A Modified Cuckoo Optimization Algorithm for Engineering Optimization

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Abstract—**Recently a new evolutionary algorithm Cuckoo Optimization Algorithm (COA), which is inspired by the life of Cuckoo has been proposed. Like other nature-inspired algorithms, COA is also a population-based method and uses a population of solutions to proceed to the global solution. In this study, Modified Cuckoo Optimization Algorithm (MCOA) has been presented. This algorithm has been applied to two constrained continuous engineering optimization problems. The results indicate that the MCOA is a powerful optimization technique that may yield better solutions to engineering problems.**

Index Terms—**Cuckoo optimization algorithm (COA), evolutionary algorithms, constraint optimization.**

I. Introduction

Many engineering design problems can be formulated as constrained optimization problems, which involve a number of constraints that the solutions had to satisfy. Generally, a constrained optimization problem can be described as follows:

$$\text{Find x to minimize } f(x)$$
$$\text{Subject to } g_i(x) \le 0, i = 1,2, \ldots, n$$
$$h_j(x) \le 0, j = 1,2, \ldots, p$$

Where $x = [x_1, x_2, \ldots, x_k]^T$ denotes the decision solution vector, n is the number of inequality constraints and p is the number of equality constraints. In a common practice, equality constraint $h_j(x) = 0$ can be replaced by a couple of inequality constraints $h_j(x) \le \delta$ and $h_j(x) \ge -\delta$. Thus, all constraints can be transformed to N=n+2p inequality constraints [1].

Over the last decades, a large number of evolutionary algorithms (EAs) have been developed to solve various optimization problems. EAs possess a number of exclusive advantages: generality, reliable and robust performance, little information requirement for the problem to be solved, easy implementation, etc [2].

Last year, a novel evolutionary computation technique, Cuckoo Optimization Algorithm has been proposed [3]. This optimization algorithm is inspired by the life of a bird family, called Cuckoo. Special characteristics of cuckoos in egg laying and breeding had been the basic motivation for development of this new optimization algorithm. Each individual in the algorithm has a habitat around which she starts to lay eggs. In case the eggs survive, they grow and become mature cuckoos. Then, for reproduction purposes cuckoos immigrate toward best habitat, found up to now. The diversion occurred when moving toward goal habitat makes the population search more area than the case population moves straightforward on a line. After some immigration, all cuckoo population gather the same habitat, which is the area's best position [3].

In this study modified COA (MCOA) has been proposed and has been applied to two engineering optimization problem. It has been observed that, the MCOA produces successful results.

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II. Cuckoo Optimization Algorithm

Cuckoo Optimization Algorithm, which is inspired by lifestyle of a bird family called cuckoo has been introduced by Rajabioun [3]. Specific egg laying and breeding of cuckoos is the basis of this algorithm. Cuckoos used in this modeling exist in two forms: mature cuckoos and eggs. Mature cuckoos lay eggs in some other birds' nest and if these eggs are not recognized and not killed by host birds, they grow and become a mature cuckoo. Environmental features and the immigration of societies (groups) of cuckoos hopefully lead them to converge and find the best environment for breeding and reproduction. This best environment is the global maximum of objective functions [3].

To solve optimization problem using COA first habitat matrix must be generated. For this population size must be determined. Let N is population size and the search space is D-dimensional. Then, the position of ith cuckoo is represented as $X_i = \left(x_{i1}, \quad x_{i2}, \quad \ldots \quad , x_{id}\right)$, i=1,2,…N. Then, some randomly produced number of eggs is supposed for each of these initial cuckoo populations. In nature, each cuckoo lays from five to twenty eggs. These values are used as the upper and lower limits of egg dedication to each cuckoo at different iterations. Another habit of real cuckoos is that they lay eggs within a maximum distance from their habitat, which is called as "Egg Laying Radius (ELR)" [3]. The ELR is defined as:

$$\mathrm{ELR} = \propto * \frac{\text{Number of current cuckoo's eggs}}{\text{Total number of eggs}} * (\mathrm{var}_h - \mathrm{var}_{l})$$

where, var_h is the upper limit and var_l is the lower limit of problem interval, α is an integer, supposed to handle the maximum value of ELR.

After some iterations, all the cuckoo population moves to one best habitat with maximum similarity of eggs to the host birds and also with the maximum food resources. This habitat will produce the maximum profit ever. The pseudocode of COA is follow [3]:

1) Initialize cuckoo habitats with some random points on the profit function
2) Dedicate some eggs to each cuckoo
3) Define ELR for each cuckoo
4) Let cuckoos to lay eggs inside their corresponding ELR
5) Kill the eggs which recognized by host birds
6) Let eggs hatch and chicks grow
7) Evaluate the habitat of each newly grown cuckoo
8) Limit cuckoos' maximum number in environment and kill those who live in worst habitats
9) Cluster cuckoos and find best group and select goal habitat
10) Let new cuckoo population immigrate toward goal habitat
11) If stop condition is satisfied stop, if not go to 2.

III. Modified Cuckoo Optimization Algorithm

Let α is selected as 1, the search space is the interval (-55, 55) and there are twenty cuckoos in population. Since in nature each cuckoo lays from 5 to 20 eggs, in this study has been supposed that the five cuckoos with less profit lay 5 eggs and other fifteen lays the eggs in the interval [6, 20] proportional to her profit. Hence, the total number eggs will be 220. For the cuckoo whose profit is in the fifth order the ELR is calculated as:

$$\text{ELR} = 1 \times \frac{16}{220} \times 110 = 8$$

It means that cuckoo with the profit of 16 degree lays eggs in the circle with radius 8. Suppose the distance from cuckoo position to best habitat is equal to two, then it is not reasonable to lay eggs with the distance eight since cuckoo may move away from best habitat. Hence, in this study the modified ELR equation has been used. For this aim the new variable has been defined:

$$t = \frac{\text{max \_iter}}{c}$$

c is the constant, which is selected between (0,20] and max_iter is the maximum number of iterations. Let

$$e = \text{var}_\text{h} - \text{var}_\text{l}$$

$$a = [\![\text{iteration/t}]\!] + 1$$

where$[\![\quad]\!]$ means the integer part of the number inside it. The e is modified in every t iteration using following equation:

$$e_{new} = \frac{e_{old}}{a}$$

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IV. Engineering Optimization Examples

A. Pressure Vessel Design

The objective is to minimize the total cost $\left(f(\vec{x})\right)$, including the cost of material, forming and welding. There are four design variables: T_s (thickness of the shell), T_h (thickness of the head), R inner radius and L (length of the cylindrical section of the vessel, not including the heat). T_s and T_h are integer multiplies of 0.0625 in, which are available thickness of rolled steel plates, and R and L are continuous. The problem can be stated as:

$$\text{Min} \quad f(\vec{x}) = 0.6224x_1x_3x_4 + 1.7781x_2x_3^2 + 3.1661x_1^2x_4 + 19.84x_1^2x_3$$

Subject to

$$g_1(\vec{x}) = -x_1 + 0.0193x_3 \le 0$$

$$g_2(\vec{x}) = -x_2 + 0.00954x_3 \le 0$$

$$g_3(\vec{x}) = -\pi x_3^2 x_4 - \frac{4}{3}\pi x_3^3 + 1296000 \le 0$$

$$g_4(\vec{x}) = x_4 - 240 \le 0$$

$$g_5(\vec{x}) = 1.1 - x_1 \le 0$$

$$g_5(\vec{x}) = 0.6 - x_2 \le 0$$

The Modified COA algorithm has been run for 2000 iteration. 7037.9770 has been found as min $f(\vec{x})$, where $x_1 = 1.1$, $x_2 = 0.6$, $x_3 = 56.721834721777$ and $x_4 = 52.5913366743$. g_i i=1,2,3,4,5,6 have been obtained as $g_1(x) = -0.0052685899$, $g_2(x) = -0.0588736969$, $g_3(x) = -8.0775610241$, $g_4(x) = -187.4086633257$, $g_5(x) = -7.3138606282e-011$ and $g_6(x) = -1.7707624256e-010$. The comparison of the results with other methods can be seen in Table I.

TABLE I: Comparison of the Results for The Pressure Vessel Design Problem

Method	Best	Mean	Worst	Std. dev.
MCOA	7037,9770	8184,8982	9466,2993	8187,4438
COA	7193,2645	8257,9456	9534,1941	754,1417
IHPS [4]	7197,730	N/A	N/A	N/A
PHS [4]	7197,896	N/A	N/A	N/A
Harmony Search [5]	7198,433	N/A	N/A	N/A

B. Welded Beam Design

The welded beam design problem is taken from Coello [6]. A welded beam is designed for the minimum cost subject to constraints on shear stress (s); bending stress in the beam (h); buckling load on the bar (Pc); end deflection of the beam (d); and side constraints. There are four design variables as h(x1), l(x2), t(x3) and b(x4). The problem can be stated as:

Min $f(x) = 1.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2)$

Subject to

$$g_1(x) = \tau(x) - \tau_{\max} \le 0$$

$$g_2(x) = \sigma(x) - \sigma_{\max} \le 0$$

$$g_3(x) = x_1 - x_4 \le 0$$

$$g_4(x) = 1.10471 x_1^2 x_2 + 0.04811 x_3 x_4 (14.0 + x_2) - 5 \le 0$$

$$g_5(x) = 0.125 - x_1 \le 0$$

$$g_6(x) = \delta(x) - \delta_{\max} \le 0$$

$$g_7(x) = P - P_c(x) \le 0$$

where

$$\tau(x) = \sqrt{(\tau')^2 + 2\tau'\tau''\frac{x_2}{2R} + (\tau'')^2}$$

$$\tau' = \frac{P}{\sqrt{2} x_1 x_2}, \quad \tau'' = \frac{MR}{J}$$

$$M = P\left(L + \frac{x_2}{2}\right)$$

$$R = \frac{1}{2}\sqrt{x_2^2 + (x_1 + x_3)^2}$$

$$J = \frac{\sqrt{2}}{2} x_1 x_2 \left[\frac{x_2^2}{3} + (x_1 + x_3)^2\right]$$

$$\sigma(x) = \frac{6PL}{x_4 x_3^2} \qquad \delta(x) = \frac{4PL^3}{E x_4 x_3^3}$$

$$P_c(x) = \frac{4.013E\sqrt{\frac{x_3^2 x_4^6}{36}}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right)$$

$$P = 6000 lb$$

$$L = 14 in \qquad E = 30*10^6\, psi$$

$$G = 12*10^6\, psi \qquad \tau_{\max} = 13600\, psi$$

$$\sigma_{\max} = 30000\, psi \qquad \delta_{\max} = 0.25 in$$

$$0.1 \le x_1 \le 2,\ 0.1 \le x_2 \le 10,\ 0.1 \le x_3 \le 10,\ 0.1 \le x_4 \le 2$$

The Modified COA algorithm has been run for 2000 iteration. 1.589835 has been found as min $f(\vec{x})$, where $x_1 = 0.1687234371$, $x_2 = 4.0534721323$, $x_3 = 9.97817528265$ and $x_4 = 0.1687357465$. g_i i=1,2,3,4,5,6,7 have been obtained as
$g_1(x) = -0.138132774949554$
$g_2(x) = -0.005045583839092 g_3(x) = -1.230945153762875E-005$
$g_4(x) = -3.534659078438523$
$g_5(x) = -0.043723437079392$
$g_6(x) = -0.236904755530051$ and
$g_7(x) = -1.208953586144751E+005$. The comparison of the results with other methods can be seen in Table II

TABLE II: COMPARISON OF THE RESULTS FOR THE WELDED BEAM DESIGN

Method	Best	Mean	Worst	Std. dev.
MCOA	1,5898	1,7462	1.9728	0.0946
COA	1,6027	1,6152	1,6364	0,0081
PHS [4]	1,7248	N/A	N/A	N/A
IHPS [4]	1,7248	N/A	N/A	N/A
HPSO [1]	1,72485	1,74904	1,814295 0	0,04005
Coello, 2000 [6]	1,74831	N/A	N/A	N/A
Harmony Search [5]	2,38	N/A	N/A	N/A

V. CONCLUSION

This paper introduced a Modified Cuckoo Optimization Algorithm (MCOA). MCOA was employed to solve the two engineering optimization problem namely pressure vessel design problem with and welded beam design problem. By comparison with the other methods, it can be seen COA has provided successful and consistent results while the MCOA is better.

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