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INNOVATION AS AN INITIATOR OF THE DEVELOPMENT

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INNOVATIONS

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„Иновативна делатност – савремени изазови и решења“

INNOVATION AS AN INITIATOR OF THE DEVELOPMENT

“Innovative Activities – Contemporary Challenges and Solutions”

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ПРЕДГОВОР

У савременом друштву, појам иновација и иновирања постао је веома значајан, у тој мери, да је у већини мисија и визија савремених компанија коришћење ове речи постало обавеза. Међутим, посматрано и шире, суштина свих развојних промена, углавном, огледа се у иновативности. Иновације су свуда око нас. То што су иновације толико присутне у целокупном подручју људске активности, намеће потребу да иновативност постане уводна тачка приликом анализе комплексности нове економије, друштва и културе у настајању, укључујући и индивидуу. Овај процес даље имплицира неминовно разматрање повратне спреге иновација и развоја. Управо отуда проистиче покретачки мотив да се Факултет за примењени менаџмент, економију и финансије из Београда заједно са суорганизаторима бави ове године на Четвртој међународној научно-стручној конференцији темом „Иновације као покретач развоја“.

Традиционално организовање овог међународног научног скупа има за циљ да покаже да иновација није само део пословне стратегије предузећа, већ да покреће економску добробит и утиче на прогрес целе једне земље.

Примерено теми и циљу научног скупа установљене су две сесије: I сесија: Иновације – темељ развоја (Тематски зборник) и II сесија: Иновативна делатност – напредак и будућност (Зборник радова са међународног скупа). Избор теме скупа и свеприсутност иновација, као и понуђени већи број тематских области утицао је да су у овој публикацији радови многих угледних универзитетских професора, истакнутих истраживача, експерата и научних радника, како из Србије, тако и из иностранства.

Зборник радова са међународног скупа, као резултат конференције, публикован је на CD-у и биће доступан широј научној јавности. Радови у овој публикацији значајно доприносе утврђивању нераскидиве везе између иновација и развоја. Истовремено смо показали да подручје иновација дефинитивно више није везано само за техничко – технолошки прогрес. У складу са тим, радови могу бити корисни како научној, тако и стручној јавности и свим заинтересованим за утицај иновација на развој.

Београд, Уредници

Децембар, 2019. Др Дарјан Карабашевић

Др Светлана Вукотић

FOREWORD

In contemporary society, the notions of "innovation" and "innovating" have become very significant, that being so to an extent that, in the majority of the missions and visions of contemporary companies, the use of this word has become mandatory. From a broader perspective, too, however, the essence of all developmental changes mainly reflects in innovativeness. Innovations are all around us. The fact that innovations are, to such an extent, present in the overall field of the human activity imposes the need for innovativeness to become the introductory point in carrying out the analysis of the complexity of the newly-emerging economy, society and culture, also including an individual. This process is further implicative of the unavoidable consideration of the innovation-development feedback. Thence exactly arises the driving motive for the Faculty of Applied Management, Economics and Finance in Belgrade to deal with the foregoing, together with the co-organizers, at the Fifth International Scientific-Professional Conference, entitled "Innovation as an initiator of the development".

This international scientific conference is traditionally organized with the aim of demonstrating that innovation is not only a part of an enterprise's business strategy, but also drives economic wellbeing and influences the progress of one whole country.

Suitably to the theme and the goal of the scientific conference, the two sessions are established: Session 1 – Innovations – development prospects (Thematic Proceedings), and Session 2 – Innovative activities – contemporary challenges and solutions (International Conference Proceedings). The choice of the conference theme and the omnipresence of innovations, as well as the offered larger number of the thematic fields, have influenced the inclusion of the papers by many distinguished university professors, eminent researchers, experts and scientific workers both from Serbia and from abroad in this publication.

As a result of the Conference, the *Conference Proceedings* are published on CD and the same will be available to a wider scientific audience. The papers in this publication significantly contribute to the establishment of an inextricable liaison between innovations and development. Simultaneously, we have demonstrated that the field of innovations is definitely no longer only related to technical-technological progress. In accordance with that, the papers may also be beneficial to both the scientific and the professional public and to all those interested in the impact of innovations on development.

Belgrade, Editors

December, 2019 Darjan Karabašević, PhD

Svetlana Vukotić, PhD

САДРЖАЈ / CONTENT:

ПЛЕНАРНА ПРЕДАВАЊА

PLENARY LECTURES

MODIFIED ACCELERATED PARTICLE SWARM OPTIMIZATION ALGORITHM FOR CONSTRAINED OPTIMIZATION

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Abstract: Particle swarm optimization algorithm represents one of the most widely used swarm intelligence algorithms in solving hard optimization problems. This paper presents a modified accelerated particle swarm optimization algorithm for constrained optimization problems. The main modification of the original algorithm is the incorporation of a mutation operator in order to provide useful diversity in the population. For constraint handling, the proposed approach uses certain feasibility-based rules in order to guide the search to the feasible region. The developed modified accelerated particle swarm optimization algorithm is tested on nine frequently used benchmark functions. Obtained results are compared to those of the state-of-the-art metaheuristic algorithms.

Keywords: constrained optimization, particle swarm optimization, metaheuristics, nature-inspired algorithms

1. INTRODUCTION

A general constrained minimization problem may be written as follows:

$$\min_{x \in S} f(x)\ , \tag{1}$$

$$g_j(\mathrm{x}) \le 0,\ j = 1, \dots, q,$$
$$h_j(\mathrm{x}) = 0,\ j = q+1, \dots, m, \tag{2}$$

where x represents a solution to the problem with *D* parameters, x_i is a parameter or variable, $f(x)$ is the objective function to be minimized, $g_j(x)$ are the inequality constraints, $h_j(x)$ are the equality constraints, *q* is the number of inequality constraints, and *m*-*q* is the number of equality constraints for a given problem. Each parameter x_i, i= 1,2, . . .,*D* is limited by its lower and upper bounds $l_i<x_i<u_i$, which define the search space. A solution is feasible if it satisfies all constraints, while an infeasible solution does not satisfy at least one constraint. Feasible solutions can be hard to find because constraints shrink the feasible search space.

Solving constrained optimization problems (COPs) is challenging task since the optimum solution must be feasible (De Mello & Carosio, 2012). Finding optimal solutions to COPs requires efficient optimization algorithms. Sincedeterministic methods use a variety of assumptions about the search space before they start the search process, their applicability is limited (Yeniay, 2005). During last decades, there has been an increasing interest to employ the methauristic algorithms for solving hard optimization problems. These methods have ability to search very large spaces of candidate solutions and require little information about the problem being optimized (Liu *et al*., 2010). Some notable metaheuristics applied to solve COPs are genetic algorithms (Holland 1992), particle swarm optimization (Kennedy & Eberhart, 1995), differential evolution (Storn & Price, 1997) and artificial bee colony (Karaboga, 2005).In general, more and more metaheuristic algorithms are being developed and applied to solve problems from different research fields (Fister *et al*., 2013). After their invention, these algorithms have been modified in order to make their performances more successful (Liu *et al*., 2010, Brajevic, 2015; Mohamed, 2018; Brajević & Ignjatović, 2019).

A simplified version of the PSO called accelerated particle swam optimization (APSO) algorithm for solving numerical optimization problems is proposed by Yang (Yang, 2008). The major modification is the removal of the particles velocities vectors from the original PSO. Also, the APSO uses only the global best positions to update the position of particles and randomness is employed to replace the contribution of particle personal best positions. Although the APSO has shown good performance in solving unconstrained numerical optimization, its disadvantage is weak diversity when solving highly nonlinear optimization problems (Guedria, 2016).

Motivated with these reasons, this paper presents a modified accelerated particle swarm optimization algorithm (MAPSO) to improve its capabilities to solve COPs. In the MAPSO algorithm, in order to increase diversity in the population, apart from the APSO search strategy, a mutation operator is employed. Also, the MAPSO incorporates three feasibility rules in order to guide the search in the feasible region of the search space and uses improved boundary constraint handling scheme.

The rest of the paper is organized as follows.The Section 2 presents an overview of the PSO and APSO algorithms.The proposed MAPSO algorithm is described in the Section 3.In the Section 4 benchmark problems, parameter settings and analysis of the obtained results are presented.Concluding remarks are provided in Section 5.

2. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population metaheuristic algorithm inspired by the swarming behavior of animals such as bird flocking (Kennedy & Eberhart, 1995). PSO algorithm has been studied by many researchers and new PSO variants have been described to solve different classes of optimization problems.

A basic variant of the PSO algorithm works by having a population of candidate solutions, called particles. Each particle is a moving object and it is attracted to previously visited locations with high fitness. The standard particle swarm optimization employs both the current global best and the individual best solution. The reason for using the individual best solution is mainly to increase the diversity in the quality solutions.

Let x_i and v_i be the position vector and velocity for particle i, respectively. The movement of each particle i, i = 1, 2, … SP, is guided by their own best-known position in the search-space p_i as well as the entire swarm's best-known position p_g. At each iteration step t, the particle velocity and position are updated using following equations:

$$v_i^{t+1} = v_i^t + \alpha \cdot r_1 \cdot (p_i^t - x_i^t) + \beta \cdot r_2 \cdot (p_g^t - x_i^t), \tag{3}$$

$$x_i^{t+1} = v_i^{t+1} + x_i^t, \tag{4}$$

where r_1 and r_2 are uniformly distributed random numbers between (0,1), parameters α and β are the learning parameters or acceleration constants, which can typically be taken as $\alpha = \beta = 2$. It is important to mention that parameters r_1 and r_2 are generated for each component of the velocity vector.

Accelerated particle swarm optimization (APSO) algorithm is a simplified version the PSO proposed by Yang (Yang, 2008). In the APSO the update of the location of a particle can be written by the equation:

$$x_i^{t+1} = (1-\beta)x_i^t + \beta \cdot p_g^t + \alpha \cdot \epsilon \;, \tag{5}$$

where ϵ is a random vector uniformly distributed in the range [0, 1], the parameter α = 0.1L~ 0.5L, where L is the scale of each variable, while the parameter $\beta$is from [0.1, 0.7]. It is worth noting that velocity does not appear in the equation (3), and there is no need to deal with initialization of velocity vectors. Hence, the APSO algorithm is much simpler. Compared to many PSO variants, APSO uses only two parameters, and the mechanism is simple to understand.

It was found that the performance of the APSO can be enhanced by reducing the randomization parameter as iterations proceed. The reducing of the parameter α can be described by following equation:

$$\alpha = \alpha_0 \cdot \gamma^t, \tag{6}$$

where α_0 is the initial value of the randomness parameter from [0.5, 1] and $0 < \gamma < 1$ is a control parameter.

3. THE PROPOSED APPROACH: MAPSO

In order to solve constrained optimization problems, the proposed modified APSO algorithm introduces three modifications in the APSO algorithm. The main modification is the incorporation of the mutation search strategy originally proposed for differential evolution (DE) algorithm. The remaining modifications are the usage of the three feasibility-based rules in order to guide the search to the feasible region of the search and the improved boundary constraint handling method.

With the aim to create a new promising solution, the mutation operator, called rand/1 is used in the MAPSO (Liu et al. 2010).The update of a particle can be described by the following equation:

$$g_{i,k} = \begin{cases} (1-\beta)x_{i,k}^t + \beta \cdot p_{g,k}^t + \alpha \cdot \epsilon_k & ,if \;\; rand_k < 0.5 \\ x_{r1,k}^t + F \cdot (x_{r2,k}^t - x_{r3,k}^t), otherwise \end{cases} \tag{7}$$

In the Eq. (7), F is the scaling factor. In DE, the scaling factor F is a positive control parameter from [0,2] which controls the amplification degree of the differential variable. Also, a new control parameter called modification rate MR is introduced. For each parameter $x_{i,k}$ a uniformly distributed random real number, (0 <R_k< 1), is produced. If the produced real number is less than the MR value, the parameter $x_{i,k}$is modified according to Eq. (7). Otherwise, the parameter $x_{i,k}$ remains unchanged.

The constraint handling mechanism incorporated along with a metaheuristic algorithm has influence on its performance (Mezura-Montes & Coello, 2011). The MAPSO uses a set of three feasibility criteria proposed by Deb in order to provide the selection process between the old solution x_i, and the new created solution g_i. These rules are as follows (Deb, 2000): (1) any feasible solution is preferred to any infeasible solution, (2) between two feasible solutions, the one having better objective function value is preferred, and (3) if both solutions are infeasible, the one with the lowest sum of constraint violations is preferred.

The MAPSO uses the boundary constraint handling method which ensures that if variables of a created solution go outside of boundaries, a diverse set of values is generated. This method is described by the following equation:

$$x_{i,k} = \begin{cases} 2l_k - x_{i,k} & , \text{if} \quad x_{i,k} < l_k \\ 2u_k - x_{i,k} & , \text{if} \quad x_{i,k} > u_k \\ x_{i,k} & , \text{otherwise} \end{cases} \tag{8}$$

The proposed MAPSO algorithm uses five specific control parameters to manage the search process: the initial randomness parameter α_0, the parameter the parameter β, the parameter γ, the parameter modification rate *MR* and the scaling factor *F*. The MAPSO also employs the size of population *SP* and maximum cycle number *MCN*, which are common control parameters for all population-based metaheuristics. The pseudo code of the propose MAPSO is given as Algorithm 1.

Algorithm 1. *Pseudo code of the MAPSO algorithm*

Initialize algorithm's parameters *SP, MCN,* α_0, β, γ, *MR, F*;
Generate initial population of particles x_i, $i = 1, 2, \ldots, SP$ randomly in the search space;
Evaluate each x_i, $i = 1, 2, \ldots, SP$;
$t = 0$;
while (t <Maximum Cycle Number (*MCN*))**do**
 for i= 1 do *SP* **do**
  for k = 1 do *D***do**
   if ($R_k < MR$) **then**
  if ($rand_k < 0.5$) **then**
$g_{i,k} = (1-\beta)x^t_{i,k} + \beta \cdot p^t_{g,k} + \alpha^t \cdot \epsilon_k$
 else
$g_{i,k} = x^t_{r1,k} + F \cdot (x^t_{r2,k} - x^t_{r3,k})$
    end if
   end if
end for
   Apply control of the boundary conditions on the created solution $g_{i,k}$ by Eq.8 and evaluate it;
Apply selection process based on Deb's method;
 end for
Update the α^t value by Eq. 6;
$t = t + 1$;
end while

4. EXPERIMENTAL STUDY

To test the performance of the proposed algorithm MAPSO, nine constrained benchmark problems are used. Mathematical formulations of these problems can be found in (Karaboga & Akay, 2011). This set of nine benchmark problems includes various forms of objective functions such as linear, nonlinear and quadratic. Type of objective function, the optimal or best-known solution, the number of linear equalities (LE), nonlinear equalities (NE), linear inequalities (LI), nonlinear inequalities (NI) and the number of optimization parameters (*D*) are given in Table 1. Also, in Table 1, ρ is an estimate of the ratio between the feasible region and the entire search space computed by ρ= F / S where F is the number of feasible solutions and S is the total number of solutions randomly generated.

Table1. *Summary of main properties of the benchmark functions*

Prob.	Optimal/Best known	Type of function	D	ρ (%)	LI	NI	LE	NE
g01	-15.000	Quadratic	13	0.0003	9	0	0	0
g02	-0.8036191	Nonlinear	20	99.9962	1	1	0	0
g03	-1.000	Nonlinear	10	0.0002	0	0	0	1
g04	-30,665.539	Quadratic	5	26.9089	0	6	0	0
g06	-6,961.814	Nonlinear	2	0.0065	0	2	0	0
g07	24.306	Quadratic	10	0.0001	3	5	0	0
g08	-0.095825	Nonlinear	2	0.8488	0	2	0	0
g11	0.7499	Quadratic	2	0.0099	0	0	0	1
g12	-1.000	Quadratic	3	4.7452	0	9	0	0

The proposed MAPSO was implemented in Java programming language on a PC with Intel(R) Core(TM) i5-4460 3.2GHz processor with 16GB of RAM and Windows OS. The performance of the MAPSO is compared with the performance of genetic algorithm (GA), particle swarm optimization (PSO) and differential evolution (DE) and artificial bee colony (ABC) algorithm. The results obtained by the GA, DE, ABC and PSO four algorithms were taken from (Karaboga & Akay, 2011).

4.1. Parameter Settings

In the GA the population size is 200, maximum number of iterations is 1200, crossover rate is 0.8, mutation rate is 0.6 and the number of objective function evaluations is 240000. All equality constraints have been converted into inequality constraints, with ε varying dynamically.

In the DE algorithm, population size is 40, maximum number of iterations 6000, the parameter F which affects the differential variation between two solutions and set to 0.5 and the crossover rate is 0.99.

In the ABC algorithm, the colony size is 40 and the maximum cycle number is 6000. Therefore, ABC performs 240000 objective function evaluations. The value of modification rate (MR) is 0.8, the value of limit and *SPP* is equal to *SN***D**0.5, where *D* is the dimension of the problem and *SN* is the number of solutions in the population.

In the PSO algorithm the population size is 50 and the maximum cycle number is 7000. Therefore, the PSO performs 350000 objective function evaluations. Inertia weight is uniform random real number in the range [0.5,1], while cognitive and social components are both set to 1.

In the MAPSO algorithm, the population size is 80, maximum number of iterations is 3000. Hence, ABC performs 240000 objective function evaluations.The value of *MR* parameter is 0.5, the value of parameter *F* is 0.8, the value of α_0 is 0.7, the value of β is 0.5 andthe value of γ is 0.9.

The GA, DE, ABC, PSO and MAPSO uses Deb's rules for constraint handling. In DE, ABC, PSO and MAPSO all equality constraints have been converted into inequality constraints, $|h_j| \leq \varepsilon$, with $\varepsilon = 0.001$.

4.2. Results and Discussion

In Table 2 the statistical results of the MAPSO when it was applied to 9 benchmark problems are presented. Comparative results of the best and mean solutions of the GA, DE, ABC, PSO and MAPSO are presented in Table 3 and Table 4.

From Table 2 it can be seen that our approach was able to find the global optimum or best known result in 8 out of 9 benchmarks (g01, g02, g03, g04, g06, g08, g11, g12). The only exception is problem g07, where the MAPSO reached solution which is close to the global optimum.

If we compare the performance of MAPSO algorithm with the performance of the GA it can be noticed that the MAPSO algorithmperforms better, since it reached better best results for 6 out of 9 benchmark problems and better mean results for 7 out of 9 results.

Table 2. *Statistical results obtained by MAPSO for 9 test functions over 30 independent runs*

Prob.	Best	Mean	Worst	Std.
g01	-15.000	-15.000	-15.000	1.93E-14
g02	-0.803619	-0.801953	-0.782549	4.59E-03
g03	1.005	1.005	1.005	2.45E-05
g04	-30665.539	-30665.539	-30665.539	7.21E-11
g06	-6961.814	-6961.814	-6961.814	1.46E-09
g07	24.320	24.357	24.419	2.36E-02
g08	0.095825	0.095825	0.095825	1.07E-17
g11	0.75	0.75	0.75	5.94E-16
g12	1.000	1.000	0.991	1.64E-03

Table 3. *The best solutions obtained by GA, PSO, DE, ABC and MAPSO for 9 test functions over 30 independent runs*

Prob.	GA	DE	ABC	PSO	MAPSO
g01	-14.440	-15.000	-15.000	-15.000	-15.000
g02	0.796231	0.472	0.803598	0.669158	-0.803619
g03	0.990	1.000	1.000	0.993930	1.005
g04	-30626.053	-30665.539	-30665.539	-30665.539	-30665.539
g06	-6952.472	-6954.434	-6161.814	-6161.814	-6161.814
g07	31.097	24.306	24.330	24.370153	24.320
g08	0.095825	0.095825	0.095825	0.095825	0.095825
g11	0.75	0.752	0.750	0.749	0.75
g12	1.000	1.00	1.000	1.000	1.000

Table 4. *The mean solutions obtained by GA, PSO, DE, ABC and MAPSO for 9 test functions over 30 independent runs. A result in boldface indicates a better result or that the global optimum (or best-known solution) was reached.“–”means that no feasible solutions were found.*

Prob.	GA	DE	ABC	PSO	MAPSO
g01	-14.236	-14.555	**-15.000**	-14.710	**-15.000**
g02	0.788588	0.665	0.792412	0.419960	**-0.801953**
g03	0.976	1.000	1.000	0.764813	**1.005**
g04	-30590.455	**-30665.539**	**-30665.539**	**-30665.539**	**-30665.539**
g06	-6872.204	–	-6961.813	**-6961.814**	**-6161.814**
g07	34.980	**24.310**	24.473	32.407	24.357
g08	0.095799	**0.095825**	**0.095825**	**0.095825**	**0.095825**
g11	**0.75**	0.901	**0.750**	**0.749**	**0.75**
g12	**1.000**	**1.000**	**1.000**	0.998875	**1.000**

When comparing our approach with respect to DE algorithm, we can see that MAPSOalgorithm found a better best solution for 4 benchmarks (g02, g03, g6 and g011), a worse best result for test function g07 and the same solutions for problems g01, g04, g08 and g12. From the mean results, MAPSO algorithm outperforms DE on 5 benchmarks (g01, g02, g03, g06 and g11) and performs the same on the remaining problems, except for g07 where MAPSO performs worse.

Compared with ABC, our approach found a better best and mean resultsand for 3 benchmarks (g02, g03 and g07) and similar best result for the remaining 6benchmarks. From the mean results, MAPSO shows a better performance on 4 problems (g02, g03, g06 and g7) and similar performance for the remaining 5 benchmarks.

When comparing the MAPSO with respect to PSO algorithm, we can see that MAPSO algorithm found a better best solution for 3 benchmarks (g02, g03 and g07), and similar results for the remaining 6benchmarks. From the mean results, MAPSO algorithm outperforms PSO on 5 benchmarks (g01, g02, g03, g07and g12) and performs the same on the remaining 4 problems.

CONCLUSION

In this paper, the modified accelerated particle swarm (MAPSO) optimization algorithm for constrained problems is presented. The proposed approach incorporates a mutation operator in order to provide useful diversity in the population and constraint handling technique based on three feasibility rules into the basic firefly algorithm in order to prefer feasible solutions to infeasible ones. The MAPSO has been tested on nine well-known benchmark functions. Comparisons show that MAPSO algorithm outperforms or performs similarly to four other state-of-the-art algorithms such as GA, DE, ABC and PSO.

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