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Proceedings of the International Conference on Computing in Civil and Building Engineering
W Tizani (Editor)

Shuffled complex evolution optimizer for truss structure optimization

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Keywords: structural optimization, truss, shuffled complex evolution, constrained optimization

This paper presents evolutionary-based optimization procedure, the Shuffled Complex Evolution optimizer (SCEO), for solving the nonlinear constrained truss structure optimization problems. It handles the problem-specified constraints using non-stationary penalty functions where the penalty values are dynamically modified.

The primary objective of the present study is to explore the capabilities of SCEO for the optimal design of the nonlinear constrained truss structure optimization problems. The mathematical form of a single objective size optimization problem for truss structure can be expressed as follows:

Find	$A^T = \{A_1, \quad A_2, \quad .... \quad A_n\}$		(1)
To Minimize	$F = W(A) = \rho \sum_{i=1}^{n} L_i A_i$		(2)
Subject to	$G_j^L \le G_j(A) \le G_j^U$	$j = 1, 2, ... m$	(3)
and	$A_i^{\min} \le A_i \le A_i^{\max}$	$i = 1, 2, ... n$	(4)

Where ρ = the material density, L_i = the member length, A_i = member cross-sectional area.

The SCE method starts with a population of points distributed randomly in the feasible space. The population is then divided into several complexes, each of which is allowed to evolve independently on the basis of a statistical reproduction process that employs the complex geometric shape to direct the search in a refined direction. After a number of steps, the complexes are shuffled together and new complexes formed such that the information gained separately by each complex is shared. The shuffling and the evolution procedures are repeated until the optimization criteria are satisfied. The SCE has good convergence properties and high probability of succeeding in finding the global optimum (Duan and Sorooshian, 1993).

The most common constraint–handling technique is the use of penalty functions. A non-stationary penalty function is, generally, defined as

$$f(X) = F(X) + h(k)H(x) \tag{5}$$

Where *F(x)* is the original objective function of the constrained optimization problem in Eq. (5); $h(k) = \sqrt{k}$ is a dynamically modified penalty value, where k is the algorithm's current iteration number; and *H(x)* is a penalty factor, defined as

$$H(x) = \sum_{i=1}^{m} \theta\left(q_i(x)\right)\left[q_i(x)\right]^{\gamma\left(q_i(x)\right)} \tag{6}$$

Where $q_i(x)$ = max {0, $G_i(x)$}, i = 1… m, and $g_i(x)$ are the constraints. The functions $h(k)$, $\theta(q_i(x))$ and $\gamma(q_i(x))$, are problem dependent and the same values reported by (Parsopoulos and Vrahatis, 2002) were used.

The SCEO is tested on a 10-bar planar truss structure optimization and is compared with other evolutionary algorithms. The material density is 0.1 lb/in^3, L is 360 in, and the modulus of elasticity is 10,000 ksi. The members are subject to stress limitations of ±25 ksi and all nodes in both directions are subject to displacement limitation of ±2.0 in. Two cases of loading are considered: Case 1, the single loading condition of P_1=100 kips and P_2=0; and Case 2, the single loading condition of P_1=150 kips and P_2=50 kips. The SCEO algorithm was applied to the above loading cases. Table 1 gives the best discovered optimum solutions for Cases 1 and 2 and also provide a comparison between the optimal design of other published results, for the same case and the present work.

The best solutions for Cases 1 and 2 were obtained using SCEO after approximately 30,000 and 25,000 searches, respectively. We can see that the SCE provides good results as compared with other methods for the same problem. The optimal solutions found by the SCE meet all constraints and have only two active constraints including the displacements at nodes 3 and 6.

Table 1 Optimization results for the 10-bar planar truss - Load Cases 1 and 2

	Variable	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Weight (lb)
Case 1	This work SCEO	30.47	0.1	23.19	15.23	0.1	0.55	7.45	21.02	21.59	0.1	5060.85
	Lee and Geem, 2004	30.15	0.1	22.71	15.27	0.1	0.54	7.54	21.56	21.45	0.1	5057.88
	Perez and Behdinan, 2007	33.5	0.1	22.77	14.42	0.1	0.1	7.53	20.47	20.39	0.1	5024.21
	Rizzi , 1976	30.73	0.1	23.93	14.73	0.1	0.1	8.54	20.95	21.84	0.1	5061.6
Case 2	This work SCEO	23.53	0.1	25.28	14.37	0.1	1.97	12.8	12.39	20.33	0.1	4676.92
	Lee and Geem, 2004	23.25	0.1	25.73	14.51	0.1	1.98	12.2	12.61	20.36	0.1	4668.81
	Rizzi , 1976	23.53	0.1	25.29	14.37	0.1	1.97	12.4	12.83	20.33	0.1	4676.92
	Khan and Willmert, 1979	24.72	0.1	26.54	13.22	0.1	4.84	12.7	13.78	18.44	0.1	4792.52

The result shows that the SCEO method presented in this paper is able to find optimal results, which are better, or at the same level of other structural optimization methods. The SCE simplicity of implementation along with the simplicity of the proposed constraints handling makes it an ideal method when dealing with global non-convex constrained structural optimization problems.

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