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Duraisamy Jude Hemanth*, Subramaniyan Umamaheswari, Daniela Elena Popescu, and Antoanela Naaji

Application of Genetic Algorithm and Particle Swarm Optimization techniques for improved image steganography systems

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Abstract: Image steganography is one of the ever growing computational approaches which has found its application in many fields. The frequency domain techniques are highly preferred for image steganography applications. However, there are significant drawbacks associated with these techniques. In transform based approaches, the secret data is embedded in random manner in the transform coefficients of the cover image. These transform coefficients may not be optimal in terms of the stego image quality and embedding capacity. In this work, the application of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have been explored in the context of determining the optimal coefficients in these transforms. Frequency domain transforms such as Bandelet Transform (BT) and Finite Ridgelet Transform (FRIT) are used in combination with GA and PSO to improve the efficiency of the image steganography system.

Keywords: Transforms; image steganography; Genetic Algorithm and Particle Swarm Optimization

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1 Introduction

The important issue in media is data security due to the growth of the internet. The information sent through channel requires more data security. Hence, to secure the data,

the information hiding approaches like cryptography, watermarking and steganography have been used. Among all these techniques, steganography plays a major role in data security. Steganography hides the secured data on to the original or cover image and the resultant stego image is sent through the channel. The secret data may be video, image, audio or text. The steganography word is obtained from the Greek words ‘stegos’, meaning ‘cover’ and ‘grafia’, meaning ‘writing’ thus it is called as ‘Cover Writing’. During the 5th century, the king Darius had taken a Greek Tyrant Histiaeus as a prisoner in Susa. Tyrant used a steganography method to send message to his son-in-law. He shaved a slave’s head and tattooed the message on his scalp. After few days, slave’s hair was grown which hid the message and slave was sent to his son-in-law with that message on his scalp [1]. There are number of steganography approaches [2] used to embed secret information in the original cover image. The Steganography approaches are commonly divided into spatial domain and frequency domain approaches [3]. In spatial domain, the information is hidden directly in the Least Significant Bit (LSB) plane of cover image [4–6]. But the drawback of this approach is fidelity of stego image is not maintained. In frequency domain approaches, the information is hidden in the transform coefficients.

The spatial domain in Steganography has two methods namely, LSB matching and LSB substitution method. In LSB matching, the secret data bits are matched with LSB plane which has been proposed by Luo *et al.* [4]. In the LSB substitution method, LSB’s plane is replaced directly without modifying the cover image. Bedi *et al.* [5] has proposed the spatial domain combined with optimization technique in order to find the best pixel location with distortion tolerance. However, emphasis was given on distortion tolerance rather than embedding capacity and quality of stego image. The transforms used in frequency domain approaches are Discrete Fourier Transform (DFT), Discrete Curvelet transform (DCT), Discrete Cosine Transform (DCoT), Contourlet transform, and Discrete Wavelet

*Corresponding Author: Duraisamy Jude Hemanth: ECE Department, Karunya University, Coimbatore, India; Email: jude_hemanth@rediffmail.com

Subramaniyan Umamaheswari: EIE Department, SRM University, Kanchipuram, India

Daniela Elena Popescu: Oradea University, Romania

Antoanela Naaji: Vasile Goldis Western University of Arad, Romania



Transform (DWT). Chang *et al.* [6] and Lin [7] have hidden the secret data in DCT coefficients with more security. The DWT based data hiding method has been proposed using bit-plane compression technique [8, 9]. Subhedar and Mankar [10] has used the redundant discrete wavelet transform and QR factorization method to hide the data. Jero *et al.* [11] has used the ant colony optimization to hide the ECG signal in patient data. But, this optimization method is computationally expensive when we need to hide the EEG signals. So, the PSO optimization tools can be used to find the correct set of parameters and also it is simple in method.

In this paper, the Bandelet Transform (BT) and Finite Ridgelet Transform (FRIT) are combined with optimization techniques to improve the fidelity of stego image. The BT and FRIT is chosen to yield the high embedding capacity. GA and PSO find the most significant coefficients for better information hiding. The proposed methodology increases the fidelity of the stego image and embedding capacity and also provides more security. The experimental results of the proposed approaches has been compared with recent works. The GA and PSO are the strong algorithms, these tools in combination with BT and FRIT is a novel attempt to enhance the efficiency of the steganography system. The rest of this paper is organized as follows: Section 2 describes an overview of the BT, FRIT, GA and PSO, Section 3 discusses the proposed methodology, Section 4 gives the experimental results and Section 5 provides the conclusion of proposed work.

2 Overview of Techniques

This section briefly discusses the four techniques: (1) Bandelet transform (2) Finite Ridgelet transform (3) Genetic Algorithm (4) Particle swarm optimization.

2.1 Bandelet Transform (BT)

Bandelet Transform (BT) is a multiscale and multi directional transform which is mainly used to represent the edges and texture of image efficiently [12]. It takes the advantage of sharp image transitions in digital image. In BT, the bandelet bases are formed by geometric flow of vectors which is used to represent the edges of image. The bandelet bases leads to optimal approximation rates for geometrical images. The geometrical images have smooth regions surrounded by regular curves. In most of the applications, the bandelet transform is used for image fusion. In

this work, bandelet transform is used for data hiding. Figure 1 shows the geometry flow and sample one level bandelet decomposition of image.

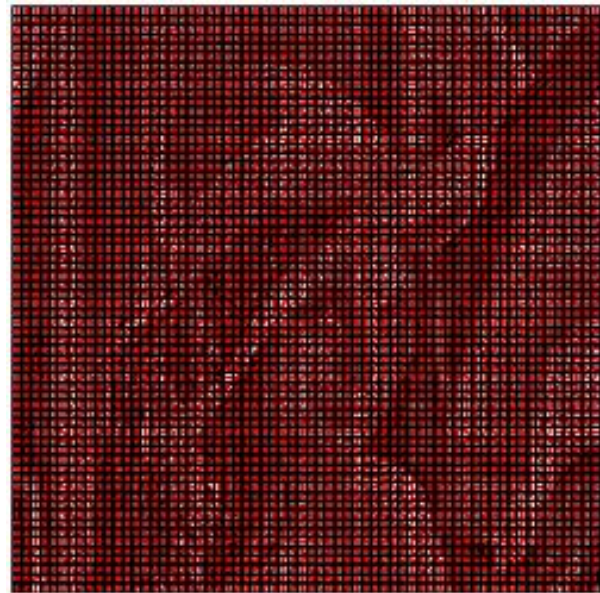


Figure 1: Geometry flow of Lena image.

2.2 Finite Ridgelet Transform (FRIT)

The finite ridgelet transform has been advanced from the finite radon transform as shown in Figure 2. The ridgelet transform is used for sparse representation of digital images [13]. The periodization effect in the finite transform, Finite Radon Transform (FRA) was introduced. The Finite Ridgelet transform (FRIT) is obtained by performing the one dimensional (1-D) wavelet transform on each direction (d) of FRAT. The FRIT is non-redundant and invertible in nature. It shows optimal performance than the wavelet transform in performing with straight edges. The sample one level FRIT decomposition of image is shown in Figure 3.

2.3 Genetic Algorithm (GA)

Genetic algorithm (GA) is an evolutionary search technique based on the fact of natural genetics. It is a random search technique, developed by Holland in 1960 [14] and later it was popularized by Goldberg. One of the significant parameters in the GA is chromosome. Chromosome is represented with binary strings. The elements in the chromo-

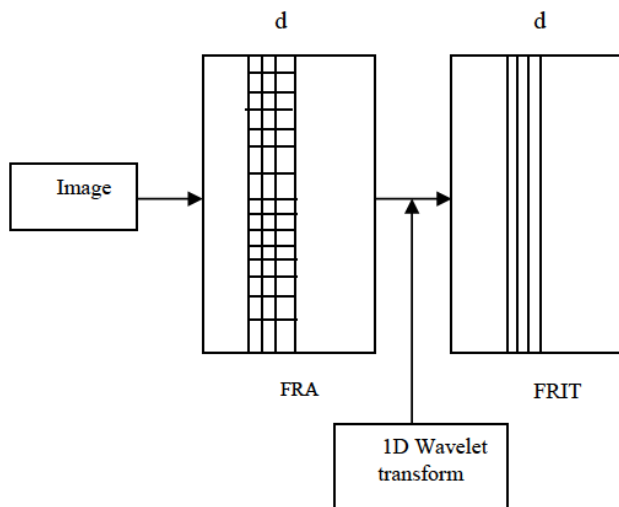


Figure 2: Description of finite ridgelet transform.

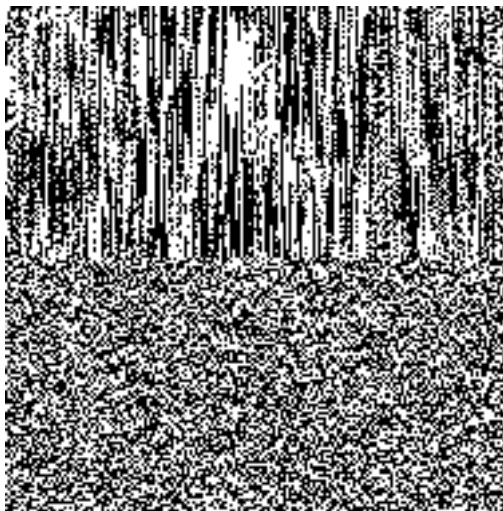


Figure 3: Sample one level FRIT decomposition of Lena image.

some are adjusted based on fitness value. The fitness value is derived from the fitness function which can be minimization function or maximization function. Based on the fitness value, the chromosomes are changed using reproduction operation. This procedure is repeated for a specific number of iterations. The optimal output is obtained at the end of specified iteration. A detailed approach is given in [15].

2.4 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a population based optimization techniques, which has been developed by Kennedy and Eberhats in 1995. The potential solution is

represented by each individual. Each particle's position is altered according to its neighbors and with its own practical experience. In each iteration, the predetermined particles correspondingly produce fitness value from the fitness function and also have velocity to direct the movement of the particle. Each particle in a population keeps track of its best solution (fitness) in the search space which has achieved so far by that particle. This fitness value is called pbest (personal best). PSO keep track of another best solution that is obtained so far by any particle in the neighborhood of that particle. This is known as gbest (global best). A detailed algorithm is given in [16].

3 Proposed Methodology

The block diagram of embedding phase is shown in Fig. 4. The explanation of data embedding and data extraction phase are given below.

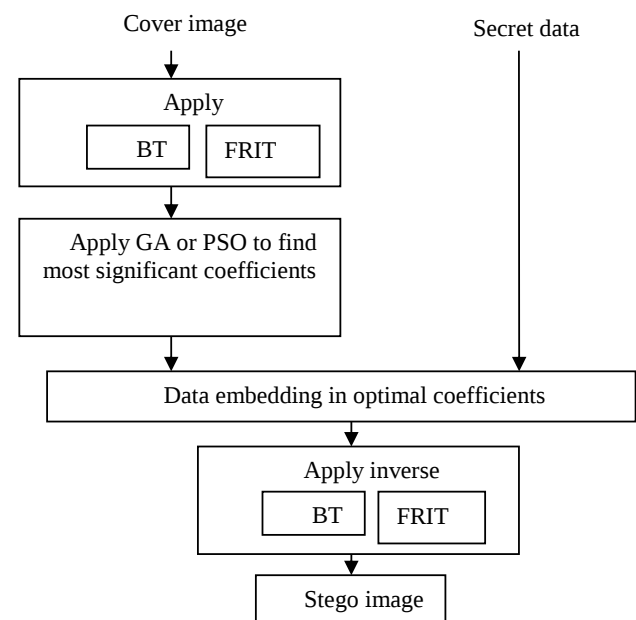


Figure 4: Block diagram of Data embedding.

3.1 Embedding Phase

The first step of embedding phase is to read the cover image $A(x, y)$. The cover image is decomposed using specific transforms (BT & FRIT). Then, the most significant coefficients are selected using GA and PSO. Embedding the secret data in the most significant coefficients, that will in-

crease the fidelity stego image. The explanation of GA and PSO are given in the next section. The optimized most significant transform coefficients are placed in the matrix Ri_m for m^{th} block. The matrix X has the specific transform coefficients.

$$Ri_m = [I'[1, A(x, y)] \dots I'[p + 1, A(x, y)]^T \quad (1)$$

Next step is to read the secret data $B(x, y)$. The secret data $B'(x, y)$ is hidden in the most significant coefficients according to the following embedding law,

$$Ri^S(x, y) = Ri_m + \delta \cdot B'(x, y) \cdot Ri_m \quad (2)$$

Where, δ is the scaling factor and its value used in this work is $\delta = 0.30$. Finally, The inverse specific transform (BT and FRIT) is applied to obtain the stego image.

3.2 Extraction Phase

The extraction phase extracts the embedded secret data and cover image separately. Decompose the stego image using specific transform (BT and FRIT). Then use the positions of most significant coefficients to determine the extraction key. The extraction key possesses the position of most significant coefficients. The selected most significant coefficient positions are placed in a matrix $P^*(i, j)$. A correlation detector (C), which gives the average correlation between each row of $R(x, y)$ and secret message, is obtained by,

$$C = \frac{1}{m} \sum_{i=1}^m \left(\frac{1}{P} \sum_{j=1}^P R(x, y) B'(x, y) \right) \quad (3)$$

Thus, the secret message is extracted using equation 4. The cover image is obtained by applying inverse specific transform.

$$B''(x, y) = CB'(x, y) \quad (4)$$

3.3 Implementation

The implementation aspects of GA and PSO based data embedding and data extraction are discussed below.

3.3.1 GA based data embedding

The procedure of GA for finding the most significant coefficients in BT and FRIT is given below.

Step 1. Parameter Representation: The parameter representation of GA is given in Table 1.

Table 1: Representation of GA Parameter.

Parameters	Value
Iteration	100
Individuals	15
Each individual is composed	$256 \cdot 256 / 8 \cdot 8 = 1024$ chromosomes
Each chromosome length	64
Cross over probability	0.25
Mutation probability	0.05
Selection probability	0.5
No of position to embed the secret data	64

The number of individuals are randomly chosen as 15. Each individual is composed of 1024 chromosomes. The size of specific transform coefficients ($256 \cdot 256$) is divided by size of secret message to obtain the number of chromosomes. Length of each chromosome is chosen as 64. The number of positions to hide the secret message depends on the size of the secret message. In this paper, the size of secret message is $8 \cdot 8 = 64$. The other parameters are chosen randomly.

Step 2. Fitness Function

In order to enhance the quality of stego image, Peak Signal-to-Noise ratio (PSNR) equation is taken as a fitness function. GA and PSO search for the chromosomes with highest fitness value from the fitness function. PSNR is measured between cover image and stego image. If PSNR value is high, the fidelity of stego image is also high. The fitness function is given in equation 5 and 6.

$$MSE = \frac{1}{m \cdot n} \sum_{i=1}^m \sum_{j=1}^n [A(x, y) - Stego(x, y)]^2 \quad (5)$$

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE} \right) \quad (6)$$

Step 3. Selection Process:

According to the rank selection method, the 1st rank will be allotted to the highest fitness value and 2nd rank will be allotted to the next highest fitness value. The procedure is adopted for all 1024 chromosomes for each individual. The 15 individuals are reordered according to the rank allotted. The first top two fitness individuals (P_{good}) undergo crossover and mutation. The last two weak fitness individuals (P_{bad}) are discarded and leave a space for 2 new offspring for the next iteration.

Step 4. Reproduction operators: Crossover and mutation are the two reproduction operators.

Two individuals are chosen from P_{good} to produce new offspring. In this paper, two point cross over is used for generating new chromosomes. The mutation process is also used for offspring formation. In this method, bits are swapped to form the new chromosomes. After crossover and mutation, the discarded offsprings are replaced with new offsprings.

Step 5. Test for convergence: Repeat the above mentioned procedure for specific number of iteration. The resulting most significant coefficients selected by GA are considered as the optimal solution which will give a better stego image quality.

3.3.2 PSO based data embedding

PSO is used to give the most significant coefficients in BT and FRIT to embed the secret data. The most significant coefficients are obtained by following steps,

Step 1. Parameter Representation: The parameter representation of PSO is given in Table 2.

Table 2: Representation of PSO Parameter.

Parameters	Value
Iteration	100
Inertia weight (w)	0.4
c_1 & c_2 (cognitive and social acceleration factors)	1.49
$r_1(t)$ & $r_2(t)$ (random numbers)	1
No of position to hide the secret message	64

Step 2. Fitness function: The fitness function for PSO is same as used in GA.

Step 3. Initialization: In the 1st iteration, PSO randomly select the position and velocity. Then, for each particle the fitness value is calculated from the fitness function which is measured between cover and stego image.

Step 4. Calculate pbest and gbest: After the fitness function evaluation, estimate pbest as gbest using the equation 7. Considering the maximization problem, the global best

position is calculated as,

$$gbest = \begin{cases} P_x(t+1) & \text{if } F(P_x(t+1)) \geq F(pbest) \\ pbest & \text{if } F(P_x(t+1)) < F(pbest) \end{cases} \quad (7)$$

where, P is the fitness function which measures the closest optimum solution.

Step 5. Update particle position and velocity: Let $P_x(t)$ be the current position of particle x in the search space at time t . The current position ($P_x(t)$) is updated to new position ($P_x(t+1)$) according to the velocity $V_x(t+1)$ is given by,

$$P_x(t+1) = P_x(t) + V_x(t+1) \quad (8)$$

In every iteration, each particle is updated according to the pbest and gbest value. The velocity of particle x is updated according to the equation 9.

$$V_x(t+1) = w \cdot V_x(t) + c_1 r_1(t) [pbest - P_x(t)] + c_2 r_2(t) [gbest - P_x(t)] \quad (9)$$

where, $V_x(t)$ is the current velocity of particle x at time t , w is the inertia weight factor, $P_x(t)$ is the current position of particle x at time t , c_1 & c_2 are cognitive and social acceleration constants, $r_1(t)$ & $r_2(t)$ are the random values in the range between $[0,1]$.

Step 6. Test Convergence: Repeat the above procedure till there is no change in particle positions.

The resulting best coefficients selected by PSO are considered as the optimal solution which will give a better stego image quality. The best positions selected by PSO in the data embedding are taken as key and will be later used in the data extraction for the extraction of secret data.

4 Experimental Results and Discussions

The software used for implementation is MATLAB. Four gray-level images such as “Sailboat”, “Barbara” “Girl” and “Tiffany” are used in this work. The cover gray-level images are shown in Fig. 5.

The performance measures used in this paper are Peak signal-to-noise ratio (PSNR) and embedding capacity (bits). The PSNR performance measure is used to measure the quality of stego image. The PSNR is defined through the mean square error (MSE). Embedding capacity (bits) gives the amount of data that can be hidden in the cover image. A high embedding capacity is always required for all steganography system. Tamper Assessment Factor (TAF)

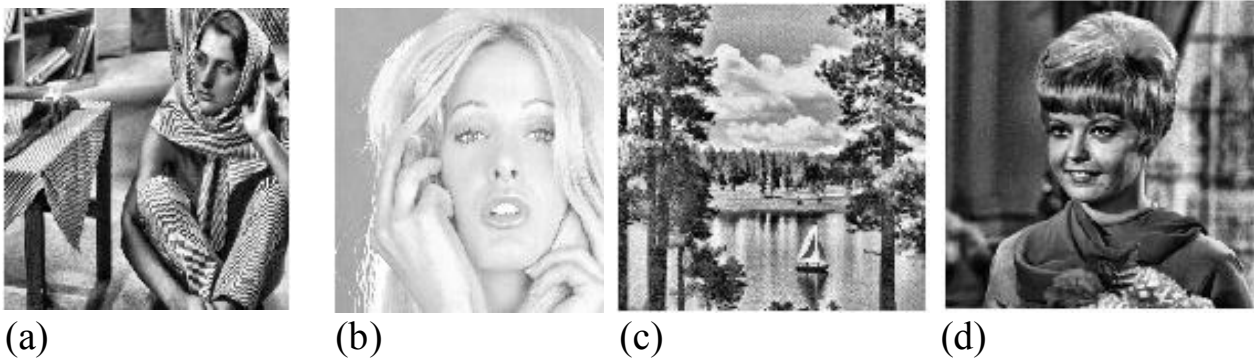


Figure 5: Sample cover images: (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

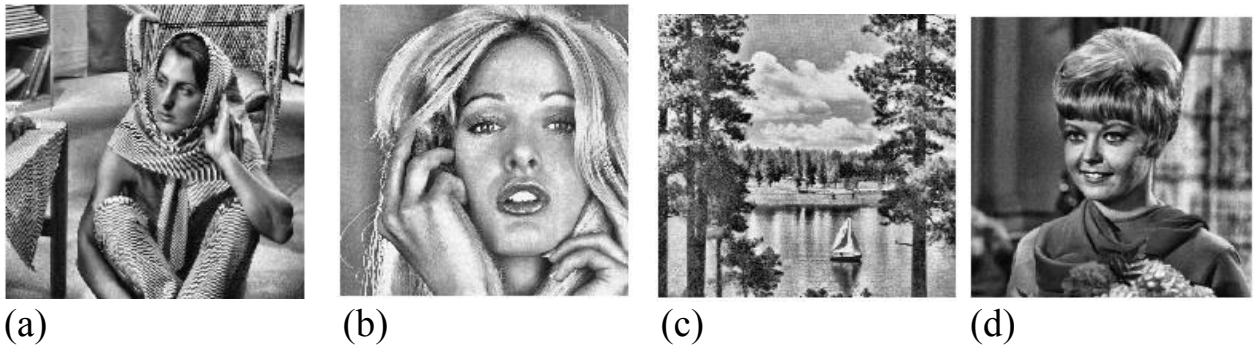


Figure 6: Stego images using Bandelet transform with GA of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

measures the quality of retrieved secret data. The value of TAF should be between 0-1. The Normalized absolute error (NAE) measures the quality of reconstructed cover image. Let $A(x, y)$ be the cover image, $B(x, y)$ be the secret message, $B'(x, y)$ be the retrieved secret message and $C'(x, y)$ be the restored cover image where, x and y denote the row and column. TAF and NAE, are defined in equation 10 & 11 respectively,

$$TAF = \frac{1}{m \cdot n} \sum_{i=1}^m \sum_{j=1}^n [B(x, y) \oplus B'(x, y)] \quad (10)$$

$$NAE = \frac{\sum_{i=1}^m \sum_{j=1}^n |A(x, y) - A'(x, y)|}{\sum_{i=1}^m \sum_{j=1}^n |A(x, y)|} \quad (11)$$

4.1 Results of Bandelet transform with GA and PSO- Embedding Phase

In the first experiment, Bandelet transform with GA and PSO is performed. The Bandelet transform efficiently represent the sharp edges of cover image. In this paper, GA and PSO are used to increase the fidelity of stego image.

and PSO are used to give the most significant coefficients in the Bandelet transform. After GA and PSO, the most significant coefficients are obtained to embed the secret data. The stego images using GA and PSO are shown in Fig 6 & 7. The Performance measures of GA based bandelet transform for embedding phase is shown in Table 3 & 4.

Table 3: Combined GA and Bandelet transform approach- PSNR values.

Images	PSNR(dB)	Embedding Capacity (bits)
Barbara	37.36	350860
Tiffany	37.50	337516
Sail boat	37.17	348970
Girl	38.23	321304
Average	37.56	339662

From Table 3, it is evident that good fidelity of stego image is obtained at the 100th iteration. An average PSNR value of 37.56 dB and average embedding capacity of 339662 bits has been achieved.

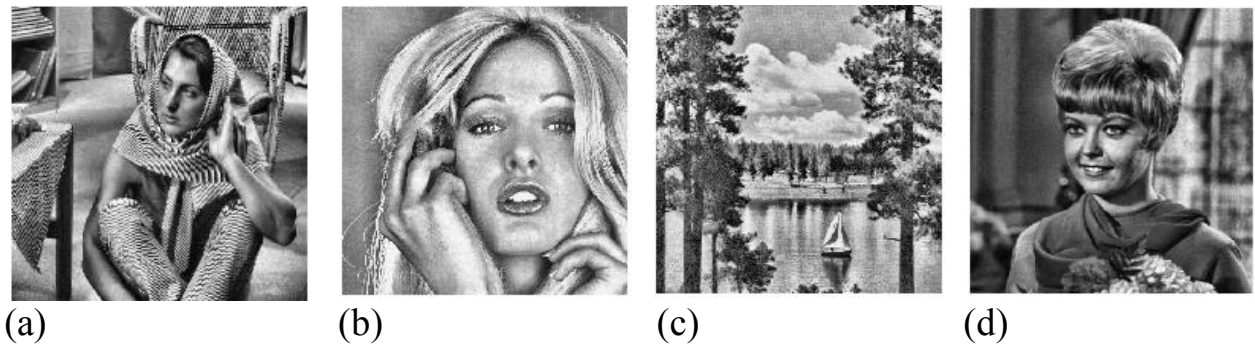


Figure 7: Stego images using Bandelet transform with PSO of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

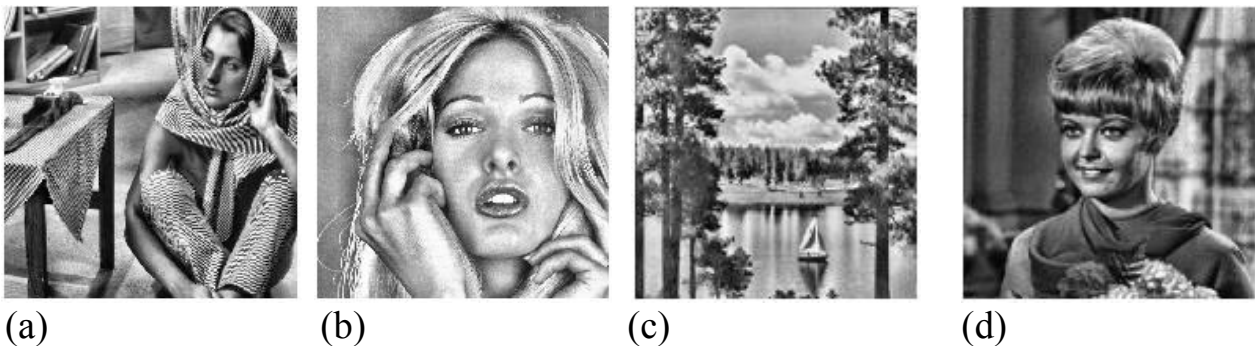


Figure 8: Restored cover image using Bandelet transform with GA of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

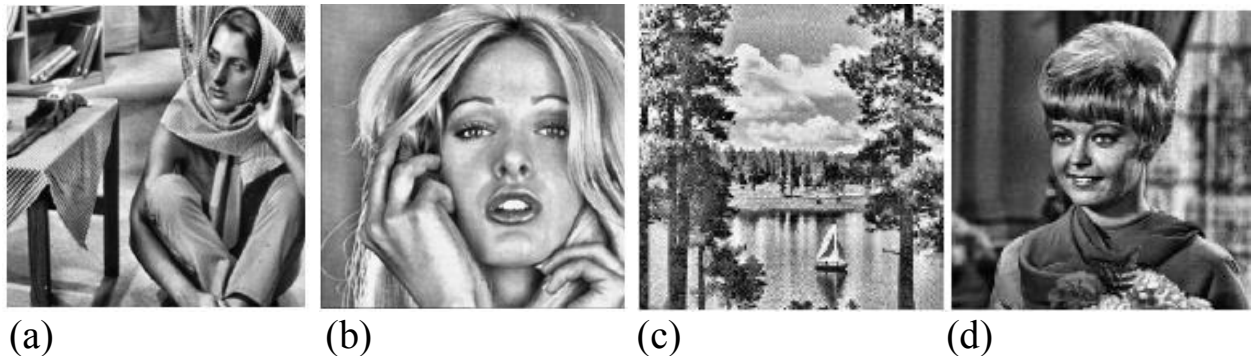


Figure 9: Restored cover image using Bandelet transform with PSO of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

Table 4: Combined PSO and Bandelet transform approach- PSNR values.

Images	PSNR(dB)	Embedding Capacity (bits)
Barbara	43.89	350191
Tiffany	43.83	341297
Sail boat	42.68	350191
Girl	43.83	341297
Average	43.55	345744

From Table 4, it is evident that the best PSNR value is obtained at the 100th iteration. An average PSNR value of 43.5 dB and average embedding capacity of 345744 bits has been achieved.

4.2 Results of Bandelet transform with GA and PSO- Extraction Phase

The restored cover image of Bandelet transform combined with GA and PSO is shown in Fig 8 & 9. The Performance

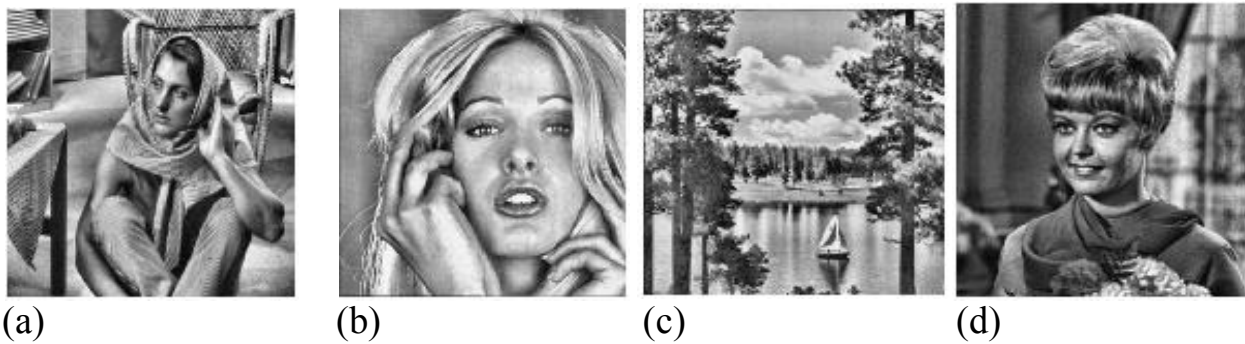


Figure 10: Stego image using FRIT with GA of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

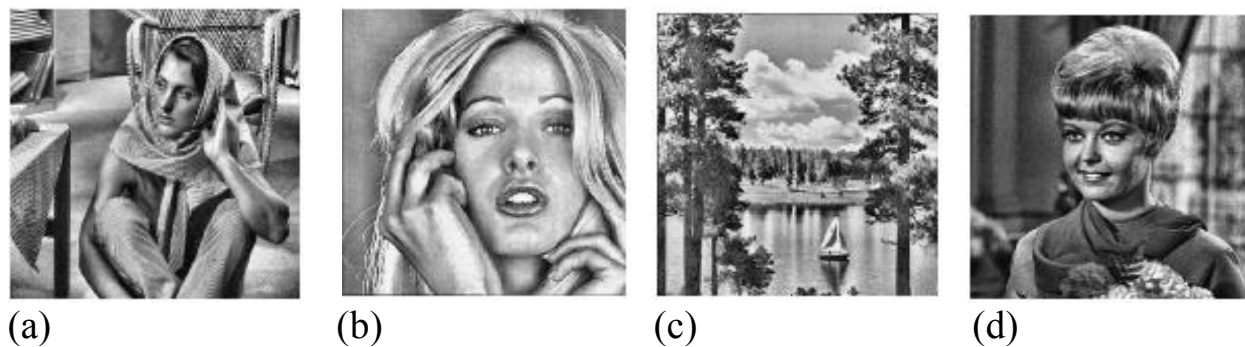


Figure 11: Stego image using FRIT with PSO of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

Table 5: Combined optimization techniques and Bandelet transform approach- TAF and NAE values.

Images	GA		PSO	
	TAF	NAE	TAF	NAE
Barbara	0.62	0.008	0.02	0.026
Tiffany	0.62	0.008	0.02	0.026
Sail boat	0.62	0.008	0.02	0.026
Girl	0.62	0.008	0.02	0.026
Average	0.62	0.008	0.02	0.026

measures of GA based bandelet transform for extraction phase is shown in Table 5.

From Table 5, the proposed methodology has been achieved, an average TAF value of 0.62 and NAE value of 0.008 for GA and an average TAF value of 0.02 and NAE value of 0.026 for PSO. By comparison made between the BT with GA and PSO in terms of TAF and NAE, the TAF and NAE values are low for PSO than GA. So, BT restores the secret data better and retrieves the cover image better with PSO than GA.

4.3 Results of Finite Ridgelet transform with GA and PSO- Embedding Phase

In the second experiment, finite Ridgelet transform with GA and PSO is performed. GA and PSO are used to find the most significant coefficients in the FRIT. After GA and PSO, the most significant coefficients are obtained to embed the secret data. The stego image using GA and PSO is shown in Fig. 10 & 11. The Performance measures of GA based FRIT for embedding phase is shown in Table 6 & 7.

Table 6: Combined GA and FRIT approach- PSNR values.

Images	PSNR(dB)	Embedding Capacity (bits)
Barbara	40.45	157527
Tiffany	40.81	157421
Sail boat	40.66	157554
Girl	40.61	157172
Average	40.63	157418

From Table 6, it is evident that the best PSNR value is obtained at the 100th iteration. An average fitness value of

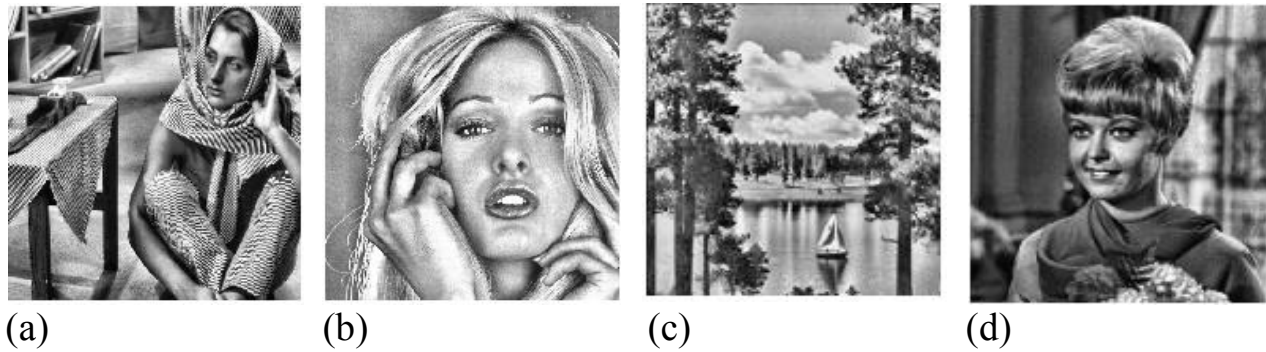


Figure 12: Restored cover image using FRIT with GA of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

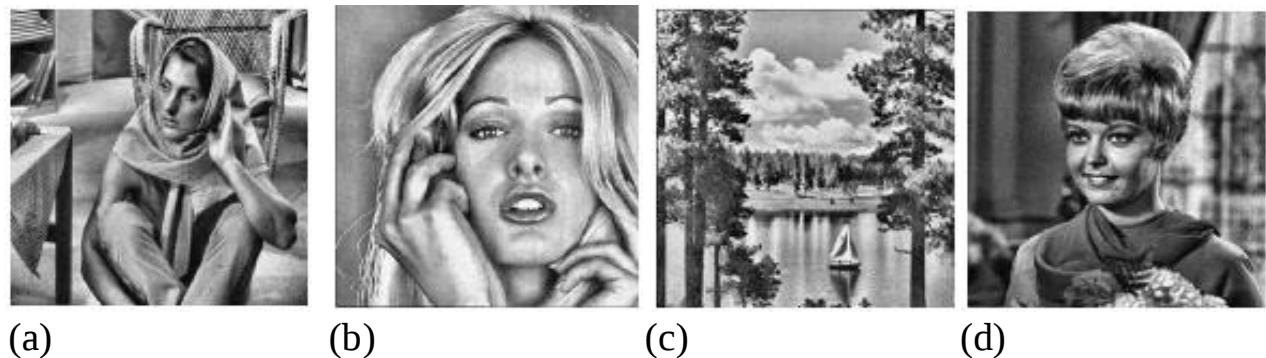


Figure 13: Restored cover image using FRIT with PSO of (a) Babara, (b) Tiffany (c) Sail boat & (d) Girl.

40.63 dB and average embedding capacity of 1574178 bits has been achieved.

From Table 7, it is evident that the best PSNR value is obtained at the 100th iteration. An average fitness value of 46.06 dB and average embedding capacity of 157700 bits has been achieved.

4.4 Results of FRIT with GA and PSO- Extraction Phase

The restored cover image of FRIT with GA and PSO is shown in Fig. 12 & 13. The Performance measures of GA based FRIT for extraction phase is shown in Table 8.

From Table 8, the proposed methodology has been achieved, an average TAF value of 0.69 and NAE value of 0.014 for GA and an average TAF value of 0.69 and NAE value of 0.006 for PSO. By comparison made between the FRIT with GA and PSO in terms of TAF and NAE, the TAF and NAE values are low for PSO than GA. So, FRIT restores the secret data better and retrieves the cover image better with PSO than GA.

Table 7: Combined PSO and Bandelet transform approach- PSNR values.

Images	PSNR(dB)	Embedding Capacity (bits)
Barbara	45.87	157728
Tiffany	46.28	157707
Sail boat	46.14	157724
Girl	45.95	157641
Average	46.06	157700

Table 8: Combined optimization techniques and FRIT approach- TAF and NAE values.

Images	GA		PSO	
	TAF	NAE	TAF	NAE
Barbara	0.69	0.014	0.69	0.006
Tiffany	0.69	0.014	0.69	0.006
Sail boat	0.69	0.014	0.69	0.006
Girl	0.69	0.014	0.69	0.006
Average	0.69	0.014	0.69	0.006

4.5 Comparative analysis

The comparative analysis of the proposed methodologies is shown in Table 9.

Table 9: Comparison of optimization techniques based Bandelet transform and FRIT- PSNR values.

Images	PSNR(dB)			
	BT	FRIT	BT	FRIT
	GA	GA	PSO	PSO
Barbara	37.36	40.45	43.89	45.87
Tiffany	37.50	40.81	43.83	46.28
Sail boat	38.23	40.61	43.83	45.95
Girl	37.56	40.63	43.55	46.06
Average	37.36	40.45	43.89	45.87

From Table 9, it is proven that PSO gives better result than GA for both BT and FRIT, because GA is random in nature. An approximate of 3–6 dB is received with FRIT based optimization techniques over the BT based optimization techniques.

Table 10: Comparison of optimization techniques based Bandelet transform and FRIT- Embedding capacity (bits).

Images	Embedding capacity (bits)			
	BT	FRIT	BT	FRIT
	GA	GA	PSO	PSO
Barbara	350860	157527	350191	157728
Tiffany	337516	157421	341297	157707
Sail boat	321304	157172	341297	157641
Girl	339662	157418	345744	157700
Average	350860	157527	350191	157728

From Table 10, PSNR values and embedding capacity is high for PSO based techniques than GA. The average embedding capacity of 902136 bits is obtained with FRIT with GA and PSO. Thus, the optimization techniques have significantly increased the efficiency of the steganography system.

5 Conclusion

In this paper, the frequency domain Steganography and optimization techniques are combined to design the efficiency improved steganography system. The transform

used are bandelet transform and Finite Ridgelet transform with optimization techniques such as GA and PSO is used in this paper. The proposed algorithm is mainly used for secure communication. The Steganography system is designed with better fidelity of stego image and with high embedding capacity. GA and PSO are used to give the most significant coefficients to embed more amounts of secret data. The proposed methodology maintains the fidelity of stego image with an average PSNR value of 37.56 dB for bandelet combined with GA, average value of 43.55 dB for bandelet combined with PSO, average value of 40.63 dB for Finite Ridgelet combined with GA and average of 46.06 dB Finite Ridgelet combined with PSO. The proposed method performance has been compared with the other related works.

References

- [1] Neil Johnson F., Sushil J., Steganography: Seeing the Unseen, IEEE Computer., 1998, 26–34.
- [2] Cheddad A., Condell J., Curran K., Mc Kevitt P., Digital image steganography – survey and analysis of current methods, J Signal Process., 2010, 90, 752–825.
- [3] Gonzalez R., Woods R., Digital image processing., 2nd edition, Prentice Hall India, 2005.
- [4] Luo W., Huang F., Huang J., Edge Adaptive Image Steganography Based on LSB Matching Revisited, IEEE Transactions on Information Forensics and Security., 2010, 5, 201–214.
- [5] Bedi P., Bansal R., Sehgal P., Using PSO in a spatial domain based image hiding scheme with distortion tolerance, Computers and Electrical Engineering., 2013, 39, 640–654.
- [6] Chang C. C., Lin C. C., Tseng C. S., Tai W. L., Reversible hiding in DCT-based compressed images, Information Sciences., 2007, 177, 2768–2786.
- [7] Lin Y. K., High capacity reversible data hiding scheme based up on discrete cosine transformation, The Journal of Systems and Software., 2012, 85, 2395–2404.
- [8] Chan Y. K., Chen W. T., Yu S. S., Ho Y. A., Tsai C. S., Chu Y. P., A HDWT-based reversible data hiding method, The Journal of Systems and Software., 2009, 82, 411–421.
- [9] Yeh H. L., Gue S. T., Tsai P., Shih W. K., Wavelet bit-plane based data hiding for compressed images, International Journal of Electronics and Communication., 2013, 67, 808–815.
- [10] Subhedar M. S., Mankar V. H., Image steganography using redundant discrete wavelet transform and QR factorization, Computers and Electrical Engineering., 2016, 54, 406–422.
- [11] Jero E.S., Ramu P., Swaminathan R., Imperceptibility – Robustness tradeoff studies for ECG steganography using Continuous Ant Colony Optimization, Expert Systems With Applications., 2016, 49, 123–135.
- [12] Qu X., Yan J., Xie G., Zhu Z., Chen B., A novel image fusion algorithm based on bandelet transform, Chinese optics letters., 2007, 5, 569–572.
- [13] Do M. N., Vetterli M., The Finite Ridgelet Transform for Image Representation, IEEE Transactions on Image Processing., 2009,

1, 1–14

- [14] Holland J. H., *Adaptation in Natural and Artificial Systems*, The University of Michigan Press, Ann Arbor, MI, 1975.
- [15] Goldberg D. E., *Genetic Algorithms in Search, Optimization and Machine Learning*, Addison-Wesley, Reading, MA, 1992.
- [16] Bajaj R., Bedi P., Pal S. K., Best hiding capacity scheme for variable length messages using particle swarm optimization, *Proceedings of SEMCCO, LNCS.*, 2010, 6466, 237–244.