Biogeography-Based Optimization by Using Crossover Operator for Chemical Engineering Problems

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Abstract

Biogeography-based optimization (BBO), meta-heuristic optimization, is a new effective population optimization algorithm based on the biogeography theory with inherently insufficient exploration capability. The initial solution will be randomly selected before applying the process of generating a new solution, which is migration and mutation. To address this limitation, we proposed a new technique to enhance biogeography-based optimization (BBO). A new technique is adding the genetic algorithm named cross-over operator to update a new position, which can adopt more information from cross-over functions to increase other habitats to enhance the exploration. In this research, extensive experimental tests are conducted on two benchmark functions and four the real working fields (four chemical engineering problems with different design conditions) to show the effectiveness of the proposed algorithm. The results of applied enhanced BBO have been compared with the results of applied original BBO algorithms. Finally, enhanced BBO gave more accuracy because enhanced BBO have fewer percentages of error than, enhanced BBO is more efficient than BBO but in some case, enhanced BBO need to adjust the value of some parameters to achieve the optimum results.

Keywords:

Biogeography based optimization; meta-heuristic optimization; genetic algorithm; cross-over operator; migration and mutation algorithm

1. Introduction

Optimization problems are the problem of finding the best solution from all feasible solutions. In most combinatorial optimization problems, there is more than one local solution. However, evaluating each solution in order to find a globally optimal solution is not feasible due to the exponential growth of most solution spaces. In the case of a large search space and high complexity of optimization problems, the use of conventional mathematics is not a good choice.Therefore, there is a need for a good technique that will not have a greedy approach to selectthe best optimal solution, which means balancing between local and global search is required. To avoid this limit of local search technique, in recent years, many nature-inspired algorithms have been developed. The original biogeography-based optimization (BBO), which is a population-based meta-heuristic algorithm, is inspired by the geographical distribution of species within islands. Migration and mutation are two important operators in the original BBO. Technically, the original BBO is started with a random population. Generation after generation, the original BBO employs migration and mutation operators controlled by emigration, immigration rates, and mutation rate, respectively. After that, the replacement operator has to take over to achieve the survival of the fittest principle. This process proceeds until a steady-state generation is reached. Then enhanced BBO is started with the same method but is added crossover operator to apply for problems. The main objective of this paper is to propose a new operator in BBO, which is a crossover operator, the new version of BBO is called enhanced BBO, and to compares the results of 5 chemical engineering problems and 1 benchmark, which is applied with the original BBO and enhanced BBO. The comparison is based on efficiency, reliability, and accuracy of the exact value.

2. Background of Biogeography-Based Optimization Algorithm

Biogeography-based optimization (BBO) is a new emerging population-based algorithm proposed through mimic species migration in natural biogeography. In BBO algorithm, each possible solution is a habitat, and their features that characterize suitability are called suitability index variables (SIVs). The goodness of each solution is named as habitat suitability index (HSI). In BBO, a habitat His a vector of N value (SIV_S) reaching global optima through migration step and mutation step.

The phenomena of biogeography, we use birds as a population that lives on an island. Then, the environment has changed, and it affected the suitability of living. Then, the birds will move from the old to a new island. The old island called “Emigrating habitat” and the new island called “immigrating habitat”. Comparing the old island and the new one, some groups of birds prefer to move to another island, which provides more suitable living conditions. In the new island, there are some changes in the species based on environment availability. This means the crossover has occurred between populations in old and new islands, and then the mutation has happened, and the new generation of species is evaluated. And because of the geographic barriers. Inspired by previous phenomena, Dan Simon invented a BBO algorithm in 2008. The main idea behind this algorithm is the distribution of living species through time and space, which could be briefly presented by the relation between the number of species and rate of migration.

2.1 Immigration and emigration operator

In original migration, information is shared among habitats based on the immigration rate λ_i and emigration rate μ_i whichare linear functions of the number of species in the habitat. The linear model can be calculated as follows:

$$\lambda_i = I(1 - \frac{i}{n}) \quad (1)$$

$$\mu_i = \frac{E_i}{n} \quad (2)$$

Where E is the maximum possible emigration rate, I is the maximum possible immigration rate, n is the maximum number of species, and i is the number of species of the i^{th} solution.

2.2 Mutation operator

Because of the ravenous predator or some other natural catastrophe, ecological equilibrium may be destroyed, which could lead to drastically changing the species count and HSI of habitats. This phenomenon can be modeled as SIV mutation, and species count probabilities are used to determine mutation rates. The mutation probability m_i is expressed as follows

$$m_i = m_{max}(\frac{1-p_i}{p_{max}}) \quad (3)$$

Where m_{max} is a user-defined parameter and $p_{max} = \text{argmax } p_i, i = 1,2, \ldots, n$

In the original mutation operator, the SIV in each solution is probabilistically replaced with a new feature, randomly generated in the whole solution space,which will tend to increase the diversity of the population. Gong et al. [9] modified this mutation operator and suggested three mutation operators, Gaussian mutation operator, Cauchy mutation operator, and Lévy mutation operator, used in real space.

3. Enhanced Biogeography-Based Optimization

3.1 Genetic operator: Crossover operator

Crossover is the most significant phase in a genetic algorithm. For each pair of parents to be mated, a crossover point is chosen at random from within the genes. Thenew generation offspring comes by carring genes from both parents. The amount of genes carried from each parent is random.

For example,consider the crossover point to be 3 as shown below. Offspring are created by exchanging the genes of parents among themselves until the crossover point is reached. The new offspring are added to the population.

Figure 1 Crossover mechanism

In this report, the reproduction mechanism that affects the survival of birds in new habitats from the above reasons, the crossover process was taken to enhance the efficiency of biogeography-based optimization. The operator will cross the breed of karma of the original bird with the migrating bird, resulting in the distribution vector of 0 to 1. It effects the greater natural selection that more realistic variety, so the answer is closer to the actual value.

$$X_{i,m} = \begin{cases} X_{r,m} & rand_{i,m} < Cr \\ X_{i,m} & else \end{cases} \quad (4)$$

$$Cr = 0.7$$

Where Cr is the crossover probability, 0.7-1.0 (Yang, 2008) is recommended. In this paper, minimum probability is selected.

4. Overview method of Enhance biogeography-based optimization

BBO is a Global optimization method that represents organism distribution in our biological system in terms of a mathematical model. BBO is an evolutionary algorithm whose working principle is based upon mathematical models of biogeography describe speciation (the evolution of new species), the migration of species (animals, fish, birds, or insects) between islands, the mutation of species and the crossover.

Migration mechanisms of species from one habitat to others depending upon the fitness of the habitat, which is favorable to them. Islands with a high HSI can support many species. Therefore habitat which has a high value of HSI have high emigrating rate; it is ready to send its SIV to other habitats, while the habitat having a low value of HSI have a low value of species count, and their immigrating rate is high; that is it as ready to accept species towards itself. HSI of a habitat can be effected on the basis of SIV (suitability index variables), which are independent variables.

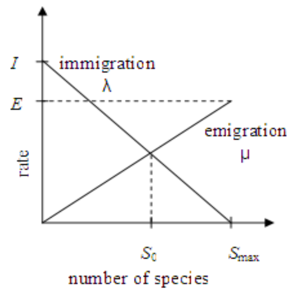

Figure 2 Model of immigration λ and emigration μ probabilities

Note: S0 is the equilibrium species count, and Smax is the maximum number of species that the island can support. I and E are the maximum immigration and emigration rates, respectively.

Figure 2 illustrates an island migration model.[3] The immigration rate λ and the emigration rate μ are functions of the number of species on the island. The maximum possible immigration rate I occur when there are zero species on the island. As the number of species increases, the island becomes more crowded; fewer species are able to survive immigration and the immigration rate decreases. The largest possible number of species that the habitat can support is Smax, at which point the immigration rate is zero. If there are no species on the island, then the emigration rate is zero. As the number of species on the island increases, it becomes more crowded, more species representatives can leave the island and the emigration rate increases. When the island contains the largest number of possible species, Smax, the emigration rate reaches its maximum possible value E.

5. BBO Flowchart

5.1 Enhanced BBO Algorithm

Firstly, the question arises why there is a need for modification of BBO. We are dealing with biological issues that are dynamic in nature, so we have to modify our solution, which can take care of all dynamic constraints of nature.

The Modified BBO algorithm can be summarized through the flowchart of Fig.3, which adding a Crossover operator to apply with chemical optimization problems and benchmark problems.

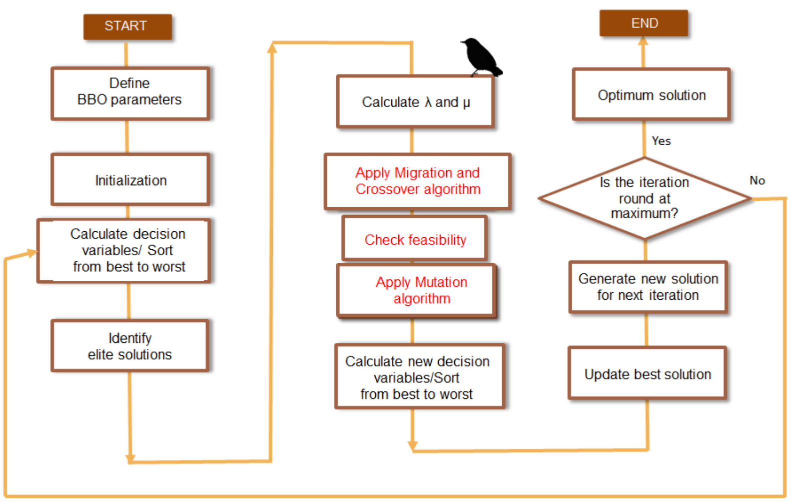

Figure 3 Enhance BBO flowchart

The processing details relating to the MATLAB code is presented on: https://www.youtube.com/watch?v=4Dk8qyiIMbs&t=7s

Table 1 The benchmark and chemical engineering functions

No.	Dimension	Name	Defined functions
B01	10	Keane's "bump" function	$F(x) = -\lvert\{\sum_{i=1}^{m} cos^4(x_i) - 2\prod_{i=1}^{m} cos^2(x_i)\}/(\sum_{i=1}^{m} ix_i^2)^{0.5}\rvert$
B02	2	Cross-in-Tray function	$-0.0001\left(\left\lvert sin(x_1)\,sin(x_2)\,exp\left(\left\lvert 100 - \frac{\sqrt{x_1^2 + x_2^2}}{\pi}\right\rvert\right)\right\rvert + 1\right)^{0.1}$
C01	6	Thermal Cracker	$F(x) = 2.84x_1 -0.22x_2-3.33x_3+1.09x_4+9.39x_5+9.51x_6$
C02	2	Liquid Extraction Column Flowrates	$F(x) = \frac{x_2\,F[1-\exp\{N(1-F)\}]}{1-F\,\exp[N(1-F)]}$ $F(x) = \frac{mx_1}{x_2}$, $N=4.81(\frac{x_1}{x_2})^{0.24}$
C03	7	Alkylation Process	$F(x)=0.063x_4x_7-5.04x_1-0.035x_2-10x_3-3.36x_5$
C04	6	three- stage process system with recycle	$F(x)= x_1^{0.6} + x_2^{0.6} + x_3^{0.4} - 4x_3 + 2x_4 + 5x_5 - x_6$

6. Result and discussion

The section is showing how the performance of biogeography based optimization Algorithm that is solving adjustment to the appropriate value in many various experiments on two benchmark problems and design problems of chemical engineering, which we have the purpose of modifying an optimal solution and comparing performance between Biogeography-based Optimization Algorithmwith Enhanced Biogeography based Optimization Algorithm, and both optimization methods is used the same a personal computer, all problems, and other factors.

All optimization problems, there are two benchmark problems and four chemical engineering problems which are evaluated the efficiency of the algorithm. In table 1, there is the method name and function detail that letter "B" stands for benchmark function, and "C" stands for chemical engineering problems. In table 2, there are constraints all problems. In table 3, this show on the result of comparing performance between Exact Optimum with BBO Optimum, Enhanced BBO Optimum

Code and running results can be obtained: https://drive.google.com/file/d/1CWDHQqx9IVImpmnWSA9OfqrSLQhbcYDy/view?usp= sharing

Table 2 The benchmark and chemical engineering constraints

No.	Dimension	Name	Constraints
B01	10	Keane's bump	$g_1(x): 0.75 - \prod_{i=1}^{m} x_1 - 7.5m < 0$ $0 < x_i < 10$
B02	2	Cross in-Tray function	-
C01	6	Thermal Cracker	$1.1x_1 + 0.9x_2 + 0.9x_3 + x_4 + 1.1x_5 + 0.9x_6 \leq 200000$ $0.5x_1 + 0.35x_2 + 0.25x_3 + 0.25x_4 + 0.5x_5 + 0.35x_6 \leq 100000$ $0.01x_1 + 0.15x_2 + 0.25x_3 + 0.18x_4 + 0.01x_5 + 0.15x_6 \leq 20000$ $0.4x_1 + 0.06x_2 + 0.04x_3 + 0.05x_4 - 0.6x_5 + 0.06x_6 = 0$ $0.1x_2 + 0.01x_3 + 0.01x_4 - 0.09x_6 = 0$ $6857.6x_1 + 364x_2 + 2032x_3 - 1145x_4 - 6857x_5 + 364x_6 + 21520x_7 = 20000000$ $(0, 0, 0, 0, 0, 0, 0) \leq x_i \leq (100000, 50000, 50000, 50000, 100000, 50000, 100000)$
C02	2	Liquid Extraction Column Flowrates	$x_1 + x_2 \leq 0.2$ $(0, 0) \leq x_i \leq (1, 1)$
C03	7	Alkylation Process	$x_1 = 1.22x_4 - x_5$ $x_9 + 0.222x_{10} = 35.82$ $3x_7 - x_{10} = 133$ $x_7 = 86.35 + 1.098x_8 - 0.038x_8^2 + 0.325(x_6 - 89)$ $x_4x_9 + 1000x_3 = 98000\, x_3/x_6$ $x_2 + x_5 = x_1x_8$ $1.12 + 0.13167x_8 - 0.00667x_8^2 \geq x_4/x_1$ $(1, 1, 0, 1, 85, 90, 3, 1, 2, 145) \leq x_i \leq (2000, 16000, 120, 5000, 2000, 93, 95, 12, 4, 162)$
C04	6	three-stage process system with recycling	$x_4 - 100 = 0.0012\,(x_1)(300 - x_4)$ $x_5 - x_4 = 0.0008\,(x_2)(400 - x_5)$ $500 - x_5 = 0.04\,(x_3)$ $(0, 0, 0, 0, 0, 0) \leq x_i \leq (3, 4, 4, 2, 2, 6)$

Table 3 Result of applying BBO on benchmarks and chemical problems

No.	Objective function	Exact Optimum	BBO Optimum	%Error of Exact and BBO Optimum	Enhanced BBO Optimum	%Error of Exact and Enhanced BBO Optimum	%Error of BBO and Enhanced BBO Optimum
B01	$-\left\lvert\left\{\sum_{i=1}^{m} cos^4(x_i) - 2\prod_{i=1}^{m} cos^2(x_i)\right\}\Big/\left(\sum_{i=1}^{m} ix_i^2\right)^{0.5}\right\rvert$	-0.7600	-0.4904	35.474	-0.64706	14.86	20.614
B02	$-0.0001\left(\left\lvert sin(x_1)\, sin(x_2)\, exp\left(\left\lvert 100-\frac{\sqrt{x_1^2+x_2^2}}{\pi}\right\rvert\right)\right\rvert+1\right)^{0.1}$	-2.0626	-2.2093	7.112	2.2043	6.870	0.242
C01	F(x) = $2.84x_1$ $-0.22x_2$- $3.33x_3$+$1.09x_4$+$9.39x_5$+$9.51x_6$	369,560	306842.782	16.95	342688.020	7.27	9.68
C02	F(x) = $\frac{x_2 F[1-\exp\{N(1-F)\}]}{1-F\exp[N(1-F)]}$ F(x) = $\frac{mx_1}{x_2}$, N=4.81$(\frac{x_1}{x_2})^{0.24}$	0.225	0.1541	31.35	0.20673	7.16	24.19
C03	F(x)=$0.063x_4x_7$-$5.04x_1$-$0.035x_2$-$10x_3$-$3.36x_5$	1768.75	1163.3214	34.23	1762.6739	0.34	33.89
C04	F(x)= $x_1^{0.6} + x_2^{0.6} + x_3^{0.4} - 4x_3 + 2x_4 + 5x_5 - x_6$	-13.401904	-13.401117	0.0059	-13.4014	0.0038	0.0021

From table 3, the result shows that enhanced BBO is more accuracy comparing with the exact solution. In some case enhanced BBO can apply with a wider range of boundary than original BBO for example, C01(Thermal Cracker), the original BBO use lower boundary equal to 15000 and upper boundary equal to 50000 and 10000 but enhanced BBO use lower boundary equal to 0 and the same upper boundary. Moreover, C04 (three-stage process system with recycling), the original BBO use keep rate equal to 0.2 but enhanced BBO use keep rate equal to 0.85 instead.

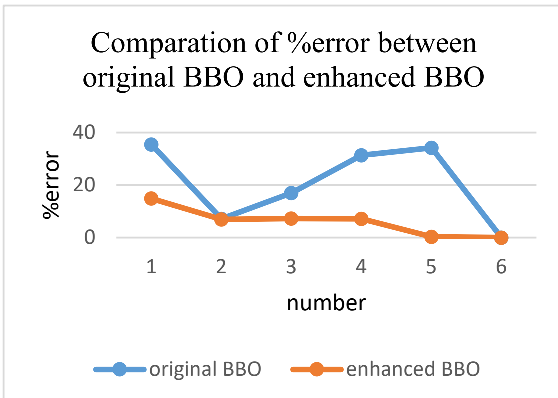

Figure 4 The comparison of the error of the best value between the original BBO and enhanced BBO

7. Conclusion

The optimization depends on the original biogeography; there is the program's error that occurred because, in the past that there was only migration and mutation, which was not true to nature as it should be. In fact, nature has been chosen through the reproduction process of living organisms. This problem has been brought to solving called enhanced biogeography-based optimization. It is the way of the reproduction process. It is called a crossover. Natural selection occurs a new generation in which there is genetic overlapping. Crossover can improve the efficiency of the algorithm for dealing with difficult solutions makes the answer more realistic when compared to the exact value. From the result obtained from 2 benchmark and 4 chemical engineering problems. The result of all problems shows that enhanced biogeography-based optimization for chemical engineering problems is more effective than original biogeography-based optimization because the result of the answer is closer to the exact value more that original method. Enhanced biogeography-based optimization has fewer percentages of error than biogeography-based optimization original method, so it can prove that the method has been improved is better than the original method.

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