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A NEW MODIFICATION OF GENETIC ALGORITHM FOR SOLVING ENGINEERING OPTIMIZATION PROBLEMS

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Abstract: *Today, for solving complex engineering problems it is necessary to use optimization methods. Popular methods for finding optimal characteristics are heuristic methods, and the most predominant in use is the genetic algorithm. This paper presents a new modification of the genetic algorithm (iGA) and its testing on complex engineering problems. Results are compared to relevant results from literature for genetic algorithm and other modern optimization methods. The developed modification represents a contribution for practical optimization of engineering problems.*

Key words*: genetic algorithm, iGA , optimization, engineering problems, heuristic*

1. INTRODUCTION

Engineering problems are clearly defined and must comply with certain constraints. For their adequate operation, adapted for real world application, the need for implementing optimization which grows with the increase of the problems complexity arises. Optimization is used with a clearly defined objective function, optimization variables, existing constraints, feasible solutions and optimization method. Heuristic methods are preferred when it comes to engineering problems due to their favorable characteristics, such as their capability to operate with a large number of variables, overcoming local extremes, speed and efficiency of work, field of use, low threshold of needed facts about the problem in order to find a solution, etc. Optimization is finding solutions from a group of alternative possible solutions. These solutions entail better characteristics of the construction, while at the same time decreasing invested work and expended costs.
There is a large number of heuristic methods such as the Genetic Algorithm (GA) [1], Particle Swarm Optimization (PSO) [2], Artificial Bee Colony (ABC) [3, 4], Ant Colony Optimization (ACO) [5], Teaching-Learning-Based Optimization (TLBO) [6], etc. What is common for these methods is that they work on the principle of mimicking natural occurrences and processes. The most commonly used method is GA, and it is used for solving complex problems with a large number of variables and constrains. The use of this method implies adequate control of algorithm parameters, such as population size, number of generations, selection, crossbreeding and mutation with referencing. Changing parameters of optimization in any method changes the efficiency of the methods operation for solving optimization problems.
The motivation behind this research is the development of a new modification of the genetic algorithm method, in order to achieve better performances for solving complex engineering problems. This approach improves the optimization process and removes shortcomings which the genetic algorithm has.

2. PROPOSED MODIFICATION OF GA

The principle of operation of the genetic algorithm is based on the mechanism of genetics and natural selection. The algorithm has three phases in its structure: selection, crossbreeding, and mutation. The current versions of GA are based on operation with real numbers (RCGA – real coded genetic algorithm), simulating genetic structure in the evolutionary process. This method was developed for a long time and has a large number of modifications and versions. For the purposes of this research the basic goal is to decrease the number of influencing algorithm parameters. Control of a large number of parameters presents a serious task for adequate use of this method, which limits use.
The development of a modification implies the change of structure and operation of some algorithm, which would achieve better optimization characteristics. This procedure is very complex and requires absolute knowledge of the algorithm in question, its advantages, shortcomings, only after which the new version can be created to improve processes by which the algorithm can be improved. This process requires a large number of tests, checks, attempts and settings, in order to achieve the desired effect. Aside from that, regardless of invested efforts there is no full guarantee that the algorithms convergence will be as the development intended. The modification developed based

on classic GA is based only on managing the population size and number of generations, which widens practical application possibilities of this method. The problem of managing the algorithm and the influence of the user on the results is decreased. The structure of the suggested iGA is presented in fig.1.

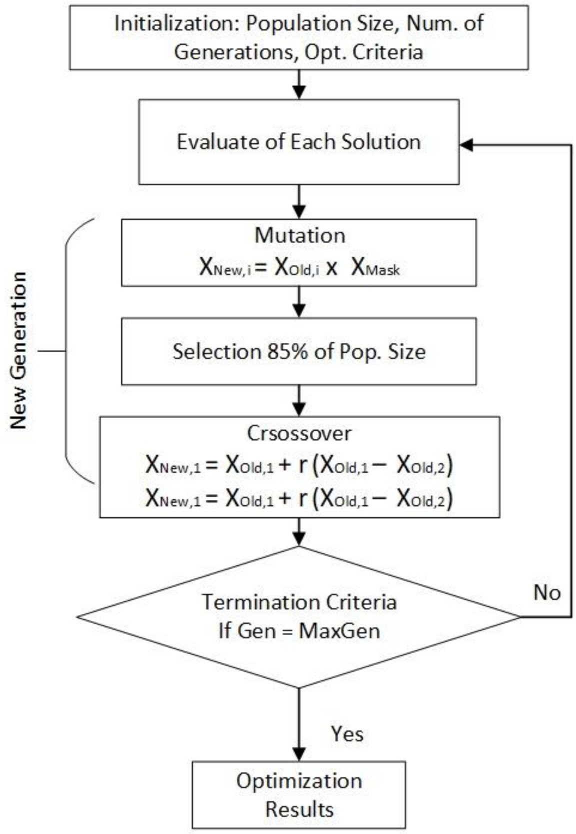

Fig.1: GA structure

This modification can perform like modern heuristic methods, and its operation is simplified for use with practical problems. This modification is efficient, easy for software implementation and most importantly useful for practical application in solving complex engineering problems.

3. EXPERIMENTAL SIMULATION

Every new method, modified method, or hybrid, must be tested on a group of test problems from literature and be compared to results achieved to date. An original software written in C++ for testing this method was developed. Testing was done according to suggestions from literature, with 25 consecutive repetitions of the experiment and for standard engineering problems for testing [7]. Testing was done for problems weld beam, tension compression spring, and gear train. These problems classify algorithms, dependent on whether they are adequate for solving practical engineering problems or not.

3.1. Welded beam

The welded beam problem is a standard test example for engineering optimization. A schematic view of this problem is shown in fig.2.

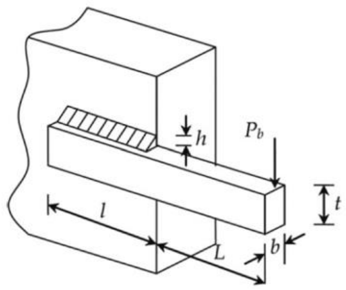

Fig.2: Schematic view of the welded beam problem

This problem is very complex and contains for variables and seven complex constraints. The goal is to minimize costs using the following objective function:

$$f(x) = 1.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14 + x_2) \quad (1)$$

The following constraints must be met:

$$\begin{aligned} & g_1(x) = \tau(x) - \tau_{\max} \le 0,\ g_2(x) = \sigma(x) - \sigma_{\max} \le 0, \\ & g_3(x) = x_1 - x_4 \le 0, \\ & g_4(x) = 0.10471 x_1^2 + 0.04811 x_3 x_4 (14 + x_2) - 5 \le 0, \\ & g_5(x) = 0.125 - x_1 \le 0,\ g_6(x) = \delta(x) - \delta_{\max} \le 0, \\ & g_7(x) = P - P_c(x) \le 0 \end{aligned} \quad (2)$$

Where:

$$\begin{aligned} & \tau(x) = \sqrt{(\tau')^2 + 2\tau'\tau'' \frac{x_2}{2R} + (\tau'')^2}, \quad \tau' = \frac{P}{\sqrt{2} x_1 x_2}, \\ & \tau'' = \frac{MR}{J}, \quad \sigma(x) = \frac{6PL}{x_4 x_3^2}, \quad \delta(x) = \frac{4PL^3}{E x_3^3 x_4}, \\ & P_c(x) = \frac{4.013E\sqrt{\frac{x_3^2 x_4^6}{36}}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right) \\ & x_1 = h, \quad x_2 = l, \quad x_3 = t, \quad x_4 = b, \\ & P = 6000 lb, \quad L = 14 in, \quad E = 30 \times 10^6 psi, \\ & G = 12 \times 10^6 psi,\ \tau_{max} = 13600 psi, \\ & \sigma_{max} = 30000 psi, \quad E = 30 \times 10^6 psi, \quad \delta_{max} = 0.25 in \\ & 0.1 \le x_1 \le 2,\ 0.1 \le x_2 \le 10,\ 0.1 \le x_3 \le 10,\ 0.1 \le x_4 \le 2 \end{aligned} \quad (3)$$

The best known value of this problem is f (X) = 1.724852.

3.2. Tension / compression spring

On fig.3 the tension/compression spring problem is shown schematically. This problem falls in the group of standard engineering problems for testing optimization methods. The expected optimal value (best known) is f(X)= 0.012665.

Fig.3: Schematic view of tension/compression spring problem

The problem is to optimize the objective function:

$$f(x) = (x_3 + 2) x_2 x_1^2 \quad (4)$$

The following constraints must be met:

$$g_1(x)=1-\frac{x_2^3x_3}{71785x_1^4}\leq 0,$$

$$g_2(x)=\frac{4x_2^2-x_1x_2}{12566\left(x_2x_1^3-x_1^4\right)}+\frac{1}{5108x_1^2}-1\leq 0, \tag{5}$$

$$g_3(x)=1-\frac{140.45x_1}{x_2^2x_3}\leq 0,\quad g_4(x)=\frac{x_1+x_2}{1.5}\leq 0,$$

$$x_1=d,\quad x_2=D,\quad x_3=P\ ,$$

$$0.05\leq x_1\leq 2,\ 0.25\leq x_2\leq 1.3,\ \ 2\leq x_3\leq 15,$$

$$x_1=d,\quad x_2=D,\quad x_3-spring\,lenght,$$

3.3. Gear train

This problem is formulated to contain one discrete, and six continual variables. The best known solution for this problem is *f* (X) = 2996.348465. The problem also contains 4 linear and 7 non leaner constraints in forms of inequality.

The goal function for this problem is:

$$f(x)=0.7854x_1x_2^2\left(3.3333x_3^2+14.9334x_3-43.0934\right) \\ -1.508x_1\left(x_6^2+x_7^2\right)+7.4777\left(x_6^3+x_7^3\right)+0.7854\left(x_4x_6^2+x_5x_7^2\right) \tag{6}$$

Following the constraints given as:

$$g_1(x)=\frac{27}{x_1x_2^2x_3}-1\leq 0,\ \ g_2(x)=\frac{397.5}{x_1x_2^2x_3^2}-1\leq 0,$$

$$g_3(x)=\frac{1.93x_4^3}{x_2x_3x_6^4}-1\leq 0,\ \ g_4(x)=\frac{1.93x_5^3}{x_2x_3x_7^4}-1\leq 0,$$

$$g_5(x)=\frac{\sqrt{\left(\frac{745x_4}{x_2x_3}\right)^2+16.9e6}}{110x_6^3}-1\leq 0,$$

$$g_6(x)=\frac{\sqrt{\left(\frac{745x_5}{x_2x_3}\right)^2+157.5e6}}{85x_7^3}-1\leq 0, \tag{7}$$

$$g_7(x)=\frac{x_2x_3}{40}-1\leq 0,\quad g_8(x)=\frac{5x_2}{x_1}-1\leq 0,$$

$$g_9(x)=\frac{x_1}{12x_2}-1\leq 0,\quad g_{10}(x)=\frac{1.5x_2+1.9}{x_4}-1\leq 0,$$

$$g_{11}(x)=\frac{1.1x_7+1.9}{x_5}-1\leq 0,$$

$$2.6\leq x_1\leq 3.6,\ 0.7\leq x_2\leq 0.8,\ 17\leq x_3\leq 28,\ 7.3\leq x_4\leq 8.3,$$

$$7.8\leq x_5\leq 8.3,\quad 2.9\leq x_6\leq 3.9,\quad 5\leq x_7\leq 5.5.$$

4. RESULTS

By comparing the developed modification its efficiency can be noted. For all 25 repeated simulations the best value, worst value, mean value and number of calculations is given for the goal function (FEs) in the optimization process. These values are considered as an evaluation of the method with standard algorithm testing.

In table 1 the results of the analyzed methods of optimization of the welded beam are given. The methods analyzed are: GA (Matlab GA-toolbox), PSO-DE, TLBO, ABC, WCA and the developed modification iGA. The FEs value is different for each method. It is obvious that the iGA is a contender to modern heuristic methods of optimization and that it gives much better results compared to traditional GA. The used values for FEs is 20000, as iGA achieves optimum at that value, and the increase of this value leads the mean value closer to the optimum.

Table 1: Results of analyzed methods for the welded beam problem

Method	Best	Worst	Mean	FEs
GA[8]	2,026769	3,162137	2,76033	25000
PSO-DE [9]	1,724852	1,724852	1,72485	66600
TLBO [6]	1,724852	N/A	1,72844	20000
ABC [10]	1,724852	N/A	1,74191	30000
WCA 1 [7]	1,724856	1,744697	1,72642	46450
WCA 2 [7]	1,724857	1,801127	1,73594	30000
iGA	1,724852	2,134913	1,75364	20000

For the problem of tension/compression spring, the analyzed methods are GA (Matlab GA-toolbox), PSO, PSO-DE, TLBO, ABC, WCA, and the developed iGA (table 2). The used values for FEs is 20000 for this problem as well. Results for this value converge to optimal, and the increase of this value may lead to increased precision.

Table 2: Results of analyzed methods for the tension / compression spring problem

Method	Best	Worst	Mean	FEs
GA [8]	0,012671	0,012693	0,012683	25000
PSO [9]	0,012857	0,071802	0,019555	2000
PSO-DE [9]	0,012665	0,012665	0,012665	42100
TLBO [6]	0,012665	N/A	0,012666	20000
ABC [10]	0,012665	N/A	0,012709	30000
WCA 1 [7]	0,012665	0,012952	0,012746	11750
WCA 2 [7]	0,012665	0,015021	0,013013	2000
iGA	0,012784	0,016049	0,014155	20000

Table 3 gives the results of optimization for the geared speed reducer problem for different optimization methods. Used methods are GA (Matlab GA-toolbox), PSO-DE, ABC, TLBO, and the developed iGA. The method performs perfectly with this problem, which is confirmed by achieving the optimal value in every repetition with only 6500 FEs.

Table 3: Results of analyzed methods for the geared speed reducer problem

Method	Best	Worst	Mean	FEs
GA [8]	2996,41544	2997,57529	2996,627632	25000
PSO-DE [9]	2996,34817	2996,348174	2996,348174	54350
ABC [10]	2997,058	N/A	2997,058	30000
TLBO [6]	2996,34817	N/A	3996,34817	20000
iGA	2996,348165	2996,348165	2996,348165	6500

The developed modification of the genetic algorithm has potential for use with practical engineering optimization problems. The method is available for implementation and is easy to use. It operates rapidly and efficiently, and achieves the optimum in a finite number of iterations, which are the basic requirements for practical application of a method.

5. CONCLUSION

This research is oriented on the development of a new modification of the genetic algorithm called iGA. This problem is very complex. The basic goal is to decrease the influence of parameters, changes in structure and method of using the algorithm. The algorithm is developed for use on engineering problems with constraints, and its testing is done on this group of problems. Tests show that the developed modification works significantly better than certain traditional methods, and that it can answer to application needs with the same quality as current heuristic methods. Testing was conducted on three engineering examples. These examples present standard test examples, which are in literature used to verify the operation of optimization methods. Changes made to the algorithm structure, decrease parameters, and its ease of use have proven to be better compared to the initial algorithm, which verifies the modification as successful. The perspective for use of this modification in engineering practice is creating constructions of optimal characteristics, which will be the subject of future research.

REFERENCES

[1] HOLLAND, J. (1975) *Adaptation in Natural and Artificial Systems*, University of Michigan Press, Ann Arbor

[2] KENNEDY, J., EBERHART, R. (1995) *Particle swarm optimization*, Proceedings of IEEE International Conference on Neural Networks, vol.1944, pp 1942-1948

[3] KARABOGA, D. (2005) *An Idea Based on Honey Bee Swarm for Numerical Optimization*, Erciyes University, Engineering Faculty Computer Engineering Department Kayseri, Türkiye

[4] KARABOGA, D., BASTURK, B., (2008) *On the performance of artificial bee colony (ABC) algorithm*, Applied Soft Computing, Vol. 8, pp 687-697

[5] DORIGO, M. (1992) *Optimization, Learning and Natural Algorithms*, Polit.di Milano.

[6] RAO, R.V., SAVSANI, V.J., VAKHARIA, D.P. (2011) *Teaching–learning-based optimization: A novel method for constrained mechanical design optimization problems*, Computer-Aided Design, Vol. 43, pp 303-315

[7] ESKANDAR, H., SADOLLAH, A., BAHREININEJAD, A., HAMDI, M. (2012) *Water cycle algorithm – A novel metaheuristic optimization method for solving constrained engineering optimization problems*, Computers & Structures, Vol. 110-111, pp 151-166

[8] SAVSANI, P., SAVSANI, V. (2016) *Passing vehicle search (PVS): A novel metaheuristic algorithm*, Applied Mathematical Modelling, Vol. 40, pp 3951-3978

[9] LIU, H., CAI, Z., WANG, Y. (2010) *Hybridizing particle swarm optimization with differential evolution for constrained numerical and engineering optimization*, Applied Soft Computing, Vol. 10, pp 629-640

[10] AKAY, B., KARABOGA, D. (2010) *Artificial bee colony algorithm for large-scale problems and engineering design optimization*, Journal of Intelligent Manufacturing, Vol. 23, pp 1001-1014

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