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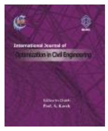

A SIMPLIFIED DOLPHIN ECHOLOCATION OPTIMIZATION METHOD FOR OPTIMUM DESIGN OF TRUSSES

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ABSTRACT

Simplified Dolphin Echolocation (SDE) optimization is an improved version of the Dolphin Echolocation optimization. The dolphin echolocation (DE) is a recently proposed metaheuristic algorithm, which was imitated dolphin's hunting process. The global or near global optimum solution modeled as dolphin's bait, dolphins send sound in different directions to discover the best bait among their search space. This paper introduced a new optimization method called SDE for weight optimization of steel truss structures problems. SDE applies some new approaches for generating new solutions. These improvements enhance the accuracy and convergence rate of the DE; SDE does not depend on any empirical parameter. The results of the SDE for mathematical and engineering optimization problems are compared to those of the standard DE and some popular metaheuristic algorithms. The results show that SDE is competitive with other algorithms.

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KEY WORDS: optimization; metaheuristic algorithm; dolphin echolocation; simplified dolphin echolocation; truss optimization

1. INTRODUCTION

Optimization is an important active topic in engineering which leads to the correct use of funds and time and materials. Nowadays, the use of metaheuristic algorithm has become prevalent and various methods are provided in this regard. These methods are usually

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adapted from natural mechanisms because they have a long history of existence. Many new metaheuristic algorithms are applied for structural optimization. Some efforts on the optimal design of structures have focused on utilizing metaheuristic methods. Some of these methods can be listed:

Genetic Algorithms (GA) [1-2], Simulated Annealing (SA) [3], Ant Colony Optimization (ACO) [4], Harmony Search algorithm (HS) [5], Particle Swarm Optimizer (PSO) [6], Charged System Search method (CSS) [7], Bat algorithm [8], Water Cycle Algorithm [9], Ray optimization algorithm (RO) [10], krill-herd algorithm [11], Colliding Bodies Optimization algorithm (CBO) [12] and Enhanced colliding bodies optimization [13].

Recently, Kaveh and Farhoudi have proposed a new optimization method named Dolphin Echolocation (DE) [14]. This algorithm was adopted from hunting Dolphins. Dolphin can send sound in the form of click in different orientations and when this sound strikes an object, some part of the energy of the sound is reflected back to the Dolphin as echo [15]. Then, the Dolphin hears them and decides to make a decision at this time. Dolphin knows a range of distance and orientation of the best bait. Hunting stage is started and dolphin moves to bait, sending sound and receiving echo continue until Dolphin hunts the bait. Obviously, during this approach, the probability of hunting increases every time and search space decreases continuously. When the dolphin hunts bait, the probability of hunting is one hundred percent and search space is the lowest. When dolphin received echo from different orientations, it is time to process this information. Dolphin can decide to choose next step, which is a very important stage. In Simplified Dolphin Echolocation (SDE) more attention is paid to this problem in order to increase the number of processing. By this increase, first all the data is processed and reordered and then assessment of fitness runs is performed. In addition for increasing the accuracy, the use of some parameters and formation of matrices which are time consuming, are ignored. As a result, the speed of algorithm in Simplified Dolphin Echolocation (SDE) is more than Dolphin Echolocation (DE).

The remaining sections of this paper are organized as follow: SDE algorithm with a brief overview of the standard DE is provided in Section 2. Weight optimization of steel truss structures is performed in Section 3. Finally, the paper is concluded in section 4.

2. SIMPLIFIED DOLPHIN ECHOLOCATION ALGORITHM

This section provides the proposed Simplified Dolphin Echolocation (SDE) algorithm. Before providing SDE algorithm, some explanations are needed as follows:

When Dolphin starts hunting, the probability of hunting increases every time and this is shown with $P(Loop_i)$. This parameter is determined by Eq. (1). In addition, this parameter controls the two stages of the search consisting of exploration and exploitation. In exploration stage, the algorithm performs a global search and in exploitation it concentrates on investigation of better answers. If this parameter is not large, the search space is in exploration phase but when this parameter increases, the search space goes to exploitation phase, because the search space always became smaller. It means that the algorithm is going to local search. The probability of every step to get target is obtained by Eq. (1) and it increases in every loop until it reaches to one hundred percent at the final Loop.

$$P(Loop_i) = P(Loop_1) + [1 - P(Loop_1)]\frac{Loop_i - 1}{LoopNumber - 1} \tag{1}$$

Where $P(Loop_i)$ is the probability of each Loop in the final result. $P(Loop_1)$ the probability of first loop, usually is less than 0.1 or 10%. LoopNumber is the number of loops, $Loop_i$ the number of the current loop. $P(Loop_1)$ can also be calculated by Eq. (2), it is often achieved approximately 10% and cannot affect the accuracy of convergence and final results.

DE algorithm has a power parameter. When this parameter is one, the desired accuracy can be obtained. Thus, it has been considered as a constant variables in the SDE algorithm. In SDE, a new parameter is introduced to determine the accuracy of each variable shown with AC. Also the Re parameter defined in DE algorithm is assumed as constant variable as the $\frac{1}{4}$ of the search space of related variable.

Steps of SDE algorithm include:

Step 1) Generate $[L]_{NL\times NV}$ matrix, in which NL and NV are the number of locations and the number of variables, respectively. This matrix is generated with random numbers in intervals of every variable in the first loop and this matrix will be generated for other loops according to the previous loop.

Step 2) Calculate $P(Loop_i)$ using Eq. (1) for every loop. For first loop, $P(Loop_1)$ can be equal to 10% or when $[L]_{NL\times NV}$ is generated for the first loop, calculates maximum mode for each variable called it as $Mode_i$.

$$C_i = \frac{Mode_i}{NL}, P(Loop_1) = \frac{\sum_{i=1}^{NV} C_i}{NV} \tag{2}$$

Where C_i is the modal answer among all answers. After calculating $P(Loop_1)$, it is usually less than 0.1 or 10% .

Step 3) Evaluate fitness of vectors of $[L]_{NL\times NV}$ matrix and generate $[Fitness]_{NL\times 2}$. This matrix has NL rows and puts fitness of every rows of $[L]_{NL\times NV}$ matrix in the same rows and second column of fitness matrix, first column is the rows number of $[L]_{NL\times NV}$ matrix. Before evaluating fitness, $[L]_{NL\times NV}$ matrix should reorder; this process has high effect on reduction of loop numbers and increases accuracy of results. There is more information about the reorder of $[L]_{NL\times NV}$ matrix in the following. This is one of the important changes on DE algorithm. After this section, all of variables are considered individually until information is obtained for next Loop.

Step 4) Evaluate accumulative fitness; it is assumed that all variables of all locations are equal to one point in the coordinate system (horizontal axis is numbering of the alternatives and vertical axis is such fitness) and there is a triangle distribution on the left and right of that point. This distribution is 2×R, where R is effective radius. It is illustrated in Fig.1 schematically.

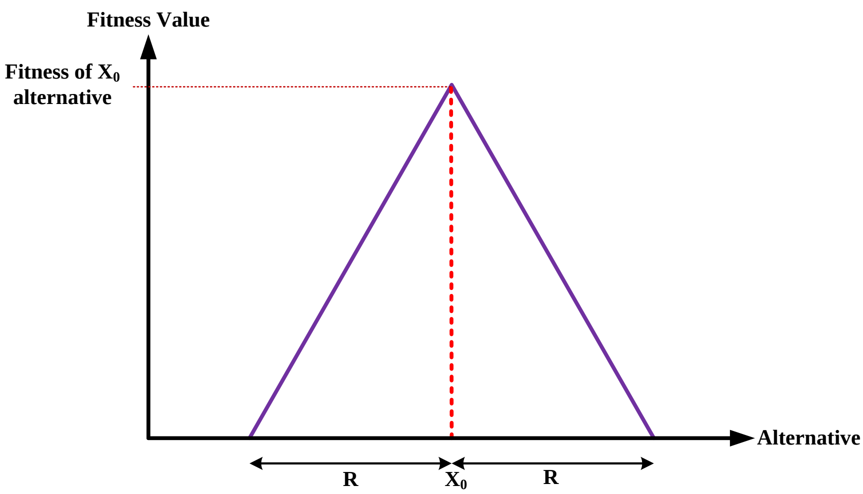

Figure. 1 The triangle distribution of fitness function

There are clearly overlaps occur in some parts. Whatever area under curve is higher; the probability of result is higher. Hence, the Accumulative Fitness (AF) is introduced. AF considers overlaps and sums of all fitness for every alternative.

In SDE algorithm, the alternatives matrix is ignored. Alternatives matrix is being used due to all of search spaces should be numbered for every variable. In Alternatives matrix, it should put all of search space for every variable (each column) as ascending order. To calculate the numbering of $[L]_{NL\times NV}$ matrix, should search the jth variable in alternatives matrix in same column. The numbering of elements starts from one to $\frac{b-a}{AC}+1$ for every variable.

Where a and b are start of interval and end of interval, respectively. In SDE algorithm, the number of L indicated with A, is calculated using Eq. (3).

$$A(i,j)=\frac{L(i,j)-a}{AC}+1 \tag{3}$$

When search space is large, finding elements of $[L]_{NL\times NV}$ matrix in alternatives matrix need more times, thus Alternatives matrix is not employed in SDE algorithm. First column of AF matrix is from one to length of search space for every variable. This matrix is calculated for every independent variable.

As mentioned, there is a triangle distribution for neighborhood fitness; sometimes this neighborhood is put out of range. In his time, borders of range act like a mirror that this Neighborhood is reflected to the range. Fig. 2 shows distribution (1) and (2) are reflected to their ranges like (1)’ and (2)’. They are accumulated with initial value of distribution.

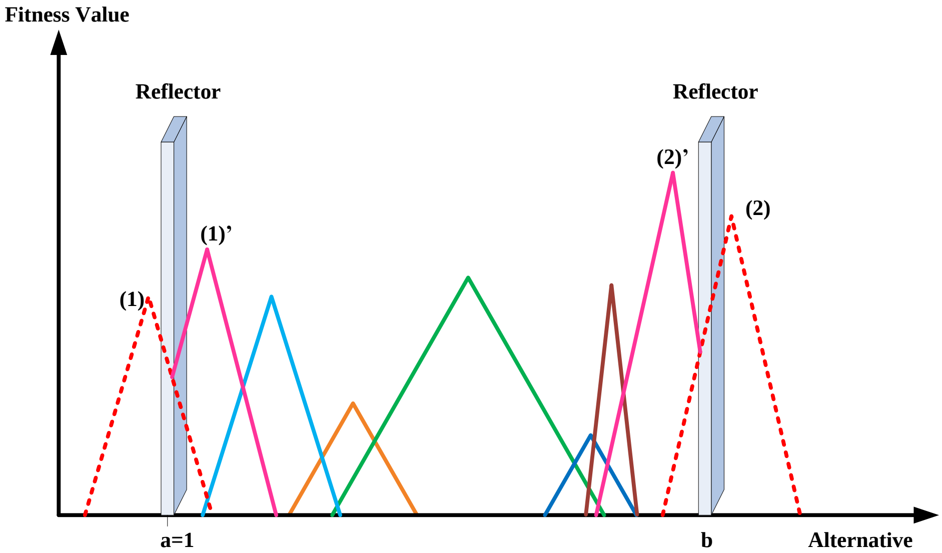

Figure 2. The triangle distribution and their overlaps and reflects

Find rows of L that has maximum fitness, best alternatives, and put their accumulative fitness equal to zero and spread probability of $1\text{-}P(Loop_i)$ to another search space then give probability $P(Loop_i)$ to element which has maximum fitness, this process is done for all variables of that row of L. Sometimes existence some maximum fitness specially at final steps. In SDE, algorithm predicted this topic and probability of $P(Loop_i)$ is spread relative to their repetition.

Step 5) Plot AF for every variable (horizontal axis is first column of AF and vertical axis is second column of AF). Now area under curve, should be equal to one or one hundred percent. Calculate area under curve for all alternatives of every variable using Eq. (4):

$$MArea_{ij} = \frac{Area_{ij}}{\sum_{i=1}^{NL} Area_{ij}} \tag{4}$$

Where $MArea_{ij}$ and $Area_{ij}$ are the modified area and area under the AF curve for the ith row and jth variable, respectively. Now generated $[MArea]_{NOL\times 2}$ and the first column of this matrix is like $[AF]_{NOL\times 2}$ and the second column of this matrix is $MArea_{ij}$, if plot this matrix like AF, area under curve is equal to one or one hundred percent.

DE algorithm using Eq. (5) for this aim [14]

$$P_{ij} = \frac{AF_{ij}}{\sum_{i=1}^{LA_j} AF_{ij}} \tag{5}$$

However, Eq. (5) did not guarantee that area under curve is equal to one.

Step 6) In this section, as result of the current loop, should fill $[L]_{NL\times NV}$ matrix for the next Loop. Different actions can be done for this aim, in SDE algorithm for picking the new answers for $[L]_{NL\times NV}$ matrix. One of the simplest ways is selected. Since the curve under

MArea is equal to one or one hundred percent algorithm pick, the new number to increase from this curve in area under curve is as specify percent. Specific value is $\frac{100\%}{NL}$. So for increasing this value of percent, SDE algorithm pick new element this process continue until every column is filled (for every variable) for $[L]_{NL\times NV}$ matrix. Then, pick NL elements from every MArea curve.

As mentioned in section 2.1 and step 3 after all steps were done independently for every variable, we should do some process for the integration this matrix. If this act is not done, there is no assurance that it occurs well results in one row together. It can be modeled as information processing in dolphin's brain. When information is received, the dolphin first processes them and then decides for the next movement, so $[L]_{NL\times NV}$ matrix should be reordered. This is the most important change in SDE algorithm. In SDE algorithm, one of the simplest ways to reorder $[L]_{NL\times NV}$ matrix before evaluating fitness is as follow:

For the jth variable, put other variables equal to constant value and Evaluate fitness then arrange the jth variable in order of ascending fitness do this process for all variables. Now the final row of $[L]_{NL\times NV}$ matrix is the best result of same Loop. In addition, it is better to replace first row of $[L]_{NL\times NV}$, worst one, with last row of the previous Loop to give a memory to algorithm not to get away from better answer. It is better to reorder $[L]_{NL\times NV}$ matrix for first Loop too, this can increase the speed of convergence. Repeat step 1 to step 2 as Loop numbers. Number of evaluation in SDE is [Locations + (NV × Locations)] × LoopNumber.

3. WEIGHT OPTIMIZATION OF STEEL TRUSS STRUCTURES PROBLEMS

In this section, to show the efficiency of the SDE algorithm and to compare its results with other methods some famous truss problems are presented. Stiffness method applied for analysis of trusses and Matlab software is used for optimal design of trusses. The penalty approach used for control of constraints. Clearly if the constraints are not violated, the coefficient of the penalty will be zero. The aim is to find a minimum weight for elements groups of trusses considering the constraints.

3.1 A 25-bar spatial truss

Size optimization of the 25-bar planar truss shown in Fig. 3 is considered. This is a well known problem in weight optimization of the structures literature. The material density is considered as 0.1 lb/in^3 and the modulus of elasticity is taken as 10,000 ksi . Table 1 illustrates the two load cases for this problem. The structure includes 25 members, which are divided into eight groups, as follows: (1) A1, (2) A2–A5, (3) A6–A9, (4) A10–A11, (5) A12–A13, (6) A14–A17, (7) A18– A21 and (8) A22–A25.

Maximum displacement limitations of ±0.35 in, are imposed on every node in every direction. The range of the cross-sectional areas varies from 0.01 to 3.4 in^2. This optimization problem is solved by proposed algorithm and the results are shown in Table 2, which is compared with GA [16], PSO [17], HS [18], RO [10] and CBO [12]. The best weight of the SDE is 547.86 with AC equal to 4. Fig. 4 shows the convergence diagram of the SDE in 10 loops. Number of evaluations in this problem is only 1800 with SDE, which is less than other methods, for example number of evaluations in PSO, HS, RO and CBO are 9596, 15000, 13880 and 9090, respectively. Location number considered 20 for this problem.

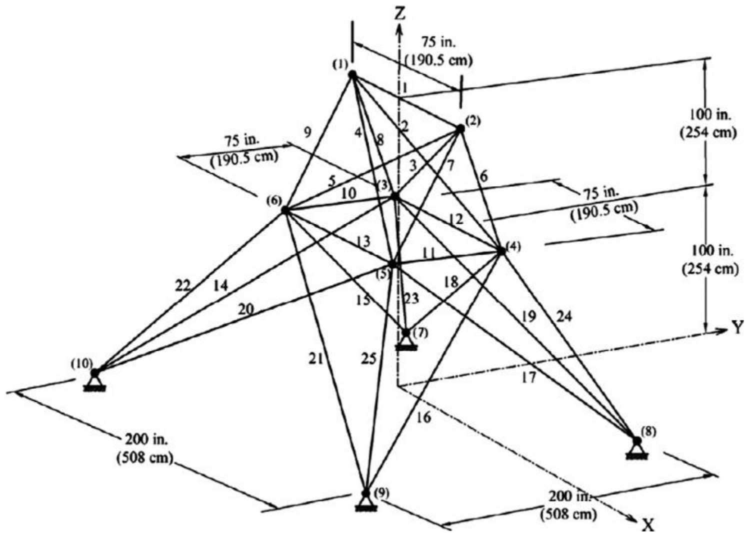

Figure 3. Schematic of a 25-bar spatial truss

Table 1: Loading conditions for the 25-bar spatial truss

Node	Case 1			Case 2		
	P_x kips	P_Y kips	P_z kips	P_x kips	P_Y kips	P_z kips
1	0	20	-5	1	10	-5
2	0	-20	-5	0	10	-5
3	0	0	0	0.5	0	0
4	0	0	0	0.5	0	0

Table 2: Comparison of SDE results with other methods in the 25-bar spatial truss

Element Group		Optimal cross-sectional areas (in^2)						
		GA	PSO	HS	RO	CBO	SDE (AC=3)	SDE (AC=4)
1	A1	0.1	0.01	0.047	0.0157	0.01	0.01	0.01
2	A2-A5	1.8	2.121	2.022	2.0217	2.1297	1.93	2.0832
3	A6-A9	2.3	2.893	2.95	2.9319	2.8865	2.872	2.9141
4	A10-A11	0.2	0.01	0.01	0.0102	0.01	0.01	0.01
5	A12-A13	0.1	0.01	0.014	0.0109	0.01	0.01	0.01
6	A14-A17	0.8	0.671	0.688	0.6563	0.6792	0.9	0.6959
7	A18-A21	1.8	1.611	1.657	1.6793	1.6077	1.79	1.6319
8	A22-A25	3	2.717	2.663	2.7163	2.6927	2.515	2.7272
Weight (lb)		546	545.21	544.38	544.656	544.31	552.9891	547.86

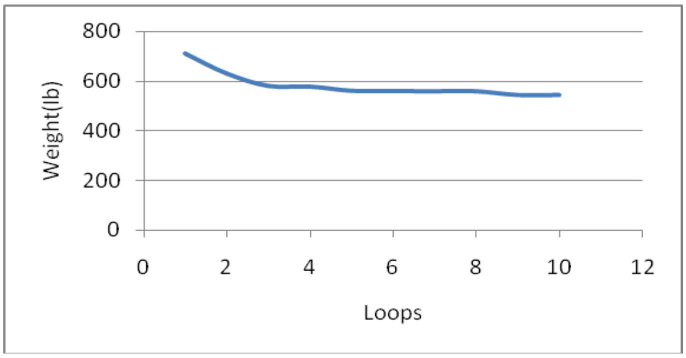

Figure. 4 The convergence diagram for the 25-bar spatial truss

3.2 A 52-bar planar truss

Wu and Chow [19], Lee and Geem [20] and Li et al [21] have analyzed the 52-bar planar truss structure shown in Fig. 5. The members of this structure are divided into 12 groups: (1) A1_A4, (2) A5_A10, (3) A11_A13, (4) A14_A17, (5) A18_A23, (6) A24_A26, (7) A27_A30, (8) A31_A36, (9) A37_A39, (10) A40_A43, (11) A44_A49, and (12) A50_A52. The material density is 7860 kg/m^3 and the modulus of elasticity is 2.07×105 MPa. The members are subjected to stress limitations of ±180 MPa. Both of the loads, P_x=100 kN and P_y=200 kN, are considered. The discrete variables are selected from Table 3.

Table 4 shows the comparison of optimal design results, which is compared with GA [19], HS [20], PSO [21], Particle Swarm Optimizer with Passive Congregation (PSOPC) [21], A heuristic particle swarm optimizer (HPSO) [21]. The best weight of the SDE is 1904.126 kg. Fig. 6 shows the convergence diagram of the SDE in 20 loops. Number of evaluations in this problem is only 3900 with SDE, which is less than other methods. Location number considered 15 for this problem.

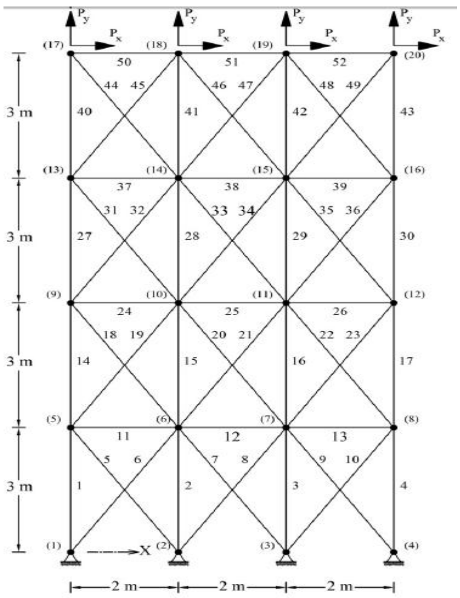

Figure 5. Schematic of a 52-bar planar truss

Table 3: The available cross-section areas of the AISC code

The available cross-section areas of the AISC code					
No	In^2	mm^2	No	In^2	mm^2
1	0.111	71.613	33	3.84	2477.414
2	0.141	90.968	34	3.87	2496.769
3	0.196	126.451	35	3.88	2503.221
4	0.25	161.29	36	4.18	2696.769
5	0.307	198.064	37	4.22	2722.575
6	0.391	252.258	38	4.49	2896.768
7	0.442	285.161	39	4.59	2961.284
8	0.563	363.225	40	4.8	3096.768
9	0.602	388.386	41	4.97	3206.445
10	0.766	494.193	42	5.12	3303.219
11	0.785	506.451	43	5.74	3703.218
12	0.994	641.289	44	7.22	4658.055
13	1	645.16	45	7.97	5141.925
14	1.13	729.031	46	8.53	5503.215
15	1.228	792.256	47	9.3	5999.988
16	1.266	816.773	48	10.85	6999.986
17	1.457	939.998	49	11.5	7419.43
18	1.563	1008.385	50	13.5	8709.66
19	1.62	1045.159	51	13.9	8967.724
20	1.8	1161.288	52	14.2	9161.272
21	1.99	1283.868	53	15.5	9999.98
22	2.13	1374.191	54	16	10322.56
23	2.38	1535.481	55	16.9	10903.2
24	2.62	1690.319	56	18.8	12129.01
25	2.63	1696.771	57	19.9	12838.68
26	2.88	1858.061	58	22	14193.52
27	2.93	1890.319	59	22.9	14774.16
28	3.09	1993.544	60	24.5	15806.42
29	3.38	2180.641	61	26.5	17096.74
30	3.47	2238.705	62	28	18064.48
31	3.55	2290.318	63	30	19354.8
32	3.63	2341.931	64	33.5	21612.86

Table 4: Comparison of SDE results with other methods in the 52-bar planar truss

Element Group		Optimal cross-sectional areas (mm^2)					
		GA	HS	PSO	PSOPC	HPSO	SDE
1	A1-A4	4658.055	4658.055	4658.055	5999.988	4658.055	4658.055
2	A5-A10	1161.288	1161.288	1374.19	1008.38	1161.288	1161.288
3	A11-A13	645.16	506.451	1858.06	2696.38	363.225	363.225
4	A14-A17	3303.219	3303.219	3206.44	3206.44	3303.219	3303.219

5	A18-A23	1045.159	940	1283.87	1161.29	940	939.998
6	A24-A26	494.193	494.193	252.26	729.03	494.193	641.289
7	A27-A30	2477.414	2290.318	3303.22	2238.71	2238.705	2238.705
8	A31-A36	1045.159	1008.385	1045.16	1008.38	1008.385	1008.385
9	A37-A39	285.161	2290.318	126.45	494.19	388.386	363.225
10	A40-A43	1696.771	1535.481	2341.93	1283.87	1283.868	1283.868
11	A44-A49	1045.159	1045.159	1008.38	1161.29	1161.288	1161.288
12	A50-A52	641.289	506.451	1045.16	494.19	792.256	641.289
Weight (kg)		1970.142	1906.76	2230.16	2146.63	1905.49	1904.126

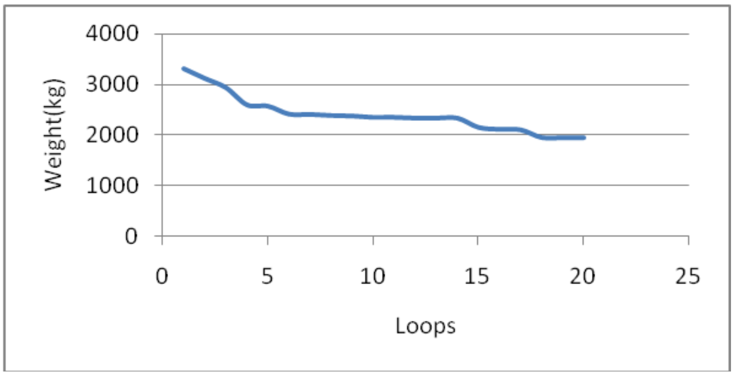

Figure 6. The convergence diagram for the 52-bar planar truss

3.3 A 72-bar spatial truss

For the 72-bar spatial truss structure shown in Fig. 7, the elements are sorted in 16 design groups:

(1) A1_A4, (2) A5_A12, (3) A13_A16, (4) A17_A18, (5) A19_A22, (6) A23_A30, (7) A31_A34, (8) A35_A36, (9) A37_A40, (10) A41_A48, (11) A49_A52, (12) A53_A54, (13) A55_A58, (14) A59_A66 (15), A67_A70, and (16) A71_A72.

The material density is 0.1 lb/in^3 and the modulus of elasticity is taken as 10,000 ksi. The members are subjected to the stress limits of ±25 ksi. The nodes are subjected to the displacement limits of ±0.25 in. The minimum permitted cross-sectional area of each member is taken as 0.10 in^2, and the maximum cross-sectional area of each member is 4.00 in^2. The loading conditions are considered as:

1. Loads 5, 5 and -5 kips in the x, y and z directions at node 17, respectively.
2. A load -5 kips in the z direction at nodes 17, 18, 19 and 20.

Table 5 shows the results obtained by SDE and those of the previously reported researches. The best result of the SDE method is 380.28 Ib. The results are compared with GA [22], ACO [23], PSO [24], Big Bang–Big Crunch optimization (BB–BC) [25], RO [10], Cuckoo Search algorithm with levy flights (CS) [26] and CBO algorithm [12]. Fig. 8 shows the convergence diagrams in terms of the number of loops and AC equal to 10 and 3, respectively. Number of evaluations in this problem is only 6800 with SDE, which is less than other methods, for example, number of evaluations in ACO, BB–BC, RO, CS and CBO algorithm are 18500, 19621, 19084, 10600 and 15600, respectively. Location number considered 20 for this problem.

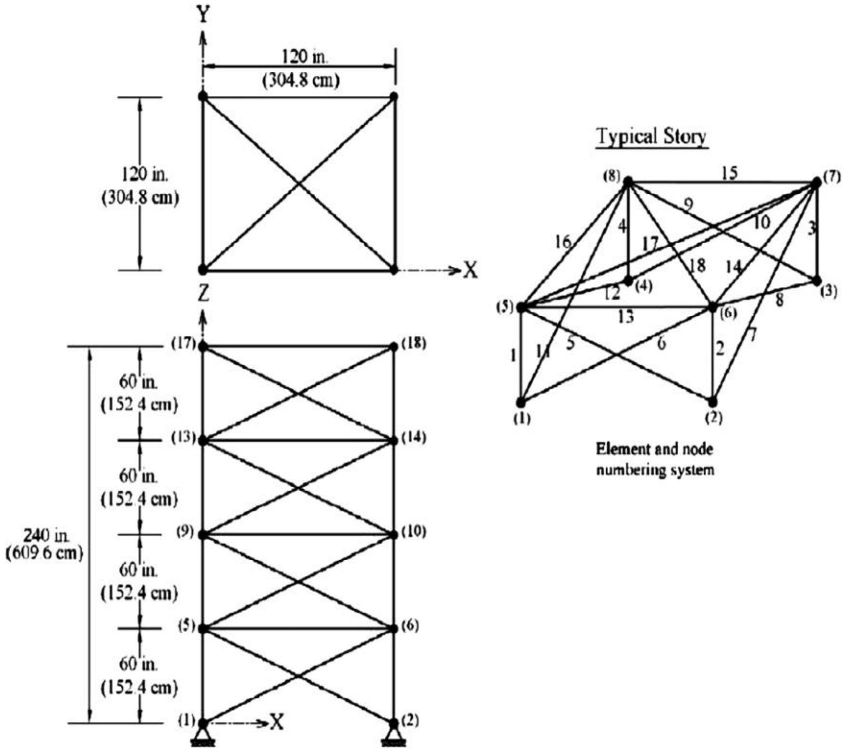

Figure 7. Schematic of a 72-bar spatial truss

Table 5: Comparison of SDE results with other methods in the 72-bar spatial truss

		Optimal cross-sectional areas (in^2)								
Element Group		GA	ACO	PSO	BB-BC	RO	CS	CBO	SDE AC=1	SDE AC=3
1	A1-A4	1.755	1.948	1.7427	1.8577	1.8365	1.9122	1.9028	2	1.91
2	A5-A12	0.505	0.508	0.5185	0.5059	0.5021	0.5101	0.518	0.5	0.513
3	A13-A16	0.105	0.101	0.1	0.1	0.1	0.1000	0.1001	0.1	0.1
4	A17-A18	0.155	0.102	0.1	0.1	0.1004	0.1000	0.1003	0.1	0.1
5	A19-A22	1.155	1.303	1.3079	1.2476	1.2522	1.2577	1.2787	1.3	1.257
6	A23-A30	0.585	0.511	0.5193	0.5269	0.5033	0.5128	0.5074	0.5	0.515
7	A31-A34	0.1	0.101	0.1	0.1	0.1002	0.1000	0.1003	0.1	0.1
8	A35-A36	0.1	0.1	0.1	0.1012	0.1001	0.1000	0.1003	0.1	0.1
9	A37-A40	0.46	0.561	0.5142	0.5209	0.573	0.5229	0.524	0.5	0.512
10	A41-A48	0.53	0.492	0.5464	0.5172	0.5499	0.5177	0.515	0.5	0.515
11	A49-A52	0.12	0.1	0.1	0.1004	0.1004	0.1000	0.1002	0.1	0.114
12	A53-A54	0.165	0.107	0.1095	0.1005	0.1001	0.1000	0.1015	0.1	0.114
13	A55-A58	0.155	0.156	0.1615	0.1565	0.1576	0.1566	0.1564	0.2	0.155
14	A59-A66	0.535	0.55	0.5092	0.5507	0.5222	0.5406	0.5494	0.6	0.541
15	A67-A70	0.48	0.39	0.4967	0.3922	0.4356	0.4152	0.4029	0.4	0.41
16	A71-A72	0.52	0.592	0.5619	0.5922	0.5971	0.5701	0.5504	0.6	0.565
Weight (lb)		385.76	380.24	381.91	379.85	380.458	379.63	379.6943	385.54	380.28

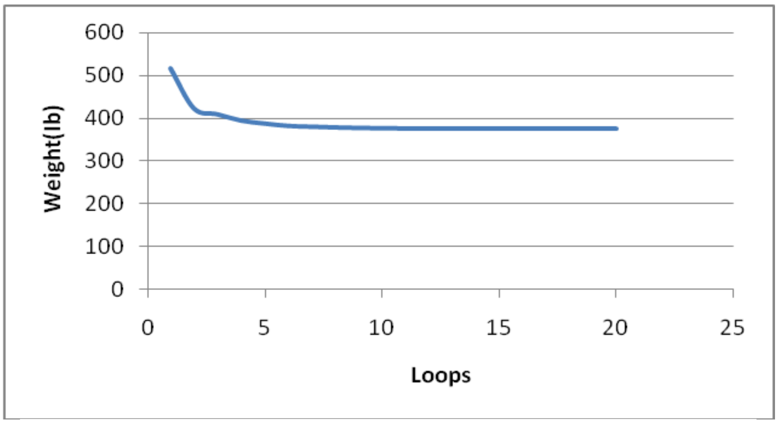

Figure 8. The convergence diagram for the 72-bar spatial truss

3.4 A 582-bar tower truss

The 582-bar tower truss with the height of 80 m, shown in Fig. 9. This problem is chosen as the last problem. The symmetry of the tower around x-axis and y-axis is considered to group the 582 members into 32 independent size variables. A single load case is considered such that it consists of lateral loads of 5.0 kN applied in both x and y directions and a vertical load of -30 kN applied in the z-direction at all nodes of the tower. A discrete set of 137 economical standard steel sections selected from W-shape profile list based on area and radii of gyration properties is used to size the variables. The lower and upper bounds on size variables are taken as 39.74 cm^2 and 1387.09 cm2, respectively. The stress limitations of the members are imposed according to the provisions of ASD-AISC [27], as Eqs. (6)-(8).

$$\begin{cases} \sigma_i^+ = 0.6F_y & for\sigma_i \geq 0 \\ \sigma_i^- = & for\sigma_i < 0 \end{cases} \tag{6}$$

where σ_i^- is calculated according to the slenderness ratio

$$\sigma_i^- = \begin{cases} (1-\frac{\lambda_i^2}{2C_c})F_y/(\frac{5}{3}+\frac{3\lambda_i}{8C_c}-\frac{\lambda_i^3}{8C_c^3}) & for\lambda_i < C_c \\ 12\pi^2 E/23\lambda_i^2 & for\lambda_i \geq C_c \end{cases} \tag{7}$$

Where E= the modulus of elasticity; F_y=the yield stress of steel; C_C=the slenderness ratio (λ_i) dividing the elastic and inelastic buckling regions ($C_C=\sqrt{2\pi^2 E/F_y}$); λ_i = the slenderness ratio (λ_i = kL_i/r_i); k = the effective length factor; L_i= the member length and r_i = the radius of gyration. The other constraint is the limitation of node displacements (no more than 8.0 cm or 3.15 in. in any direction). In addition, the maximum slenderness ratio is limited to 300 for tension members, and it is recommended to be 200 for compression members according to ASD-AISC design code provisions, which can be formulated as follows:

$$\begin{cases} \lambda_m = \dfrac{k_m l_m}{r_m} \le 300 & \text{for tension members} \\ \lambda_m = \dfrac{k_m l_m}{r_m} \le 200 & \text{for compression members} \end{cases} \tag{8}$$

where k_m is the effective length factor of the mth member (k_m= 1 for all truss members), and r_m is its minimum radius of gyration.

SDE has obtained the best design compared to some other methods such as SA, tabu search, ACO, HS and GA reported by Hasançebi et al [28]. Table 6 shows the best solutions of the PSO [28] and Particle Swarm Ant Colony Optimization (DHPSACO) [29] and SDE algorithms. The optimum result of the SDE is 21.225 m^3, while it is 22.39 m^3 and 22.06 m^3 for the PSO and DHPSACO algorithms. Fig. 10 compares the allowable and existing stress ratio and displacement values of the SDE. The maximum values of displacements in the x, y and z directions are 7.99 cm, 7.6 cm and 2.39 cm, respectively and the maximum stress ratio is 90.52%. Fig. 11 shows the convergence diagram of the SDE in 10 loops. Number of evaluations in this problem is only 6600 with SDE, which is less than other methods. Location number considered 20 for this problem.

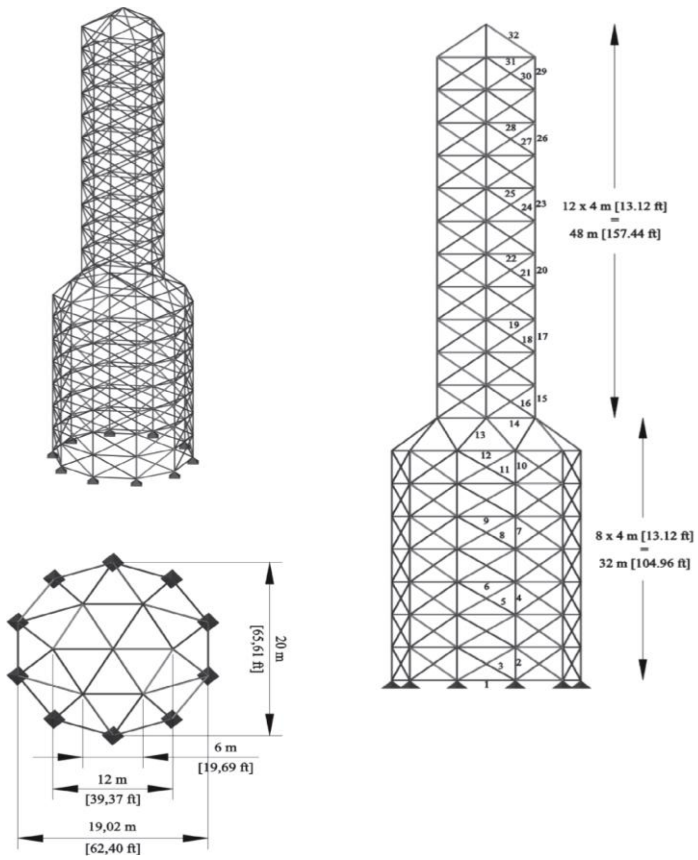

Figure 9. Schematic of a 582-bar tower truss

Table 6: Comparison of SDE results with other methods in the 582-bar tower truss

Element Group	Optimal cross-sectional areas (in^2)		
	PSO	DHPSACO	SDE
1	39.74	45.68	39.74186
2	149.68	136.13	136.1288
3	45.68	53.16	53.2257
4	113.55	109.68	115.4836
5	45.68	45.68	45.67733
6	39.74	45.68	39.74186
7	90.97	92.9	92.90304
8	45.68	45.68	45.67733
9	39.74	45.68	39.74186
10	85.81	75.48	85.80628
11	45.68	56.71	45.67733
12	129.03	136.129	123.2256
13	140.65	143.87	146.4513
14	90.97	92.9	92.90304
15	143.87	154.84	143.8707
16	55.9	58.84	58.90311
17	39.74	115.48	115.4836
18	127.1	45.68	45.67733
19	45.68	39.74	39.74186
20	39.74	75.48	64.516
21	75.48	45.68	45.67733
22	45.68	41.87	39.74186
23	39.74	58.84	47.35474
24	41.87	53.16	45.67733
25	45.68	39.74	39.74186
26	39.74	39.74	39.74186
27	39.74	45.68	45.67733
28	45.68	53.16	39.74186
29	39.74	68.39	39.74186
30	39.74	45.68	45.67733
31	45.68	39.74	39.74186
32	45.68	45.68	49.35474
Volume(m^3)	22.3958	22.0607	21.225

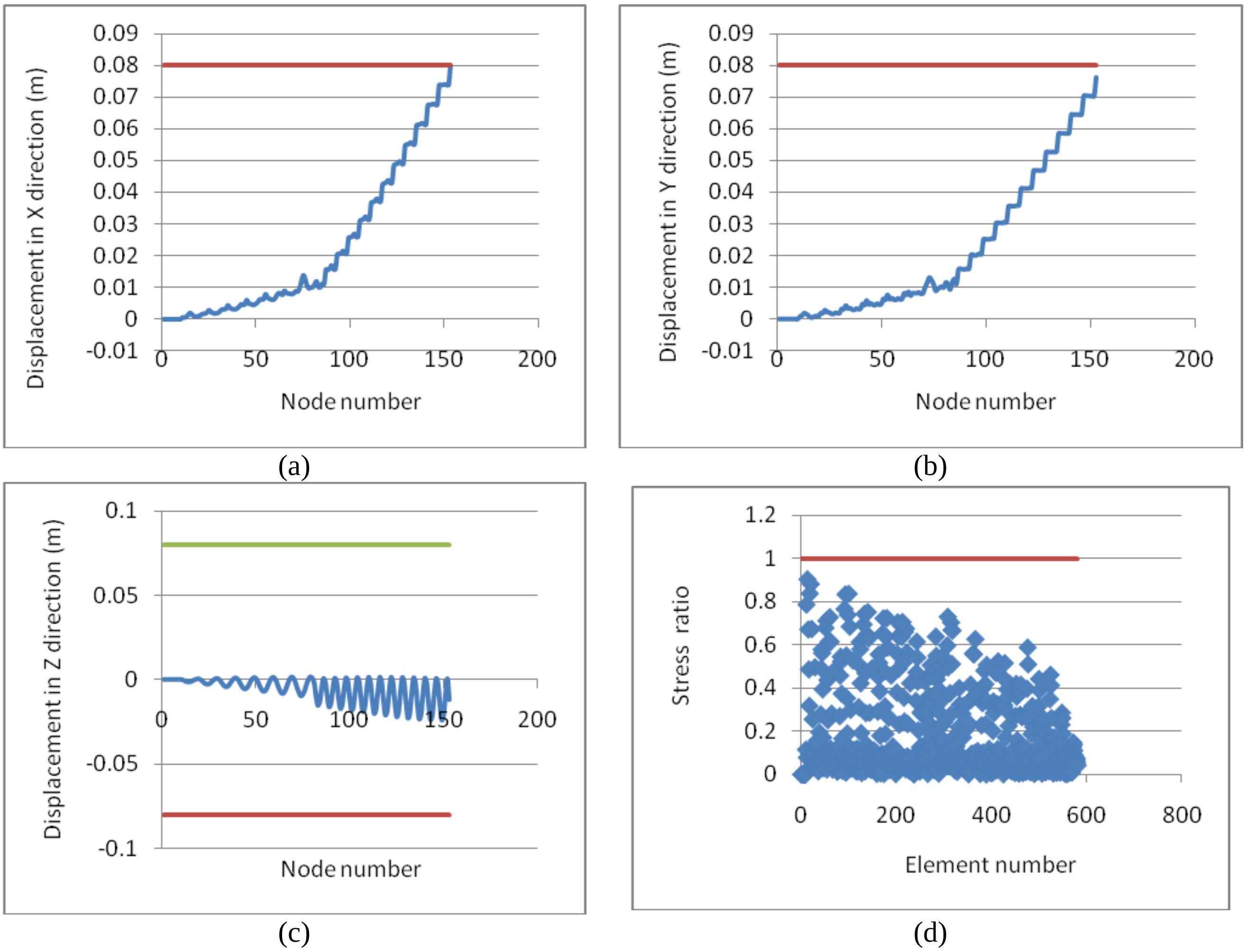

Figure 10. Comparison of the allowable and existing constraints for the 582-bar truss using the SDE. (a) Displacement in the X-direction. (b) Displacement in the Y-direction. (c) Displacement in the Z-direction. (d) Stress ratio

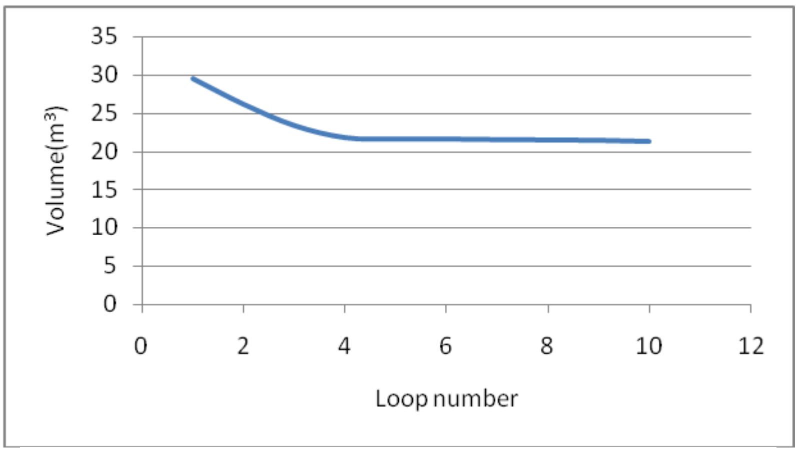

Figure 11. The convergence diagram for the 582-bar tower truss

4. CONCLUSIONS

A new metaheuristic method called SDE is developed to improve the performance of the DE algorithm. DE algorithm adopted from hunting dolphins. Dolphin can send sound in the form of click and then receive it as echo then choose the best bait and it's orientation but in this paper, dolphin process information before choose the bait. Four well-studied Weight optimization of steel truss structures problems are considered to show the efficiently of SDE method.

SDE algorithm has more accuracy compared with DE algorithm and speed of convergence is higher than DE algorithm. In SDE algorithm, does not need Alternatives matrix, when search space is large, more time is needed to generate this matrix and find the position of $[L]_{NL\times NV}$. Also SDE algorithm do not need power, ε and Re parameters, R_e calculates automatically. A new parameter is defined as AC that can determine the accuracy of variables. Prediction probability of occurrence is the same in maximum fitness in SDE algorithm. In SDE algorithm, is guaranteed to be equal to 100 percent or 1 in the area under the curve. Reordering of $[L]_{NL\times NV}$ matrix in SDE algorithm causes to increase the accuracy of algorithm and increases the speed of convergence.

The results of some benchmark problems illustrate that the SDE has a good performance and it can be used for other optimization problems, the results show that SDE is competitive with other algorithms. Finally, SDE algorithm can be used for continuous and discrete variables but DE algorithm only can be used for discrete variables.

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