A Robust Watermarking Using RDWT and Slant Transform Using Hybrid Firefly and Differential Evolution Optimization Algorithm

K. Meenakshi, K. Swaraja, Padmavathi Kora, and G. Karuna

Abstract In this work, an optimized watermarking framework is proposed with the hybrid combination of two metaheuristic algorithms-firefly optimization and differential evolution, namely HFADE. The cover image is partitioned into 4×4 sub-blocks, and the watermark is concealed in the slant domain using Quantized Index Modulation (QIM). The optimized thresholds obtained with HFADE used in quantization to improve imperceptibility and robustness. Peak Signal to noise ratio(PSNR) and Normalized Cross Correlation (NCC) are used for evaluation of the proposed watermarking scheme. The fitness function for HFADE is taken as the reciprocal of mean square error between the watermarked and cover image. Simulation outcomes convey that the proposed scheme maintains improved imperceptibility, and the watermark extracted from a seriously distorted image.

Keywords Differential evolution · Firefly · Slant transform · Quantization index modulation

1 Introduction

The improvement of Internet and computer input-output devices has made the broadcast and alteration of digital content without difficulty. With the advanced editing technologies, an edited copy appears similar to the original. So, the security of ownership of digital content has become the utmost concern. Digital watermarking [1–16] is evolved to protect the interests of owners from the copyright infringement. The three trade-off parameters of watermarking scheme are transparency, robustness and capacity. Further, it must not suffer from the false positive problems. Optimization algorithms such as Fuzzy logic [17, 18], Genetic Algorithm [19], Differential Evolution (DE) [1] are used to optimize the mutually conflicting parameters of transparency and robustness.

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In [20], a novel blind image watermarking technique, is proposed based on the Redundant Discrete Wavelet Transform (RDWT) [21] and singular value decomposition (SVD) employing self-adaptive differential evolution (SADE) algorithm.The algorithm is found to be imperceptible, robust and has high capacity. The false positive problem in [3, 22] is avoided by sending 8 bit signature at the sender side along with the cover image. Reference [23] developed a multipurpose image watermarking scheme using Artificial Bee colony optimization(ABC) for copyright protection and tamper detection. The main drawback of ABC is that it suffered with slow convergence.

Reference [24] proposed image hashing based on slant transform (ST), which is widely used in content authentication, content based retrieval, and image watermarking. Reference [25] employed ST for video watermarking. The advantage of a slant transform is that it is recursive. This feature is explored in this scheme to produce robust and imperceptible watermarking.

The proposed algorithm explores hybrid combination of RDWT and ST, and identify multiple thresholds in slant transform by using a novel hybrid optimization algorithm of a combination of Firefly and Differential evolution HFADE. The fitness function used in the optimization is the reciprocal of mean square error between the watermarked and cover image.

The research contribution of the paper:

- RDWT is used for obtaining the low approximation coefficients of the image.
- Slant transform is applied to low approximation coefficients of RDWT.
- Later, using QIM, the slant transform is adjusted with a threshold to obtain modified slant transform coefficients.
- The thresholds which give the better PSNR and NCC are selected by HFADE optimization.

2 Preliminaries

The proposed watermarking used a hybrid combination of Redundant Discrete wavelet transform and slant transform, and the watermark is embedded in the selected slant coefficients using quantization index modulation. HFADE obtains the optimum thresholds. In this a brief introduction of Redundant Discrete wavelet transform, slant transform, and HFADE are described below.

2.1 Redundant Discrete Wavelets

In place of DWT, RDWT attracted researchers in watermarking field due to several advantages of it over DWT:

- RDWT is shift invariant.

- The size of RDWT transformed image is four times that of DWT. So there is an improvement of capacity in RDWT based watermarking scheme compared to DWT.
- Previous research reveals that if subband is having the same dimension of cover image, the watermarking scheme offers high imperceptibility. This feature in RDWT helps to boost imperceptibility in the proposed watermarking scheme.

2.2 Slant Transform

ST is a recursive orthogonal transform widely used in image processing due to its speed of processing. The transform comprises slant basis functions. The middle frequency coefficients of slant are used for watermark insertion in the proposed work.

2.3 Hybrid Firefly and PSO Algorithm (FFAPSO)

Yang devises firefly optimization in the year 2007 [26]. FA was conceived by mimicking the flashing (mating) activity of fireflies.

Fireflies employ light to attract another firefly or prey (mate). The light intensity attraction '*B*' of fireflies is inversely proportional to distance '*r*'. Hence, most fireflies are constraint only up to several hundreds of meters. To execute this algorithm, the fitness function is articulated based on the fluorescence light behavior of fireflies. For simplicity, it is imagined that the light intensity attractiveness of the firefly is determined by its brightness '*B*', which is connected with the fitness function.

Fireflies attractiveness μ_λ at light absorption factor λ is defined as

$$\mu_\lambda = \mu_0 \mathrm{e}^{-\lambda r_{k,l}^2} \tag{1}$$

where r is the distance between kth firefly and lth firefly and λ is the light absorption factor and μ_0 is the initial attraction at distance r_{kl}=0. The distance r_{kl} between two fireflies k and l at position x_k and x_l are computed as given in Eq.

$$||x_k - x_l|| = \sqrt{\sum_{k=1}^{d} x_{k,d} - x_{l,d})} \tag{2}$$

where $x_{l,k}$ is the kth component of the position x_l of lth firefly. The firefly k attracted to another more attractive (brighter) firefly l is determined by y_k

$$xk \to x_k + \mu_0 e^{-\lambda r_{k,l}} (x_l - x_k) + \eta \left(rand1 - \frac{1}{2} \right) \tag{3}$$

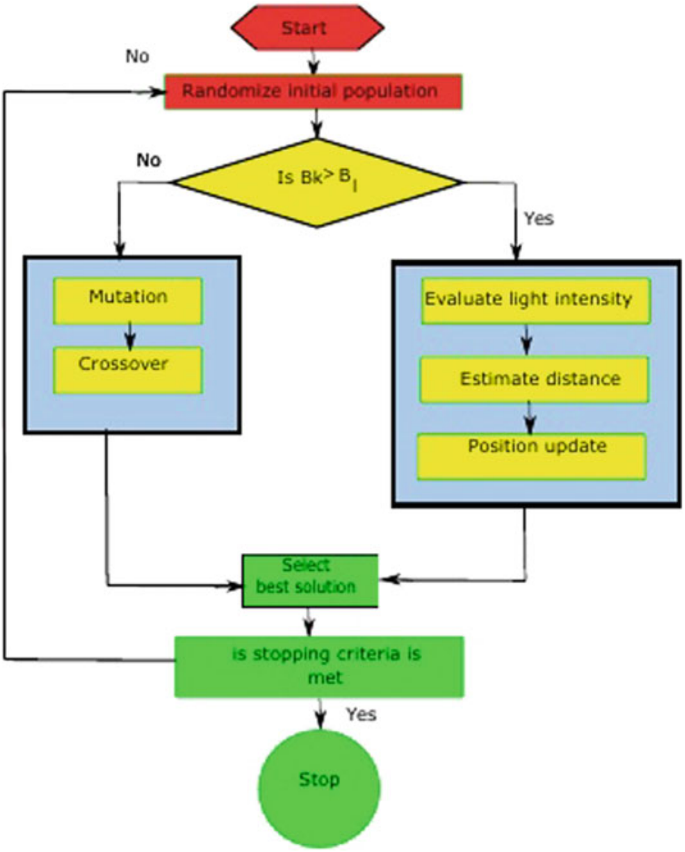

Fig. 1 Flowchart of HFADE

In Eq. 15, the x_k and x_l are the positions of kth and lth firefly and η is a randomization parameter. If the light absorption factor $\lambda \rightarrow 0$, the μ_λ=μ_0. Hence flashing fireflies can be seen within the search domain. On the other hand, if $\lambda = \infty$, the attractiveness is almost zero, and the firefly moves randomly. When fireflies move randomly, there is plenty of chance for the FA to limit local maxima, resulting in premature convergence. As FA has these limitations, the randomness in FA replaced by DE in the HFADE hybridization algorithm. FA and DE's hybrid algorithm (HFADE) has been proposed to avoid FA's premature convergence. The DE algorithm updates the position of firefly based on the mutation and crossover operators. Firefly settle in the local best when it is used alone. As shown in Fig. 1 crossover and mutation operator in DE are used to move the fireflies towards the global best.

3 Watermark Embedding and Extraction Algorithm

The watermark embedding steps are as follows:

Step 1 Perform 1-level RDWT onto the Host image to Partition it into its four sub-bands, which are I_{LL}, I_{LH}, I_{HL} and I_{HH}.
Step 2 Extract I_{LL} in RDWT band for watermark insertion.
Step 3 Segment I_{LL} band into 4 × 4 Blocks.
Step 4 Apply Slant Transform to each 4 × 4 Block.
Step 5 Two AC coefficients AC_x and AC_y in each block are identified based on HVS weightage matrix generated using Eq. 1–5 in [25].
Step 6 The slant coefficients AC_y are replaced with AC_x with T based on bits in the watermark.
Step 7 If watermark bit is zero

$$AC_y = AC_x - T \tag{4}$$

else

$$AC_y = AC_x + T \tag{5}$$

Step 8 The N/4 × N/4 times threshold values are generated using HFADE algorithm using random population.
Step 9 With modified coefficients with thresholds, the inverse slant is applied to obtain the lower approximation coefficients of RDWT LL_{new}.
Step 10 Merge ILL_{new}, I_{LH}, I_{HL} and I_{HH} bands.
Step 11 Apply inverse RDWT to obtain the watermarked image.

The steps of watermark extraction from the watermarked image are as follows.

Step 1 Perform 1-level RDWT onto the watermarked image to Partition it into its four sub-bands, which are Iw_{LL}, Iw_{LH}, Iw_{HL} and Iw_{HH}.
Step 2 Apply block-based ST on Iw_{LL} of the watermarked image.
Step 3 AC_x are identified and if $AC_y > AC_x$, watermark bit zero is extracted; else watermark bit 1 is extracted.

The steps of HFADE is formulated as follows:

Step 1 Define the fitness function, numbers of variables, and the values for population size, crossover rate, mutation rate, initial attraction parameter, and light absorption factor of firefly and number of generations (or any other terminating criteria).
Step 2 Initialize the population stochastically.
Step 3 Generate a watermarked image by applying random solutions in the population utilizing the concealing process. The solutions are the threshold values in each block.
Step 4 Calculate the NC values between the host image and each watermarked images.

Step 5 Apply the attack functions upon the watermarked images one by one.
Step 6 Extract out the watermarks from the attacked images using the extraction procedure.
Step 7 Calculate the NC values between the watermark and the extracted ones.
Step 8 Evaluate the fitness value for each corresponding solution.

The fitness function of HFADE is the 1/MSE, where MSE is the mean square error between the watermarked and original image.

4 Simulation Outcomes

This section validates the efficiency of the proposed watermarking scheme by taking the Lena image as the host image and cameraman as the watermark. The physical distinction between the host and watermarked image is negligible, and a PSNR of 65–75 dB is achieved with the proposed RDWT and slant based watermarking employing HFADE optimization. The attacked watermarked images with Gaussian noise, median filtering, symmetric cropping, and rotation by 30° is shown in Fig. 2. Further, the extracted watermarks are shown for the attacked images in Fig. 3.

The simulations we conducted with the MATLAB 2018, pentium processor with 8 GB RAM. We compared the proposed scheme against the related works using svd based GA and DCT and SVD based DE. The PSNR of the proposed algorithm is

Fig. 2 Attacked watermarked images **a** Gaussian noise, **b** median filtering, **c** symmetric cropping, **d** rotation

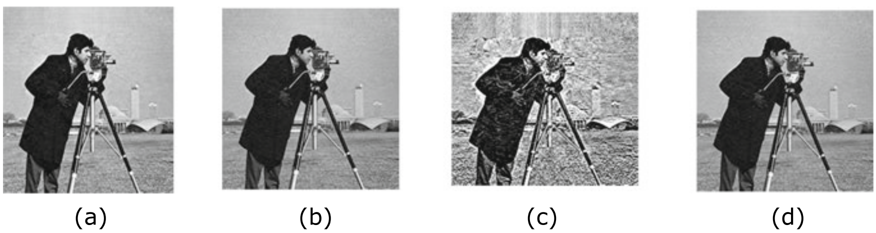

Fig. 3 Extracted watermarks from **a** Gaussian noise, **b** median filtering, **c** symmetric cropping, **d** rotation

Table 1 NCC applied for different attacks

Parameters	SVD+GA	DCT+SVD+DE	Proposed scheme
Gaussian noise	0.9662	0.9912	1
Median filtering	0.9677	0.998	0.998
Symmetric cropping	0.9788	0.9822	0.9122
Rotation	0.9956	0.9956	0.933

65.55 db, where as the PSNR of SVD based GA and DCT, SVD based DE is 37.88 and 44.33 dB. The NCC of the proposed algorithm compared to SVD based GA and DCT,SVD based DE are tabulated in Table 1. The results demonstrate the efficiency of the algorithm in terms of imperceptibility and robustness.

5 Conclusion

The proposed algorithm is false positive free, imperceptible and robust. The computational complexity of the HFADE is less because both FA and DE requires less parameters and simple in implementation.

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