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# A Survey of Digital Image Watermarking Optimization based on Nature Inspired Algorithms NIAs

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### *Abstract*

*Nature-inspired algorithms (NIAs) have gained a significant popularity in recent years to tackle hard real world problems and solve complex optimization functions whose actual solution does not exist. Many new algorithms have been developed which show their capabilities almost in every aspect, where rapid solutions are needed. A survey of the NIAs that are used to find the optimal digital image watermarking has been presented in this paper. Different paradigms have been considered, Genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), ant colony optimization (ACO), bee algorithm (BA), cat swarm optimization (CSO), firefly algorithm (FA) and cuckoo search algorithm (CS) that help to find the optimal digital image watermarking.*

***Keywords:*** *Optimal Watermarking, Nature Inspired Algorithms (NIAs)*

## 1. Introduction

Digital watermarking has become the most interesting and active filed of research recently due to the ever growing multimedia and digital information representation. Digital watermarking is a technology being developed to ensure and facilitate data authentication, security and copyright protection of digital media.

Digital watermarking techniques can be classified into spatial domain and frequency domain according to the domain used for embedding watermark. Spatial domain based watermarking, focuses on modifying the pixels of one or two randomly selected subsets of images. It directly loads the raw data into the image pixels. Spatial domain has weak robustness against common image signal processing and attacks such as noise, filtering, and compression, and may be easily destroyed by distortion.

Frequency domain based watermarking, this technique is also called transform domain. Where the values of certain frequencies are altered from their original to another form. There are several common used transform domain methods, such as Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT) and Singular

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Valued Decomposition (SVD). The process embeds a watermark into the selected portion of frequency domain by modifying the coefficients. The frequency domain based watermarking is known as more robust and imperceptible technique than the spatial domain based watermarking, so the frequency domain is mostly used in recent watermarking methods.

There are requirements and constraints in designing effective watermarking algorithms, the three most fundamental requirements are watermark imperceptibility: watermark cannot be seen by human eye or not be heard by human ear, only be detected through special processing or dedicated circuits. It can be detected by an authorized agency only. Such watermarks are used for content or author authentication and for detecting unauthorized copier. Second is watermark robustness: refers to that the watermark embedded in data has the ability of surviving after a variety of processing operations and attacks. Then, the watermark must be robust for general signal processing operation, geometric transformation and malicious attack. Third requirement is watermark capacity: defined as the maximum amount of information that can be embedded in the cover work. The number of watermark bits in a message in data payload and the maximum repetition of data payload within an image is the watermark capacity. An invisible and robust watermark may be the most difficult challenge among all the types of watermarks.

Many algorithms have been proposed and they have shown great potential in solving tough engineering optimization problems such as particle swarm optimization (PSO), differential evolution (DE), ant colony optimization (ACO), bee algorithm (BA), cat swarm optimization (CSO), firefly algorithm (FA) and cuckoo search (CS). Recently, NIAs have emerged as powerful optimization algorithms for solving complex problems. In the application of digital image watermarking optimization, the uses of NIAs have helped in the complex task of finding the optimal positions and preferable parameters for watermark embedding. This paper provides a quick survey of the current NIAs for optimal watermarking. The rest of this paper is organized as follows: in section 2, we offer a brief overview of the basic concepts from NIAs and present a comprehensive review of the most representative works in digital image watermarking optimization techniques. Performance analysis of digital image watermarking optimization is given in section 3; finally the conclusions are drawn in section 4.

## 2. Nature Inspired Algorithms (NIAs) for Optimal Watermarking

It is always preferable improve the performance of digital image watermarking techniques by exploiting NIAs as optimization algorithms. The digital image watermarking problems can be viewed as an optimization problem. Therefore, in this section we offer a brief overview of the basic concepts from NIAs and present a comprehensive review of the most representative works in digital image watermarking optimization techniques.

### 2.1. Genetic Algorithm (GA)

GA is the most popular evolutionary algorithm widely used for optimization developed by Holland [1] in the 1960s and 1970s as a basic principle, and finally popularized by Goldberg [2]. For the genetic algorithms, the chromosomes represent set of genes, which codes the independent variables. Every chromosome represents a solution of the given problem. Individual and vector of variables will be used as other words for chromosomes. The selection of the best individuals is based on an evaluation of fitness function or fitness functions. A simple GA in its simplified form is shown in Figure 1.

Various techniques for digital image watermarking have been optimized based on GA in Spatial and Frequency Domains by many of the Researchers. A robust algorithm for DCT-based GA-watermarking has been presented by Shieh, *et al.,* [3]. The GA is utilized to train the frequency set for the watermark embedding and to improve the watermarked image quality. Chu, *et al.*, [4] propose an optimized scheme for zerotree-based image watermarking in which GA is used to select zerotrees in a wavelet transform to achieve both optimized watermarked image quality and better robustness for the proposed algorithm. Anwar, *et al.*, [5] introduced an adaptive high payload watermarking method in spatial domain. GA has been used in this method to intelligently find the host region in the cover image for secret image blocks. The authors only focus on the visual quality of the watermarked image without taking into account the robustness. Vahedi, *et al.,* [6] propose a robust color image watermarking algorithm using wavelet transformation. In the optimization process, the GA is used to search for optimal parameters which are data hiding depth factors. The experimental results show that this algorithm yields a watermark which is invisible to human eyes and robust to a wide variety of common attacks. A simple GA is used by Papakostasa, *et al.*, [7] in order to optimize the set of parameters that significantly influences the locality properties alongside with the overall performance of the watermarking procedure. This method produces watermarked images with high quality and ensures high detection rates under several non-geometric attacks, by using less prior-knowledge at the detector's side.

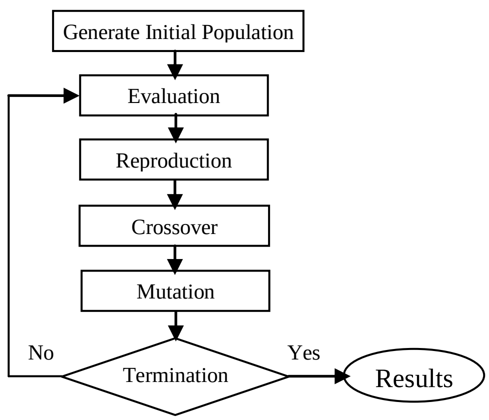


**Figure 1. A Simple GA**

There are crucial aspects regarding watermark embedding, namely optimal positions and strength parameters selection, these aspects attracted many researchers in the recent past years. In the works of [8-10], GA played the role for identifying the suitable locations for watermark insertion within a cover image. While in the works of [11-14], GA is used to decide the optimal watermark strength for digital image watermarking.

### 2.2. Particle Swarm Optimization (PSO)

PSO is a population based stochastic optimization technique to solve multidimensional optimization problems, developed by Kennedy and Elberhart [15], inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as the GA [16]. Initially, like GA, a population of particles instead of chromosomes is generated randomly and then the optimum is found by performing iterative search. A velocity vector as well as a position vector is associated with each particle. Based on position, velocity of each particle and fitness criteria, best position in the swarm is found for each particle. Best particle amongst all the local best particles found is known as the global best particle. The following equations [17]:

$$v_{in} = w * v_{in} + c_1 * rand() * (b_{in} - p_{in}) + c_2 * rand() * p_{gn} - p_{in} \tag{1}$$

$$p_{in} = p_{in} + v_{in} \tag{2}$$

Where *w* the inertia weight is a user defined parameter. Parameters $c_1$ (cognitive parameter) and $c_2$ (social parameter) are the acceleration weights and control the previous values of the particle velocities on its current one. Function *rand ( )* is a random number that is uniformly distributed in the interval [0 1]. New velocity of the particle is calculated by using Equation (1), three measures are required i.e. the pervious velocity of the particle, the collaborative effect of the particles, and the distance between the particle's current position and its own best historical position. The particle has support of all particles so that information sharing can be done between them. Particles' new position is updated on the basis of Equation (2). PSO algorithm is illustrated briefly in Figure 2.

Inertial weight is introduced by Shi and Eberhart [18] embedding it into the original PSO algorithm. Inertial weight is used to balance the search ability of the algorithm over global and local exploration and exploitation. While the higher inertial weight increases the global exploration ability, the lower inertial weight increases the local exploration ability [19].

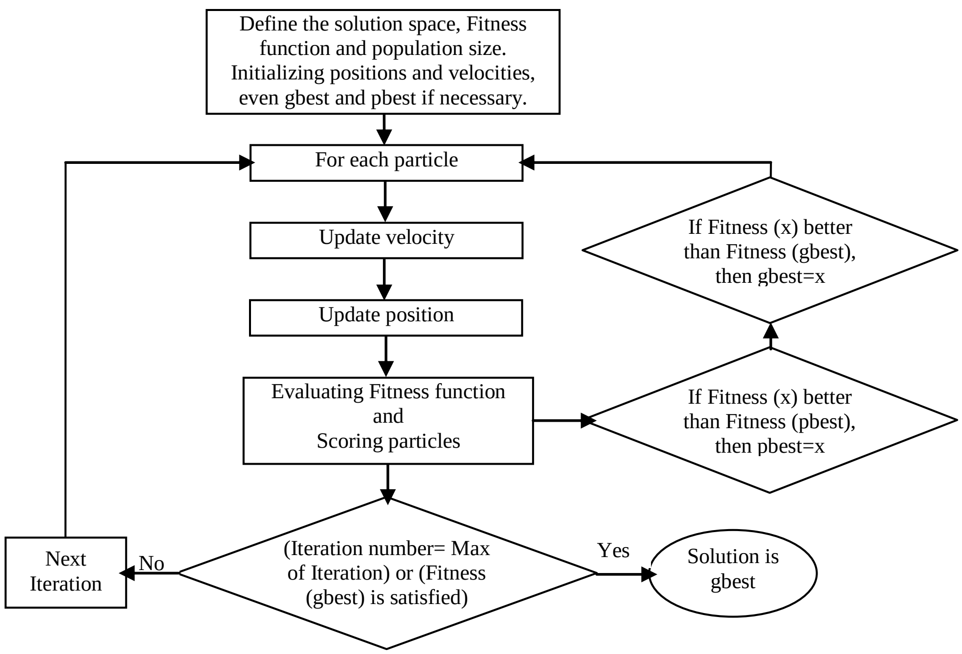


**Figure 2. PSO Algorithm**

According to the mentioned papers, inertial weight is used as the following equation:

$$\omega = \frac{it_{max} - it}{it_{max}} \tag{3}$$

where ω is inertial weight; it shows the current iteration number; and $it_{max}$ shows the maximum iteration number. It can be seen from the equation that the inertial weight ω will be [0, 0.99].

PSO has undergone many changes since its introduction in 1995. Considering the utilization of PSO algorithms for various purposes in the digital image watermarking concept, several studies in literature can be referred to. Fındık, *et al.,* [20] introduce a novel robust watermarking technique using PSO to protect the intellectual property rights of color images in the spatial domain. The authors have used the symmetric cross-shape to extract the features from the blocks in which the watermark is embedded and the control blocks which would be used as training data in the extraction algorithm. Two centroids belonging to each of the watermark binary values are obtained by PSO utilizing the features obtained from the control blocks. Afterwards, the watermark is extracted using these centroids by the k-nearest neighbor classifier system. According to the test results, embedded watermark is extracted successfully even if the watermarked image is exposed to various image processing attacks. Wang, *et al.*, [21] propose an intelligent watermarking by using PSO technique in wavelet domain. The coefficients are randomly selected from different sub bands to make up a block to increase the security where an unauthorized party is unable to remove the watermark or to detect the existence of the watermark. The strength of embedding watermark in different blocks is adaptive by invoking PSO. Through the PSO algorithm, the perceptual transparency and robustness can be optimized. Also, in the work of [22], the watermark strength is intelligently selected through PSO. Another version of PSO named dynamic particle swarm optimization (DPSO) is used in works of [23, 24] in order to determine a setting of embedding parameters of digital watermarking system such that the trade-off between watermark robustness and image fidelity is optimized. In order to obtain the highest possible robustness without losing the imperceptibility, PSO algorithm is employed by Li [25] to search the optimal embedding parameter of the watermarking system.

In the works of [26-28], PSO is used for digital image watermarking to optimize different scaling factors. While in the works of [29-33], PSO is used to select the best coefficients for embedding the watermark adaptively.

### 2.3. Differential Evolution (DE)

DE is significantly faster and robust for solving numerical optimization problem and is more likely to find true global optimum of functions introduced by Storn and Price [34]. It starts with a population of initial solutions each of dimension $D$, $X_{i,G}$, $i = 1, . . . ,NP$, where the index $i$ denotes the $i^{th}$ solution of the population and $G$ is the generation to which the population belongs. It has three main operators, mutation, crossover and selection. 1) Mutation: It is the most important operation of DE which applies the vector difference between the existing population members in determining both the degree and direction of perturbation. Corresponding to target individual $X_i$, randomly selecting three solutions $X_{r1}$, $X_{r2}$ and $X_{r3}$ from the population, $i^{th}$ perturbed individual, $V_{i,G}$, is generated as:

$$V_{i,G} = X_{r1,G} + F \times (X_{r2,G} - X_{r3,G}) \tag{4}$$

where, $i = 1. . . NP$, $r1, r2, r3 \in \{1. . . NP\}$ are randomly selected such that $r1 \neq r2 \neq r3 \neq i$, and F is the control parameter such that $F \in [0, 1]$; 2) Crossover: Crossover operation is performed between perturbed individual $V_{i,G}$ and target individual $X_{i,G}$ to generate the trial individual, $T_{i,G}$. It promises that trial individual will be different at least in one component. Mathematical equation of trial individual generation is as:

$$t_{j,i,G} = \begin{cases} v_{j,i,G} & if\, rand_j \leq C_r \vee j = k \\ x_{j,i,G} & otherwise \end{cases} \tag{5}$$

where, $j = 1, ... , D$, $k \in \{1, ... , D\}$ is a random parameter's index, chosen once for each $i$ and $Cr \in [0, 1]$ is the crossover rate; 3) Selection: It is the operation that selects the better individuals from the current population and its corresponding trial solution according to the following rule:

$$X_{i,G+1} = \begin{cases} T_{i,G} & if\, f(T_{i,G}) \leq f(X_{i,G}) \\ X_{i,G} & otherwise \end{cases} \tag{6}$$

In the DE, these three kinds of operations will be repeated until the maximum number of iterations is reached, or any predefined termination condition is satisfied. Figure 3 is the operation process of DE algorithm.

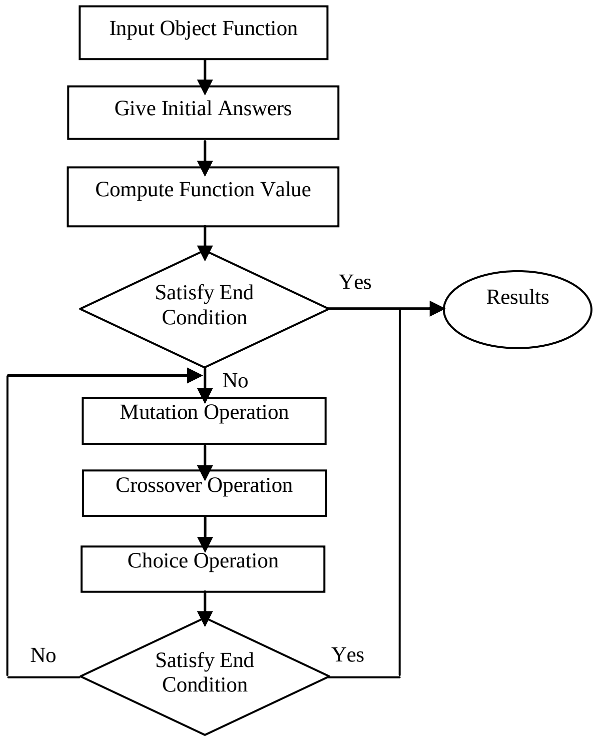


**Figure 3. DE Algorithm**

The problem of digital image watermarking has acquired the status of optimizing twin parameters visibility of signed and attacked images and robustness of the watermark embedding scheme. The issue of using embedding strength based on single scaling factor or multiple scaling factors is found to converge with this objective. Aslantas [35] present an optimal robust image watermarking technique based on SVD using DE. The singular values of the host image are modified by multiple scaling factors to embed a watermark image. The modifications are optimized using DE to achieve maximum robustness and transparency. Ling, *et al.,* [36] shows that the work of [35] has a serious fundamental flaw and should not be used for proof of ownership application. Robust watermarking approach with the combination of wavelet transform, SVD and DE optimization is proposed in [37] that effectively embed double watermarks into the original host images by modifying the Singular values of different blocks. DE is used to optimize the quantization steps for controlling watermark strength with the specially designed fitness function to provide a good watermark transparency and a high robustness against various attacks. In the work of [38], optimal DWT- SVD based image watermarking scheme is presented in which DE algorithm is used to search optimal scaling factors to improve the quality of watermarked image and robustness of the watermark. Ali and Ahn [39] present another optimal DWT- SVD based image watermarking scheme that the self-adaptive DE algorithm is used to optimize the scaling factors. A robust DCT-SVD based image watermarking scheme using DE is proposed by Ali, *et al.*, [40]. The role of DE algorithm is to find the suitable multiple scaling factors and application of Arnold transform for randomizing the watermark.

### 2.4. Ant Colony Optimization (ACO)

Marco Dorigo and colleagues introduced the first ACO algorithms in the early 1990's [41-43]. The ACO, as we know it today, was first formalized by Dorigo and colleagues in 1999 [44]. The development of these algorithms was inspired by the observation of ant colonies. Ants are social insects. They live in colonies and their behavior is governed by the goal of colony survival rather than being focused on the survival of individuals. The behavior that provided the inspiration for ACO is the ants' foraging behavior, and in particular, how ants can find shortest paths between food sources and their nest. When searching for food, ants initially explore the area surrounding their nest in a random manner. While moving, ants leave a chemical pheromone trail on the ground. Ants can smell pheromone. When choosing their way, they tend to choose, in probability, paths marked by strong pheromone concentrations. As soon as an ant finds a food source, it evaluates the quantity and the quality of the food and carries some of it back to the nest. During the return trip, the quantity of pheromone that an ant leaves on the ground may depend on the quantity and quality of the food. The pheromone trails will guide other ants to the food source [45]. The outline of the generic ACO algorithm is presented in Figure 4.

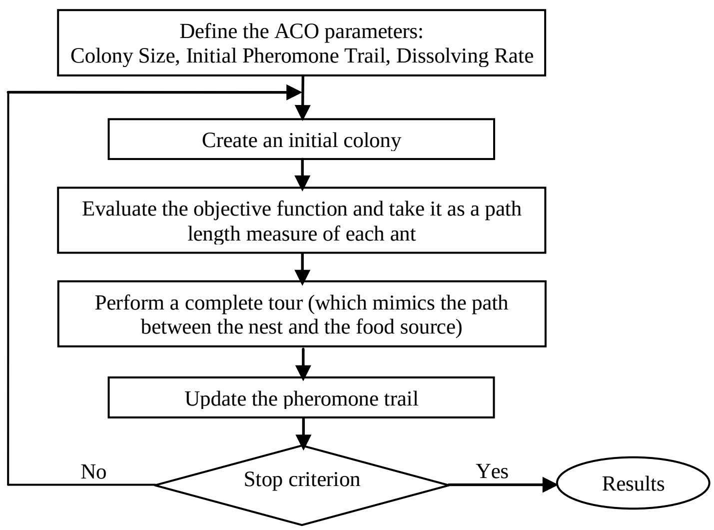


**Figure 4. Generic ACO Algorithm**

There have been several works reported in the literature optimizing digital image watermarking using different kinds of ACO algorithms. Qaheri, *et al.*, [46] propose an implementation of watermarking embedding and retrieval technique using ACO. The essential construct of ACO is pheromone; hence the detection part of watermark is followed through ant's pheromone trace. The advantage of this work is bi-focal, *i.e.*, the incorporation of modified Fractional Fourier domain and subsequently the sharp and noiseless pheromone maps during retrieval reinforce the security against deliberate tampering if any. Another kind of ACO is used in the works of [47, 48] in which an optimal watermarking algorithms using multi-objective ant colony optimization (MOACO) are presented to achieve the highest possible robustness without losing watermark transparency. MOACO is used to find the optimal values for the multiple scaling factors.

### 2.5. Bee Algorithms (BA)

Bees-inspired algorithms are more diverse, and some use pheromone and most do not. Almost all bee algorithms are inspired by the foraging behavior of honey bees in nature. Interesting characteristics such as waggle dance, polarization and nectar maximization are often used to simulate the allocation of the foraging bees along flower patches and thus different search regions in the search space. Different variants of bee algorithms use slightly different characteristics of the behavior of bees. For example, in the honeybee-based algorithms, forager bees are allocated to different food sources (or flower patches) to maximize the total nectar intake [49-51].

In the virtual bee algorithm (VBA), developed by Yang in 2005, pheromone concentrations can be linked with the objective functions more directly [49]. On the other hand, the artificial bee colony (ABC) optimization algorithm was first developed by D. Karaboga in 2005 [50]. In the ABC algorithm, the bees in a colony are divided into three groups: employed bees (forager bees), onlooker bees (observer bees) and scouts. Unlike the honey bee algorithm which has two groups of the bees (forager bees and observer bees), bees in ABC are more specialized [52]. The essence of bee algorithms are the communication or broadcasting ability of a bee to some neighborhood bees so they can know and follow a bee to the best source, locations or routes to complete the optimization task. The detailed implementation will depend on the actual algorithms, and they may differ slightly and vary with different variants [59]. A summary of all the bee algorithms can be shown in Figure 5.

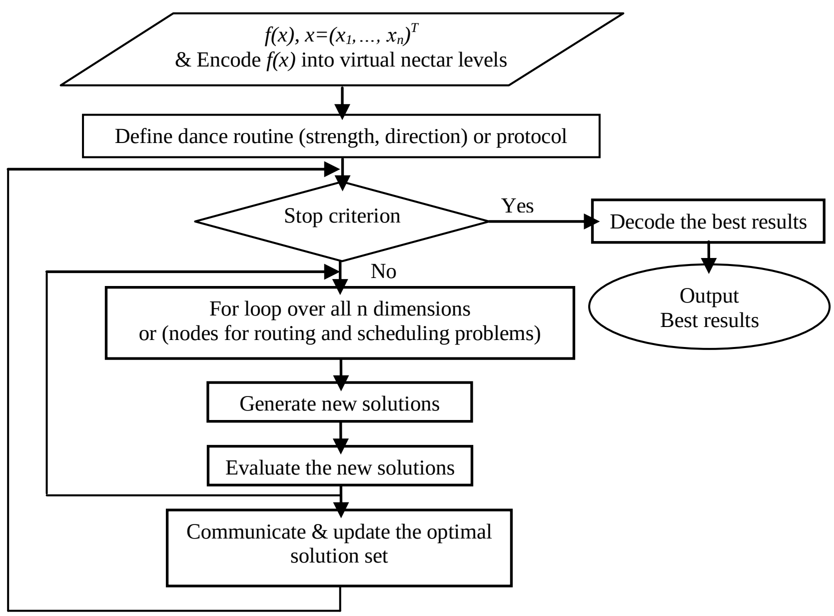


**Figure 5. Generic Bee Algorithms**

There are little works reported in the literature for optimizing digital image watermarking using different kinds of BA. Farhan and Bilal [53] propose a novel technique for embedding watermarks in the wavelet domain of digital images that takes inspiration from the BA. The BA is used to search for best quality flower patches over large distances. Simulation results show that the technique consumes far less time in comparison to other classical evolutionary algorithms. Chen, *et al.*, [54] propose a robust image watermarking scheme based on SVD and DWT with ABC Algorithm. ABC algorithm is employed to find optimal scaling factor so as to achieve better transparency and robustness. Lee, *et al.*, [55] introduced a new image watermarking scheme based on multi-objective bees algorithm (MOBA). The MOBA-based watermarking scheme can get better visual quality in the watermarked images, higher NCs in the extracted watermarks and can also provide solutions with higher stability.

### 2.6. Cat swarm Optimization (CSO)

CSO algorithm is first introduced by Chu and Tsai in 2006 [56]. This optimization algorithm was proposed based on two major behaviors of cats, termed as “seeking mode” and “tracing mode”. To apply CSO in the optimization problem, the first parameter in CSO is the number of cats. For each cat a position vector of M-dimensions and a velocity for each dimension is considered. After evaluating the position of each cat in the fitness function a fitness value is also considered for each cat. In order to identify the mode of the cats a flag is assigned to each cat. To combine the two modes into the algorithm, a mixture ratio (MR) is defined. This parameter is chosen from the interval of [0, 1] and it determines what percentage of cats that are in seeking mode and what percentage of cats are in tracing mode. The best solution of each cat is saved in accordance with the corresponding cat and the algorithm is iterated until the stop criterion is achieved. Figure 6 shows the flowchart of CSO algorithm.

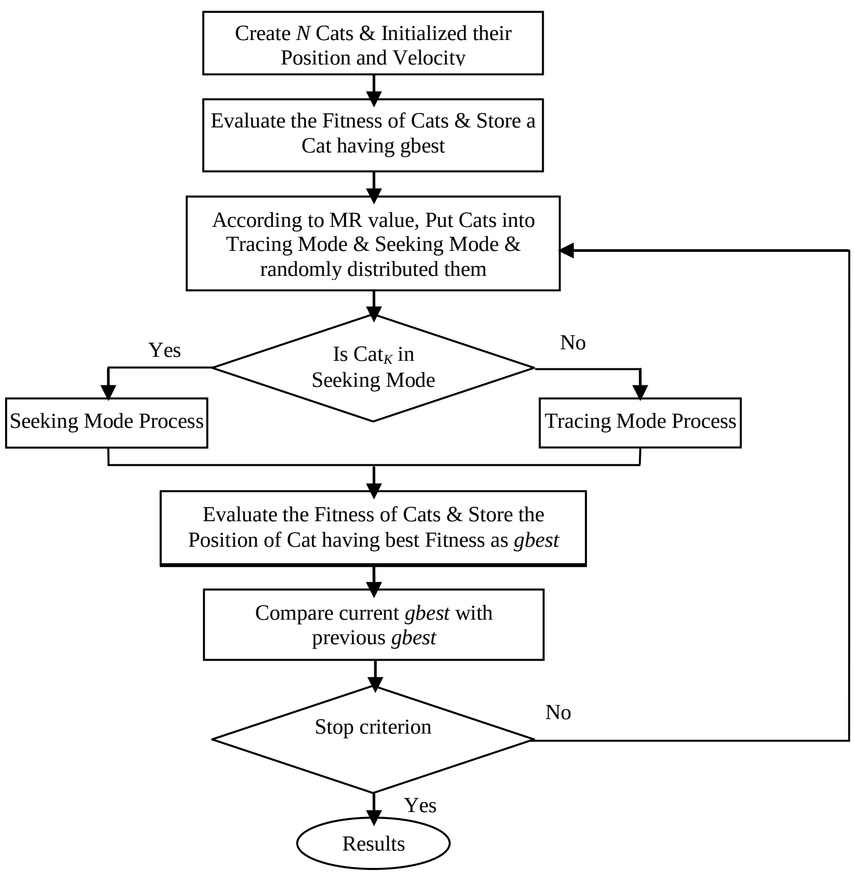


**Figure 6. CSO Algorithm**

An attempt has been made to retrieve watermark same as original watermark using CSO technique is proposed in the works of [57, 58]. CSO is used to correct rounding errors caused by conversion of real numbers into the integers in the process of transformation of an image from frequency domain to spatial domain.

### 2.7. Firefly Algorithm (FA)

Fireflies are one of the most special creatures in nature. Most of fireflies produced short and rhythmic flashes and have different flashing behavior. Fireflies use these flashes for communication and attracting the potential prey. Yang used this behavior of fireflies and introduced Firefly Algorithm in 2008 [59]. The firefly algorithm has three idealized constraints which are derived from firefly features. 1) All fireflies are unisex. So, one firefly will be attracted to other fireflies regardless of their sex; 2) Attractiveness is proportional to their brightness. Thus, for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If there is no brighter one than a particular firefly, it will move randomly; 3) The brightness of a firefly is affected or determined by the landscape of the objective function [59]. Based on the above three rules, the execution process of FA is shown in Figure 7.

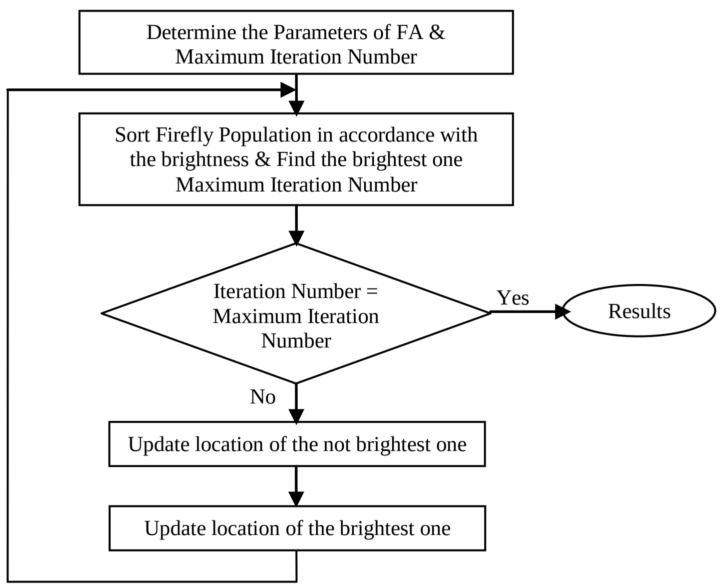


**Figure 7. Firefly Algorithm**

As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the attractiveness $\beta$ of a firefly by:

$$\beta = \beta_0 e^{-\gamma r^2}, \tag{7}$$

where $\beta_0$ is the attractiveness at $r = 0$.

The movement of a firefly $i$ is attracted to another more attractive (brighter) firefly $j$ is determined by:

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2}\left(x_j^t - x_i^t\right) + \alpha_t \in_i^t, \tag{8}$$

 

where the second term is due to the attraction. The third term is randomization with $\alpha_t$ being the randomization parameter, and $\epsilon_i^t$ is a vector of random numbers drawn from a Gaussian distribution or uniform distribution at time *t*. If $\beta_0 = 0$, it becomes a simple random walk. On the other hand, if $\gamma = 0$, it reduces to a variant of particle swarm optimization. Furthermore, the randomization $\epsilon_i^t$ can easily be extended to other distributions such as Lévy flights [60].

From the beginning of year 2014, the FA has been used by several researchers in the application of digital image watermarking optimization. In the work of [61], a novel image watermarking scheme using FA is proposed. The location of the coefficients to be modified by the watermark are identified and selected by using FA. The authors concluded that the embedding, extraction and robustness for the algorithm are well optimized. A novel approach is proposed in the work [62] in which the FA is used to find the best possible scaling factors, to design a robust biomedical content authentication system by means of combined (DWT-DCT-SVD) based approach of watermarking in order to provide an accurate authentication system for information exchange along with high level of robustness, imperceptibility, and payload. Also, in the work of [63], The Multiple Scaling factors are optimized using FA having an objective function which is a linear combination of imperceptibility and robustness.

### 2.8. Cuckoo Search Algorithm (CS)

Cuckoo search (CS) is a new class of meta-heuristic algorithm and modern approach for optimization purposes, proposed by [yang & Deb] [64]. This algorithm is based on the obligate brood parasitic behaviour found in some cuckoo species and in the meantime combining the Lévy flight behaviour discovered in some birds and fruit flies. From a quick look, it seems that there is some similarity between CS and hill-climbing, in combination with some large scale randomization. But there are some significant differences that the authors summarized as follows [64]: firstly, CS is a population-based algorithm, in a way similar to GA and PSO, but it uses some sort of elitism or selection similar to that used in harmony search; secondly, the randomization is more efficient as the step length is heavy-tailed, and any large step is possible; thirdly, the number of parameters to be tuned is less than GA and PSO, and thus it is potentially more generic to adapt to a wider class of optimization problems. In addition, each nest can represent a set of solutions; CS can thus be extended to the type of meta-population algorithm. For the ease in describing CS, the three idealized rules are described as follows [64]: 1) Each cuckoo lays one egg at a time, and dumps its egg in randomly chosen nest; 2) The best nests with high quality of eggs will carry over to the next generations; 3) The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability pa ∈ [0, 1]. In this case, the host bird can either throw the egg away or abandon the nest, and build a completely new nest. Based on these three rules, the basic steps of the CS are depicted in the flowchart shown in Figure 8.

Because CS algorithm is considered relatively new, no many papers in the literature working on digital image watermarking optimization, we can mention here the application of the cuckoo search technique to the image watermarking problem for finding the optimal scaling factors that purposed by Ali, *et al.*, [65]. In this work the authors didn't explain deeply how the CS algorithm deals with finding the scaling factors and they didn't mention the number of iterations needed to reach their optimal solution.

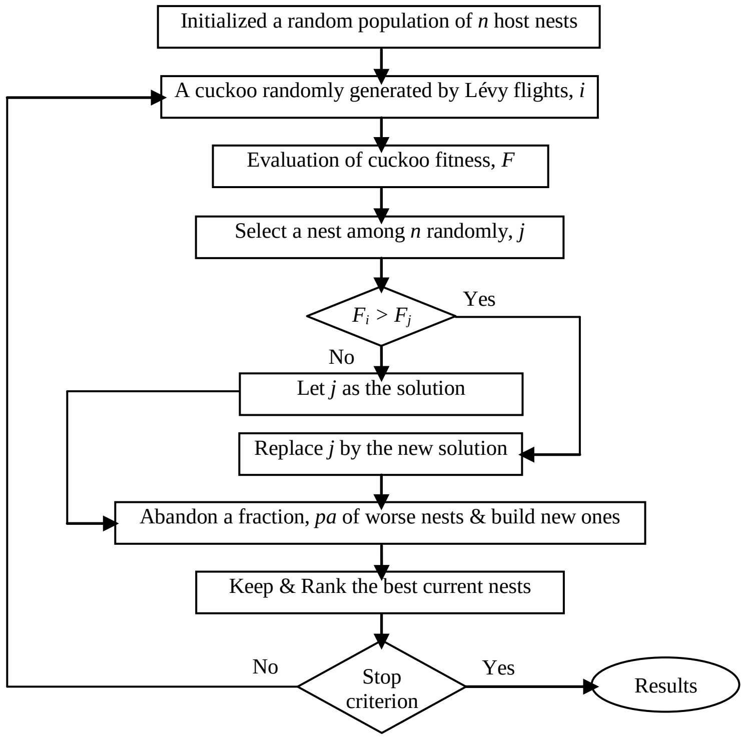


**Figure 8. Cuckoo Search Algorithm**

## 3. Performance Analysis of Digital Image Watermarking Optimization

The total number of papers published per year is shown in Figure 9, describing the application of optimization algorithms for digital image watermarking.

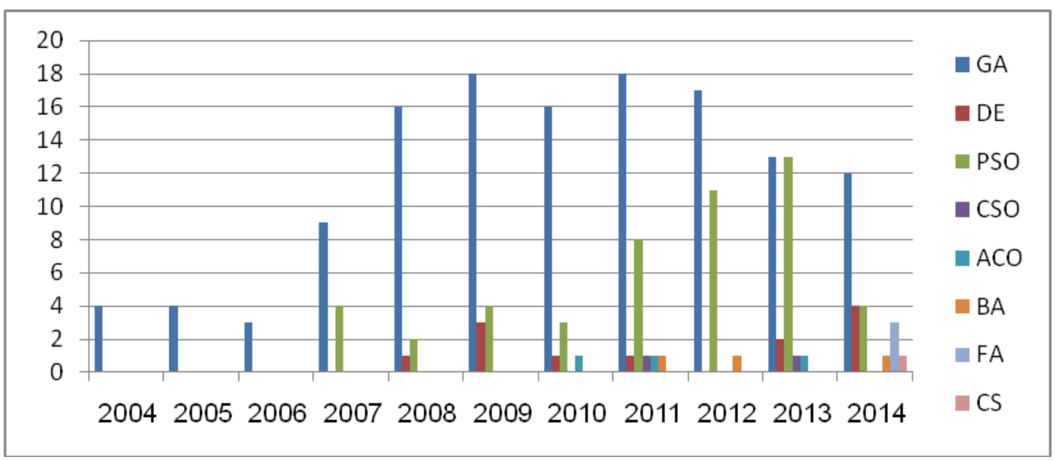


**Figure 9. Distribution of Publications per Year (2004–2014)**

The previously presented contribution were NIAs have been applied to optimize digital image watermarking are summarised in Table 1 and Table 2. The comparison in these tables is based on the following criteria: author names, year of publication, reference number, fitness function and performance.

Regarding fitness calculation $f$ is the fitness function, *PSNR* is the peak signal to noise ratio [21], *SSIM* is the structural Similarity Index [31], *Corr* is the correlation value which is used to measure the similarity between the host image *I* (or watermark *w*) and watermarked image *I'* (or extracted watermark *w'*) [54], *NC* is the normalized cross correlation [66], *BCR* is the percentage of correctly extracted bits to the embedded watermark capacity [4], $\lambda$ is the weighting factor.

As performance criterions, for imperceptibility; the average optimized *PSNR* value is between 50-above, 40-49 and 30-39 for high, medium and low metrics respectively. For robustness; the average optimized *NC* value is between 1.0- 0.9, 0.89-0.8 and 0.79-under for high, medium and low metrics respectively, and the average optimized *BCR* value is between 100%-90%, 89%-80%, 79%-under for high, medium and low metrics respectively.

**Table 1. NIAs Strength Parameters Selection Problem Solving in Digital Image Watermarking**

| Author(s), Year | Ref. No. | NIAs | Fitness Function | Performance | | | |
|---|---|---|---|---|---|---|---|
| | | | | Imperce-ptibility | Robust-ness | Image Size | Watermark Size |
| Aslantas, 2008 | [11] | GA | $f=\left[1/\left(\frac{1}{N\,attacks}\sum_{i=1}^{N}Corr(w,w'_i)\right)-Corr(I,I')\right]$ | Low | High | 256*256 | 32*32 |
| Aslantas et al., 2008 | [26] | PSO | $f=\left[1/\left(\frac{1}{N\,attacks}\sum_{i=1}^{N}Corr(w,w'_i)\right)-Corr(I,I')\right]^{-1}$ | - | High | 512*512 | 256*256 |
| Aslantas, 2009 | [35] | DE | $f=\left[1/\left(\frac{1}{N\,attacks}\sum_{i=1}^{N}Corr(w,w'_i)\right)-Corr(I,I')\right]^{-1}$ | Low | High | 256*256 | 32*32 |
| Wang et al., 2011 | [21] | PSO | $f=\frac{PSNR}{100}+\sum_{i=1}^{3}NC(w,w'_i)$ | Medium | Medium | 512*512 | 512 bits |
| Farhan and Bilal, 2011 | [53] | BA | $Fitness=SSIM\,(w,w')$ | Medium | - | 256*256 | 32*32 |
| Lai et al., 2012 | [13] | GA | $f=PSNR+30\,.\sum_{i=1}^{N\,attacks}BCR(w,w'_i)$ | Medium | Medium | 512*512 | 32*32 |
| Rao et al., 2012 | [27] | PSO | $f=Max\left(\frac{1}{N\,attacks}\sum_{i=1}^{N}Corr_i(w,w')\right)+Corr(I,I')$ | Low | Medium | 512*512 | 256*256 |
| Run et al., 2012 | [28] | PSO | $f=Max\left(\frac{1}{N\,attacks}\sum_{i=1}^{N}Corr_i(w,w')+Corr(I,I')\right)$ | Low | High | 512*512 | 256*256 |

 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chen et al., 2012 | [54] | BA | $f = Min(N\,Attacks/(\sum_{i=1}^{N\,Attacks} corr(w,w'_i) - corr(I,I')))$ | Low | High | 512*512 | 64*64 |
| Lei et al., 2013 | [37] | DE | $f = Max(0.5 \times SSIM + 0.5 \times \frac{1}{N\,Attacks}\sum_{i=1}^{N} w_i \times NC(w,w'_i))$ | Medium | High | 512*512 | 64*64 |
| Loukhao-ukha, 2013 | [48] | ACO | $F(P) = \left(\frac{1}{NC(I,I')}\ \frac{1}{NC(W,W')}\ \frac{1}{NC(W,W'_{p,1})} \cdots \frac{1}{NC(W,W'_{p,T})}\right)^T,$ $f = \sum_{i=1}^{T+2}(e^{10}-1).e^{1(F(x)-10)}$ | High | High | 256*256 | 32*32 |
| Li et al., 2014 | [25] | PSO | $f = \frac{PSNR}{100} + 1.1 \times (\sum_{i=1}^{5} NC(w,w'_i))/5$ | Medium | Medium | 512*512 | 32*64 |
| Ali et al., 2014 | [38] | DE | $f = Min(\frac{N\,Attacks}{\sum_{i=1}^{N} NC(w,w'_i)} - NC(I,I'))$ | Low | High | 256*256 | 64*64 |
| Ali and Ahn, 2014 | [39] | DE | $f = Max\left(\frac{\sum_{i=1}^{N} NC(w,w'_i)}{N\,attacks} + NC(I,I')\right)$ | Low | High | 512*512 | 256*256 |
| Ali et al., 2014 | [40] | DE | $f = Min\left(\frac{N\,attacks}{\sum_{i=1}^{N} NC(w,w'_i)} - NC(I,I')\right)$ | Low | High | 512*512 | 64*64 |
| Mishraa et al., 2014 | [63] | FA | $f = PSNR + \lambda \times \left[NC(w,w') + \sum_{i=1}^{5} NC(w,w'_i)\right]$ | High | Medium | 256*256 | 32*32 |
| Ali et al., 2014 | [65] | CS | $f = Min\left(\frac{N}{\sum_{i=1}^{N} NC(w,w'_i)} - NC(I,I')\right)$ | Low | High | 256*256 | 256*256 |

## Table 2. NIAs Positions Selection Problem Solving in Digital Image Watermarking

| Author(s), Year | Ref. No. | NIAs | Fitness Function | Performance | | | |
|---|---|---|---|---|---|---|---|
| | | | | Impercepti-bility | Robustness | Image Size | Watermark Size |
| Shieh et al., 2004 | [3] | GA | $f = PSNR + \sum_{i=1}^{3} NC(w,w'_i).\lambda$ | Low | Low | 512*512 | 128*128 |
| Huang et al., 2007 | [8] | GA | $f = PSNR + \lambda_1.\frac{1}{N\,attacks}\sum_{i=1}^{N} BCR(w,w'_i) + \lambda_2.No\ of\ bits$ | Medium | - | 512*512 | 128*32 |
| Chu et al., 2008 | [4] | GA | $f = PSNR + \lambda.BCR(w,w')$ | Medium | Medium | 256*256 | 32*32 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rohani and Avanaki, 2009 | [29] | PSO | $f = 1 - SSIM(I, I')$ | Medium | - | 256*256 | 40*40 |
| Anwar et al., 2010 | [5] | GA | $f = PSNR$ | High | - | 512*512 | 64*64 |
| Venkatesan et al., 2010 | [9] | GA | $f = PSNR$ | High | - | 512*512 | 256 bit |
| Bedia et al., 2012 | [31] | PSO | $f = (1 - SSIM(I, I')) + \lambda(1 - NC(w, w'))$ | Medium | Medium | 512*512 | 90*90 |
| Mingzhi et al., 2013 | [10] | GA | $f = abs[(40 - PSNR) + (1 - NC(w, w')]$ | Medium | Medium | 512*512 | 32*32 |
| Lee et al., 2014 | [55] | BA | $f = Average\ NC(w, w'_N)$ | Medium | High | 256*256 | 32*32 |

## 4. Conclusions

There are several types of watermarking algorithms; each type of algorithms has its own advantages and limitations. Unfortunately there is no method that can provide a fully comprehensive solution. Each type of solution has a specific robustness to some type of attacks but is less resilient to some other types of attacks. In the previous sections we have presented representative calculations of the different NIAs that have been applied in the optimal digital image watermarking techniques. However genetic algorithms have been used more frequently to optimize the watermarking techniques. In problem solving of optimal digital image watermarking, PSO and DE techniques have attracted more attention and have also been applied with some degree of success. Harmony search and Bat algorithm are examples of other NIAs that at the moment have not been applied to the optimization of digital image watermarking techniques and that may be worth mentioning in the near future in the area of digital image watermarking techniques optimization. It is expected that these approaches and similar ones could be applied at any time in this fruitful area of research, it is expected in the near future that newer optimization techniques would also be tried.

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