ISME2012-3072

An Improved Bees Algorithm For Solving Optimization Mechanical Problems

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Abstract
This paper describes the first application of the Bees Algorithm to optimization problems. The Bees Algorithm (BA) is a search procedure inspired by the way honey bees forage for food. The paper presents the results obtained showing the robust performance of the BA. The results of comparative studies of the Bees Algorithm against other various discrete and continuous optimization algorithms for various design problems are reported to show the efficiency of the former. It is observed that Bees Algorithm finds the region of the search space containing the global optimum.

Keywords: Bees Algorithm, optimization, cantilever beam, speed reducer, welded beam.

Introduction
Many search and optimization problems in science and engineering involve a number of constraints which the optimal solution must satisfy. Constraint handling methods used in classical optimization algorithms can be classified into two groups: (i) generic and (ii) specific methods. Generic methods, such as the penalty function method, the Lagrange multiplier method, and the complex search method [1,2] are popular, because each one of them can be easily applied to any problem without much change in the algorithm. specific methods, such as the cutting plane method and the reduced gradient method [1,2], are applicable either to problems having convex feasible regions only or to problems having a few variables. Since Bees Algorithm (BA) is generic search methods, most applications of BA to constraint optimization problems have used the penalty function approach of handling constraints.

Recently, Bees Algorithms (BA), simulated annealing and evolutionary programming have attracted attention amongst the engineering design optimization community [3]. These new approaches show certain advantages over the more classical optimization procedures, e.g. they can successfully be applied to a broad range of diverse problem areas.

The Bees Algorithm Steps
The Bees Algorithm is a search procedure inspired by the foraging behavior of honey bees. For more details, the reader is referred to references [3].

Table 1 shows the pseudo code for the Bees Algorithm in its simplest form which is dependent to some parameters described in Table 2.

TABLE 1: Pseudo code of the Bees Algorithm

1-Initialize population with random solutions.
2-Evaluate fitness of the population.
3-While (stopping criterion not met) // forming new population.
4-Select sites for neighborhood search and determine the path size.
5-Recruit bees for selected sites (more bees for best e sites) and evaluate fitness
6-Select the fittest bee from each path.
7- Assign remaining bees to search randomly and evaluate their fitnesses.
8-End while.

TABLE 2: Parameter of the Bees Algorithm

Population	n
Number of selected sites	m
Number of top-rated sites out of m selected sites	e
Number of bees recruited for best e sites	n_{ep}
Number of bees recruited for the other (m – e) selected sites	n_{sp}
Initial patch size	n_{gh}
Number of iteration	i_{max}

Mechanical Component Design
In this section we deal with the optimal design of a cantilever beam, the speed reducer and welded beam which are important mechanical parts widely used in aerospace industry, automobile industry, lathe, etc.

The Cantilever Beam Design
The problem is to design a cantilever beam to carry a specific load. Fig. 1 shows a cantilever beam subject to the load P = 50000N. There are 10 design variables corresponding to the height (H_i) and width (B_i) of the rectangular cross-section of each of the five constant steps. The variables B_1 and H_1 are integer, B_2 and B_3 assume discrete values to be chosen from the set 2.4, 2.6, 2.8, 3.1, H_2 and H_3 are discrete and chosen from the set 45.0, 50.0, 55.0, 60.0 and, finally, B_4, H_4, B_5, and H_5 are continuous. The objective function is the volume V of Cantilever Beam which should be minimized:

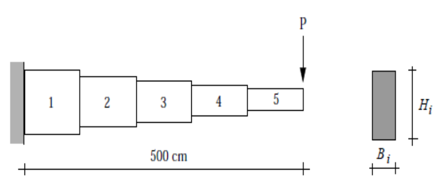

Figure 1: The cantilever beam

$$V(H_i,B_i)=100\sum_{i=1}^{5}H_iB_i \qquad (1)$$

The constraints can be formulated as [2]

$$g_i(H_i,B_i)=\sigma_i \le 14000\frac{N}{cm^2} \quad i=1...5$$

$$g_{i+5}(H_i,B_i)=\frac{H_i}{B_i}\le 20 \qquad i=1...5 \qquad (2)$$

$$g_{11}(H_i,B_i)=\delta \le 27$$

Where δ is the tip deflection of the beam in the vertical direction.

The Speed Reducer Design

The objective is to minimize the weight W of a speed reducer. The design variables are the face width ($b = x_1 \in [2.6, 3.6]$), the module of teeth ($m = x_2 \in [0.7, 0.8]$), the number of teeth on pinion ($n = x_3 \in [17, 28]$), the length of the shaft 1 between the bearings ($l_1 = x_4 \in [7.3, 8.3]$), the length of the shaft 2 between the bearings ($l_2 = x_5 \in [7.8, 8.3]$), the diameter of the shaft 1 ($d_1 = x_6 \in [2.9, 3.9]$), and, finally, the diameter of the shaft 2 ($d2 = x_7$). The variable x_3 is integer and all the others are continuous. Fig. 2 shows a speed reducer. The objective function is given by

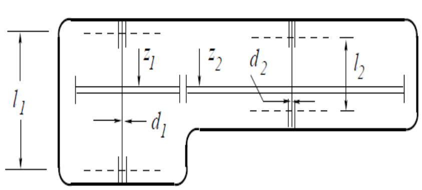

Figure 2: The speed reducer

$$\begin{aligned}W&=0.7854x_1x_2^2(3.3333x_3^2+14.9334x_3-43.0934)\\&-1.508x_1(x_6^2+x_7^2)+7.4777(x_6^3+x_7^3)+\\&0.7854(x_4x_6^2+x_5x_7^2)\end{aligned} \qquad (3)$$

The constraints can be formulated as

$$\begin{aligned}
&g_1(x)=27x_1^{-1}x_2^{-2}x_3^{-1}\le 1\\
&g_2(x)=397.5x_1^{-1}x_2^{-2}x_3^{-2}\le 1\\
&g_3(x)=1.93x_2^{-1}x_3^{-1}x_4^{3}x_6^{-4}\le 1\\
&g_4(x)=1.93x_2^{-1}x_3^{-1}x_5^{3}x_7^{-4}\le 1\\
&g_5(x)=\frac{1}{0.1x_6^3}\left[(\frac{745x_4}{x_2x_3})^2+\{16.9\}10^6\right]^{0.5}\le 1100\\
&g_6(x)=\frac{1}{0.1x_7^3}\left[(\frac{745x_5}{x_2x_3})^2+\{157.5\}10^6\right]^{0.5}\le 850 \qquad (4)\\
&g_7(x)=x_2x_3\le 40\\
&g_8(x)=\frac{x_1}{x_2}\ge 5\\
&g_9(x)=\frac{x_1}{x_2}\le 12\\
&g_{10}(x)=(1.5x_6+1.9)x_4^{-1}\le 1\\
&g_{11}(x)=(1.1x_7+1.9)x_5^{-1}\le 1
\end{aligned}$$

Welded Beam Design

A uniform beam of rectangular cross-section needs to be welded to a base to be able to carry a load of 6000 lbf.

The configuration is shown in Fig. 3.The beam is made of steel 1010.

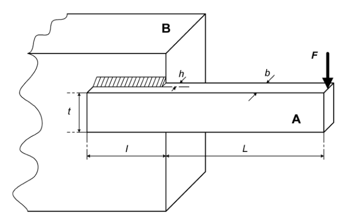

Figure 3: The welded beam design

The length L is specified as 14 in. The objective of the design is to minimize the cost of fabrication while finding a feasible combination of weld thickness h, weld length l, beam thickness t, and beam width b. The objective function can be formulated as [2]

$$\min imum\ f=(1+c_1)h^2l+c_2tb(L+1) \qquad (5)$$

Where f is the cost function including setup cost, welding Labor cost, and material cost, c1 the unit volume of weld material cost (= 0.10471$/in3), c2 the unit volume of bar stock cost (= 0.04811$/in3), and L the fixed distance from load to support (= 14 in).

Not all combinations of h, l, t, and b that can support F are acceptable. There are limitations that should be considered regarding the mechanical properties of the weld and bar, for example, shear and normal stresses, physical constraints (no length less than zero), and maximum deflection. The constraints are as follows [2]

$$g_1 = \tau_d - \tau \geq 0$$
$$g_2 = \sigma_d - \sigma \geq 0$$
$$g_3 = b - h \geq 0$$
$$g_4 = l \geq 0$$
$$g_5 = t \geq 0 \qquad (6)$$
$$g_6 = P_c - F \geq 0$$
$$g_7 = h - 0.125 \geq 0$$
$$g_8 = 0.25 - \delta \geq 0$$

Where τ_d is the allowable shear stress of the weld (=13600 psi), τ the maximum shear stress in the weld, σ_d the allowable normal stress for the beam material (= 30 000 psi), σ the maximum normal stress in the beam, P_c the bar buckling load, F the load (= 6000 lbf), and δ the beam end deflection.

Normal and shear stresses and buckling force can be formulated as [2]

$$\sigma = \frac{2.1952}{t^3 b}$$

$$\tau = \sqrt{(\tau')^2 + (\tau'')^2 + (l\tau'\tau'') / \sqrt{0.25\left[l^2 + (h+t)^2\right]}} \qquad (7)$$

where

$$\tau' = \frac{6000}{\sqrt{2}hl}$$

$$\tau'' = \frac{6000(14+0.5l)\sqrt{0.25\left[l^2+(h+t)^2\right]}}{2\left\{0.707hl\left[l^2/12+0.25(h+t)^2\right]\right\}} \qquad (8)$$

$$P_c = 64746.022(1-0.0282346t)tb^3$$

Result and Discussion

The empirically chosen parameters for the Bees Algorithm are given in Table 3.

TABLE 3: Parameters of the Bees Algorithm for Mechanical problems

Problems	n	m	e	n_{ep}	n_{sp}	n_{gh}	i_{max}
CANTILEVER BEAM	70	20	5	10	8	0.1	60
REDUCER SPEED	65	5	2	40	10	0.1	200
WELDED BEAM DESIGN	80	5	2	50	10	0.1	750

The Cantilever Beam Design

Fig. 4 shows how the lowest value of the objective function changes with the number of iterations (generations) for three independent runs of the algorithm. It can be seen that the objective function decreases rapidly in the early iterations and then gradually converges to the optimum value. A variety of optimization methods have been applied to this problem by other researchers [7, 8].The Table 4 shows the design variables values corresponding to the best solutions.

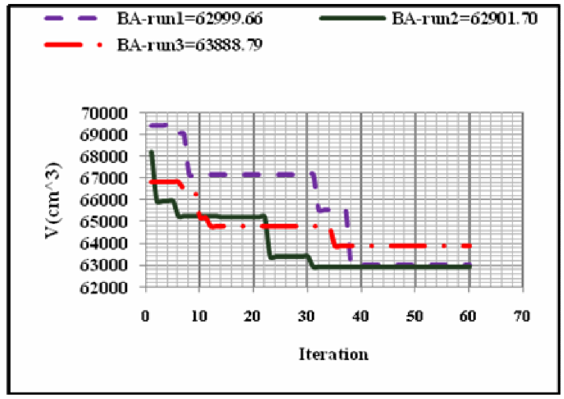

Figure 4: Evolution of the lowest volume in each iteration

TABLE 4: RESULT FOR CANTILEVER BEAM DESIGN PROBLEM OBTAINED USING BA AND ANOTHER OPTIMIZATION METHOD

	GAOS [7]	**AIS –GA [8]**	**AIS-GA^C [8]**	**AIS-GA^H [8]**
B_1	3	3	3	3
B_2	3.1	3.1	3.1	3.1
B_3	2.6	2.8	2.6	2.6
B_4	2.3	2.2348	2.3107	2.2947
B_5	1.8	2.0038	2.2254	1.8250
H_1	60	60	60	60
H_2	55	55	60	55
H_3	50	50	50	50
H_4	45.5	44.3945	43.1857	45.2153
H_5	35	32.878708	31.250282	35.1191
V	64815	65559.6	66533.47	64834.70
	APM^{bc} [8]	**SR [8]**	**APM^{rc} [8]**	**BA**
B_1	3	3	3	3
B_2	3.1	3.1	3.1	2.4
B_3	2.6	2.6	2.6	2.6
B_4	2.2094	2.2837	2.2987	2.3411
B_5	2.0944	1.7532	1.7574	2.0950
H_1	60	60	60	61
H_2	60	55	55	60
H_3	50	50	50	50
H_4	44.0428	45.5507	45.5037	44.5476
H_5	31.986782	35.0631	34.9492	32.3281
V	66030.05	64599.65	64647.82	**62901.70**

The Speed Reducer Design

Fig. 5 shows the evolution of the best value of the objective function, with the number of iterations (generations) for three independent runs. Again, it can be seen that the objective function decreases rapidly in the early iterations and then gradually converges to the optimum value.

The speed reducer design problem has been solved by other researchers [8, 9]. The results obtained by those optimization tools are given in Table 5.

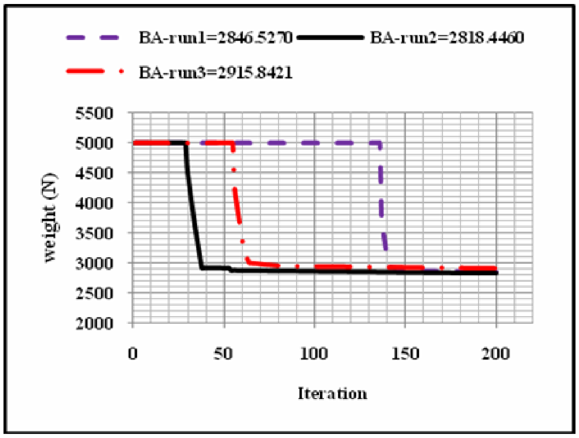

Figure 5: Evolution of the lowest weight in each iteration

TABLE 5: RESULT FOR REDUCER SPEED DESIGN PROBLEM OBTAINED USING BA AND ANOTHER OPTIMIZATION METHOD

	ES.Coello [9]	AIS –GA [8]	AIS-GA^{C} [8]	AIS-GA^{H} [8]
x_1	3.506163	3.500001	3.500000	3.500001
x_2	0.700831	0.700000	0.700000	0.700000
x_3	17	17	17	17
x_4	7.460181	7.300019	7.300001	7.300008
x_5	7.962143	7.800013	7.800000	7.800001
x_6	3.362900	3.350215	3.350215	3.350215
x_7	5.308949	5.286684	5.286684	5.286683
W	3025.0051	2996.3494	2996.3484	2996.3483
	APM^{bc} [8]	**SR [8]**	**APM^{rc} [8]**	**BA**
x_1	3.500000	3.500000	3.500000	3.583064
x_2	0.700000	0.700000	0.700000	0.708787
x_3	17	17	17	15
x_4	7.300000	7.300001	7.300000	8.008602
x_5	7.800000	7.800001	7.800000	7.861453
x_6	3.350215	3.350215	3.350215	3.650601
x_7	5.286683	5.286683	5.286683	5.287184
W	2996.3482	2996.3483	2996.3482	**2818.4460**

The Welded Beam Design

Fig. 6 shows how the lowest value of the objective function changes with the number of iterations (generations) for three independent runs of the algorithm. It can be seen that the objective function decreases rapidly in the early iterations and then gradually converges to the optimum value. A variety of optimization methods have been applied to this problem by other researchers [8, 10, 11, 12]. The results they obtained along with those of the Bees Algorithm are given in Table 6.

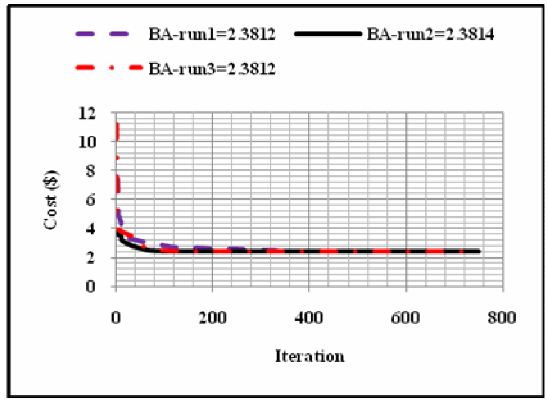

Figure 6: Evolution of the lowest cost in each iteration

TABLE 6: result for welded beam design problem obtained using BA and another optimization method result

methods	Design variable				cost
	h	**l**	**t**	**b**	
Approx [10]	0.2444	6.2189	8.2915	0.2444	2.38
David [10]	0.2434	6.2552	8.2915	0.2444	2.38
GP [10]	0.2455	6.1960	8.2730	0.2455	2.39
GA [12] (three independence run)	0.2489	6.1730	8.1789	0.2533	2.43
	0.2679	5.8123	7.8358	0.2724	2.49
	0.2918	5.2141	7.8446	0.2918	2.59
Improved GA [11] (three independence run)	0.2489	6.1097	8.2484	0.2485	2.40
	0.2441	6.2936	8.2290	0.2485	2.41
	0.2537	6.0322	8.1517	0.2533	2.41
Simplex [10]	0.2792	5.6256	7.7512	0.2796	2.53
Random [10]	0.4575	4.7313	5.0853	0.6600	4.12
APM^{bc} [8]	0.2442	6.2231	8.2915	0.2444	2.3814
BA (three independence run)	0.2444	6.21903	8.2917	0.2444	**2.3812**
	0.2443	6.2161	8.2959	0.2443	**2.3814**
	0.2444	6.2182	8.2922	0.2444	**2.38112**

Conclusion

Three different constrained optimization problems were solved using the Bees Algorithm. In each case, the algorithm converged to the optimum without becoming trapped at local optima. The algorithm generally outperformed other optimization techniques in terms of the accuracy of the results obtained. A drawback of the algorithm is the number of parameters that must be chosen. However, it is possible to set the values of those parameters after only a few trials. Indeed, the Bees Algorithm can solve a problem without any special domain information, apart from that needed to evaluate fitnesses. In this respect, the Bees Algorithm shares the same advantage as global search algorithms such as the GA. Further work should be addressed at reducing the number of parameters and incorporating better learning mechanisms to make the algorithm even simpler and more efficient.

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