Универзитет Привредна академија у Новом Саду
University Business Academy in Novi Sad

Факултет за примењени менаџмент, економију и финансије Београд
Faculty of Applied Management, Economics and Finance Belgrade

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МЕЂУНАРОДНА НАУЧНО-СТРУЧНА КОНФЕРЕНЦИЈА

INNOVATION AS AN INITIATOR OF THE DEVELOPMENT

ИНОВАЦИЈЕ КАО ПОКРЕТАЧ РАЗВОЈА

INTERNATIONAL CONFERENCE PROCEEDINGS

ЗБОРНИК РАДОВА СА МЕЂУНАРОДНОГ СКУПА

INNOVATIONS

December 2nd
Belgrade, 2021

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ПРЕДГОВОР

Иновације су и даље свуда око нас, па и ове године, као и шест претходних, Факултет за примењени менаџмент, економију и финансије је на основу пристиглих чланака, свеобухватног тематског аспекта припремио зборник радова. Примерено наслову „Иновације као покретач развоја“ иновације означавају и генеришу будућност, али почињу у садашњости која мора бити осветљена, анализирана и разматрана. Управо су то учинили многи угледни универзитетски професори, истакнути истраживачи, експерти и научнии радници, како из Србије, тако и из иностранства послатим радовима (преко 60), које смо уврстили у овај зборник.

Зборник радова, категорисан у домаћој науци као М33, је у форми дигиталне едиције и биће доступан широј научној и стручној јавности. Радови у овој публикацији значајно доприносе утврђивању нераскидиве везе између иновација и развоја. Истовремено смо тиме показали да подручје иновација дефинитивно више није везано само за техничко – технолошки прогрес. У складу са тим, радови могу бити корисни и широј научној и стручној јавности, као и свим заинтересованим за утицај иновација на развој.

Београд, Уредници

Децембар, 2021.

Др Дарјан Карабашевић

Др Светлана Вукотић

Др Габријела Поповић

FOREWORD

Innovations are still all around us, so this year, as well as the previous six, the Faculty of Applied Management, Economics and Finance have prepared a book of proceedings of comprehensive thematic aspect based on the received articles. Appropriate to the title " Innovation as the initiator of development", innovation means and generates the future, but it begins in the present that must be illuminated, analyzed, and considered. This is exactly what many eminent university professors, prominent researchers, experts, and scientists, both from Serbia and abroad, have done with the submitted papers (over 60), which we have included in this collection.

The book of proceedings, categorized in domestic science as M33, is in the form of a digital edition and will be available to the wider scientific and professional public. The papers in this publication significantly contribute to establishing the unbreakable link between innovation and development. At the same time, we have shown that the field of innovation is no longer related only to technical-technological progress. Accordingly, the works can be useful to the general scientific and professional public, as well as to all those interested in the impact of innovation on development..

Belgrade, Editors

December, 2021 Darjan Karabašević, PhD

Svetlana Vukotić, PhD

Gabrijela Popović, PhD

САДРЖАЈ / CONTENT

РАДОВИ СА КОНФЕРЕНЦИЈЕ

CONFERENCE PAPERS

A multi-strategy artificial bee colony algorithm for solving minimax problems

Вишестратегијски алгоритам инспирисан ројевима пчела за решавање минимакс проблема

Ivona Brajević[1]; Miodrag Brzaković[2]; Dušan Rajčević[3]

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Abstract: *The artificial bee colony (ABC) algorithm is a notable swarm intelligence algorithm which has many applications in solving hard optimization problems from different areas. In this paper a novel multi-strategy artificial bee colony algorithm (MSABC) is proposed for solving minimax optimization problems. In the proposed method three search equations with diverse search advantages are combined to obtain a good ratio between exploration and exploitation and to improve the search capability of the artificial bee colony algorithm. Experiments are conducted on ten well-known minimax problems and obtained results were compared to the results obtained by artificial bee colony algorithm. The experimental results reveal that the proposed method can considerably enhance the performance of the artificial bee colony metaheuristic.*
Keywords: *minimax problems, global optimization, artificial bee colony algorithm, multi-strategy, nature inspired metaheuristics*

Апстракт: *Алгоритам инспирисан ројевима пчела (ABC) је истакнут алгоритам интелигенције ројева који се може применити за решавање тешких оптимизационих проблема из различитих области. У овом раду предложен је нови вишестратегијски алгоритам инспирисан ројевима пчела (MSABC) за решавање минимакс проблема. У предложеној методи три једначине претраге које имају различите предности приликом претраживања се комбинују да би се постигао добар однос између експлорације и експлоатације. На овај начин се побољшава способност претраге алгоритма инспирисаног ројевима пчела. Предложени приступ тестиран је за решавање десет познатих минимакс проблема. Добијени резултати су упоређени са резултатима основног алгоритма инспирисаног ројевима пчела и показују да предложени алгоритам значајно побољшава перформансе основног алгоритма.*
Кључне речи: *минимакс проблеми, глобална оптимизација, алгоритам инспирисан ројевима пчела, више стратегија, природом инспирисане метахеуристике*

Introduction

Artificial bee colony (ABC) proposed by Karaboga is a prominent population-based metaheuristic method (Karaboga, 2005). The ABC and other metaheuristic algorithms such as particle swarm optimization (PSO) (Kennedy & Eberhart, 1995), harmony search (HS) (Geem et al., 2001), gravitational search algorithm (GSA) (Rashedi et al., 2009), firefly algorithm (FA), cuckoo search (CS) (Yang, 2008), etc, have been successfully used for solving many hard optimization problems. The aim of this paper is to improve the performance of the ABC algorithm for solving minimax optimization problems. There are numerous real-life applications where minimax optimization problems are found. Some of them are optimal control, warehouse location problem, engineering design, game theory, robot path planning problems, scheduling problem, signal, and data processing (Zhang et al., 2021; Thiruvady et al., 2021).

Minimax optimization handles a composition of an inner maximization problem and an outer minimization problem. The general form of the minimax problem can be defined as (Tawhid et al., 2019):

$$min\, F(x), \tag{1}$$

where

$$F(x) = max\, f_i\,(x),\ i = 1, 2, \dots, m, \tag{2}$$

$with\ f_i(x): S \subset R^n \rightarrow R, i = 1, 2, \dots, m.$

Additionally, a nonlinear programming problem, with inequality constrains, of the form

$$\begin{gathered} min\, F(x), \\ g_i(x) \geq 0, \quad i = 1, 2, \dots, m \end{gathered} \tag{3}$$

can be transformed to minimax problems as follows:

$$min\ max\, f_i\,(x),\ i = 1, 2, \dots, m \tag{4}$$

where

$$\begin{gathered} f_1(x) = F(x), \\ f_i(x) = F(x) - \alpha_i(x) \cdot g_i(x) \\ \alpha_i > 0 \end{gathered} \tag{5}$$

for $i = 1, 2, \dots, m.$ The optimum point of the minimax problem coincides with the optimum point of the nonlinear programming problem when α_i is large enough.

Minimax problems are challenging because these problems are often nonlinear with multiple local optimums. The common strategies for solving minimax problems, such as sequential quadratic programming and smoothing techniques perform local minimization and require derivatives information for the objective function. This information is not analytically available in most applications.

In the last decades, many metaheuristic algorithms were applied to solve minimax optimization problems. These techniques are problem-independent optimization methods which can obtain high-quality solutions in an acceptable amount of time. Their search equations use some randomness, which can enable the algorithm to escape from the local optimum to search more beneficial regions on a global level.

In this paper, a novel multi-strategy artificial bee colony algorithm (MSABC) is developed for solving minimax optimization problems. The proposed MSABC algorithm uses three distinct ABC search equations throughout the search process. The use of different search equations which have different abilities so that they support each other during the search, helps the proposed algorithm to efficiently investigate the vicinity of good solutions.

The rest of the paper is organized as follows. Section 2 introduces the ABC algorithm. Section 3 presents the proposed multi-strategy artificial bee colony algorithm. Experimental results of the ABC and MABC algorithms are given in Section 4.

The ABC algorithm

Foraging behavior of a bee swarm motivated the development of the artificial bee colony metaheuristic technique (Karaboga, 2005). Employed bees, onlooker bees and scout bees are included in a population of artificial bees. Employed bees make one-half of the population, while onlookers and scout bees make the other half. All bees that are currently exploiting a food source are employed bees. The onlooker bees aim to choose promising food sources from those discovered by the employed bees according to the probability proportional to the quality of the food source. After the selection of the food source, the onlookers search food around the selected food source. The scout bees are transformed from several employed bees that abandon their disadvantageous food sources to search new ones.

In the initialization step of the ABC algorithm a randomly distributed initial population is generated. After this phase, employed, onlooker and scout phases are repeated for a certain number of generations. The best-found solution is saved after each generation.

In the employed phase, the operator used to create a novel solution v_i from the old one x_i is given by:

$$v_{ij} = x_{ij} + \varphi_i \left(x_{ij} - x_{kj}\right), \qquad (6)$$

where x_{ij} denotes the jth parameter of x_i, j is a randomly picked index, φ_i is a uniform random number in range (-1,1), x_k represents the other solution selected randomly from the population.

Greedy selection between old and new solution determines whether the old solution will be replaced by the new one. In the onlooker phase, the solutions which will be subjected to the update process are selected according to the fitness proportionate selection. In this phase the update process is the same as in the employed bee phase. In the scout phase, a solution that can not be updated through a predetermined number of trials is replaced with a randomly generated solution in the search space.

There are many ABC variants for solving numerical and combinatorial optimization problems algorithms due to its good performance. For instance, the ABC version which employs a control parameter that determines how many parameters should be modified for the generation of a neighboring solution is developed in (Akay & Karaboga, 2009). The proposed method is applied to solve integer programming problems. A hybrid method, which combines firefly algorithm and ABC, is developed for solving numerical optimization problems (Brajević et al., 2020). The ABC algorithm that integrates the elitism strategy, recovery and local search methods is a recently proposed ABC version for solving the operating room scheduling problem (Lin & Li, 2021). Generally, application areas of the ABC algorithm are, neural networks, image processing, data mining, cryptanalysis, data clustering and engineering (Karaboga et al., 2014; Brajević, 2015).

Proposed algorithm: MSABC

The standard ABC algorithm in both bee phases uses the same solution search strategy, which performs good in exploration but poorly in exploitation. Motivated by the advantages of combining search equations which have different characteristics a novel multi-strategy artificial bee colony (MSABC) algorithm is developed. In the proposed approach three search strategies coexist throughout the search process and compete to generate more quality solutions.

The first search strategy employed in the MSABC is given by Eq. (1). According to this search strategy, the potential solution is generated by moving the parent solution to a randomly selected individual from the population. Consequently, this search equation is random enough for exploration and can obtain solutions with ample of diversity.

The second search equation used in the MSABC is given as follows:

$$v_{ij} = \{x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}) + \omega_{ij}(y_j - x_{kj}), if\ R_j \leq MR \quad x_{ij}, otherwise \tag{7}$$

where φ_{ij} is a uniform random number in range (-1, 1), w_{ij} is a uniform random numbers in range (0, 1.5), x_k k is a randomly selected food source that is different from x_i, y_j is the *j*th element of the global best solution, R_{ij} is a randomly chosen real number in range (0,1), *MR* is modification rate control parameter whose value is in the range (0, 1), $j \in \{1, 2, \ldots, D\}$ and *D* is the number of optimization parameters or dimensions of the problem. The novel control parameter *MR* controls possible modifications of optimization parameters and it can take value between 0 and 1. This search equation is inspired by particle swarm optimization (Zhu & Kwong, 2010) algorithm. As stated in Eq. (7), the information of the global best solution is used to guide the search of candidate solutions. Therefore, this search equation can improve the exploitation ability of the ABC algorithm.

The third search strategy employed in the MABC is described as follows:

$$v_{ij} = \{x_{im} + \varphi_i(x_{im} - x_{km}), if\ R_j \leq MR \quad x_{im}, otherwise \tag{8}$$

where *m* is a randomly chosen parameter index, φ_i is a uniform random number in range (-1, 1), x_k represents the other solution selected randomly from the population, R_{ij} is a randomly chosen real number in range (0,1), and $j = 1,2...D$. It is expected that the search equation given by Eq. (6) provides good exploration ability but slower convergence speed. On the other hand, the Eq. (7) and Eq. (8) could obtain better convergence speed and good exploitation.

Algorithm 1. Dynamic rule for solution search equation

if $f(v_i) < f(x_i)$ **then**
$x_i = v_i$;
{solution x_i is updated and its assigned solution search equation S_i is kept for further search}
else
Randomly select a strategy S_k from the set $\{S_1. S_2, S_3\}$ and $S_k \neq S_i$;
$S_i = S_k$;
$x_i = x_i$;
{solution x_i is kept and its assigned solution search equation is replaced for further search}

An encoding method is used with the intention to determine how to assign these search strategies to solutions from the population. Let us denote the search strategy given by the Eq. (6) as S_1, the search strategy given by the Eq. (7) as S_2 and the search strategy given by the Eq. (8) as S_3. At the start of the search, each solution x_i is randomly assigned a solution search strategy, S_i, from the set $\{S_1. S_2, S_3\}$. During the search process, the value of S_i is changed according to the objective function value of the novel solution v_i. If the solution v_i has lower objective function value than its parent x_i, it suggests that the current solution's search equation is appropriate for the search. In that case, the parent solution is replaced with the candidate solution and the current solution's search strategy is kept for the further search. Otherwise, the parent solution is kept for next generation. Also, this case indicates that the current strategy cannot improve the quality of solution and it is replaced. This encoding method is given as Algorithm 1. The parent solution x_i and its assigned solution search strategy S_i, the potential solution v_i and the objective function f are the input of Algorithm 1. The output of this algorithm is the solution x_i and its assigned solution search equation S_i which will be used in next iteration.

Algorithm 2. Pseudo-code of the MSABC

Initialize algorithm's parameters *SP, MNI* and MR
 Initialize population of search solutions x_i, i = 1, 2, …, *SP* randomly in the search space;
 Evaluate each x_i, i = 1, 2, …, *SP*;
 t = 1;
 while (t <= *MNI*) **do**
 for i = 1 do *SP* **do**
 Create new solution v_i according to the search strategy S_i ;
 Update x_i and S_i according to Algorithm 1;
 end for
 Update the best solution obtained so far;
 $t = t + 1$;
 end while

The pseudo-code of the MSABC is presented in Algorithm 2. The input of Algorithm 2 includes the population size value *SP*, the maximum number of iterations *MNI,* the modification rate *MR* and the objective function *f*. The output of Algorithm 3 is the solution with the smallest objective function value.

Experiments and results

A comparison between the developed MSABC and ABC adjusted to solve minimax optimization problems through ten test benchmarks is presented in this section. Both metaheuristic algorithms were implemented in Java programming language on a PC Intel(R) Core(TM) i5-4460 3.2GHz processor with 16GB of RAM and Windows OS. To test the performance of the MSABC and ABC on minimax programming problems, ten problems widely used in the literature are employed. The mathematical models of these problems can be found in (Lukšan, L., & Vlček, J. (2000); Tawhid et al. (2019)). Table 1 presents the following characteristics of the used minmax problems: the name of the minimax benchmark problems, the dimension of the problem, the number of $f_i(x)$ functions and desired error goal.

Table 1. Properties of the minimax benchmark problems FM_1–FM_{10}.

Function	Dimension (D)	$\#f_i(x)$	Desired Error Goal
FM_1	2	3	1.9522245
FM_2	2	3	2
FM_3	4	4	−40.1
FM_4	2	2	10^{-4}
FM_5	10	10	10^{-4}
FM_6	2	2	10^{-4}
FM_7	4	4	−40.1
FM_8	7	5	680.9
FM_9	4	21	0.1
FM_{10}	9	41	$0.61852848 \cdot 10^{-2}$

In the MSABC and ABC algorithms the size of population *SP* was set to 20 and the maximum number of function evaluations executed by these methods for all benchmarks was set to 20,000. The run is counted as successful when the desired error goal is achieved within the maximum number of function evaluations. In the ABC, values of MR and limit control parameters were set to 0.8 and 5 * D * SP. The same values of these parameters are employed in the respective original paper (ABC integer, 2009). The results of the MSABC and ABC algorithms were reached over 30 runs.

To estimate the performances of the ABC and MSABC algorithms the following metrics are employed. The mean number of function evaluations required to achieve the desired value can be considered a measure of the convergence speed. The convergence speed is faster if the mean value is smaller. Standard deviation (SD) values are measured to investigate the stability of each algorithm. The performance of a method is less stable if the standard deviation value is higher. The metric success rate (SR) is used to demonstrate robustness of metaheuristics. The success rate is defined as the ratio of successful runs in the total number of performed runs. The mean, standard deviation values and SR values of the artificial bee colony and proposed MSABC for the test functions FM1–FM10 over 30 runs are presented in Table 2. The best mean results are in bold.

Table 2. Comparison results of the ABC and MSABC for the FM1–FM10 minimax problems. The best results are indicated in bold.

	ABC			MSABC		
	Mean	SD	SR	Mean	SD	SR
FM_1	7522.0	5486.06	29/30	**1515.33**	**467.46**	**30/30**
FM_2	1997.2	741.59	**30/30**	**841.33**	**148.94**	**30/30**
FM_3	600.8	130.71	**30/30**	**495.33**	**96.56**	**30/30**
FM_4	1854.0	400.80	**30/30**	**1259.333**	**152.9**	**30/30**
FM_5	19,022.8	2028.13	24/30	**2441.33**	**288.718**	**30/30**
FM_6	2215.2	2197.82	**30/30**	**495.33**	**219.31**	**30/30**
FM_7	2986.8	2327.84	**30/30**	**921.33**	**405.85**	**30/30**
FM_8	18,442.8 3	3707.93	18/30	**7864.0**	**4473.15**	**28/30**
FM_9	3244.4	2562.20	**30/30**	**1320.66**	**777.09**	**30/30**
FM_{10}	20,000.0	0.0	0/30	**13644.6**	**5404.66**	**23/30**

From the reached results, it can be noticed that the proposed MSABC algorithm outperforms the standard ABC algorithm for all benchmark problems. The obtained mean and standard deviation values indicate that the MSABC method converges faster and that it is more stable in comparison with the ABC technique. Additionally, the SR results indicate that the MSABC performance is more robust in comparison with the ABC on four benchmark problems (FM_1, FM_2, FM_5, FM_8 and FM_{10}), while both methods reached the same SR results for the rest of the test problems.

Conclusion

In this paper, a multi-strategy artificial bee colony algorithm (MSABC) is proposed for solving minimax optimization problems. To obtain more refined search of the search space, the proposed approach uses three search strategies with different characteristics. The proposed MSABC algorithm was applied to solve ten minimax problems taken from the literature and it showed a good performance. Compared to the basic ABC, the MSABC method converges faster and it is more robust. In the future work, the performance of the MSABC technique applied to other practical optimization problems will be investigated.

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