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Digital Image Watermarking using Discrete Wavelet Transform (DWT) and Flower Pollination Algorithm (FPA)

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ABSTRACT
Digital Image watermarking is the enabling technology to prove ownership of copyrighted material, to solve the problem of piracy and to detect the originator of illegally made copies. In this paper, to solve the authentication problem an effective, imperceptible and secure blind image watermarking algorithm is proposed which uses Flower Pollination Algorithm to select the blocks in the image in which watermark information is embedded. To keep the algorithm imperceptible only few blocks on the basis of fitness function are selected and watermark is embedded into transform domain using DWT. The performance of algorithm is tested using MATLAB software on various images of size 512 X 512 and watermark image of size 32 X 32. The experimental results show that the proposed scheme is highly imperceptible, more secure and highly robust against salt & pepper noise and histogram equalization.

General Terms
Digital Watermarking, Security, Imperceptibility, Robustness

Keywords
Image Watermarking, DWT, FPA, Entropy, PSNR, MSE, BER, SSIM

1. INTRODUCTION
In the past duplicating art work was quite complicated and required a high level of expertise for the counterfeit to look like the original. However, in the digital world this is not true. Now it is possible for almost anyone to duplicate or manipulate digital data and not lose data quality. So watermarking has become a major field to solve the problems of illegal manipulation, distribution and piracy of digital images or videos [1, 2]. Image watermarking is the process of embedding copyright information or verification messages in digital picture. Video watermarking research received less attention than image watermarking due to its inherit difficulty, however, many algorithms have already been proposed [3, 4, 5, 6].

The information which is embedded is called watermark. It can be text or an image. Two types of digital watermarks may be distinguished, depending upon whether the watermark appears visible or invisible to the casual viewer. Visible watermarks can be a logo or text into images or frames of videos. If it is present in selected frames then it passes off without being noticed, due to high frame rate. Invisible watermarks or Hidden watermarks on other hand are present in the file in such a way that they cannot be sighted but have to be extracted.

Watermarking algorithm should be imperceptible i.e embedding should not affect the quality of video or image. It should also be robust to various signal processing operations i.e. watermark could not be destroyed or degraded after any type of video manipulations.

Watermarking algorithm can be blind or non blind. If the extraction process needed the original data for the recovery of watermark from watermarked video or image then it is said to be non blind scheme of watermarking. If watermark can be recovered from only watermarked image or video without any need of original data then it is called blind scheme of watermarking.

2. PROBLEM STATEMENT
As digital video or image based application technologies grow, such as Internet video, wireless video, video phones, and video conferencing, the problem of illegal manipulation, copying, distribution and piracy of digital video rises more and more. The problem of this paper research work is to solve the authentication problem and embed the watermark in such a way that it could not be removed or degraded from the image using the proposed algorithm of blocks selection through FPA and embedding watermark using DWT.

3. THEORETICAL BACKGROUND
The proposed work requires certain theoretical considerations related to the concept of DWT, and performance measure parameters. The following sections contain a brief description of these concepts.

3.1 Discrete Wavelet Transform (DWT)
Wavelet transform is a multi-resolution decomposition of a signal. The low pass filter applied along a certain direction extracts the low frequency (approximation) coefficients of a signal. On the other hand, the high pass filter extracts the high frequency (detail) coefficients of a signal. In 2D applications, for each level of decomposition, first perform the DWT in the vertical direction, followed by the DWT in the horizontal direction. After the first level of decomposition, there are 4 sub-bands: LL1, LH1, HL1, and HH1. Each component undergoes two levels of decomposition. LH1, HL1, and HH1 contain the highest frequency bands present in the image tile, while LL1 contains the lowest frequency band. The two-level DWT decomposition is shown in Figure 1.

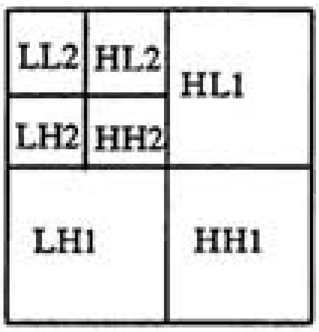

Figure 1: Discrete Wavelet Transform

3.2 Performance measures

Imperceptibility, robustness, security, complexity & data payload are considered as performance parameters for the proposed watermarking Algorithm.

3.2.1 Imperceptibility

Imperceptibility means that the perceived quality of the image should not be distorted by the presence of the watermark. As a measure of the quality of a watermarked image, Bit Error Rate (BER), Peak Signal to Noise Ratio (PSNR), Mean Squared Error (MSE) and Structural Similarity Index Metric (SSIM) is calculated between the original image and the corresponding watermarked image [8].

3.2.1.1 Mean squared error (MSE)

To measure the similarity between the original image and watermarked image an error signal is computed by subtracting the watermarked image from the original image, and then computing the average energy of the error signal. The MSE is given by equation

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j)-y(i,j))^2 \qquad (2)$$

Where *x(i, j)* is represents the pixel values of original image and *y*(*i*, *j*) represents the corresponding pixel values of watermarked image and i and j are the pixel position of the M×N image.
MSE is zero when $x(i, j) = y(i, j)$

3.2.1.2 Peak signal to noise ratio (PSNR)

The PSNR is evaluated in decibels and is inversely proportional the Mean Squared Error. It is given by the equation

$$PSNR = 10\log_{10}\frac{255}{\sqrt{MSE}} \qquad (3)$$

Higher the value of PSNR better is the quality of the watermarked image.

3.2.1.3 Bit error rate (BER)

BER is the reciprocal of the PSNR.

$$BER = \frac{1}{PSNR} \qquad (4)$$

The value of BER which is closer to zero represents more quality of the watermarked image.

3.2.1.4 Structural Similarity Index Metric (SSIM)

The structural similarity (SSIM) index is a method for measuring the similarity between the original image and watermarked image. The SSIM index is a full reference metric, in other words, the measuring of quality based on an initial distortion-free original image as reference. The difference with respect to other techniques mentioned previously such as MSE or PSNR, is that these approaches estimate *perceived errors* on the other hand SSIM considers image degradation as *perceived change in structural information.* Structural information is the idea that the pixels have strong inter-dependencies especially when they are spatially close. These dependencies carry important information about the structure of the objects in the visual scene.

The SSIM metric is calculated on various windows of any frame. The measure between two windows x and y of common size *N*×*N* is:

$$\boldsymbol{SSIM(x,y)} = \frac{(2\bar{x}\bar{y} + C1)(2\sigma_{xy} + C2)}{((\bar{x})^2 + (\bar{y}^2) + C1)(\sigma_x{}^2 + \sigma_y{}^2 + C2)} \qquad (5)$$

Where C1 & C2 are constants. $\bar{x}, \bar{y}, \sigma_x{}^2, \sigma_y{}^2$ *and* σ_{xy} are given as:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad (6)$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \qquad (7)$$

$$\sigma_x{}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x-\bar{x})^2 \qquad (8)$$

$$\sigma_y{}^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y-\bar{y})^2 \qquad (9)$$

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x-\bar{x})(y-\bar{y}) \qquad (10)$$

SSIM value closer to 1 represents the better quality of watermarked video.

3.2.2 Security

Security describes if the embedded watermarking information cannot be removed beyond reliable detection.

3.2.3 Complexity

Complexity describes the effort we need for watermark embedding and retrieval image. Another aspect addresses if we need the original data in the retrieval process or not i.e. the watermarking algorithm is non-blind or blind which influence the complexity.

3.2.4 Capacity/Payload

It describes how many information bits can be embedded.

3.2.5 Robustness

Robustness describes if the watermark can be reliably extracted from the watermarked image [3, 5]. We can say Robustness of a watermarking algorithm is a measure of the immunity or resistance of the watermark against attempts to remove or degrade it from the image manipulations by different types of digital signal processing attacks. The similarity between the original watermark and the extracted watermark from the watermarked video can be measured by using the correlation factor $\boldsymbol{\rho}$, which is computed using the following Equation:

$$\rho(w_o, w_r) = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} w_{oij} * w_{rij}}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} w_{oij}{}^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} w_{rij}{}^2}} \qquad (11)$$

Where w_{oij} is a pixel of original watermark and w_{rij} is a pixel of the recovered watermark of size M X N.

The correlation factor $\boldsymbol{\rho}$ may take values between 0 and1. The value closer to 1 represents the more similarity between the original watermark and extracted watermark.

4. PROPOSED ALGORITHM

In the proposed watermarking technique, the original image is decomposed in to four sub bands by using 1-level DWT, and the watermark bits are embedded in LH, HL and HH sub bands at selected positions which are decided by Flower Pollination Algorithm. FPA searches the positions for inserting the watermark such that the quality of the image is affected least with the presence of watermark hidden at the selected positions. The proposed watermark implanting algorithm, FPA Procedure to select positions, and watermark withdrawal algorithm is explained in detail as given below:

4.1 Watermark Embedding Algorithm

Step 1: Read original picture.
Step 2: Read a watermark image and formulate it into a vector of binary bits.
Step 3: Apply 1-level DWT using 'Haar' wavelet to decompose the input image into four sub bands LL, LH, HL, and HH.

[LL LH HL HH]=dwt2(Img,'db1') *(12)*

Step 4: Partition three sub bands LH, HL and HH into non overlapped blocks of size 8 X 8 pixels.
Step 5: Use Flower Pollination Algorithm to select blocks for watermark bits to be hidden. As many unique blocks should be selected as total number of watermark bits because only one bit is hidden in one block.
Step 6: For each watermark bit *Bi* get a unique block from the selected ones and recognize its initial horizontal coefficients *FHc*, its highest coefficient *MAXCOEF* and its least coefficient *MINCOEF*, if *Bi* is 1 then the initial constituent in *FHc* is designed by *MAXCOEF + Uj* , if *Bi* is 0 the substitution is done by *MINCOEF – Uj*, where *Uj* are the power factor constraints *(U1, U2* and *U3)* one for every sub band (LH, HL, and HH) which are estimated experimentally and chosen manually *(U1=1.95, U2=2* and *U3=2.55)*.
For every Block i

$$WmkdBlock_i(1,1) = \begin{cases} MAXCOEF(FHc) + Uj \; if \; Bi = 1 \\ MINCOEF(FHc) - Uj \; if \; Bi = 0 \end{cases} \quad (13)$$

Step 7: Place the watermarked blocks at their respective positions and rejoin all the blocks to get the modified sub bands.
Step 8: Execute the inverse DWT using modified sub bands LH, HL, & HH and non-modified sub band LL to get the watermarked picture.
Step 9: Generate the secret key using the addresses of the selected blocks by FPA for watermark embedding.

4.2 Flower Pollination Algorithm (FPA) for Blocks Selection

Here in the proposed work the main purpose for FPA is to search for the proper blocks in the selected sub bunds LH, HL and HH for the watermark embedding, these blocks addresses are used as a secret key. The FPA selects such blocks so that the presence of watermark in these blocks affects the image quality least. So PSNR (Peak Signal to Noise Ratio) between original picture and watermarked picture is used as fitness function to determine the quality of any solution provided by FPA which is described as

$$PSNR = 10\log_{10}\frac{255}{\sqrt{MSE}} \quad (14)$$

Where MSE is Mean Squared Error between original and watermarked picture of size M X N and is given by eq. 2
FPA is used considering the following steps and its flow is described in Fig. 2
Step 1: Initialize optimization problem and set parameters
To selection the appropriate blocks, algorithm utilizes inhabitants of solutions that progress toward optimizing the required fitness function i.e. to maximize the PSNR. For this purpose a fitness function is formed using eq. 4.3. Other parameters of the algorithm like Population Size, Maximum Iteration, and Switching Probability (Ps) is set.
Step 2: Prepare Candidate Set
Solutions are formed from the group of applicants i.e the available blocks' addresses. So total number of available blocks from 3 sub bands LH, HL, and HH are counted and then considered these as candidate.
Step 3: Initialization Population
A population is generated having solutions equal to Population Size. Each resolution vector is represented as address of unique blocks amongst group of candidates. And generated population is evaluated using fitness function represented by equation 4.3. And find the best solution among the initial population.
Step 4: Generation of new solution
For every member of the population generate a new solution either using global (cross) pollination or using local (self) pollination depending upon the switching probability Ps.
To generate a new solution via global pollination a step vector L is drawn which obeys levy flights and mathematically new solution can be described as

$$X_i(t+1) = X_i(t) + L*(X_i(t) - gbest) \quad (15)$$

Where $X_i(t+1)$ is new solution, $X_i(t)$ is solution/pollen in current population, gbest is current best solution among population at current generation/iteration.
To generate a new solution via local pollination below mathematically equation is used

$$X_i(t+1) = X_i(t) + epsilon*(X_j(t) – X_k(t)) \quad (16)$$

Where $X_i(t+1)$ is new solution, $X_i(t)$ is solution/pollen in current population, epsilon is random number, Xj(t) and $X_k(t)$ are two randomly selected solutions from current population at current generation/iteration.
Step 5: Update Population
The recently produced solution vector is examined in terms of the fitness function assessment. If the fitness function cost for the recent produced solution is improved than the previous best solution, then new solution is included in the population in place of the previous best solution. The resolution vector with the maximum fitness assessment can be measured the best resolution of the problem in the present iteration.
Step 6: Termination
Go to the step 4 until maximum iterations are attained. The present fit resolution is chosen from population after execution criteria is met. This is the resolution for the optimization problem devised. The addresses in this solution represent the selected blocks' address.

4.3 Watermark Extraction Algorithm

As the proposed algorithm is blind so in watermark withdrawal process the original image is not required and the process is done as follow:
Step 1: Read watermarked or attacked watermarked image
Step 2: Apply 1-level DWT to get the watermarked sub bands.
Step 3: Partition three watermarked sub bands LH, HL and HH into non overlapped blocks of size 8 X 8 pixels.
Step 4: Use secret key generated in embedding process to get the watermarked blocks.
Step 5: From each block get 1 hidden watermark bit. Extort each watermark bit *Bi* by calculating the average *MEAN* of the initial horizontal coefficients *FHc* of every watermarked block, and if first coefficient in *FHc* is greater than the MEAN then consider extracted watermark bit as 1, otherwise 0.
So for every Block i, extracted bit Bi will be

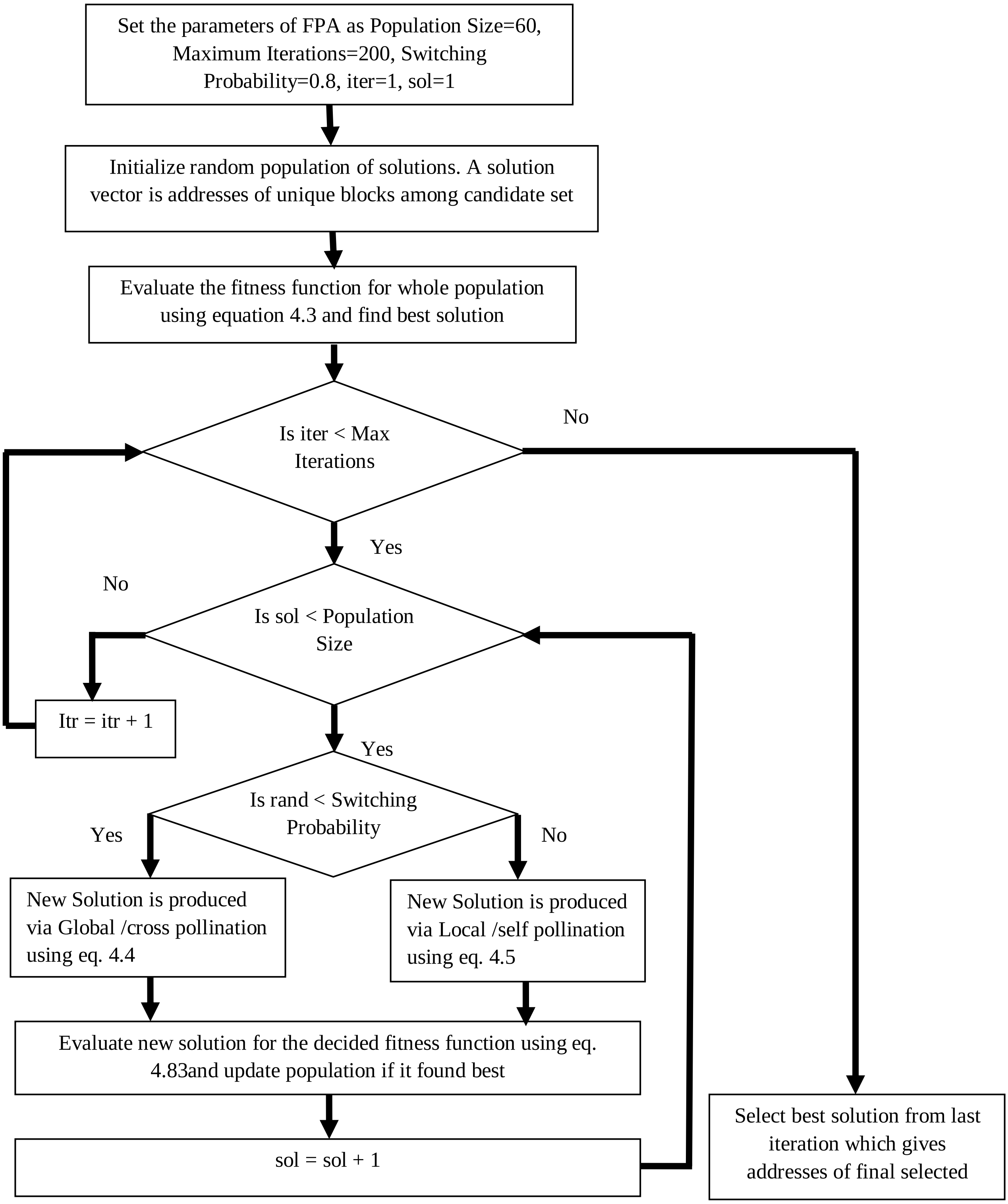

Figure 2: Flow Chart of Block Selection using FPA

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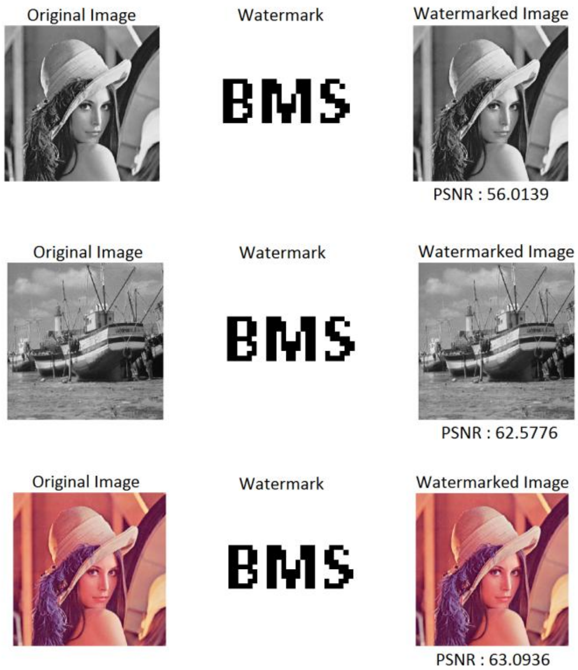
$$B_i = \begin{cases} 1, if \text{ WmkdBlocki}(1,1) \geq \text{MEAN} \\ 0, if \text{ WmkdBlocki}(1,1) < MEAN \end{cases} \quad (17)$$

Step 6: Obtain the extracted watermark.

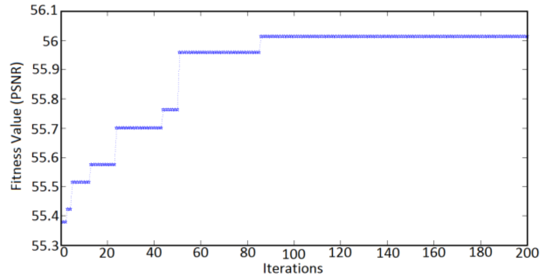
5. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

MATLAB 7.10.0 is used as the platform for implementing the proposed work & conducting experiments. The performance of the proposed image watermarking algorithm is evaluated using many colored and grayscale images. Here results are discussed for few of these. As the size of Original image is 512 X 512 so as per proposed algorithm when DWT is applied and three sub bands are divided into blocks of size 8 X 8 then total of 3072 candidate blocks will be eligible in which 1024 watermark bits of watermark of size 32 X 32 can be hidden. So FPA select the appropriate 1024 blocks to hide theses watermark bits. Population size in FPA is assumed 60, switching probability 0.8 and the algorithm is run to search the solution for 200 Iterations. Here the watermark embedding results for two images one grayscale Lena image and one colored baby image are shown in Figure 3. It shows the original, watermark and watermarked images along with PSNR Values measured between the original image and watermarked image. And it very clear that watermarked image is not distorted after embedding the watermark and is visually almost same to the original image as shown in figure 3. Table 1 contains the values of all the parameters MSE, PSNR, BER, Correlation Coefficient, and SSIM to show the imperceptibility of the algorithm. The performance of the proposed algorithm is discussed hereafter in this chapter in detail and also a comparative analysis is made between the literature techniques and the proposed method and its outperformance is proved.

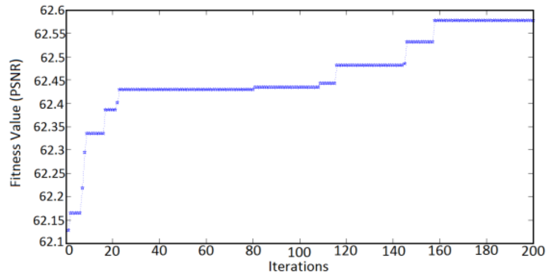


(a) (b) (c)

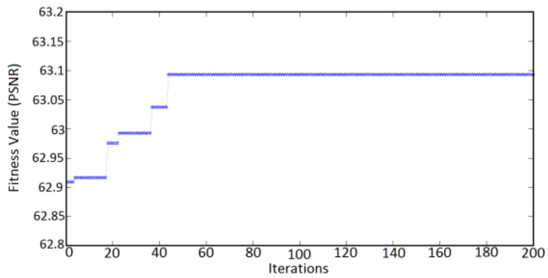
Figure 3: Watermark Embedding Results (a) Original Images (b) Watermark (c) Watermarked Image



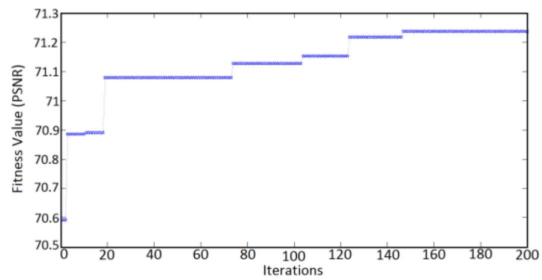
(a)



(b)



(c)



(d)

Figure 4: The Fitness Function Values versus FPA Iteration for (a) Lena (Grayscale) (b) Boat (Grayscale) (c) Lena (Colored) (d) Baby (Colored) Test Images

Figure 4 shows a clear climbing curve towards optimum results. The exact values of maximum fitness (PSNR) for these test images are 56.0139 for Lena (Grayscale), 62.5776 for Boat (Grayscale), 63.0936 for for Lena (Colored) and 71.2377 for Baby (colored). Figure represents the optimal blocks positions are selected for watermarking based on a FPA optimization for these test images.

5.1 Imperceptibility performance:

To demonstrate the planned algorithm imperceptible, as a judgment of excellence of the watermarked image MSE (Mean Squared Error), PSNR (Peak Signal to Noise Ratio), and BER (Bit Error Rate), Structural Similarity Index Metric (SSIM), and Correlation Coefficient (CC) is computed using equations 2, 3, 4, 5, and 11 respectively for watermarked image. The values for these parameters for various original images are tabulated in table 1 when BMS Logo Image is embedded in these images. Higher values of PSNR, smaller values of MSE and BER, and values close to 1 for Correlation coefficient prove the high imperceptibility of proposed algorithm.

Table 1: MSE, PSNR, BER, CC, and SSIM for various watermarked images

S. No.	Original Image	MSE	PSNR	BER	CC	SSIM
1	Lena (Gray)	0.1628	56.0139	0.0179	0.9999	1.0000
2	Boat (Gray)	0.0359	62.5776	0.0160	0.9999	1.0000
3	Baboon (Gray)	0.5886	50.4323	0.0198	0.9987	1.0000
4	Peppers (Gray)	0.1698	55.8311	0.0179	0.9999	1.0000
5	Lena (Color)	0.0319	63.0936	0.0158	0.9999	1.0000
6	Baby (Color)	0.0049	71.2377	0.0140	1.0000	1.0000

5.2 Security

The proposed algorithm is supplementary safe than the conventional algorithms due to the generated secret key in embedding process. Also the proposed algorithm is blind algorithm and it does not require any data to recover the watermark. But without use of secret key one cannot extract the watermark although algorithm is known. This makes the algorithm more secure.

5.3 Complexity

The planned algorithm is very easy and blind algorithm as for extraction process; it does not require any actual information to get back the watermark. And watermark can be recovered from watermarked image and only secret key.

5.4 Data Payload

In proposed algorithm to the algorithm more imperceptible as well as secure, a binary watermark of size 32 X 32 can be embedded into the images of the size 512 X 512 i.e. the data payload for this size is 1Kbits. And it can be increased for the images of large size.

5.5 Robustness Performance

Similarity between the original watermarks and the extracted watermarks from the watermarked image is measured by computing correlation factor ρ using the equation 11, MSE, PSNR, and BER using equations 2, 3, and 4 respectively, and SSIM using equation 5. Original watermark and extracted watermark after applying salt and pepper noise 1%0 from the watermarked images are shown in figure 5. Correlation factor (ρ), MSE, PSNR, BER, SSIM of extracted watermark from "Lena Greyscale" with the original watermark is tabulated in the table 2.

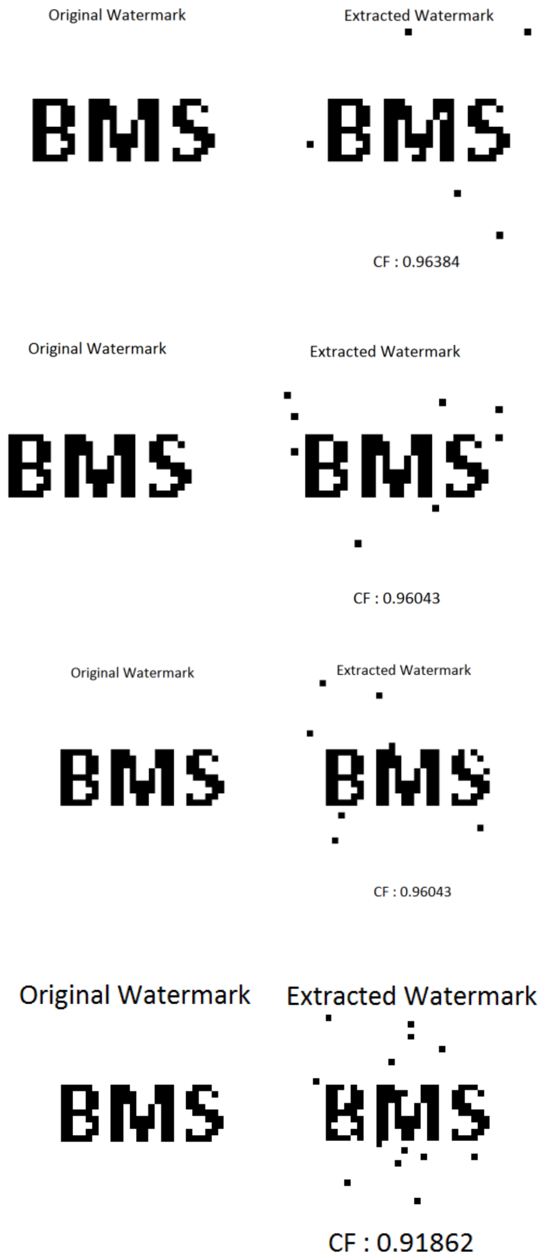


Figure 5: Watermark Extraction Results (a) Original watermark Embedded (b) Extracted watermark from Watermarked Image with salt & pepper noise 1% in these four images.

Table 2: Parameters of extracted watermarks

Attack	Parameter	Measured Value
Without Attack	Correlation factor (ρ)	0.99547
	MSE	0.00097
	PSNR	78.2338
	BER	0.0128
	SSIM	1.0000
Slat & pepper Noise Attack (1%)	Correlation factor (ρ)	0.9638
	MSE	0.0078
	PSNR	69.2029
	BER	0.0145
	SSIM	0.9998
Slat & pepper Noise Attack (10%)	Correlation factor (ρ)	0.6799
	MSE	0.0908
	PSNR	58.5490
	BER	0.0171
	SSIM	0.9977
Histogram Equalization Attack	Correlation factor (ρ)	0.9361
	MSE	0.0146
	PSNR	66.4729
	BER	0.0150
	SSIM	0.9997

Also the proposed algorithm is robust to the various attacks like salt & pepper noise attack, and histogram equalization attack. The calculated values of all the parameters are tabulated in table 5.3. High values of PSNR and correlation factor values closer to 1 show the high robustness of the proposed algorithm to the above mentioned attacks.

6. COMPARATIVE ANALYSIS

The proposed Watermarking algorithm in this research work is compared with existing algorithm described by A. Chaudhry et. al. in [9]. The performance of the algorithm described in [9] is compared with the proposed algorithm in table 3. The presented approach of image watermarking is found better than this approach of DCT using Genetic Algorithm in many aspects as discussed below. Authors presented a watermarking using DCT transform and DCT coefficients for watermark embedding are searched by GA and also watermark strength is decided by Particle Swarm Optimization. Improved values of PSNR & SSIM show the better imperceptibility of the presented algorithm than this algorithm. The presented algorithm is more secure than the existing one due to the generation of secret key in the embedding process. And without this key extraction is impossible.

Table 3: Comparison of Proposed Algorithm with existing work

Performance Parameters			Literature [11]	Proposed Algorithm
Imperceptibility Performance (Grey Images)	Lena Image (Grey)	PSNR	53.5755	56.0139
		SSIM	0.99	1.0000
	Boat Image (Grey)	PSNR	51.9532	62.5776
		SSIM	0.99	1.0000
	Peppers Image (Grey)	PSNR	52.5970	55.8311
		SSIM	0.99	1.0000
	Cameraman Image (Grey)	PSNR	52.1067	66.4735
		SSIM	0.99	1.0000
	Lena Image (Color)	PSNR	----	63.0936
		SSIM	----	1.0000
	Baby Image (Color)	PSNR	----	71.2377
		SSIM	----	1.0000

7. CONCLUSIONS

A lot of research work has been performed in the area of watermarking to solve the problems of illegal manipulation, distribution and piracy of digital videos. Various existing watermarking techniques are studied in this literature review of the report. Although the maximum techniques are robust to the digital signal processing, still these techniques are not secure. In this research work, a blind image watermarking algorithm is proposed which is made watermarking in transform domain to build it more secure from illegal copying or duplicity. In proposed algorithm, the watermark is embedded into image using the DWT transform to achieve the high imperceptibility of the algorithm. Watermark used is binary image. The algorithm is computed in terms of security, imperceptibility, data payload, complexity, and robustness. To compute the imperceptibility of algorithm MSE, PSNR, BER, Correlation Factor, and SSIM are calculated. The computed values of the parameters show that a highly imperceptible, simple blind, more secure and robust method of image watermarking against salt & pepper noise attack and histogram equalization is achieved.

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