. The extracted image is likely to be similar to the original one. Its robustness is also expected to be high even after several attacks, as evidenced by the NCC values.

Due to the limitations of frequency-only and spatial-only techniques, hybrid frequency domain schemes have been proposed to address these issues. Hybrid image watermarking involves taking the host image and implementing multiple transform domain methods called hybridization. To develop effective hybrid digital watermarking techniques, various prerequisites must be met. These include security, imperceptibility, capacity, and robustness. The Singular Value Decomposition is commonly utilized in hybrid methods due to its simplicity and stability (Assini et al., 2018; Maloo et al., 2020; Alshoura et al., 2021; Alzahrani, 2022). A hybrid non-blind method combines the DWT with the SVD for data encapsulation (Poonam et al., 2018; Anand et al., 2020; Wang et al., 2020; Tang et al., 2022). The DWT process divides the image into four bands. Singular Value Decomposition (SVD) can be viewed as a process for transforming matrices. This transformation begins by decomposing an M x N-sized image into a 2D M x N matrix. Next, SVD is applied to this M x N matrix to obtain three matrices: U, S, and V. After decomposing the cover image into four sub-bands, SVD is applied to the LL sub-band.

The efficiency of digital image watermarking techniques is mainly determined by their imperceptibility and robustness. The effect of one attribute decreases as we increase the other. There is a trade-off between these attributes. Therefore, it is necessary to balance each of these factors simultaneously to create an effective watermarking algorithm. The metaheuristic approach is the best option that emerges (Melman et al., 2023). These optimization strategies improve the performance by providing the best optimal solution under various constraints. The optimization process involves determining the best set of selection variables to solve a particular problem (Divyanshu et al., 2024). Researchers have used many optimization techniques to achieve this, including artificial bee colonies (ABC), particle swarm optimization (PSO), and many more. Optimization algorithms need to be updated to prevent premature convergence and maintain a healthy balance between exploration and exploitation (Singh et al., 2023).

The scaling factor is a crucial part of image watermarking to determine the optimal level of embeddedness. These factors determine the watermarking and can be found in the robustness and imperceptibility. However, these concepts are contradictory. For instance, the more robust the watermarking scheme is, the less imperceptibility it has, or vice versa. This study aims to maintain the balance between the two factors. A single scaling factor value can increase robustness but can also be less visible. By using multiple scaling factors (MSF) the researchers achieved the intended imperceptibility and robustness, rather than just one scaling factor. In the previous works, various optimization algorithms can be employed to meet the requirements for MSF-based optimization for an effective image watermarking scheme.

The optimal strength of a scaling factor (Cui et al., 2018, Ariatmanto et al., 2020, Sharma et al., 2021) is one of the most important factors that can be considered when optimizing the performance of a particular watermarking algorithm. The small value of a scaling factor can be beneficial in terms of the invisibility of the picture but weaken the algorithm's robustness. However, the larger value of factors can negatively affect the quality and invisibility of the cover image. Choosing the right scaling factors for an algorithm is also crucial to ensure that the imperceptibility and robustness of the method are balanced, and it can be challenging to determine the optimal embedding strength, such as the scaling factor of a particular watermarking algorithm, due to the complexity of the problem. One of the most common ways to resolve this issue is to consider it as an optimization problem.

To achieve the robustness of the watermark, the researchers used various soft computing algorithms to optimize multiple scaling factors in the digital watermarking scheme. Here, we proposed a novel hybrid GOA and GA (HGOAGA) algorithm in the hybrid frequency domain DWT-SVD for optimizing multiple scaling factors in digital watermarking. The proposed algorithm combines the two algorithms, such as the Genetic Algorithm for exploitation and the Grasshopper Optimization Algorithm for exploration functions, while integrating the main advantages of independent GOA and GA. The security analysis of the algorithm is tested with seven different attacks. The imperceptibility and robustness of the hybrid algorithm are comparable to those of existing methods.

Previous Works

Here, we present some of the research works proposed in the domain of DWT-SVD-based watermarking to optimize scaling factors using different soft-computing methods.

Mishra et al., 2014 proposed an extraction and embedding method that combines the advantages of the DWT and the SVD transformations. For the case of the host image, the singular values of LL_3 coefficients were modified using singular values of a binary watermark. The optimized MSFs by the Firefly algorithm (FA) are then supported by an objective function that combines robustness and imperceptibility. The proposed scheme mainly focuses on identifying optimal scaling factors with the help of FA. Experimental results show that it can yield high PSNR values and demonstrate that its embedded version is robust against different image processing operations.

Ansari et al. (2016) proposed an artificial bee colony (ABC) algorithm for scaling factor optimization algorithm for the watermarking scheme that would increase imperceptibility and robustness. The scheme achieved even greater imperceptibility and robustness by adding the primary watermarking elements to the maximum singular value of each host image block. The addition of principal components also eliminated false positive errors from the scheme. Even after a successful extraction, encrypting the watermark using the Arnold transform stops authentic access.

Mishra et al. (2018) presented a novel and effective method for implementing a grayscale image watermarking scheme using the Harmony Search Algorithm. The proposed method is robust against various image processing attacks but tends to perform poorly against cropping attacks. The balance between robustness criteria and visual quality has been successfully resolved. The proposed method achieves high levels of robustness and good-quality signed images due to the optimization of the MSF using the HSA. Compared to other studies' findings, the study's results show great promise.

Cui et al. (2018) proposed an adaptive method for selecting scaling factors in the wavelet domain by colour watermarking based on differential expansion (DE). These values can be used to embed information in the image. They also performed the Arnold transform to randomize the image.

Sharma et al. (2021) presented a bio-inspired algorithm, such as a grasshopper optimization algorithm for digital watermarking of images. The method takes into account the scaling factor to achieve the best possible result. Using GOA ensures that the method is efficient and has a good scaling factor. Experiments were conducted to evaluate the effectiveness of the proposed method. The results of the experiments were compared with two different techniques.

Devi et al. (2022) proposed a secure RDWT-SVD-based DIW method that can send aerial images over the Internet. The proposed algorithm is based on a hybrid G-BAT optimization method. The paper also states that a scaling factor can be used as an embedding parameter for creating a watermark. The proposed three-level encryption algorithm was compared and evaluated against other DIW schemes. The study results showed that the proposed method had better robustness and imperceptibility using the hybrid G-BAT optimization method.

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Devi et al. (2022) presented a novel digital image security and authentication scheme that uses the Redundant DWT-SVD hybrid transform. It is designed to provide a robust and efficient method for protecting digital images. The proposed scheme considers the various characteristics of the image and its data. The proposed scheme is built on the selected blocks and follows the decomposition of the image's data. It provides a robust and efficient method for protecting digital images. One of the most important factors the paper considers when implementing security is the reduction of false positive errors. To protect the image from unauthorized access, a pseudo-random key is used. This key is generated using a combination of functions, such as the mean block approach, the discrete wavelet transform, and the cosine function. It balanced the optimized scaling factor using the hybrid JAYA-Firefly optimization and exhibited high imperceptibility, security and robustness.

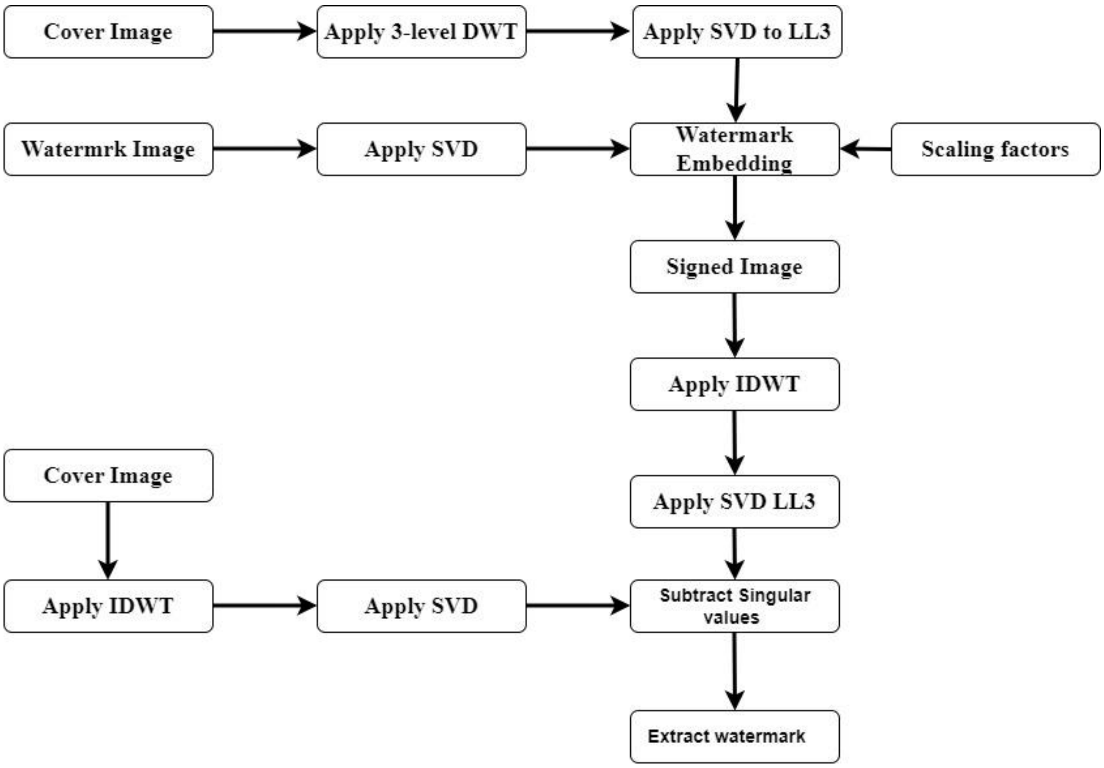

Figure 1. Hybrid DWT-SVD process.

Methodology

Materials and Methods

In this section, we discuss the following methods: the hybrid DWT-SVD Scheme and the HGOAGA algorithm.

i) Hybrid DWT-SVD Scheme

To achieve robustness, the modifications should be integrated into the low-frequency coefficients of the image (Cox et al., 2007). DWT is better than other methods for producing robust and imperceptible results, and it can additionally produce high-quality signed images (Giri et al., 2018; Pradhan, 2020). In the past few years, singular-value decomposition has been widely used for watermarking. This method provides a detailed analysis of the changes in an image. The transformations in a single vector are related to the data in the singular matrix.

SVD-based algorithm (lshoura et al., 2021; Yuan, et al., 2020; Zhu et al, 2021) combines the singular values of a host image with the watermark image to modify the singular values. The modified singular values of the resulting matrix are found by applying the SVD algorithm, which is then combined with the watermarked image to create a watermarked image. The process of extracting a watermark occurs in the reverse order. The process of extracting a watermark is done in reverse. Due to its many advantages, including stability and simplicity, SVD is used in many hybrid image watermarking schemes (Zear et al., 2016). A hybrid DWT-SVD domain watermarking scheme first uses DWT to divide the host image into four sub-bands, then applies SVD to the LL sub-band, and finally embeds the singular values of the watermark image into the LL sub-band (lshoura et al., 2021, Yasmeen et al., 2021).

In the above, we presented the DWT-SVD watermarking algorithm, which provided a robust watermarking algorithm based on multi-level security, as illustrated in Figure 1. The embedding and extraction process using hybrid DWT-SVD is given below.

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Embedding Procedure

Consider W is a watermark of size p x p and I is a cover image of size P x P.

1) Using the HAAR filter, a DWT transform at 3-level is applied to the 'I' to obtain a sub-band of LL_3 of size p x p.
2) To the sub-band of LL_3 coefficients of 'I' in step1 apply SVD using Equation (5) to get S

$$[U, S, V] = SVD(LL_3) \quad (5)$$

3) Now to the watermark image (Wi) apply SVD using Equation (6) and obtain the singular values (S_w)

$$[U_{wi}, S_{wi}, V_{wi}] = SVD(Wi) \quad (6)$$

4) The singular values S_{wi} obtained in step (6) are embedded into S values by using the following Equation (7)

$$S' = S + \delta_s \times S_{wi} \quad (7)$$

The balance between the proposed watermarking system's imperceptibility and its robustness is controlled by a single scaling factor δ_s.

5) To calculate the adjusted $LL_3{}'$ sub-band coefficients, we use Equation (8)

$$LL_3{}' = U \times S' \times V^T \quad (8)$$

To determine the signed image, inverse DWT is applied.

Extraction Procedure

The process of extracting embedded image watermarks involves a combination of a DWT and SVD. After the extraction process is completed, the extracted watermark should be received by the original host image and the signed one.

1) Using the HAAR filter, apply a DWT transform at 3-level to the hosted image I and the signed one I′ to obtain the coefficients of size p × p represented by the LL_3 and $LL_3^{'}$ sub-bands of the two images.
2) Perform SVD on the coefficients of the sub-bands. Use Equations (9) and (10) to determine S and S' respectively

$$[U_I, S_I, V_I] = SVD(LL_3) \quad (9)$$

$$[U_{I'}, S_{I'}, V_{I'}] = SVD(LL_3{}') \quad (10)$$

3) Determine watermark singular values by Equation (11)

$$S_{wi}{}' = (S_{I'} - S_I) \quad (11)$$

4) The extracted watermark can be retrieved using by Equation (12).

$$W' = U_{wi} \times S_{wi}{}' \times V_{wi}{}^T \quad (12)$$

ii) Hybrid GOA-GA Algorithm (HGOAGA)

When it comes to optimization, hybrid optimization algorithms offer several advantages. We can combine different approaches to create a global algorithm that benefits from the combination and avoids disadvantages (Gharsalli, 2022). Hybrid algorithms can combine local and global optimization techniques to achieve high-precision and optimal results (Wang et al., 2022). By merging multiple algorithmic approaches, hybrid algorithms can achieve higher improvement and faster convergence (Liu et al., 2021). However, hybrid algorithms can complicate the definition of control parameters and require specific designs for certain problems (Migallón et al., 2020). Here, we are presenting the hybrid GOA-GA (HGOAGA) algorithm for optimizing the multiple scaling factors in digital watermarking.

The Grasshopper Optimization Algorithm (GOA) is a novel population-based algorithm that draws inspiration from the swarming behaviour of grasshoppers (Sharma et al., 2021). For an optimization problem, the dynamics of grasshoppers' social interactions play an important role in determining global optimality. Due to its easy implementation, effectiveness, accuracy and robustness are extensively used in numerous optimization problems.

- Initially, the algorithm has random population (grasshoppers) solutions.
- Let Y_i represent the position of the i^{th} grasshopper in an n-dimensional space

i.e, $Y_i = (y_{i1}, y_{i2} \ldots y_{in})$.

- The positions of grasshoppers at each iteration are updated using the equation:

$$Y_i = SI_i + GF_i + WA_i \quad (1)$$

where SI_i represents the social interaction, GF_i represents the gravity force and WA_i represents the wind advection of the i^{th} grasshopper.

The random behaviour of the algorithm is achieved by appending the random variables r_1, r_2 and r_3 within the interval [0, 1]. Thus, Equation (1) can be rewritten as;

$$Y_i = r_1 SI_i + r_2 GF_i + r_3 WA_i \quad (2)$$

where

$$SI_p = \sum_{q=1, j\neq i}^{n} SI(d_{pq})\widehat{d_{pq}} \quad (3)$$

where d_{pq} represents the distance between p-th and q-th grasshopper and it is given by

$$d_{pq} = |X_p - X_q| s \quad (4)$$

s is the designed function.

However, some disadvantages of GOA are as follows: 1) An uneven process of exploration and exploitation; 2) An unstable convergence rate; and 3) The potential to reach the local optimum. As a result, several hybrid algorithms that integrate GOA with other

Algorithm 1: Pseudo-code of Hybrid GOA-GA Algorithm (HGOAGA)

```
Initialization of the parameters for GOA and GA
Start
while (searching not completed) GOA algorithm do
    Update agent position
    Evaluation
    Updating the target position
end while
while (evolution not completed) GA algorithm do
    Selection
    Crossover
    Mutation
    Elitist strategy
    Evaluation
    Updating the target position
end while
```

B. Hybrid GOA-GA-based Digital Watermarking Scheme

Here, we present the step-by-step procedure to optimize the multiple scaling factors (MSFs) using an evolutionary algorithm such as the hybrid GOA-GA, as shown below Algorithm 2. A HGOAGA that considers each component's scaling factors. Each block's scaling factor must be optimized according to its standard deviation. The suggested scheme provides different threshold values for each population taken from both algorithms, respectively, which can be utilized as a scaling factor during embedding. Experimental results of the HGOAGA algorithm are presented in the following tables. In the optimization phase, initially, the parameters for HGOAGA are considered as

1. The total number of initial grasshoppers denoted by n = 10, and
2. The simulation is run for 20 iterations repetitively.

Algorithm 2: Hybrid GOA-GA-based watermarking scheme

1. Initialize m grasshoppers randomly. Place each of them into a row vector equal to the watermark size, which is p x p.
2. For Each Grasshopper, do the following
   a) Optimizing the MSFs using Equation (13) instead of Equation (7)

   $$S' = S + \delta_{msf} \times S_w \quad (13)$$

   Where δ_{msf} is a multiple scaling factor.

   b) To generate different types of signed images with various processing attacks, we can apply seven attacks in sequence (k=7).

   c) The watermark should be extracted from the image using the procedure outlined in C of Section III.

   d) Imperceptibility between the original host image I and the signed host image I' by the PSNR value, while the robustness of the embedded watermark image and extracted watermark image by the NCC (W, W') values.

   e) Determine the fitness value of the HGOAGA using the following fitness functions given by Equation (14).

   $$F = PSNR + \phi * \left[NCC\left(W, W'\right) + \sum_{i=1}^{7} NCC\left(W, W_i'\right) \right] \quad (14)$$

   Where,

   NCC (W,W') represents the normalized cross-correlation between the original and the extracted watermarks from the signed image.

   NCC (W,W_i') represents the normalized cross-correlation between the original and extracted watermarks for all different seven attacks.

   The normalized cross correlation values are weighted by ϕ.
3. Update these m grasshoppers by the procedure of the **genetic algorithm discussed in Algorithm 1**
4. Until the maximum number of generations is reached, repeat steps 2 and 3 of the process.

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optimization algorithms have been proposed in the literature.

On the other hand, the GA algorithm (Singh et al., 2021; Alzyadat et al., 2020) was originally developed to perform complex optimization tasks involving natural selection, evolution, and genetics. It is considered one of the most powerful tools in the optimization field. Unfortunately, GA has several disadvantages when dealing with large, complex systems. It is very slow, and because it requires a larger number of iterations, it can be difficult to guarantee access to the optimal global solution over a longer search period.

Most researchers recommend integrating evolutionary algorithms to increase productivity, take advantage, and address any weaknesses in the solutions. The goal of hybridizing algorithms is to find a healthy balance between exploration and exploitation. This is done by creating a uniformly distributed population and expanding the search scope, thereby reducing computation time or producing a sophisticated convergence rate.

The hybrid form of GOA and GA algorithm1 (El-Shorbagy et al., 2020) has superior properties, with the operators of GA providing good exploitability. When GOA updates each agent's location, it takes into account both the global best position and the agent's actual position, just like with all other search agent locations. These GOA solutions search the optimization problem's domain explained in steps 1 to 2 to find the best solutions. GA does the evolution of these solutions during this process given in step 3.

Result and Discussion

For the implementation purpose of hybrid DWT-SVD-based watermarking using both hybrid GOA-GA and GTO algorithms, we considered six different grayscale images of size 512 × 512, such as Barbara.jpg, Boat.png, Baboon.jpg, Cameraman.jpg, Lena.jpg and Pirates.png as Host images and the following 256 x 256 grayscale image of 'logo.jpg' as watermark image. These are depicted in the Figures 2 and 3.

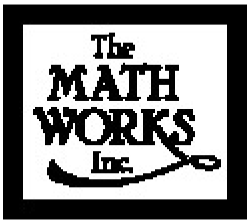

Figure 2. Watermark image.

Figure 3. Gray scale Cover Images.

Imperceptibility and Robustness Test

The NCC and PSNR are two tests computed by the following Equations (15) and (16), which are used to evaluate the imperceptibility and robustness of a watermarking method.

$$NCC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[W(i,j) - W^{'}(i,j)\right]}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[W(i,j)\right]^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[W^{'}(i,j)\right]^2}} \quad (15)$$

and

$$PSNR = 10\log_{10}\left[\frac{MAX\left((I(i,j))^2\right)}{MSE}\right] \quad (16)$$

Where,

$$MSE = \frac{1}{M*N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[I(i,j) - I^{'}(i,j)\right]^2 \quad (17)$$

The imperceptibility and robustness of the proposed algorithm are given in Table 1 and Table 2, which compare the imperceptibility of the proposed algorithm with that of the GOA algorithm. The proposed algorithm's performance measure can be estimated using the following criterion with fitness function as mentioned in the above algorithm 2.

1**. Imperceptibility**: The PSNR value is between
(a) 50 & above - High
(b) 40-49 - Medium and
(c) 30-39 - Low metrics
respectively.

2. **Robustness:** The NCC value is between
(a) 1.0- 0.9 - High
(b) 0.89-0.8 - Medium and
(c) 0.79 - Low metrics respectively

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Table 1. Performance of proposed GOA-GA algorithm.

Cover Image	PSNR	SSIM	NCC
Lena	51.0880	0.9409	1.0000
Barbara	51.1599	0.9383	1.0000
Boat	51.1599	0.9383	1.0000
Monkey	51.1599	0.9383	1.0000
Cameraman	51.1599	0.9383	1.0000
Pirate	51.0884	0.9408	1.0000

Table 2. Comparative performance of GOA-GA algorithm with GOA algorithm.

Cover Image	GOA [29]		GOA-GA	
	PSNR	SSIM	PSNR	SSIM
Lena	75.67	1	51.0880	0.9409
Barbara	NA	NA	51.1599	0.9383
Boat	NA	NA	51.1599	0.9383
Baboon	80.87	1	51.1599	0.9383
Camera man	81.47	1	51.1599	0.9383
Pirate	70.84	1	51.0884	0.9408

Security Analysis

Table 3 gives the NCC values of reconstructed images with different attacks such as Salt and Pepper (SP), Gaussian filter (GF), Sharpening (SH), Histogram (HG), Scaling (SC), Quantization (QU) and Cropping (CR) and Figures 4-9 gives the corresponding histogram analysis of NCC values of the different cover images using a proposed system with various attacks.

The above data provides a comprehensive overview of various image quality metrics for different cover images. The key columns in the dataset include "Cover image," "SP," "GF," "SH," "HG," "SC," "QU," and "CR." Each column represents a specific metric or identifier for the images, with values given in a standardized format. The "Cover image" column lists the names of the images, such as 'Lena,' 'Barbara,' 'Boat,' 'Baboon,' and 'Cameraman.' The subsequent columns, "SP," "GF," "SH," "HG," "SC," "QU," and "CR," contain numerical values representing different quality metrics. For instance, "SP" ranges from 0.9903 to 0.9953, "GF" from 0.9881 to 0.9997, "SH" from 0.9978 to 0.9999, "HG" from 0.9261 to 0.9951, "SC" is consistently 1, "QU" from 0.981 to 0.9898, and "CR" from 0.9561 to 0.9844.

Based on the first five sample data entries, we observe that all images have a perfect "SC" score of 1, indicating a uniform standard in this metric. The "SH" scores are also notably high, with values close to 1, suggesting high sharpness across the images. The "HG" scores show more variability, particularly with the 'Boat' image having a significantly lower score of 0.9261 compared to others. The "CR" values indicate a range of compression ratios, with 'Barbara' having the highest at 0.9844 and 'Boat' the lowest at 0.9561. These insights suggest that while some metrics are consistent across images, others like "HG" and "CR" show more variation, potentially impacting the overall image quality.

Table 3. NCC Values of Reconstructed Image With Different Attacks.

Cover image	SP	GF	SH	HG	SC	QU	CR
Lena	0.9928	0.9984	0.9989	0.9907	1.0000	0.9898	0.9611
Barbara	0.9932	0.9965	0.9990	0.9947	1.0000	0.9890	0.9844
Boat	0.9914	0.9979	0.9994	0.9261	1.0000	0.9824	0.9561
Baboon	0.9903	0.9881	0.9978	0.9888	1.0000	0.9841	0.9583
Cameraman	0.9950	0.9997	0.9999	0.9385	1.0000	0.9810	0.9749
Pirate	0.9953	0.9979	0.9988	0.9951	1.0000	0.9878	0.9796

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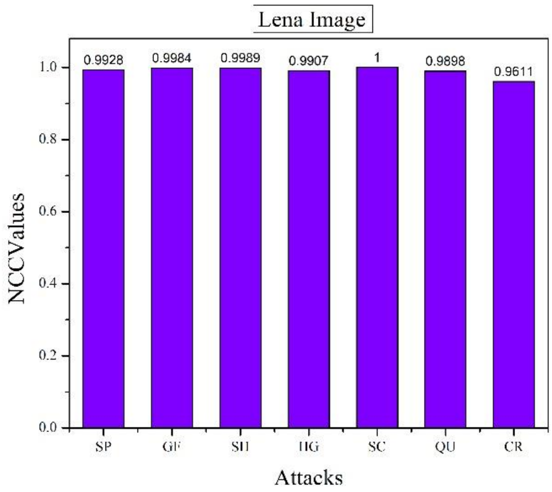

Figure 4. NCC values of various attacks on Lena's image.

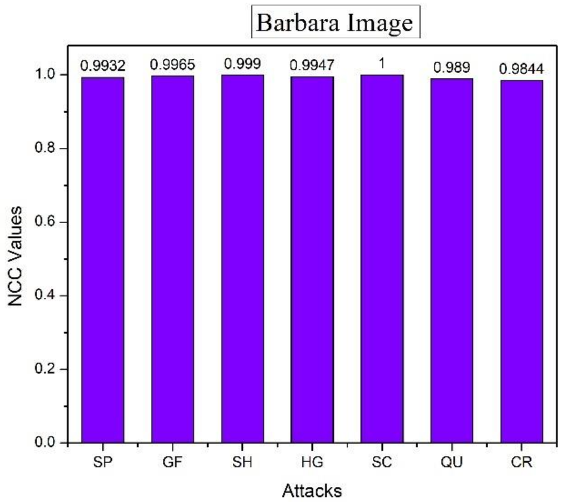

Figure 5. NCC values of various attacks on Barbara's image.

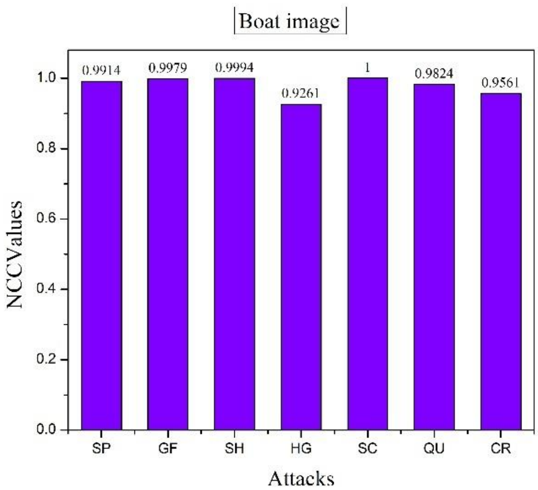

Figure 6. NCC values of various attacks on Boat's image

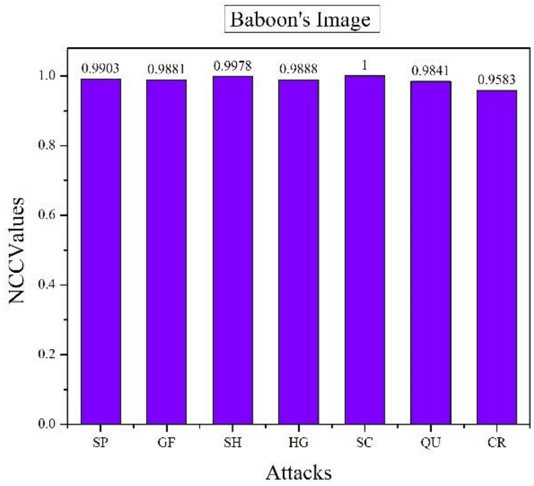

Figure 7. NCC values of various attacks on Baboon's image.

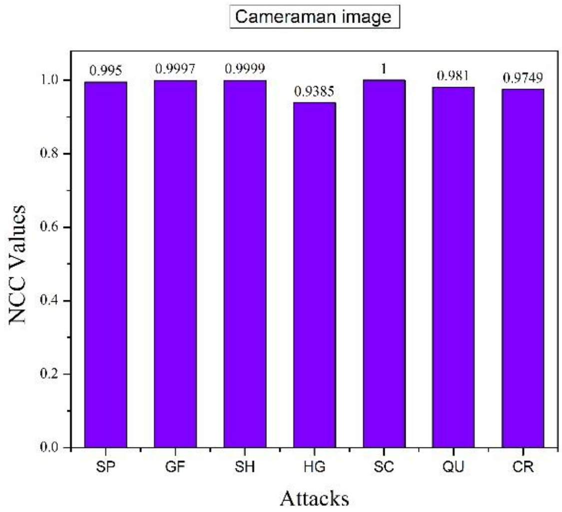

Figure 8. NCC values of various attacks on Cameraman's image.

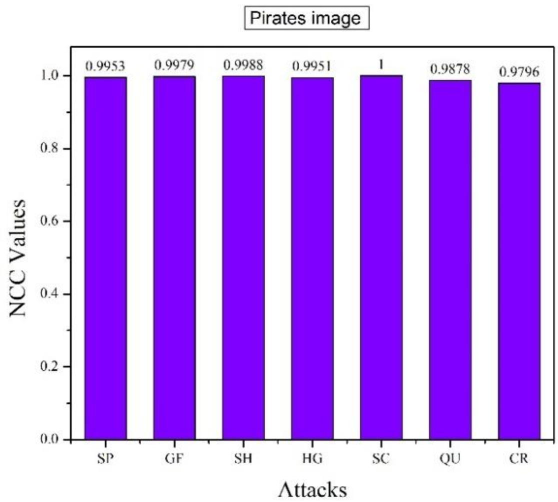

Figure 9. NCC values of various attacks on Pirate's image.

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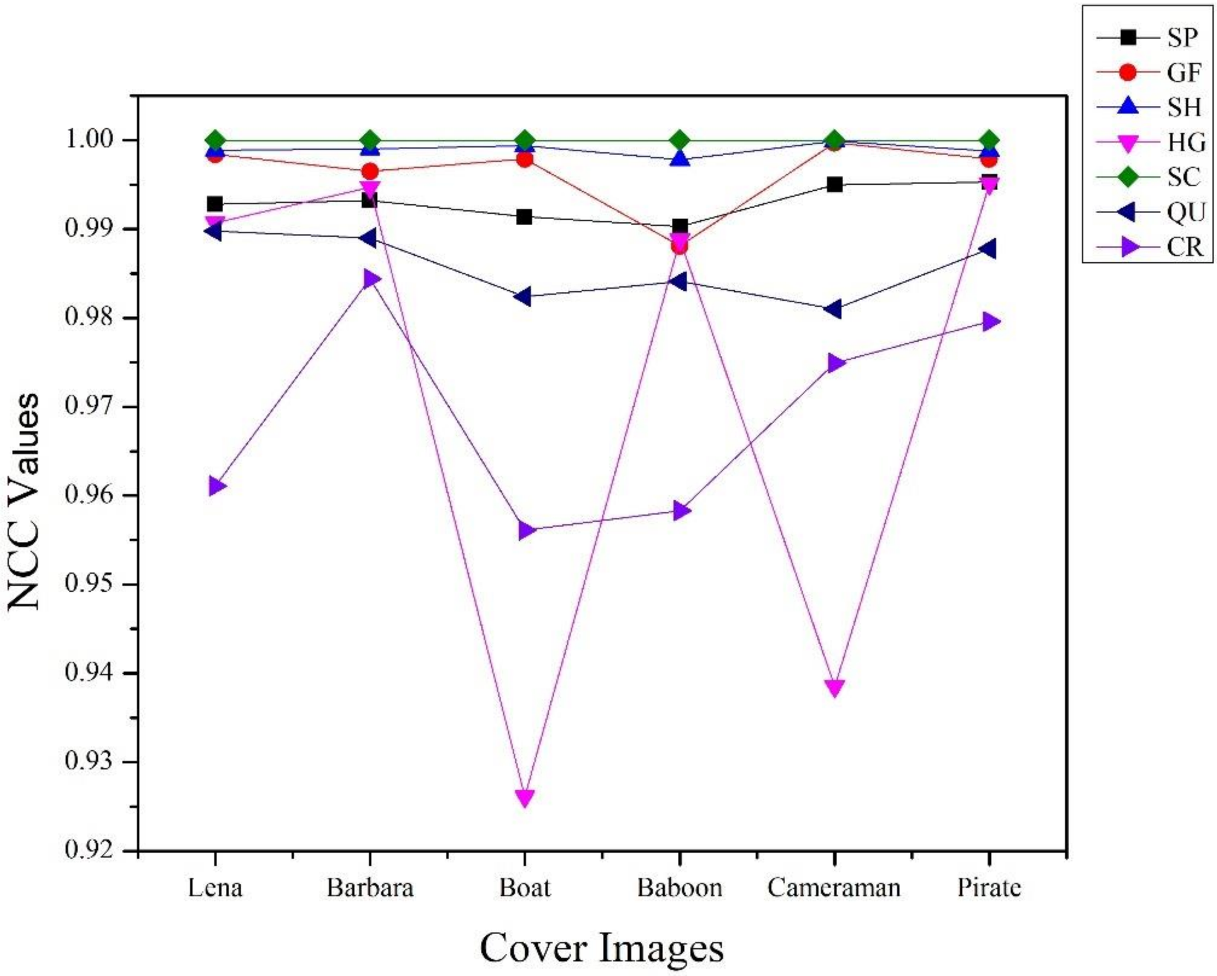

Figure 10. Comparative graph of NCC values of different attacks on cover images.

Comparative study

In this section, a comparative analysis was conducted to determine the efficiency of the proposed hybrid algorithm. The consistency of the solution primarily hinders population-based algorithms. The proposed hybrid algorithm improved the quality of its solutions by combining the advantages of two population-based algorithms, such as GOA and GA. Instead of searching for a single point to provide the globally optimal solution, our approach searches for a population, just like deterministic algorithms do.

Figure 10 shows an NCC value comparison chart for various attacks on different cover images. Table 4 shows the fitness function convergence curves for each image in the HGOAGA algorithm. Table 5 presents a comparative study of the proposed method, which performs well compared to other existing methods in terms of the PSNR value for standard images.

Conclusion

The key to the extraction phase is to maintain the appropriate MSF settings. However, the ideal MSF settings are not adaptable to variations in the watermark data. This means that if there are minor changes to the watermark, the system will have to recalculate the new MSF values. New approaches that do not use MSF parameters as keys need to be explored to provide more flexibility. Therefore, a new evolutionary algorithm, such as the hybrid Grasshopper algorithm and Genetic algorithm for optimizing the multiple scaling factors for digital watermarking, is proposed in the hybrid frequency domain scheme such as DWT and SVD. The experimental results PSNR, NCC and SSIM values of different images using seven attacks of the proposed work are compared with other existing methods. Based on the experimental results, the proposed method performs well in terms of robustness and effectiveness. Like other population-based methods (PBMs), it may have the disadvantage that no optimization problem can be solved with a guarantee of improved computational accuracy or speed. This is due to the arbitrary methodology of PBMs. Furthermore, chaotic local search can be used to strengthen the proposed hybrid algorithm in case there are possible errors.

Data Availability

The standard images from MATLAB are used to do research.

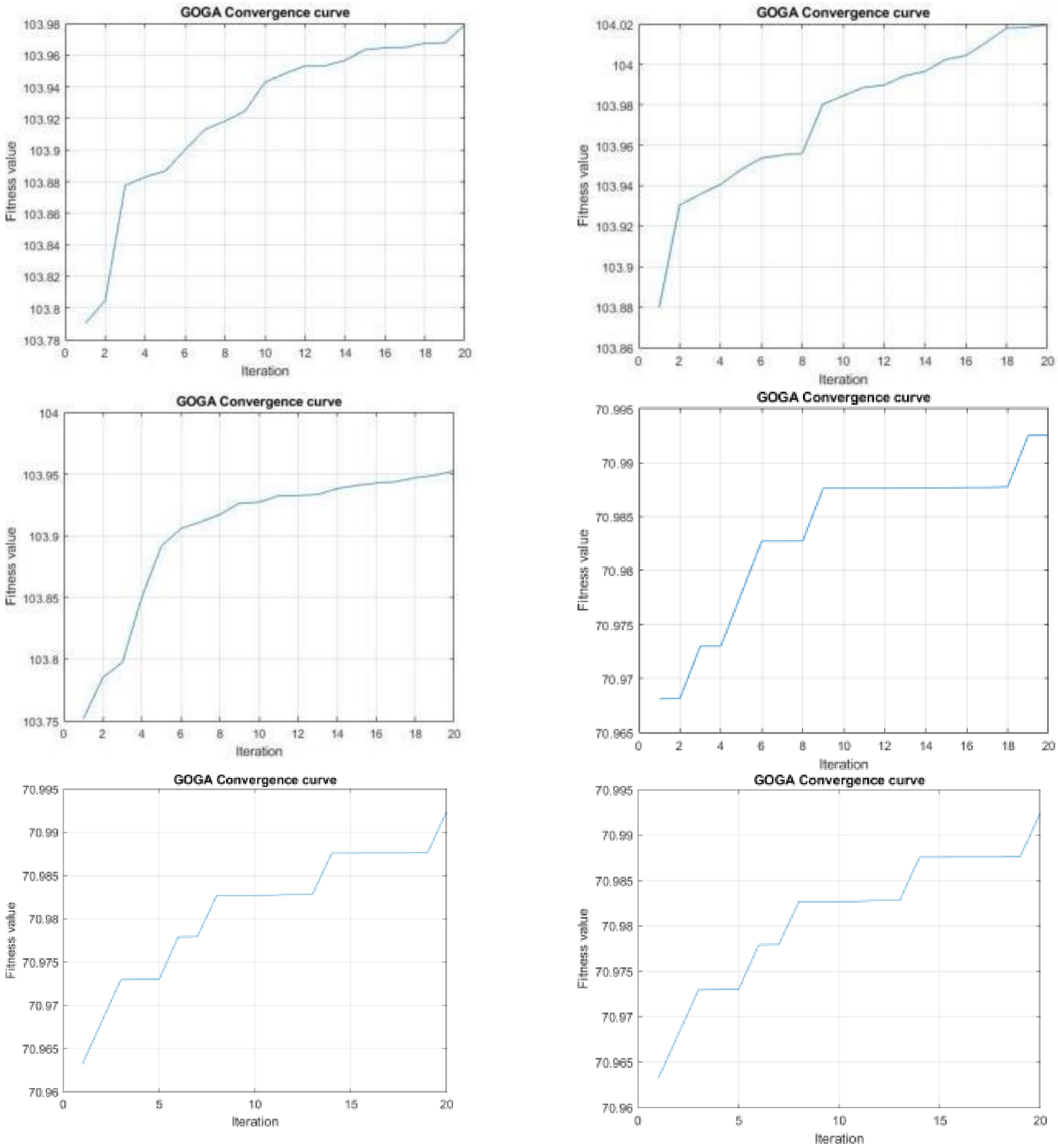

Figure 11. Convergence curves of fitness function of cover images using the HGOAGA algorithm .

sTable 4. Comparison of PSNR values with existing works.

			Cover Images			
	Reference	**Optimization algorithm used**	**Barbara**	**Lena**	**Baboon**	**Cameraman**
Existing works	Amiri et al., 2020	PSO-GA	40.5	NR	41.3	NR
	Devi et al., 2022	G-BAT	NR	NR	59.74	60.82
	Devi et al., 2022	Ji-FI	40.96	NR	NR	NR
	Hassan et al., 2021	BFO	43.7	43.6	32.3	40.1
	Sharma et al., 2020	Dragonfly	49.5	49.9	44.2	51.2
	Maloo, et al., 2020	MWOA	NR	54.61	53.44	56.13
Proposed GOA-GA Algorithm			**51.16**	**51.16**	**51.16**	**51.16**

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Conflict of Interest

The authors declare no conflict of interest.

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