DESIGN AND ANALYSIS OF OPTICAL PATTERNS USING BACTERIAL FORAGING OPTIMIZATION ALGORITHM FOR OPTIMIZED ILLUMINATION

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Abstract - Recently natured based algorithms have attracted many scientists for solving optimization problems. Bacterial foraging algorithm is a recently proposed natured inspired algorithm which is used to solve complex real world problems. It provides highly optimal solution and has high convergence rate. The main purpose of this paper is to generate optimized illumination patterns of lamps under given constraints using bacterial foraging optimization technique. The objective is to maximize cost function so that maximum area gets illuminated while satisfying certain constraints too. Cost function is designed based on various parameters including area to be illuminated, number of lamps, priority of lamps etc. In addition, effect of number of iterations on cost function has been done. Results obtained shows that 66% percent of area is covered with just 16 lamps and a total priority of 80 has been achieved.

Keywords: **BFO; illumination; optimization; optical patterns.**

1. Introduction

In recent years, nature has inspired many researchers and scientists for finding the solution of optimization problem. Optimization is process of minimization of cost or maximization of energy. To solve an optimization problem, an appropriate objective function is required to be formulated by choosing decision variables with proper constraints. Optimization Problems can be categorized as deterministic or stochastic. Foraging behaviour of animals is one of the strategies which is inspired from nature and used for developing optimization techniques. Foraging means search for food. In 1974, chemotactic behaviour of bacteria is firstly used as an optimization model [Bremermann (1974)]. In 2002, a new nature inspired computation technique after mimicking the food foraging, evolutionary reproduction and environmental elimination-dispersal behaviours of common Escherichia Coli bacteria a named it as Bacteria Foraging Optimization (BFO) algorithm [Passino (2002)]. BFOA simulates the foraging behaviour of E.Coli bacteria. The E.Coli bacterium consists of plasma membrane, cell wall and slime layer or capsule. The flagella in bacterium are used for locomotion. Each bacterium wants to gain maximum energy with lowest cost during foraging. Individual bacterium also communicates with others by sending signals. Foraging strategies in bacteria are divided in two categories i.e. individual foraging and social foraging [Shen and Zhu (2014)]. In individual foraging, forager has its own way for foraging. In social foraging, each forager depends on the other members of population and availability of resource for foraging. High convergence rate and highly optimized solution makes BFO algorithm applicable for many engineering and real world problems. BFO has been used as an image enhancement tool [Sharma *et al.* (2012)] and successfully applied to many other problems like adaptive control [Kim and Cho (2005a)], network scheduling [Liu *et al.* (2011)], machine learning [Kim and Cho (2005b)], transmission loss reduction [Mohammadi *et al.* (2017)] and for finding solution of Economic Load dispatch (ELD) problem by using BFO algorithm [Vijay (2012)]. ELD is an optimization problem to generate required amount of power with minimum cost, to meet the system load, subject to constraints of power system. Bacterial Foraging Optimization can also be used as filter to de-noise medical images like CT scan and MRI of pancreas. The performance metrics like MSE and PSNR are calculated which show that Bacterial Foraging Optimization can act as potential tool for de-noising images [Yaduwanshi and Sidhu (2013)].

Today India is facing huge energy crisis. Ever increasing requirement of power has put excessive burden on natural resources which demands efficient use of electric energy. Energy efficient technology not only maximizes energy saving but also reduces the cost of lighting used. Most important component of illumination system is the light source. Therefore, one way to optimize the electricity consumption is minimal and effective use of illumination system. In order to design an efficient lighting system various factors like type of lamp, height of fixture, intensity of lamp etc. are needed to be analysed. Also each lamp should be given a priority according to its importance in that area so that uniformity in illumination can be achieved vis-a-vis the requirements of the neighbourhood. Other techniques like Genetic algorithm [Sambyal *et al*. (2017)] which is an evolutionary algorithm, Ant colony algorithm etc. also exist which can be used for different areas for optimization[Sarwar and Mehra(2011), Sharma and Abrol(2016)].

In this paper, BFO has been applied to find best pattern of lamps for optimized illumination. An objective function with proper constraints has been formulated and BFO is applied which maximizes the objective function. Objective function depends on various factors like number of illuminated lamps, illuminated area per lamp, priority per lamp and wattage per lamp. BFO parameters like number of bacteria, dimension, number of chemotactic steps, number of reproductions etc. are properly initialized. Also, the effect of number iterations on BFO has been analysed.

Paper is organized in following sections: Section 2 explains the basic steps used in BFO technique. Section 3 describes the proposed methodology and steps for implementation of BFO. In section 4, results are evaluated and analysis of results on basis of number of iterations has been done. Finally, conclusion is drawn in Section 5.

2. Bacterial Foraging Optimization

BFO is a metaheuristic technique based on social and cooperative behaviour of E.coli bacteria. Various characteristics of bacteria like its movement, reproduction and foraging are used for development of algorithm. BFO consists of four basic mechanisms. These are chemotaxis, swarming, reproduction and elimination-dispersal [Dasgupta *et al.* (2009)].

(1) Chemotaxis: The process in which a bacterium moves by taking small steps in searching of nutrients is called chemotaxis. The movement of E.Coli bacteria can be performed through two different ways: tumble and run (swim) shown in Fig. 1. Movement of bacteria in the same direction as in previous step is called swim and the movement (unit walk) in a random direction is called tumble.

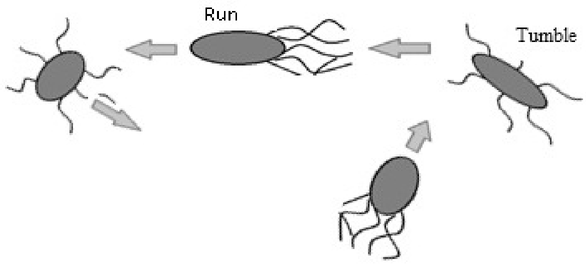

Fig. 1. Movement of E.Coli Bacteria

(2) Swarming: As each bacterium moves, it releases attractants to signal other bacteria to move towards it. Each bacterium also releases repellents to signal to other bacteria to keep a safe distance.

(3) Reproduction: After all chemotaxis steps, the reproduction step is performed. Only the best half of population survives to next reproduction step. The least health bacteria eventually die and the remaining bacteria (i.e. healthiest bacteria) will be divided into two identical ones and placed at the same location. Thus, population of bacteria keeps constant.

(4) Elimination and Dispersal: For the purpose to avoid local optima, elimination and dispersal process is performed after a certain number of reproduction steps. According to some predefined probability, a bacterium is chosen to be dispersed and moved to another position within the environment. It is done to improve global search ability of the algorithm. Elimination and dispersal has the effect of possibly destroying chemotactic progress, but they also have the effect of assisting in chemotaxis, since dispersal may place the bacteria near good food sources.

3. Proposed Methodology

In proposed research paper, optical patterns are generated for optimized illumination using BFO algorithm. For this, a objective function has been formulated with some constraints. BFO algorithm is implemented to generate optimized illumination as per given constraints. First step in BFO is to initialize position of each bacterium. Therefore, initially each bacterium is placed at some random locations which is a sequence of 0's and 1's. One bacterium means one pattern of lamps .0 represents lamp is OFF and 1 represents ON status of lamp. BFO has been applied which tries to maximize the objective function. Objective function is designed so that it tries to increase the area covered by lamps and minimizes the wattage consumption. Fig. 2 shows view of proposed methodology for optimized illumination.

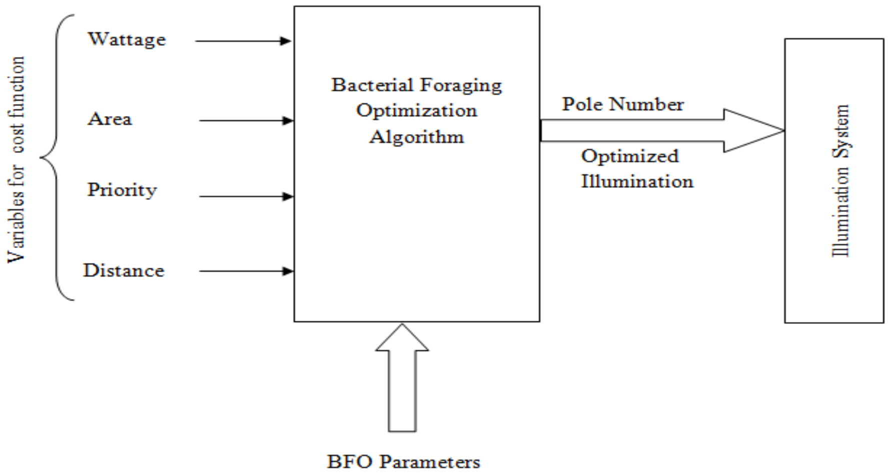

Fig. 2. Proposed methodology for generating optimized illumination patterns using BFO

3.1 Objective function:

Designing of objective function is a critical step in any optimization problem. Therefore, objective function (f_c) has been designed considering all important variables shown in Eq.(1)

$$f_c = MAX\left(\frac{\sum_{i=1}^{n} A_i \times \sum_{i=1}^{n} P_i \times D_{ij}}{\sum_{i=1}^{n} E_i \times n \times T_A}\right) \quad (1)$$

where, f_c represents objective function, n is the number of illuminated lamps, A_i is area covered by i^{th} illuminated lamps , D_{ij} is distance between alternate (i.e. i^{th} and j^{th}) illuminated lamps, E_i is energy/wattage of i^{th} illuminated lamp, P_i is priority of i^{th} illuminated lamp, T_A represents total area covered by all lamps,

with constraint :

T_{min}<T_A<T_{max} , T_{min}=0 and T_{max}=1100

Value of n ranges between 1-24 i.e. maximum numbers of illuminated bulbs should not exceed 24.

3.2 Proposed BFO algorithm:

Bacterial foraging optimization technique has been applied to maximize cost function given in Eq. (1). Steps performed for optimization of cost function using BFO technique are as follows:

(1) Initialize the value of $D, S, N_c, N_s, N_{re}, N_{ed}, P_{ed}$ and C. Description of each parameter is given in Table 1.

(2) Randomly initialize first position of each bacteria i.e P (*i, 1, 1, 1*) for *i=1:S*. Here, value of P(*i, j, k, l*) is either 0 or 1indicating ON-OFF status of lamp.

(3) Evaluate J (*i, j, k, l*) i.e. objective value of *ith* bacterium in the *jth* chemotactic step, *kth* reproduction step and l^{th} elimination –dispersal step.

(4) Elimination and dispersal loop *l=l+1*

(5) Reproduction loop *k=k+1*

(6) Chemotaxis loop *j=j+1*

 (i) For *i=1 to S*

 (ii) Save the last value of objective function

$J_{last} = J(i, j, k, l)$

(iii) Tumble: generate a random vector $\Delta(i) \in R_p$.

With each element $\Delta m(i)$ is a vector of random numbers in the range from -1to 1 and m ranges from 1 to D.

(iv) Calculate new position of bacteria by using equation given below:

$P(i, j+1, k, l)=P(i, j, k, l)+C*\Delta(i)/(\Delta^T(i)*\Delta(i))^{1/2}$

(v) If $P(i, j+1, k, l) < 0.5$ then $P(i, j+1, k, l) = 0$ else $P(i, j+1, k, l)=1$. It is done so that the bacteria position only at 0 or 1.

(vi) Calculate objective function J for new position i.e. $P(i, j+1, k, l)$

(vii) Swim:

Initialize m=0

While $m<N_s$

$m=m+1$

If $J(i, j+1, k, l) > J_{last}$ i.e. new objective is better than previous one

$J_{last}=J(i, j+1, k, l)$, stores new position

$P(i, j+1, k, l)=P(i, j, k, l)+C*\Delta(i)/(\Delta^T(i)*\Delta(i))^{1/2}$

i.e. compute the new $J(i, j+1, k, l)$

Else

$m=N_s$

End while loop

While loop continues till new value of objective function is getting increased.

(viii) if $i \neq S$, go to (i)

(7) If $j<N_c$, go to Step 6. In this case, continue chemotaxis since the life of the bacterium is not over.

(8) Reproduction:

(i) For $i=1$ to S, calculate health of each bacterium which is sum of objective functions for all chemotactic steps. Health of i[th] bacterium is given as:

$$J^{i}_{health} = \sum_{i=1}^{Nc+1} J(i, j, k, l)$$

(ii) Sort bacteria in order of descending cost J_{health}.

(iii) Half of the bacterial population with lowest J_{health} values will die and remaining bacteria with best values split.

(9) If $k < N_{re}$, go to (5)

(10) Elimination–Dispersal: This step takes after specified number of reproduction steps. At this point bacteria are eliminated and dispersed to random positions in the optimization domain according to probability P_{ed}. Elimination –dispersal step avoids the algorithm to stuck into local optimization

(11) If $l<Ned$, go to (4).

For optimization of objective function, different characteristics of lamp like intensity, priority, wattage and inter-distance of lamps are considered. Number of lamps (D) considered are 25 and total area covered by 25 lamps is 1100 m^2. According to the importance of lamp priority is assigned which ranges from 1 -10. Here, 1 represents bulb with lowest priority and 10 represents bulb with highest priority. Number of bacteria(S) considered are 10. The initial values of BFO parameters used for implementation are shown in Table 1. On the basis of intensities three categories of lamps are taken i.e. P1, P2 and P3 with intensities 30, 60 and 120 lux respectively.

Table 1. BFO parameter initialization

BFO parameters	Description	Value
D	Search space dimension	25
S	Population size	10
N_c	No. of chemotactic steps	3
N_s	No. of swim steps	2
N_{re}	No. of reproductions	2
N_{ed}	No. of elimination-Dispersal	2
P_{ed}	Probability of elimination-dispersal	0.25
C	Step size	0.05

4. Result and Analysis

As discussed above, BFO has been applied to maximize the cost function under designed constraints. Algorithm tries to cover maximum area for illumination with minimum number of lamps as well as energy consumed. The value of five variables i.e. the number of lamps illuminated, percentage of area covered, energy consumed, total priority and inter-distance of lamps has been optimized and the value of cost function for iteration number 5, 10, 50, 100 and 200 is taken. It has been observed that different sequence of optical patterns is generated at different iterations. Also, value of objective function increases as the number of iteration increases. After around 180 iterations the value of objective function (f_c) does not change. So, increase in iterations beyond this does not have any significant impact on objective function. Effect of number of iterations on cost function is plotted in Fig. 3.

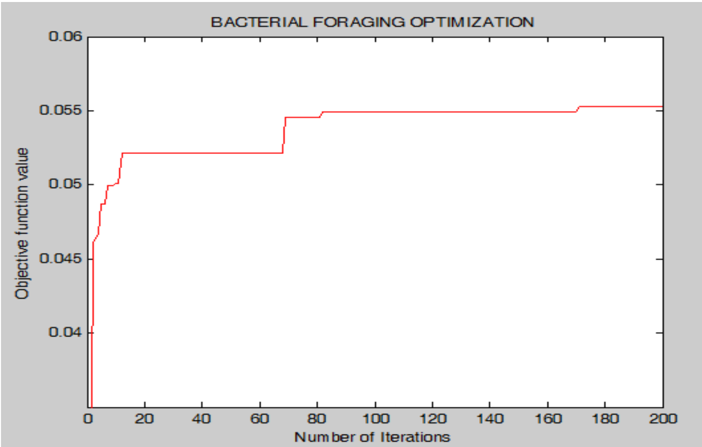

Fig. 3. Effect of number of iterations on objective function

It is evident from the results shown in Table 2. that BFO algorithm maximizes objective function. At 5th iteration, objective function value is 0.0487 which is increased to 0.0501 in 10th iteration. Finally, at 200th iteration maximum value achieved is 0.0553. Output is generated in the form of string of 0's and 1's of length 25. Each bit in the string shows the status of the lamp; 0 signifies OFF and 1 signifies ON. An optimized illumination pattern of 16 lamps is generated which covers 66% of total area with highest priority and low energy consumption.

Table 2. Optical patterns generated and other parameters optimized by BFO

Iteration No.	Optical Pattern showing Status of Lamps	No. of Illuminated lamps	Area covered (%)	Energy Consumed(W)	Total Priority	f_c
5	1101111011101011001110111	18	75	1610	78	0.0487
10	1111110011001101001011011	16	68	1490	73	0.0501
50	1111110011001101001111111	18	76	1660	85	0.0521
100	1010100011011101000111111	15	62	1370	75	0.0549
200	1010110011011101000111111	16	66	1420	80	0.0553

It is found that using the final output pattern generated by BFO technique, the energy saved is about 52%.The optimized area which can be covered with minimum energy and highest priority is shown in Fig 4. The best value obtained after applying Bacterial optimization is 66% area with energy consumption 1420W at cost function value 0.0553.

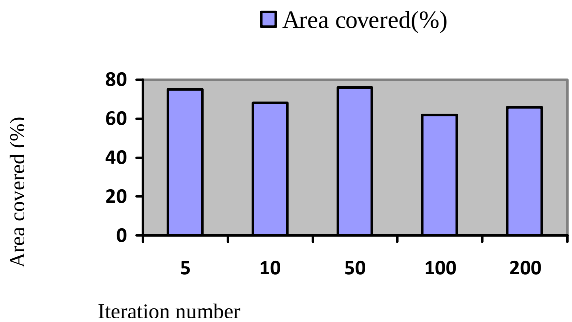

Fig. 4. Optimized areas covered in 200 iterations using BFO

5. Conclusion and Future Scope

The primary goal of the paper has been to apply bacterial foraging optimization technique to minimize the energy cost with maximize the illumination.. Experimental results show that a fairly optimized output which covers maximum area with minimum energy consumption and highest priority has been generated. Also the effect of number of iterations on cost function is analysed. This type of system can be used on both indoor and outdoor lighting of commercial, industrial, residential spaces and streets. Inefficient lighting puts additional financial burden and insufficient lightening creates unsafe conditions. An energy efficient system is need of the hour and organizational energy efficiency can significantly contribute to the energy conservation.

Further, this technique can be used with Wireless technology. Wireless Technology provides additional benefits and increased flexibility including reduced installation costs [Tiwari *et al.* (2015)]. Exterior light can be turned on or off with sunrise and sunset which can further reduce the energy consumption. This type of system can also used for security purpose by setting perimeter lights to flash if the alarm system is triggered.

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