Jaya: A new meta-heuristic algorithm for the optimization of braced dome structures

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Abstract. A new algorithm called Jaya is presented for design of the braced dome structures by taking into account the objective function as least weight with frequency constraints. The size optimization is considered for the 3D truss elements. The performance of Jaya algorithm is presented through benchmark 120-bar braced dome. This study indicated that the proposed technique is a powerful technique for the optimal design of domes with constrained problem. The developed computer program for the analysis and optimization of dome structure and the optimization algorithm for Jaya are coded in MATLAB.

Keywords: Jaya algorithm • Size optimization • Frequency constraints • Dome structure.

1 Introduction

It has been the goal of the researchers to do designs in a short time and with a fewer number of analyzes. For this aim, many optimization algorithms are proposed until now. Some of them are: bat algorithm (BA), teaching-learning-based optimization (TLBO), evolution strategies (ES), Jaya algorithm (JA), artificial bee colony (ABC), simulated annealing (SA), Grey wolf optimization algorithm (GWO), and genetic algorithm (GA). These algorithms are used to study in many engineering problem.

Dome structures like 3D trusses are considered in this study as a benchmark problem to test the Jaya algorithms. In the literature many papers are presented related to the optimization with frequency constraints for the truss structures. Bellagamba and Yang [1] was the first who studied structural optimization with frequency constraints. Least weight design of structure by taking into account dynamic and static constraints was studied by Lin et al. [2]. The genetic algorithm (GA) for optimum structural design applications of trusses structure was investigated in [3-5]. Talaslioglu [6] has developed optimization algorithm with many populations. Hybridized genetic algorithm (GA) with

Niche techniques used by Lingyun et al. [7]. Firefly algorithm (FA) and harmony search (HS) was firstly used by Miguel and Miguel [8]. The particle swarm optimization (PSO) algorithm implemented by Gomes [9] for geometry and size optimization. Kaveh & Zolghadr [10, 11] presented a study by using the democratic particle swarm optimization (DPSO), harmony search and a ray optimizer to improve the particle swarm optimization algorithm (PSRO). Kaveh & Javadi [12] developed hybrid algorithm (HRPSO). They applied this developed algorithm for optimal shape and size design of trusses by taking into account the constraints such as natural frequency.

Colliding bodies optimization (CBO) was developed by Kaveh & Mahdavi [13]. Symbiotic Organisms Search (SOS) was proposed by Tejani et al. [15] Kaveh & Ghazaan [14] studied cascade sizing optimization utilizing series of design variable configurations (DVCs). Baghlani & Makiabadi [16], Dede & Toğan [17] developed algorithm called Teaching Learning Based Optimization (TLBO). The education process from a single classroom to a school with multiple parallel classes is simulated by Farshchin et al. [18] as a new algorithm named MC-TLBO.

The aim of this study is to present an implementation of the newly developed optimization algorithm named Jaya. Rao [19, 20] in 2016 the first developed this method. Jaya is based on the assumption that the solution obtained for a given problem should be directed towards the best solution and should avoid the worst solution. Dede [21] was study optimum design of steel grillage structure. Sizing, layout and large-scale optimization problems were previously studied by Degertekin et al. [22] for the weight minimization of truss structures by using this algorithm.

2 The general structure of optimization problem

The main target of solving braced dome optimization problem is to reduce the total volume or weight of a structure without violating constraints such as natural first five frequencies of dome structure. The optimization problem can be described as given below:

Design variables: $$\{D\} = \{d_1, d_2, \ldots, d_{ng}\} \quad (1)$$

Objective function: $$F = \sum_{g=1}^{ng} \left(D_g * \rho_g * \sum_{m=1}^{nm} (L_m) \right) \quad (2)$$

Constraints: $$\omega_j \geq \omega_j^* \text{ for natural frequencies } j \quad (3)$$

$$\omega_k \leq \omega_k^* \text{ for natural frequencies } k$$

Bounds: $$\text{Lb} < \{D\} < \text{Up} \quad (4)$$

where “D” is the design variable vectors which are cross-sectional areas of the bar elements of dome, “ng” is the number of grouping if the design variables are categorized, “F” is the objective function representing the total volume or weight of the whole truss structure, “nm” is the number of member in the grouping of the structure. “ρ”, “L”, and “D” are the density of material, the length of bar element and cross-section area of the bar element, respectively. "ω_j" and "ω_k"are the naturel frequency of the structure that some of them must be greater or little than the specified frequency (ω_j^* or ω_k^*) depending on the engineering problem. “L_b" and "U_b" are the lower and upper bounds of the design variables, respectively.

To take into the constraints, the objective function must the changed as a penalty function (ϕ) including the constraint. The penalized objective function can be written in a basic form as;

$$\phi = F * (1 + P * C) \tag{5}$$

where “C” is the sum of the violations of the constraints and “P” is a constant value. For the frequency constraint “ω_j”, a violation can be calculated as;

$$g_i = \frac{\omega_j}{\omega_j^*} - 1 \geq 0 \qquad if \quad g_i < 0 \quad then \quad c_i = gi \tag{6}$$

3 Optimization with Jaya algorithm

Jaya prefers to use randomly created initial population. The main principle of this algorithm is that the updated solutions (possible candidates for the objective of the problem) are created by getting close the best candidate and moving away the worst candidate. The best solution is defined as the combination of the design variables which gives the least weight of dome structure for this study. The superiority of this method is that only the common check parameters are required. To explain the general process of the Jaya algorithms the flow chart is given in the Fig. 1.

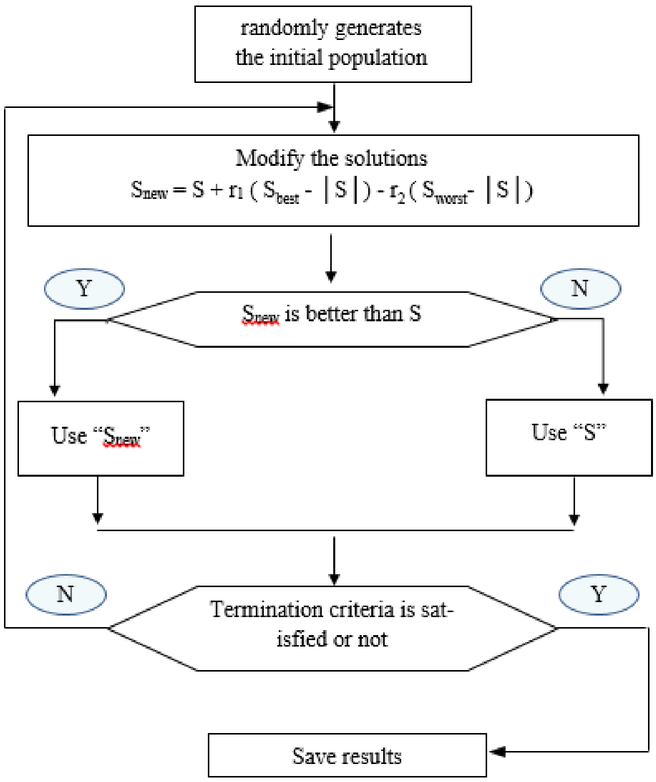

Fig. 1. Jaya optimization algorithm

In Fig. 1, "S" is the any solutions, S_{best} is the best solutions, S_{worst} is the worst solutions, And r is the random number between from 0 to1.

4 Numerical Example

In this study, frequency constraint is taking into account. 120-bar dome structure is optimized for size parameters. The design variables are selected as continuous by taking into account the lower and upper. In the optimization process, 20 independent runs are carried. Fig. 2 illustrates the configuration of the 120-bar dome structure. To obtain the geometry of this structure, initial nodal coordinates and grouping of the elements can be seen from this figure. This example was investigated by by Kaveh&Zolghadr [11] using (PSRO), Tejani et al. [15] using symbiotic organisms search (SOS-ABF), Kaveh &Mahdavi [13] using Colliding-Bodies Optimization (CBO) and Kaveh & Zolghadr [10] using Democratic Particle Swarm Optimization (DPSO).

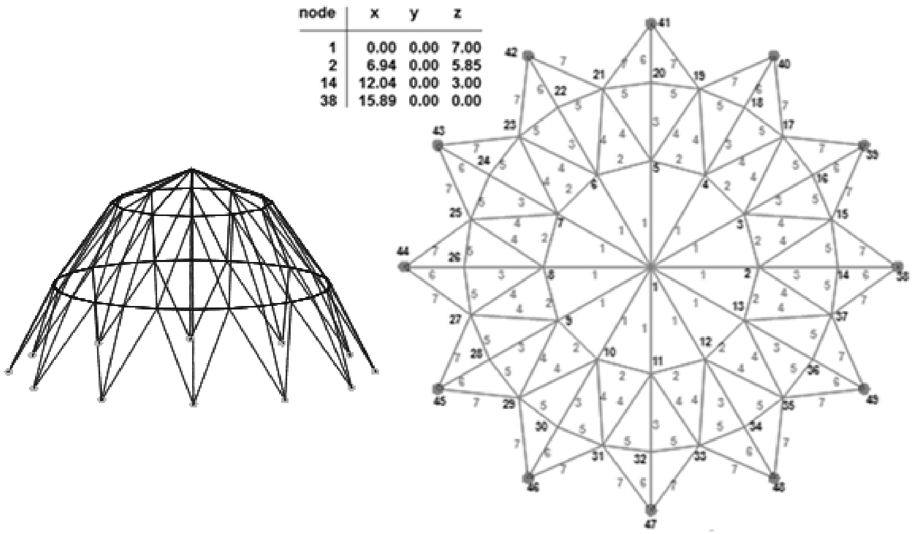

Fig. 2. Plan and 3D view with element grouping of the dome structure

The structural element of this example is classified 7 groups for the size optimization. The properties of the material, constraints for frequency and the additional mass on the free nodes masses are given in the Table 1. The size of population is 30 and the iteration is 600 for this example.

Table 1. Structural constraints and material properties for the dome structure

Properties / constraints	Symbol	Value / notes
Elasticity modulus	E	2.1×10^{11} (N/m2)
Density of material	ρ	7971.81 (kg/m3)
Non-structural mass at nodes	m	3000 for 1 (kg) 500 for 2:13 100 for 14:37
Bounds of cross-sectional area	A	$0.0001 \leq A \leq 0.01293$ (m2)
Frequency constraints	ω	$\omega_1 \geq 9$, $\omega_{2,3} \geq 11$ (Hz)

Table 2 shows the optimal solutions obtained by using different algorithms. As seen from this comparison, the best solution are given by using the proposed algorithm.

Table 2. Optimal results and comparison for the dome structure

Design variables		[11] PSRO	[15] SOS-ABF1	SOS-ABF2	[13] CBO	[10] DPSO	This study Jaya Pn=20	Pn=30
cross-sectional area (cm2)	A1	19.972	19.5449	19.5715	19.6917	19.607	19.300	19.309
	A2	39.701	40.9483	39.8327	41.1421	41.290	40.861	40.763
	A3	11.323	10.4482	10.5879	11.1550	11.136	10.697	10.791
	A4	21.808	21.0465	21.2194	21.3207	21.025	21.107	21.272
	A5	10.179	9.5043	10.0571	9.8330	10.060	9.989	9.943
	A6	12.739	11.9362	11.8322	12.8520	12.758	11.779	11.695
	A7	14.731	14.9424	14.7503	15.1602	15.414	14.743	14.579
Weight (kg)		8892.33	8712.11	8710.33	8889.13	8890.48	8712.67	8709.35
mean (kg)		8921.30	8727.42	8725.30	8891.25	8895.99	8730.17	8713.21
std (kg)		18.54	16.55	10.64	1.79	4.26	12.78	2.97
nfe or Pn/Gn		20/200	4000	4000	6000	30/200	20/200	30/600
Run		20	-	-	20	30	20	20
Frequency ω (Hz)		9.000	9.0011	9.0012	9.0000	9.0000	9.0016	9.0000
		11.000	11.0003	11.0023	11.0000	11.0000	11.0013	11.0002
		11.005	11.0003	11.0023	11.0000	11.0052	11.0013	11.0002
		11.012	11.0015	11.0056	11.0096	11.0134	11.0044	11.0008
		11.045	11.0674	11.0720	11.0494	11.0428	11.0716	11.0674

The history of the optimal solution, mean solution and the standard deviation are given in Fig. 3. To show the first part of the convergence more details, a large scaled graphic is added to the same figure. Table 3 presents the variety of the dome structure with different run.

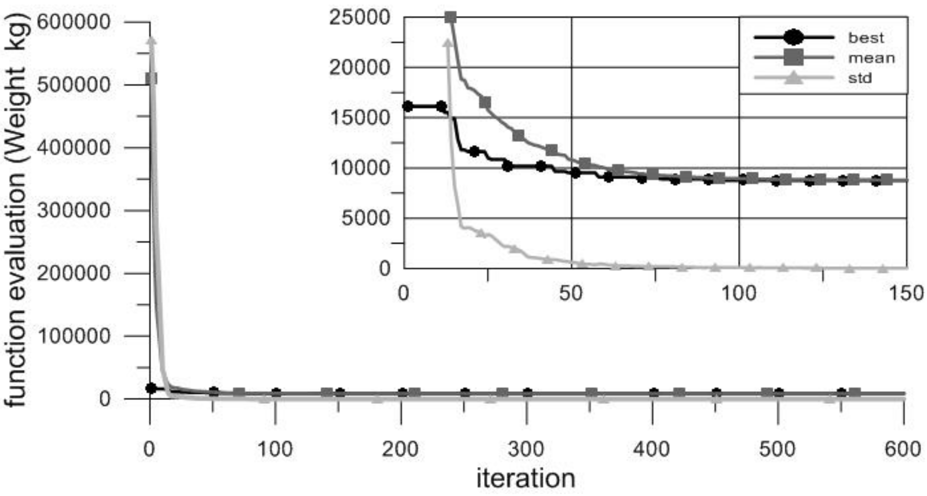

Fig. 3. Convergence history of the best solutions by using Jaya algorithm

Table 3. Diversity of the run for the dome structure

Run	Best	Run	Best
1	8709.3539	11	8714.4637
2	8715.9286	12	8715.7458
3	8711.9890	13	8712.5166
4	8709.5981	14	8715.1362
5	8710.2483	15	8713.9430
6	8710.9132	16	8719.6570
7	8711.6594	17	8719.5643
8	8713.1122	18	8713.9493
9	8711.6286	19	8715.0774
10	8710.0645	20	8709.7543
Pn/Gn	30/600	best	8709.3539
		mean CPU time [s]	1237.9688

5 Conclusion

Sizing optimization with the frequency constraints of 3D dome structure is investigated in this study. To optimize the dome structure a new and efficient algorithm called Jaya is coded in the MATLAB. The results obtained from the optimization process of the example taken from the literature as benchmark problem are compared the other solutions obtained different studies. The results of this study indicated that the Jaya algorithm gives the best solution among the other algorithms. As a result, it can be stated that the Jaya optimization algorithm can be used as an effective algorithm to find best solution for the 3D dome structures.

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