Chapter 12
Introduction to Invasive Weed Optimization Method

Dilip Kumar, B. G. Rajeev Gandhi, and Rajib Kumar Bhattacharjya

Abstract The weeds are generally defined as the unwanted plants growing in an agricultural field. The weeds are not very useful and occupy the space in the field to successfully outnumber the plants that are cultivated for regular use. Thus, a popular agronomical belief is that “The Weeds Always Win”. Weeds typically generate large numbers of seeds, supporting their spread by wind or some other natural factors. They can also grow in adverse conditions and are very adaptable. These unique properties of weed growth shows the way for the development of optimization techniques. One of the algorithms motivated by this common phenomenon in agriculture field is based on the expansion of invasive weeds. The algorithm is known as Invasive Weed Optimization (IWO). In this chapter, we have described the IWO algorithm and its use in obtaining the optimal solution of common popular functions.

Keywords Invasive weeds · Seeds · Optimization

Introduction

Weeds occupy an agricultural field by means of spreading of seeds from the plants and take control of places between the crops. Weeds generally occupy the unused space of the field and further grow to a flowering weed. This flower provides new weeds and the cycle repeats. The production capacity of the flowering plant to produce weed depends on the adaptation of the flowering weeds in the field [6].

D. Kumar (✉)
Department of Civil Engineering, G B Pant Engineering College, Pauri, Uttarakhand, India

B. G. R. Gandhi · R. K. Bhattacharjya
Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, Assam, India
e-mail: b.rajeev@iitg.ac.in; rkbc@iitg.ac.in

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The weeds with better adaptation to the environment will be able to occupy more unused space in the field. They will grow faster and will generate more seeds. These newly produced weeds are again scattered over the field and grow as new flowering weeds [5]. This cycle lasts until the number of weeds reaches its maximum capacity. Due to the competition between different weed plants, only the weeds with better adaptation capability can survive and produces new weeds i.e. they follow Darwin's principle of "survival of the fittest" [7, 8]. In brief, we can simply define the concept behind the invasive weed theory as:

(a) A measurable number of seeds are scattered over the field, known as the initial population.
(b) Each spread seed turns to a flowering plant and produces new seeds based on their adaptability with the surroundings, known as reproduction.
(c) The produced seeds are being scattered by some natural agency over the rest of the field and turn to new plants known as the spatial distribution of weeds.
(d) This cycle continues until the number of plants reaches a maximum. Once the number of plants reaches the maximum, the plants with the best fitness and adaptability survives and produce new seeds. Rest of the weak plants are eliminated which is called as competitive elimination or survival of the fittest.
(e) At last, the weed plant with the best fitness and adaptability are only present in the field.

These processes are used to design the optimization algorithm called the Invasive Weed growth Algorithm (IWO). The initialization of the population, reproduction, spatial distribution, competitive exclusion and the optimal solution are the steps involved in the design of the IWO algorithm [14, 15]. Each of these steps is described in detail in the following section.

Working Procedure of Invasive Weed Optimization Algorithm (IWO)

Initialize a Population

In general terms, the population is defined as the total number of people or residents living in a country, state or any specified region. If the region is specified to be the whole agricultural field, the initial weeds that emerge randomly over the field are the initial population. So, to replicate that in the IWO, we can define the population as initial number of seeds scattered over the field [1]. Mathematically we can define the population as the bunch of initial solutions which being expanded over the D dimensional problem space with random or blind positions.

Consider a set of population as a matrix X, with elements that are referred as plants or agents. Each plant represents possible solution in defined population size, max plant. For a D-dimensional problem and a population of size N, the matrix 'X' representing the population is given as.

$$X = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1D} \\ x_{21} & x_{22} & \ldots & x_{2D} \\ \ldots & \ldots & \ldots & \ldots \\ x_{N1} & x_{N2} & \ldots & x_{ND} \end{bmatrix} \tag{12.1}$$

The i^{th} population consists of D variables as the dimension of the problem is 'D'. Therefore the coordinates of the elements x_{i1} is limited between the boundaries, U1 and L1, *i.e.*, (L1 < xi_1 < U1) and x_{iD} is limited between two other boundaries, UD and LD i.e., (LD < x_{iD} < UD). Let the lower and upper bounds be the vectors of length 'D' represented by L and U as given in Eq. 12.2 as follows.

$$\begin{aligned} L &= [L1 \;\; L2 \;\; \ldots \;\; LD] \\ U &= \left[U1 \; U2 \ldots UD\right] \end{aligned} \tag{12.2}$$

Pseudo Code for Initialization of Population

Define Vectors L and U and dimension D
for dim = 1:D
for pop = 1:N
    *X(pop,dim) = L(1,dim)+rand()*x*{U(1,dim)-L(1,dim)}*
end
end

Using this similar code in MATLAB, the population can be initialized in the same way as the initial weeds are produced in the field.

Reproduction

The weeds present in the filed have different strengths, *i.e.* the some plants are highly adaptable and can produce a large number of offsprings whereas some of the plants die off quickly. So, the fitness of the plant decides the number of offsprings it will produce. To reproduce the same process in the IWO algorithm, the fitness of the initial population is calculated. The plant in the population is then allowed to produce seeds depending on its own fitness and the adaptability as well as the lowest and the highest fitness value of the plants in the colony [7, 8]. The number of seeds produced by each plant will increases linearly (Fig. 12.1) from the minimum possible seed (S_{min}) to its maximum level (S_{max}). The fitness of any plant 'p' can be represented as 'F_p'. The Eq. (12.3) can be used to calculate the number of seeds produced by a plant according to its fitness.

$$S_p = S_{\min} + \left(F_p - F_W\right)\left({}^{(F_B - F_w)}\Big/_{(S_{\max} - S_{\min})}\right) \tag{12.3}$$

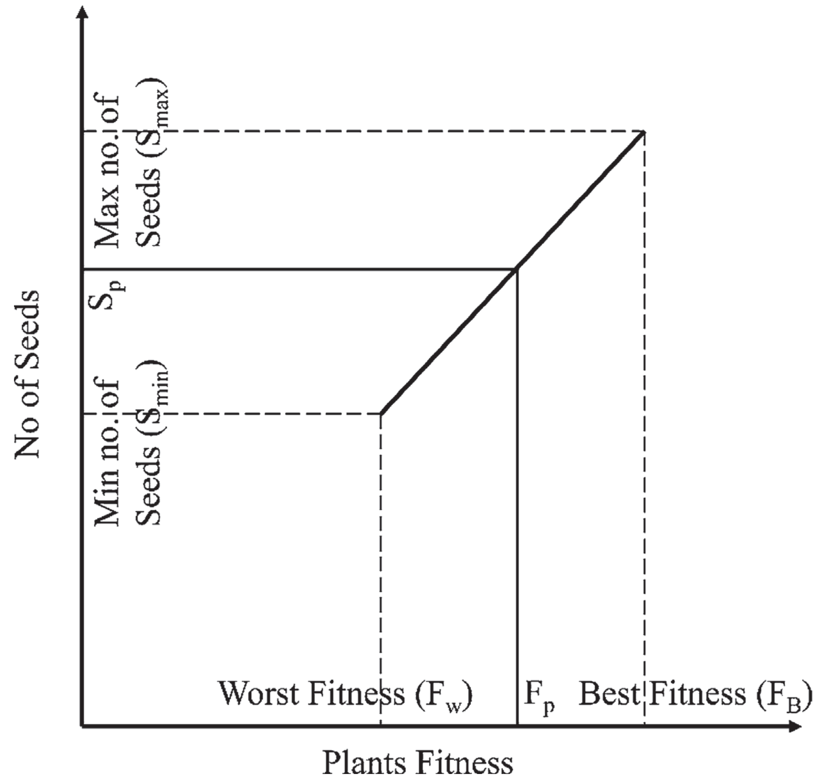

Fig. 12.1 Procedure of reproduction

Pseudo Code for Reproduction

Calculate fitness of 'N' Population as F
Scale the fitness from worst to best
Assign F_W as worst fitness and F_B as best fitness
Define minimum and maximum no of seeds as S_{min} and S_{max}
for pop = 1:N
    $S(pop) = S_{min}+(F(pop)-F_W)\text{x}\{(S_{max}-S_{min})/(F_B-F_W)\}$
end

This reproduction part is coded in MATLAB to get the number of seeds to be produced by each weed. The reproduction part decides only the number of offsprings (seeds) that are to be produced by each weed. The spread of the seeds of each of the weeds is decided in the next subsection.

Spatial Distribution of Seeds

The number of seeds that are generated according to the fitness values are to be dispersed around the parent weed. The dispersion happens by means of mostly wind. Initially, when there is enough space in the filed for the weeds to grow, the dispersion of seeds will be over a greater radius. But, as the empty space in the field gets occupied by the new weeds, the dispersion has to shrink to a minimum area close to the parent weed [3]. This process is replicated in the IWO algorithm as follows.

The seeds generated are distributed randomly over the search space. The random distribution is followed by a normal distribution with a zero mean but a variable variance. This ensures that the seeds will be randomly distributed such that they stand near the parent plant. However, standard deviation (σ) is generally reduced once you are reaching the optimal solution. As such, the standard deviation is varying from an initial value of $\sigma_{\mathrm{initial}}$ to a final value of σ_{final} in every step (generation). The following equation (Eq. 12.4) can be used to change the standard deviation in each iteration.

$$\sigma_{iter} = \frac{(iter_{\max} - iter)^n}{iter_{\max}^n}\left(\sigma_{initial} - \sigma_{final}\right) + \sigma_{final} \tag{12.4}$$

Where, $iter_{max}$ is the maximum number of iterations, σ_{iter} is the standard deviation at the present step and n is the nonlinear modulation index. The variation of the standard deviation with each iteration from maximum of 0.5 to minimum of 0.001with and 'n' value of 2 is given in Fig. 12.2.

Pseudo Code for Spatial Distribution

Define σ_{final}, $\sigma_{initial}$, *and exponent n.*
for iter = 1:Maxiter
    $\sigma_{iter} = \{(Maxiter-iter)/Maxiter\}^n \mathrm{x}\ (\sigma_{initial} - \sigma_{final}) + \sigma_{final}$
for pop = 1:N
for dim = 1:D
for seedpop = 1:S(pop)
    $X_{seed}(pop,seedpop,dim) = X(pop,dim)+\sigma_{iter}\mathrm{x}randNormal()$
end
end
end
end

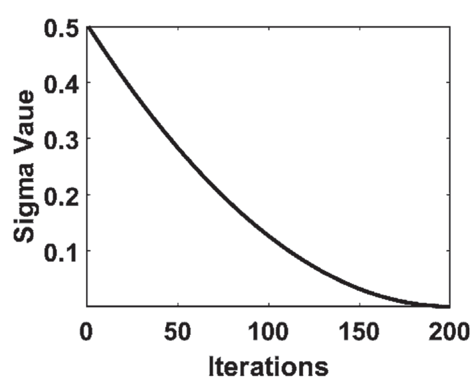

Fig. 12.2 Standard deviation varying with the iterations

This gives the population of seeds for each of the weeds distributed spatially over the area according to their respective normal distribution and the standard deviation. The spatial distribution part is also coded in MATLAB according to the pseudo code.

Competitive Elimination

By reproduction and the spatial dispersal of the seeds over a number of generations, the plants will occupy the whole field. The growth of the weeds and the seeds combined have to be limited by some principle so that the maximum number of plants and weeds in each generation is minimized to a specified value [2, 4]. Based on the minimum number of seeds (when set to zero), if a plant leaves no offspring then it would go extinct. Also, the plants producing a lesser number of offsprings would also be outnumbered by the seeds produced by the fitter weeds [5, 14]. These two processes can be incorporated into IWO by combining the whole population of weeds and seeds and then excluding the population which is not the fittest based on the maximum number of allowable population (P_{max}). This ensures that in each generation only a maximum of P_{max} population exists throughout the algorithm.

Pseudo Code for Competitive Elimination

Define the maximum population allowed P_{max}
Combine X *and* X_{seed} *to* X_{temp} *and calculate the fitness* F
Scale the fitness from best to worst and sort X_{temp}
If size(F) < P_{max}
    $X_{new} = X_{temp}$
else
    $X_{new} = X_{temp}(1{:}P_{max})$
end

This eliminates the inferior solutions of the population and the better solutions are allowed to go to the next generation. The process is then continued from reproduction to competitive elimination until the termination criteria is reached. The flow chart of the algorithm is shown in Fig. 12.3.

We have considered an area of 20×20 units to demonstrate the initialization of the population, reproduction and competitive exclusion in the following example. The function is taken as Ackley function with optimal solution at (0,0) and the initial population is 50, maximum population is 100. Figure 12.4a gives the scatter plot of the initial population, Fig. 12.4b gives the scatter plot of the reproduced population and the Fig. 12.4c gives the scatter plot of the population reduced to maximum after competitive exclusion.

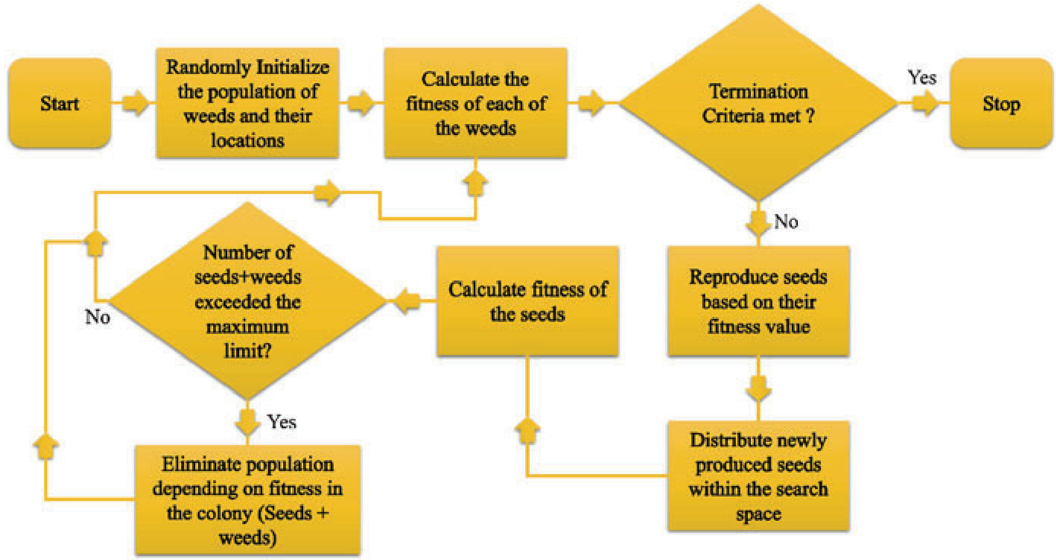

Fig. 12.3 Flowchart showing the IWO algorithm

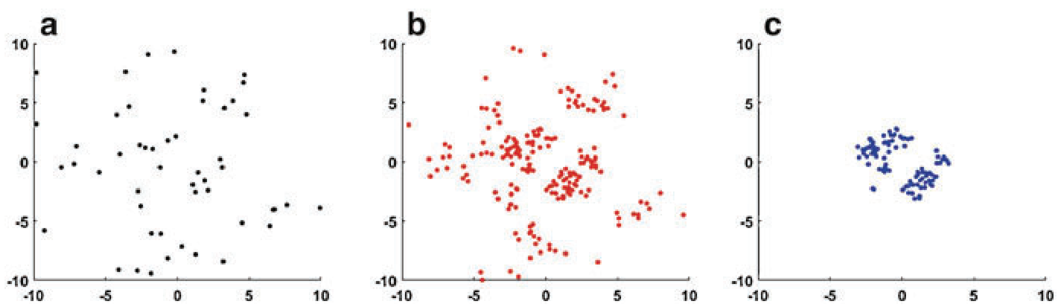

Fig. 12.4 Scatter plots of the population at different stages of the IWO algorithm. (**a**) Initial population. (**b**) Population after reproduction. (**c**) Population after competitive elimination

Standard Examples

The IWO algorithm can be used for solving the non-linear non convex problems. However, the robustness of the algorithm can be observed by solving some standard mathematical functions [11]. These mathematical functions are of different kinds such as one global optima (sphere function) and multiple global optima (Himmelblau function). There are many other functions containing of many local optima and only one global optima (Ackley function). All these functions represent different types of problems that arise in engineering optimization. The efficiency of an algorithm can be measured by obtaining the solution of these functions. The solutions for all the three functions considering two variables are discussed in the next sections. The parameters used for the optimization are as given below in Table 12.1.

Table 12.1 Parameters used for solving the problems

Parameter	Value used
Maximum iterations	200
Initial population size	10
Maximum population size	25
Minimum no. of seeds	0
Maximum no. of seeds	5
Exponent 'n'	2
Sigma-initial	0.5
Sigma-final	0.001

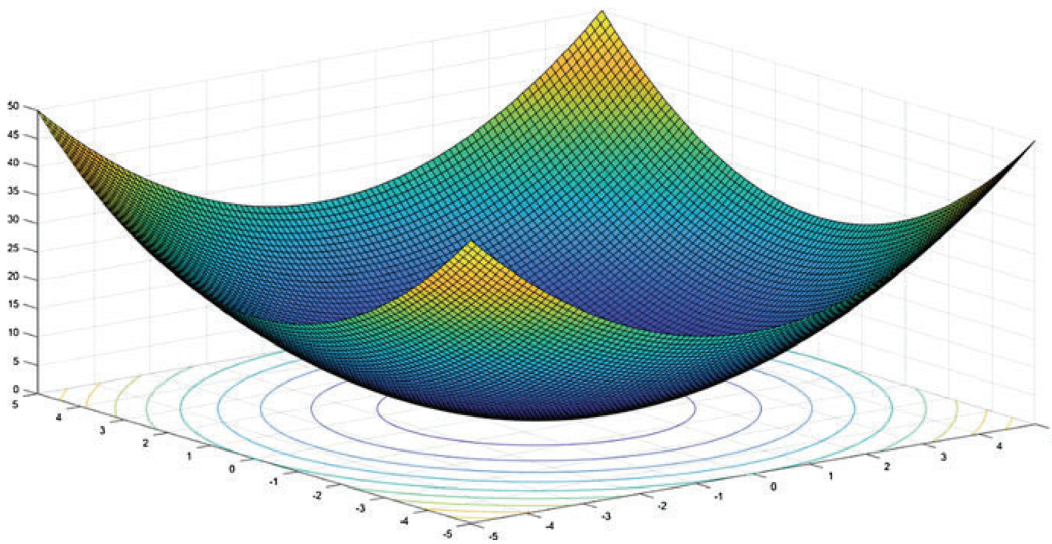

Fig. 12.5 Sphere function contour and the surface plot

Sphere Function

The sphere function is a simple part of the sphere in between the bounds. The minimum value of the function is at (0,0). The variation of the function in its bounds is given in Fig. 12.5. The equation of the sphere function is given in Eq. 12.5.

$$f(x, y) = x^2 + y^2 \tag{12.5}$$

This function is solved 20 number of times with the same parameters and the results of the best fitness for each iteration in each of the solution are presented in Fig. 12.6. It can be observed that, every time, the optimal value is reached over the total number of iterations.

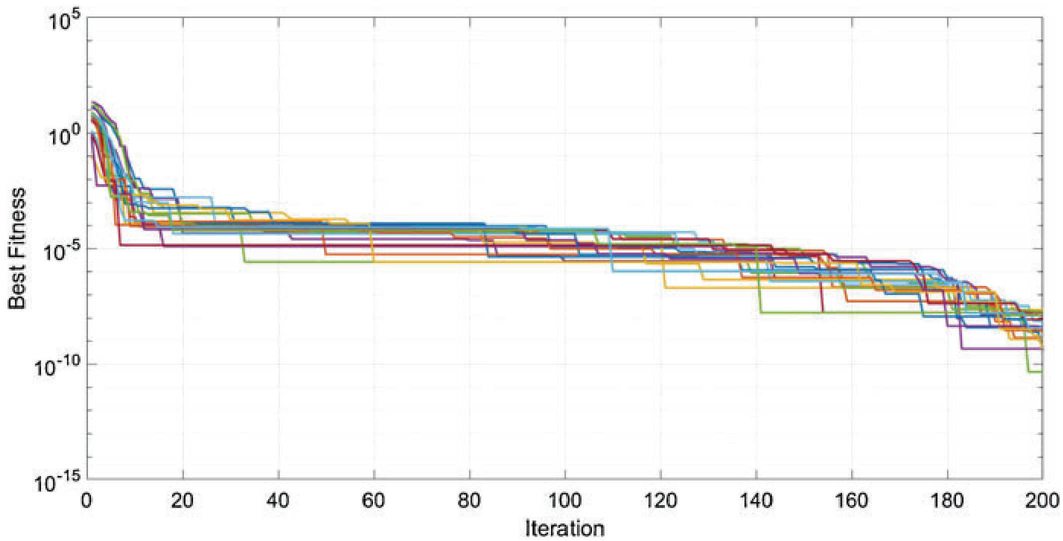

Fig. 12.6 Best fitness with number of iterations over 20 runs

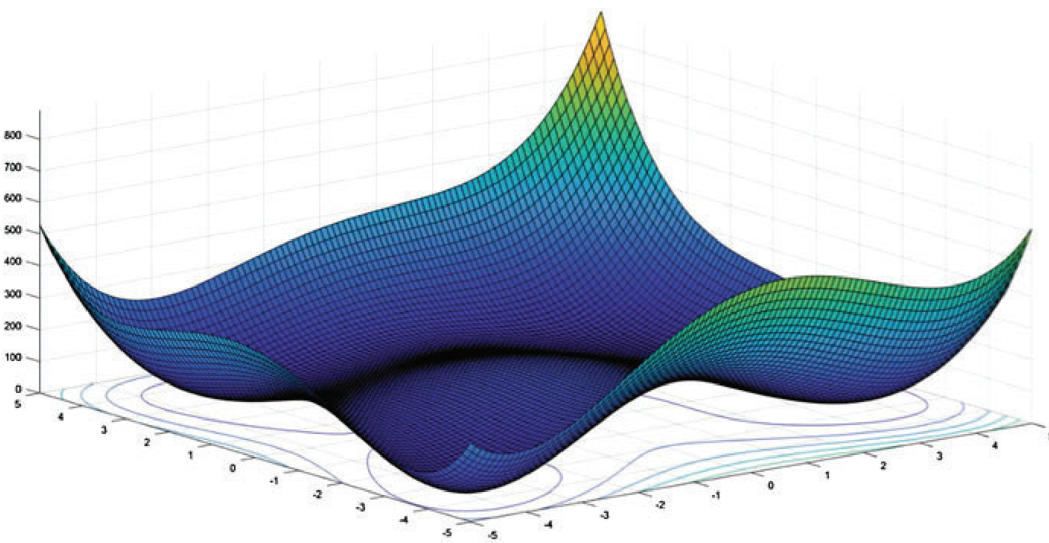

Fig. 12.7 Contour and surface plots of the Himmelblau function

Himmelblau Function

This function is defined by the equation below which has four identical minimum at (3,2), (−2.805118,3.131312), (−3.779310,−3.283186) and (3.584428,−1.848126) as (x,y) pairs where the function value is zero. The function is given in Eq. 12.6. The variation of the function can be seen in Fig. 12.7.

$$f\left(x,y\right)=\left(x^2+y-11\right)^2+\left(x+y^2-7\right)^2 \tag{12.6}$$

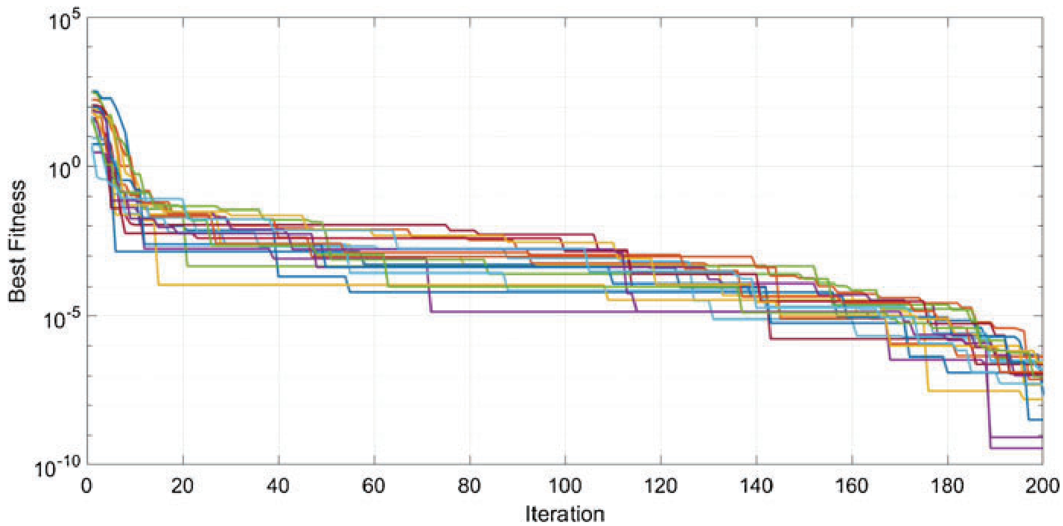

Fig. 12.8 Best fitness with number of iterations over 20 runs

The function with four identical optima is also solved 20 times with the same parameters as mentioned in the Table 12.1. The results of the best fitness with the number of iterations over 20 runs can be seen in the Fig. 12.8.

Ackley Function

This function resembles most of the functions in engineering optimization. This contains many local optima and only one global optima at (0,0). The function is given in Eq. 12.7. The figure for the variation of the function along the interval is given in Fig. 12.9.

$$f\ (x,y) = 20\left(1 - e^{-0.2\sqrt{\frac{x^2+y^2}{2}}}\right) + e - e^{\frac{\cos(2\pi x)+\cos(2\pi y)}{2}} \tag{12.7}$$

The solution of the Ackley function for 20 runs is carried out. The best fitness with the iterations for all the 20 runs are given in Fig. 12.10.

For all the three functions, the behavior of the algorithm for the best fitness did not change much. This is because of the typical behavior of the invasive weed growth optimization. The fitness initially decreases rapidly, then decreases slowly for most number of iterations and then again decreases rapidly over the end of the iterations. This can be observed in the Figs. 12.6, 12.8 and 12.10. This assures that IWO is a pure metaheuristic optimization approach. The nature of the problem does not have an effect on the solution. Thus this algorithm is efficient in solving different optimization problems in engineering and many other fields.

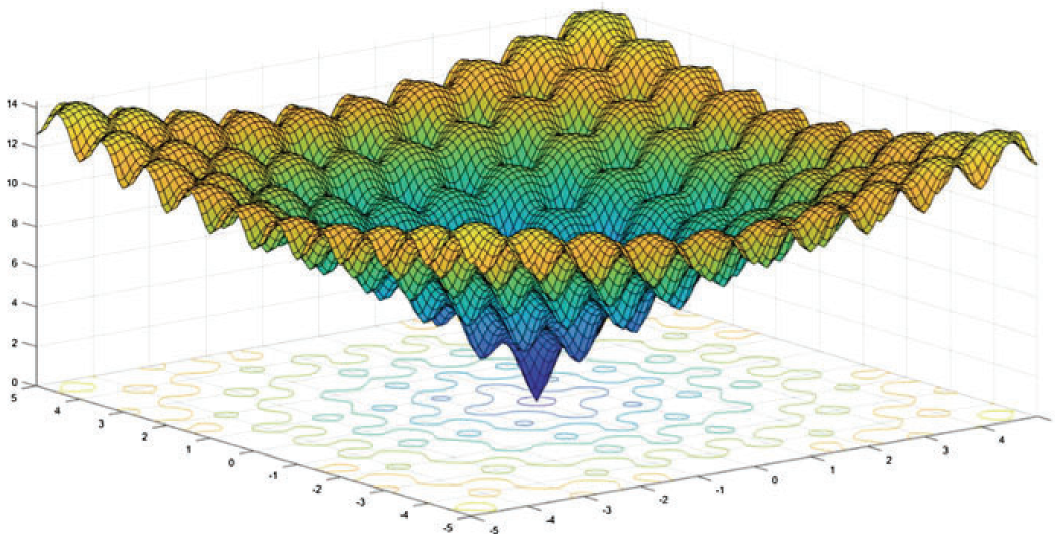

Fig. 12.9 Ackley function contour and surface plots

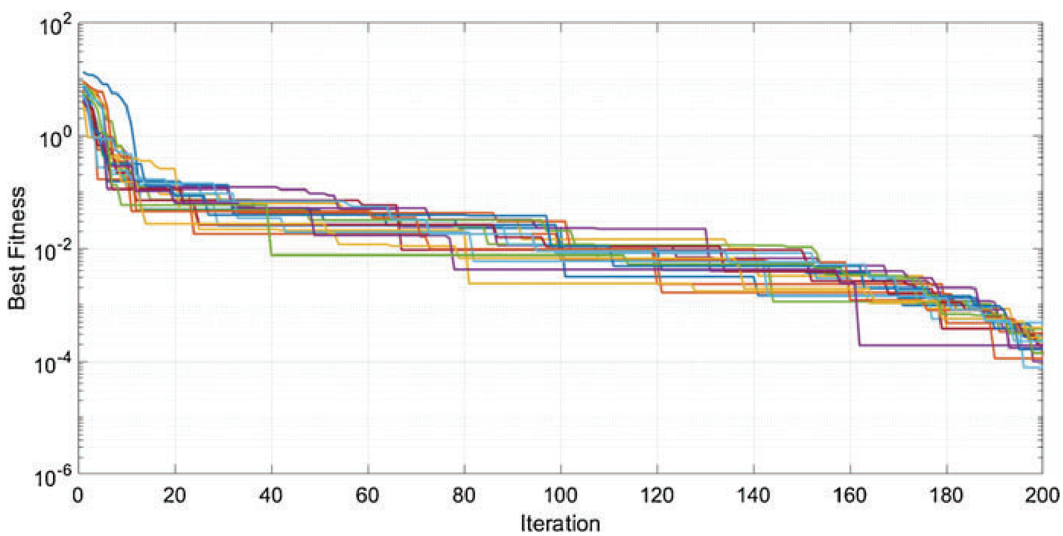

Fig. 12.10 Best fitness along with iterations for 20 runs

Conclusions

This chapter provides an overview of an IWO algorithm described from an evolutionary comparison or natural phenomena. The applications and growth of natural computing in the last decade has increased vastly. Numerous optimization problems in computer networking [13], bioinformatics [15], data mining, game theory, power systems [10], image processing, industry and engineering, robotics, applications involving the security of information systems etc [9, 12]. have been using such nature inspired optimization methods. The simulation results obtained by using IWO indicate the effectiveness and robustness of the algorithm in solving nonlinear non-convex problems.

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