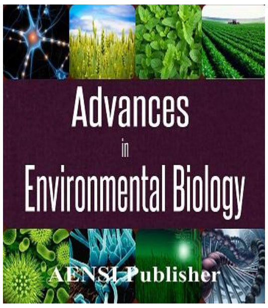
Advances in Environmental Biology, 9(2) January 2015, Pages: 267-276

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/



Shape and size optimization of truss structures by using differential evolution algorithm

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ARTICLE INFO

Received 11 October 2014
Received in revised form 21 November 2014
Accepted 25 December 2014
Available online 16 January 2015

Keywords:
Truss structures, optimizing the size, shape optimization, differential evolution algorithm

ABSTRACT

Due to the fact that one of the main factors in the cost structure is the amount of materials, thus, in addition to satisfying all engineers prefer to design constraints, to minimize the use of materials to reduce structural weight. This is done easily using the optimal design of structures is possible. In this study, the size and shape optimization of truss structures is discussed. To this end, a number of structural truss as standard examples of authoritative elected. The optimization of new optimization techniques as differential evolution algorithm is used.Design variables include cross members and coordinate structures are nodes And the total weight of the structure as well as the objective function is selected. Design constraints limit the tension members, the node locations and some geometric constraints. Optimization of differential evolution algorithm shows good performance.

To Cite This Article: Mohammad Dashtbozorgi, Shape and size optimization of truss structures by using differential evolution algorithm. ***Adv. Environ. Biol., 9(2),*** *267-276, 2015*

INTRODUCTION

Due to limited resources and equipment to carry out most of the development projects, optimal use of existing facilities to reduce costs, it is necessary. Due to major advances in optimization techniques have been achieved, its application in engineering sciences, especially in civil engineering is becoming more and more attention. In the classical methods, including methods of numerical analysis and optimization of structures were used.

But each of these methods, have their own limitations. For example, many numerical methods to achieve local optimization and the ability to find the global optimum cannot be stopped.

The analytical method requires derivatives of the objective function is

But in some engineering problems finding a clear relationship to the objective function in terms of design variables is impossible.

Development issues and the importance of optimizing the overall efficiency and accountability of the classic method, Space is full of random detection methods have been more welcoming.

Differential evolution algorithm is one of the newest methods based on population based random search To optimization problems in continuous mode is provided. In this paper, in order to optimize the weight of the truss, the complex variable crosses section as a discrete variable. And the location of nodes truss design as a continuous variable, selected the desired constraints, limitations and restrictions of stresses and displacements are satisfied.

2-The differential evolution algorithm (DE):

Differential Evolution was introduced in 1997 by Astern and Price. Stochastic differential evolution algorithm based on population counts, including evolutionary algorithms.

The behavior of this algorithm is a random behavior Using a series of proposed response optimization process begins And through a series of successive iterations to obtain better results. Besides the general similarities to other evolutionary algorithms such as genetic algorithms, differential evolution, etc,.A new method of differential evolution algorithm, a unique way.

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2-1- the differential evolution algorithm:

Differential evolution algorithm has 4 major steps which are described below, each of these steps.

The first step) initialization The first step is to determine the objective function and parameters. Parameter vector equation (1) can be expressed.

$$X_{i,G} = [\, X_{1,i,G} \;,\; X_{2,i,G} \;,\; X_{3,i,G} \;, \ldots ,\; X_{D,i,G} \,] \quad (1)$$
$$i = 1, 2, 3, \ldots NP$$

Where D is the number of parameters ,NP population size (the minimum value is equal to 4(And G is the number of iterations.Then each of the parameters of the problem, according to equation (2) between the top and bottom of your chosen randomly.

$$X_j^L \leq X_{i,j} \leq X_j^U \quad (2)$$
$$j = 1, 2, 3, \ldots, D \text{ and } i = 1, 2, 3, \ldots, NP$$

XjL XjU values and upper and lower bounds, respectively, is the j-th variable. The second step) mutation To expand the search space is the use of mutation. To create the mutant vector of equation (3) is used.

$$V_{i,j,G+1} = X_{r1,j,G} + f\,(X_{r2,j,G} - X_{r3,j,G}) \quad (3)$$
$$i = 1, 2, 3, \ldots, NP \text{ and } r_1 \neq r_2 \neq r_3 \neq i$$

Where Vi, j, G + 1 mutant vector, r1 and r2 and r3 and true random numbers in the interval [1, 2, 3, ... , NP[And f parameter scale factor (mutation) is a fixed number in the interval 0, 2] is.Step Three) intersection In order to increase the difference between the initial vector Xi, G mutant vector Vi, G + 1 from A test vector is used.

To create a test vector from equation (4) is used.

$$U_{i,G+1} = \begin{cases} V_{i,G+1} & \text{if } randb(j) \leq PCR \text{ or } j = rnbr(i) \\ X_{i,G} & \text{if } randb(j) > PCR \text{ and } j \neq rnbr(i) \end{cases} \quad (4)$$
$$i = 1, 2, 3, \ldots, NP \qquad j = 1, 2, 3, \ldots, D$$

That Ui, G + 1 vectors trial (Trial ,(ran dB (j) a random number in the interval [0, 1 of the j-th parameter, rnbr (i) and true random number in the range [1, 2, 3, ... , D [PCR and the possibility of crossing a fixed number in the interval [0, 1.[

Step Four) Select:

To create a new parameter vector Xi, G + 1, according to equation (5) the value of the objective function based on the parameters of the vector Ui, G + 1 obtained and the values of the objective function based on the parameters of the vector Xi, G specify. Now Agra target for vector parameters Ui, G + 1 better response than the vector parameters Xi, G is,

Vector parameters Ui, G + 1 in new vector Xi, G + 1 set

Otherwise, the parameter vector Xi, G's new vector Xi, G + 1 button.

$$X_{i,G+1} = \begin{cases} U_{i,G+1} & \text{if } F(U_{i,G+1}) \leq F(X_{i,G}) \\ X_{i,G} & \textit{in other hand} \end{cases} \quad (5)$$

If the algorithm terminates if convergence was achieved Otherwise, it should return to the takeoff.

3-The problem of optimization of truss structures:

Truss structure optimization problem under constraints of displacement and stress are examined

And the overall shape of the optimal design problem with equation (6) can be expressed:

$$\text{Find} : X^T = [\, x_1 , x_2 , x_3 , \ldots x_n \,] \quad (6)$$
$$\text{Minimize: } F(X)$$
$$\text{Subject to: } g_i(X) \leq 0 \qquad i = 1, 2, \ldots, m$$
$$i = 1, 2, \ldots n \qquad x_i^L \leq x_i \leq x_i^U$$

Where X is the vector of design variables, F (X) function Gi (X) constraint i is the design, xiU and xiL respectively upper and lower bounds of the variable i is

3-1- design variables:

Design variables of the cross members and coordinate node truss structure is formed by equation (7) are as follows:

X = [a1, a2, ...ang, x1, y1, x2, y2 ... .xi, yi]

Where X is the vector of design variables An cross-section of members of the group n, ng the number of groups in the structure And xi and yi coordinates of node i

3-2 design constraints:

Provisions designed to limit the stress in the member, the knots and some geometric constraints. Constraints on nodes and restraints shift in the tension members with relations (8) and (9) can be expressed:

$$g_{dj}(X) = \frac{\delta_j}{\delta_{ju}} - 1 \le 0 \quad j = 1, 2, \ldots, nj \tag{8}$$

$$g_{sj}(X) = \frac{\sigma_i}{\sigma_{ia}} - 1 \le 0 \quad i = 1, 2, \ldots, ne \tag{9}$$

Δj shift the node j δju shift allowed node j, nj the number of nodes of the structure, iσ tension member i, ia σ allowable stress in the member I And ne is the total number of structures.

3-3- The objective function:

The objective function is the total weight of truss structures with equation (10) can be expressed:

Σ_ (n = 1) ^ ng▒〖x_n Σ_ (i = 1) ^ nm▒〖γ_i l_i W (X)= (10)

The specific gravity of the material that γi i ,li the length of i ,nm n total number of group members Ng Tdadkl groups and trellises

3-4- Sub-objective function:

The purpose of this study was to function like equation (11) can be expressed:

F (X) = W (X) × (1 + rp × (Σ_ (j = 1) ^ nj▒max⁡〖 g_ (dj), 0) + Σ_ (i = 1) ^ ne▒max⁡〖 g_si, 0(〗〗((11)

Nj is the number of nodes in the structure Ne structural members Gdj mostly shift at node j Gsi mostly stress in member i And rp important factor in this study indicated that the amount of 1,000 is considered.

4- Numerical examples:

To evaluate the effectiveness of the proposed algorithm, the standard includes three examples of optimization problems dimensional 15-member truss, truss member 18 two-dimensional, three-dimensional truss member 25 is selected and the results of the current study are compared with the results presented in authoritative. In all instances the maximum number of iterations optimization is repeated 10,000 times And the algorithm convergence criterion is that the objective function is unchanged after 100 consecutive repetitions.

4-1-truss member 15:

Truss member 15 (Figure 2) is optimized by researchers in the past in different ways .This example is designed with 23 variables related to the cross-members 15 Variable 8 is designed to coordinate the structural nodes.The initial coordinates of the nodes of the structure in Figure 4 is shown.The vertical power structure kips 10 on 8 node is inserted.The maximum allowable stress is 25 ksi tensile and compression members equal.The specific gravity of the material used 0.1 lb / in3 and modulus of elasticity is equal to 10000 ksi.

Advances in Environmental Biology, 9(2) January 2015, Pages: 267-276

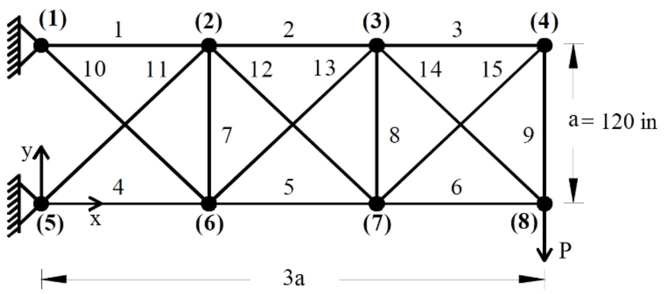

Fig. 2: 15-member truss

In order to optimize the structural coordinates of the nodes 2, 3, 6 and 7 in the direction of x and y are considered as design variables.

Because of the symmetry of the structure along the x coordinates of the nodes 6 and 7, respectively 2 and 3 are the coordinates of the nodes.

The coordinates of the nodes 4 and 8 in the y direction are also considered as design variables.

So the example in Figure 8 is used to optimize the design variables.Table 1 describes the range coordinates of the nodes.

Table 1: 15-member truss nodes coordinate range

Upper limit	Lower limit	Variety design(in)
140	100	$X_2 = X_6$
260	220	$X_3 = X_7$
140	100	Y_2
140	100	Y_3
90	50	Y_4
20	-20	Y_6
20	-20	Y_7
60	20	Y_8

Optimization of the structure of the design variables is discrete, The surface area used for optimization of {0.111, 0.141, 0.174, 0.220, 0.270, 0.287, 0.347, 0.440, 0.539, 0.954, 1.081, 1.174, 1.333, 1.488, 1.764, 2.142, 2.697, 2.800, 3.131, 3.565 , 3.813, 4.805, 5.952, 6.572, 7.192, 8.525, 9.300, 10.850, 13.330, 14.290, 17.170, 19.180} (in2) is.

Optimization of differential evolution algorithm with results from other methods in Table 2 is compared .In Table 2 we can see that the best solution to the differential evolution algorithm is an optimization method.Differential Evolution Algorithm Analysis in 5850 after structural weight is equal to 72.1596 lb In fact, the lowest weight (objective function problem) is compared with other methods Which reflects the performance of the algorithm is good.

Table 2: summarizes the results of the optimization process) truss member 15

Differential evolution algorithm	Rahami et al [6]	Tange et al [5]	Hwang and He [4]	Design variables
0.954	1.081	1.081	0.954	A_1
0.539	0.539	0.539	1.081	A_2
0.174	0.287	0.287	0.44	A_3
0.954	0.954	0.954	1.174	A_4
0.954	0.539	0.954	1.488	A_5
0.27	0.141	0.220	0.27	A_6
0.141	0.111	0.111	0.27	A_7
0.111	0.111	0.111	0.347	A_8
0.174	0.539	0.287	0.22	A_9
0.287	0.440	0.220	0.44	A_{10}
0.27	0.539	0.440	0.347	A_{11}
0.22	0.270	0.440	0.22	A_{12}
0.111	0.220	0.111	0.27	A_{13}
0.27	0.141	0.220	0.44	A_{14}
0.174	0.287	0.347	0.22	A_{15}
123.5288	101.577	133.612	118.346	X_2
239.1097	227.910	234.752	225.209	X_3
123.7913	134.790	100.449	119.046	Y_2
115.2114	128.220	104.738	105.086	Y_3
72.9700	54.860	73.762	63.375	Y_4
-13.5853	-16.440	-10.067	-20	Y_6

Advances in Environmental Biology, 9(2) January 2015, Pages: 267-276

3.8959	-13.300	-1.339	-20	Y_7
42.6027	54.850	50.402	57.722	Y_8
72.1596	76.68	79.82	104.573	Structure weight (lb)
5850	8000	8000	-------	The number of Analysis

Figure 3 graphs convergence of differential evolution algorithm with population size of 10, 30, 50, 60 and 100 shows. According to Figure 3, we can conclude that the best answer in the population size of 30 is obtained.

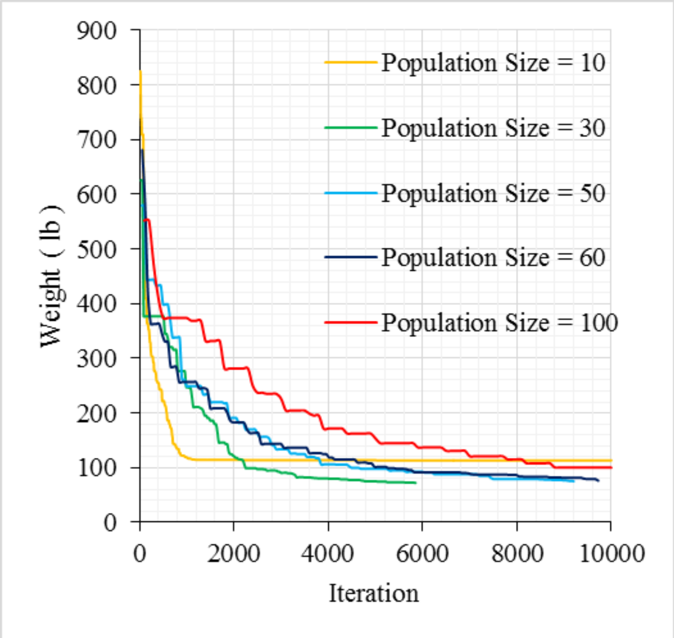

Fig. 3: graphs convergence differential evolution (truss member 15)

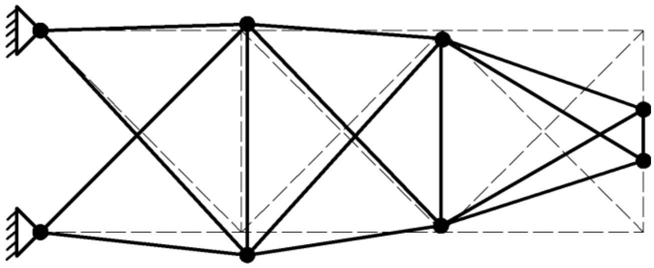

Fig. 4: shows the geometry optimization of truss member 15.

4-2- truss member 18:

Truss member 18 shown in Figure 5 A standard example is that many researchers have used it.

This example is a 12 Variable Variable 4 and 8 of the cross member variable node structure is designed to coordinate .The initial coordinates of the nodes of the structure in Figure 5 is shown.

The vertical power structure kips 20 of nodes 1, 2, 4.6 and 8 is inserted.The specific gravity of the material used 0.1 lb / in3 and modulus of elasticity is equal to 10000 ksi. The maximum allowable stress is 20 ksi tensile and compression members' equal .Euler buckling resistance of members of equation (12) is obtained.

i = 1, 2, ... , 18 b = (- 4EA_i) / (L_i ^ 2) σ (12)

In this regard, E is the modulus of elasticity, Ai Li i and the cross member I is a member

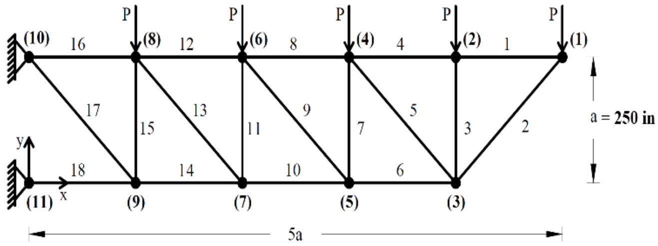

Fig. 5: 18-member truss

In order to optimize the structural coordinates of the nodes 3, 5, 7 and 9 in the x and y are considered as design variables .Table 3 describes the range coordinates of the nodes.

Table 3: changes the coordinates of the nodes of a truss member 18

Upper limit	Lower limit	Variable (in)
1225	775	X_3
975	525	X_5
725	275	X_7
475	25	X_9
245	-225	Y_3
245	-225	Y_5
245	-225	Y_7
245	-225	Y_9

In this example, the cross-section used to optimize the size of {2.25, 2.5, 2.75, 3, 3.25, 3.5, 3.75, 4, 4.25, 4.5, 4.75, 5, 5.25, 5.5, 5.75, 6, 6.25, 6.5, 6.75, 7, 7.25, 7.5, 7.75, 8, 8.25, 8.5, 8.75, 9, 9.25, 9.5, 9.75, 10, 10.25, 10.5, 10.75, 11, 11.25, 11.5, 11.75, 12, 12.25, 12.5, 12.75, 13, 13.25, 13.5, 13.75, 14, 14.25, 14.5, 14.75, 15, 15.25, 15.5, 15.75, 16, 16.25, 16.5, 16.75, 17, 17.25, 17.5, 17.75, 18, 18.25, 18.5, 18.75, 19, 19.25, 19.5, 19.75, 20, 20.25, 20.5, 20.75, 21, 21.25, 21.5, 21.75} (in2) is.The members of this structure is divided into four groups.Table (4) grouping structure member states.

Table 4: grouping 18 Part s of the truss member

Part	group
1, 4, 8, 12, 16	G_1
2, 6, 10, 14, 18	G_2
3, 7, 11, 15	G_3
5, 9, 13, 17	G_4

Optimization of differential evolution algorithm with the results of other methods (Table 5) is compared .In Table 5 we can see that the best solution to the differential evolution algorithm is an optimization method. Differential evolution algorithm after analyzing the structural weight of 4260 to 4518.3981 lb is The minimum weight (the goal is) compared to other methods is that it reflects the performance of the algorithm is good.

Table 5: The results of the optimization process) truss member 18

Differential evolution algorithm	Rahami et al [6]	Kaveh and Kalatjari [8]	Rajeev et al [7]	Design variety
12.25	12.25	12.25	12.50	A_1
17.75	18.25	18	16.25	A_2
6.25	4.75	5.25	8	A_3
3.0	3.25	4.25	4	A_4
905.4201	917.4475	913	891.90	X_3
162.0474	193.7899	186.8	145.3	Y_3
661.1116	645.3243	650	610.66	X_5
115.9873	159.9436	150.5	118.20	Y_5
416.1278	424.4821	418.8	385.40	X_7
89.1453	108.5779	97.4	72.50	Y_7
199.3669	208.4691	204.8	184.40	X_9
21.0595	37.6349	26.7	23.40	Y_9
4518.3981	4530.7	4547.9	4616.82	Structure weight (lb)
4290	-------	-------	-------	Number of analyze

Figure 6 graphs the differential evolution algorithm convergence in population size of 10, 30, 50, 60 and 100 shows. In the view of (6) we can conclude that in this case, the best response is obtained in 30 of the population.

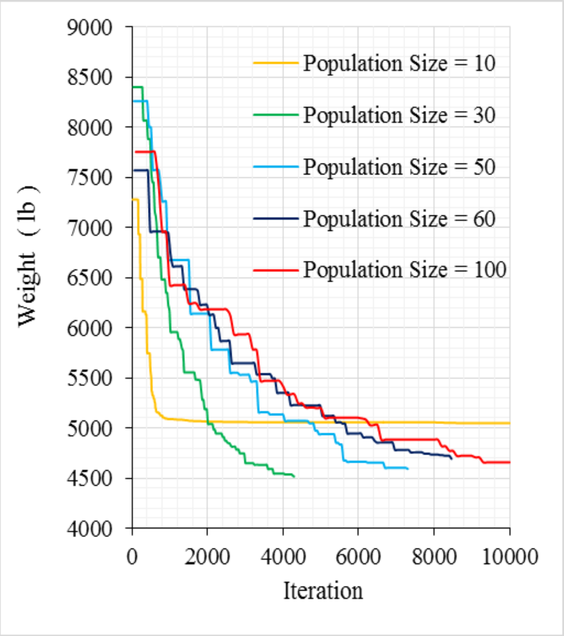

Fig. 6: graphs convergence differential evolution (truss member 18)

Figure 7 shows the geometry optimization of truss member 18:

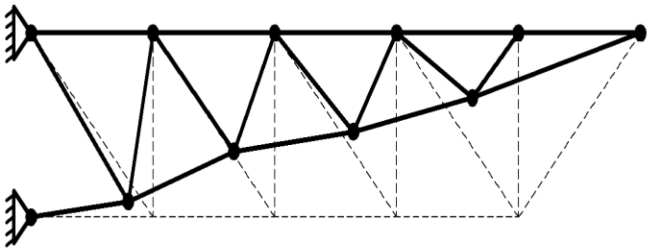

Fig. 7: optimized geometry truss member 18

4-3-truss member 25:

The truss member 25 (Figure 8) is used as the standard in some references. This example is a 13 Variable Variable 8 of the cross members and 5 variable node structure is designed to coordinate.

The initial coordinates of the nodes in the structure (8) is shown. The maximum allowable stress is 40 ksi tensile and compressive members of the And the maximum displacement of the node structure is in line with the 0.35 in.The specific gravity of the material used 0.1 lb / in3 and modulus of elasticity is equal to 10000 ksi.

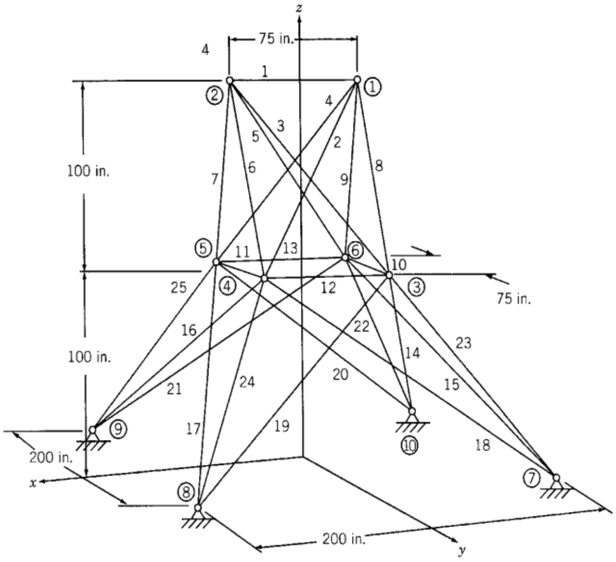

Fig. 8: 25 truss member

Loading structure (Table 6) is expressed

Table 6: loaded truss member 25

F_z (kips)	F_y (kips)	F_x (kips)	Number of nodes
-10	-10	1	1
-10	-10	0	2
0	0	0.5	3
0	0	0.6	6

The members of this structure are divided into eight groups. Table 7 shows the grouping of structural members.

Table 7: grouping 25 members of the truss member

part	group
1	G_1
2, 3, 4, 5	G_2
6, 7, 8, 9	G_3
10, 11	G_4
12, 13	G_5
14, 15, 16, 17	G_6
18, 19, 20, 21	G_7
22, 23, 24, 25	G_8

In order to optimize the structural coordinates of the nodes 3, 4, 5 and 6 in the x, y, and z coordinates of the nodes 7, 8, 9 and 10 in the x and y are considered as design variables. Because of the symmetry of the structure coordinates of nodes 3, 4, 5 and 6 in the x, y and z are equal. The coordinates of the nodes 7, 8, 9 and 10 in both the x and y are equal.So the example in Figure 5 is used to optimize the design variables.Table (8) changes the coordinates of the nodes implies

Table 8: changes the coordinates of the nodes of the truss member 25

Upper limit	Lower limit	Variable (in)
60	20	$X_4 = X_5 = -X_3 = -X_6$
80	40	$Y_4 = -Y_5 = Y_3 = -Y_6$
130	90	$Z_4 = Z_5 = Z_3 = -Z_6$
80	40	$X_8 = X_9 = -X_7 = -X_{10}$
140	100	$Y_8 = -Y_9 = Y_7 = -Y_{10}$

Cross sections consisting of {0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.8, 3.0, 3.2, 3.4} (in2) is.

Table 9 shows the response obtained in the optimization and also to compare the results of recent research results in authoritative deals By observing the results of the optimization process in the table (9), it can be concluded that the best response to the differential evolution optimization technique.

Table 9: The results of the optimization process) truss member 25

Differential evolution algorithm	Rahami et al [6]	Tang et al. [5]	Wu and Chow [3]	Design variety
0.1	0.1	0.1	0.1	A_1
0.1	0.1	0.1	0.2	A_2
0.9	1.1	1	1.1	A_3
0.1	0.1	0.1	0.2	A_4
0.1	0.1	0.1	0.3	A_5
0.1	0.1	0.2	0.1	A_6
0.1	0.2	0.2	0.2	A_7
1	0.8	0.7	0.9	A_8
36.3301	33.048	35.47	41.07	X_4
56.3445	53.5667	60.37	53.47	Y_4
126.2019	129.90	129.07	124.6	Z_4
50.8292	43.782	45.06	50.8	X_8
136.8557	136.83	137.04	131.48	Y_8
118.9665	120.115	124.94	136.2	Structure weight (lb)
5010	10000	6000	-------	Number of analyze

Figure 9 graphs convergence of differential evolution algorithm with population size of 10, 30, 50, 60 and 100 shows. With regard to the form (9), we can conclude that in this case, the best response is obtained in 30 of the population.

Advances in Environmental Biology, 9(2) January 2015, Pages: 267-276

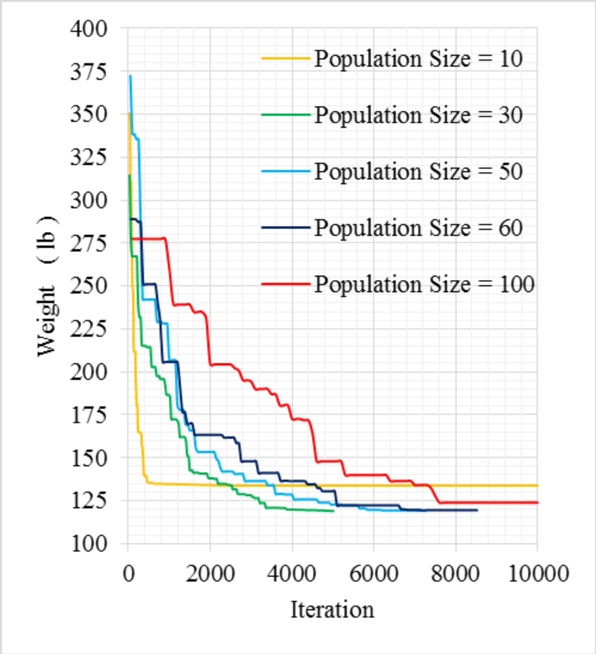

Fig. 9: Figure convergence differential evolution (truss member 25)

Figure 10 shows the geometry optimization of truss member 25:

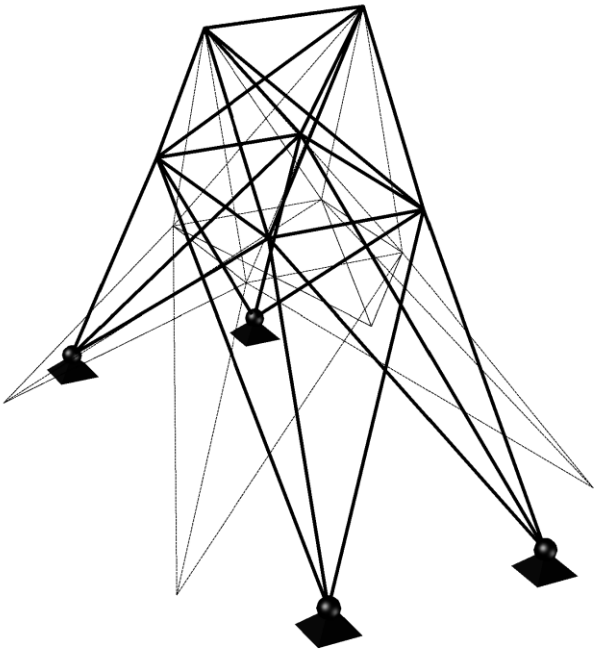

Fig. 10: geometry optimization of truss member 25

Conclusion:

In this study, the shape and size optimization of truss structures using differential evolution algorithm was discussed.To this end, a number of examples of good performance authoritative tests that the numerical results suggest that this method for the design of structures.

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