

Collaborative Optimization Computation Using Improved Genetic Algorithm and ANSYS

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Abstract. Aiming at the problems that it is difficult to calculate and establish accurate mathematical model in the structure optimization with discrete variables, the Lagrange multiplier method is proposed to deal with the constrain conditions in the improved genetic algorithm which solved the problems of “premature” and low efficiency in the simple genetic algorithm. The improved genetic algorithm is achieved by MATLAB, and it invoked the ANSYS software to conduct finite element calculations and data exchange. This collaborative algorithm is verified by two truss examples in this paper. Compared with other research results, the collaborative optimization computation using improved genetic algorithm and ANSYS based on Lagrange multiplier method can get better global optimal solution, and it also has high accuracy and good reliability.

Introduction

With the progress of science and technology, more and more large-sized and super large-sized structures are existed in actual production. These structures always should be optimized to achieving the minimum structure weight and minimum cost, one of the optimization way is to change the cross-section dimensions of the structure. But in actual cases, the large and complex structures have a large number of discrete variables, they are difficult to establish accurate mathematical model. The ANSYS is a kind of mature and practical finite element analysis software, which is usually to carry out practical and efficient numerical analysis, and it can provide parametric design to link other algorithms by APDL [1].

Due to the discreteness of design variables, the design range and objective function become discontinuous, so that the general mathematical programming method is difficult to apply. In recent years, the genetic algorithm (GA), which simulates the biological evolution and inheritance, is used to solve the problem of the optimization of discrete variables. Its ability of searching global optimal solution is excellent, but it also has low efficiency and is easy to be premature. Wenyan Tang [2] applied the method of aggregate constraint processing to improved genetic algorithm, which is used in the discrete variables optimization of truss structures, this method is achieved good results, but there are also disadvantages need to be improved.

With the purpose of the optimization of the truss structures, this paper applies the Multiplier Method constraint processing to improved genetic algorithm, which is collaborative computation with ANSYS to the size optimization of truss structures with discrete variables. The improved genetic algorithm has been optimized after a certain number of iterations to find the optimal solution quickly and efficiently through the ANSYS finite element calculation.

Optimization design model of truss structures with discrete variables

Structural optimization problem with discrete variables can be formulated as a non-linear programming problem (NLP). For optimizing size of truss structures, the cross-section areas of the members are considered as design variables. Usually, each design variable is chosen from a list of discrete cross-sections based on production standards. Typically, the objective function is the structure weight, while the design must also satisfy certain (stress, displacement, etc.) constraint

conditions. The optimization of truss structures with discrete variables can be expressed as follow model [3, 4]:

$$\begin{aligned}
 \text{Min } f(X) &= \sum_{i=1}^n \rho_i A_i L_i \\
 \text{s.t. } g_{ik}^s &= \frac{[\sigma_i]}{\sigma_{ik}} - 1 \geq 0, i = 1, 2, \dots, n, k = 1, 2, \dots, n_k, \\
 g_{jlk}^u &= \frac{[u_{jl}]}{u_{jlk}} - 1 \geq 0, j = 1, 2, \dots, m, l = 1, 2, \dots, ND, \\
 X &= (A_1, A_2, \dots, A_n)^T \geq 0, 0 \leq A_i \in S = [s_1, s_2, \dots, s_n],
 \end{aligned}$$

where $f(X)$ is the structure weight, X is the design variables, n is the number of members in the design, k is the number of load, ρ_i is the specific weight of the i th bar material, A_i is the cross-section of the i th bar, L_i is the length of the i th bar, g_{ik}^s is the stress constraints, σ_{ik} is the stress of the i th bar under k load, $[\sigma_i]$ is the maximum allowable stress in tension and compression of the i th bar, g_{jlk}^u is the displacement constraints, u_{jlk} is the displacement of the j th bar under k load in l direction, $[u_{jl}]$ is the allowable displacement, ND is the dimension of node displacement constraints, S is the number of discrete variables, s_n is the members of S .

Collaborative computation model of improved genetic algorithm and ANSYS

Genetic algorithm improvement

In order to solve the problems of premature and low efficiency in the simple genetic algorithm, the following measures have been used to improve the simple genetic algorithm:

1. Using integer encoding to improve the accuracy and search efficiency;
2. The immigration strategies are used to improve the ability of global optimization and avoid algorithm premature;
3. Elitist strategy is used during the genetic operation to ensure the fittest result can be reserved which can increase the average fitness of populations and improve the computing efficiency.

Multiplier method constraint processing

The penalty function is usually constructed to transform the constrained optimization problem into the unconstrained optimization problem. Penalty function method mainly includes outer point penalty function method, the inner point penalty function method, and multiplier method and so on. Both the outer point and the inner point method adopt sequential unconstrained minimization technique, which is easy to use and also can solve the problem that the derivative does not exist. However, as the penalty factor tends to its limits, the condition number of Hesse matrix will be increased infinitely, and the objective function will become pathological [5].

These disadvantages can be overcome by introduction of the Lagrange function and the appropriate penalty function in the multiplier method [5]. The constrained problem of truss structures transformed into an unconstrained problem by Lagrange multiplier penalty function as shown in Eq. 1:

$$j(X, I, S) = f(X) + \frac{1}{2S} \sum_{i=1}^m ([\min\{0, Sg_i(X) - I_i\}]^2 - I_i^2) \quad (1)$$

The convergence criterion is shown in Eq. 2 and Eq. 3:

$$b_k = \left(\sum_{i=1}^m \left[\min \left\{ g_i(X_k), \frac{(I_k)_i}{S} \right\} \right]^2 \right)^{1/2} \quad (2)$$

$$y_k = \left| \frac{f(X_{k+1}) - f(X_k)}{f(X_k)} \right| \quad (3)$$

The correction formula of the multiplier vector is shown in Eq. 4:

$$(I_{k+1})_i = \max\{0, (I_k)_i - g_i(X_k)\}_b \quad i = 1, 2, \dots, m \quad (4)$$

The correction formula of the penalty factor is shown in Eq. 5:

$$\text{if } b_k \geq q \cdot b_{k-1}, s_{k+1} = g \cdot s_k, \text{ else } s_{k+1} = s_k \quad (5)$$

Where λ is the Inequality constraint vector multiplier, σ is the penalty factor, γ is the growth coefficient of penalty factor, $g(X)$ is the constraint inequality. For facilitating to compare with the other research results, the convergence condition of Eq. 2 is modified, and general rule is adopt in this paper, as shown in Eq. 3. The flow chart of this method is shown in Fig. 1.

Collaborative computation using genetic algorithm and ANSYS

In this paper, the improved genetic algorithm is implemented in MATLAB, finite element calculations and data exchange is implemented by software ANSYS, and the ANSYS software is invoked by the shell commend of MATLAB. The invocation command as follows [6]:

`! "C:\ANSYSInc\v120\ansys\bin\intel\ansys120.exe" -b -p -i C:\input.txt -o "C:\output.txt"`

The ANSYS calculation data could be input via *vread* command, and output via *vwrite* command. Collaborative computation flow chart is shown in Fig.2.

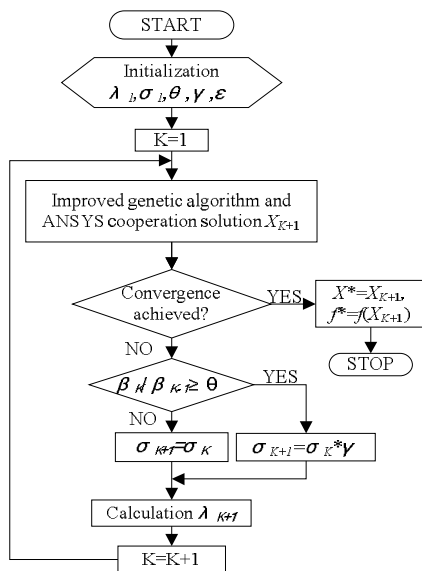


Fig. 1 Collaborative computation process

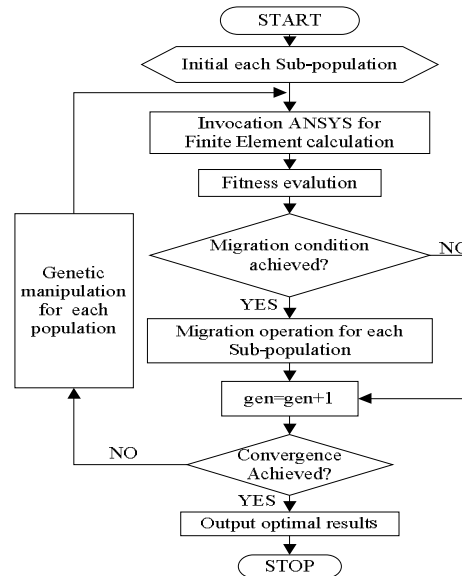


Fig. 2 The improved algorithm flow chart

Numerical examples

Two example problems are adopted to examine the search performance of the collaborative algorithm. The follow parameters are used in all examples: the material density and modulus of elasticity are $\rho=0.1\text{lb/in}^3$ ($2.7 \times 10^3 \text{kg/m}^3$) and $E=10^7 \text{psi}$ (68947.57MPa).

10-bar truss

The 10-bar truss shown in Fig.3, it has ten elements and six nodes. So the truss has ten independent design variables. The vertical load is equal to $P=100\text{kips}$ (444.8KN) in nodes 2 and 4. The allowable displacement for each node in horizontal and vertical directions is $\pm 2\text{in}$ ($\pm 0.0508 \text{m}$). The stress limitation of each member is equal to $\pm 25000 \text{psi}$ ($\pm 172.37 \text{MPa}$). The number of design variables is 42, which are selected from the set $S=[1.62, 1.80, 1.99, 2.13, 2.38, 2.62, 2.63, 2.88, 2.93, 3.09, 3.13, 3.38, 3.47, 3.55, 3.63, 3.84, 3.87, 3.88, 4.18, 4.22, 4.49, 4.59, 4.80, 4.97, 5.12, 5.74, 7.22, 7.97, 11.5, 13.5, 13.9, 14.2, 15.5, 16.0, 16.9, 18.8, 19.9, 22.0, 22.9, 26.5, 30.0, 33.5](\text{in}^2)$. The calculation parameters of the collaborative algorithm are referenced in Table 1. The comparison of optimal design results is shown in Table 2. The iterative convergence process of the object function value is shown in Fig.4.

Table 1 calculation parameters

Genetic algorithm	Population size	Sub-population	Crossover probability	Mutation probability	Migration interval	Migration probability	Maximum generation
	$NIND=15$	$SUBPOP=8$	$P_c=1.0$	$P_m=0.05$	$MIGGEN=15$	$MIGR=0.2$	$MAXGEN=50$
Multiplier method	Inequality constraint vector multiplier		Positive decimal	Penalty factor	Growth coefficient of penalty factor		convergence precision
	$\lambda_1=0$		$\theta=0.25$	$\sigma_1=1$	$\gamma=10$		$\varepsilon=1 \times 10^{-5}$

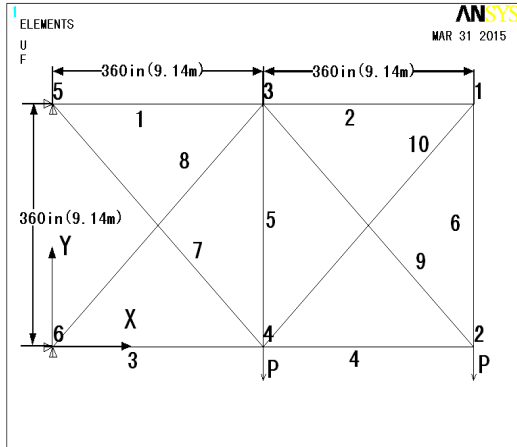


Fig. 3 10-bar plane truss

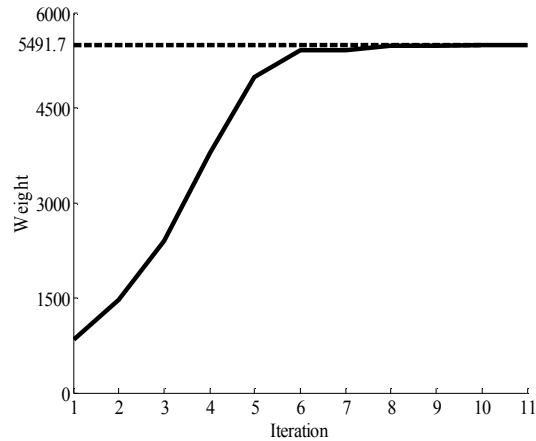


Fig. 4 10-bar truss iterative convergence process

Table 2 Comparison of results for the 10-bar plane truss

Variables		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	weight
Area	Rajeev[7]	33.5	1.62	22.0	15.5	1.62	1.62	14.2	19.9	19.9	2.62	5613.8
	Galante[8]	33.5	1.62	22.0	14.2	1.62	1.62	7.97	22.9	22.0	1.62	5458.3
	Tang[2]	30.0	1.80	22.0	13.5	1.62	1.62	11.5	22.0	22.9	1.62	5493.3
	Present	33.5	1.62	22.9	15.5	1.62	1.62	7.97	22.0	22.0	1.62	5491.7

As shown in table 2, the optimal result of ten-bar is 5491.7 lb, which is better than the results in the paper [2] and paper [7]. The optimal results of this article meet the design requirements. In table 2, the result of paper[8] is 5458.3 lb, but the displacement is 2.01 in node 2, obviously it is bigger than the design requirement, Through calculating according Tang's conditions, the average value of our paper is 5499.2 lb. which is 1.58% lighter than paper [2]. Then the algorithm is more reliable and efficient in structure optimization in this case.

25-bar spatial truss

The 25-bar truss transmission tower shown in Fig.5, it has 25 elements and ten nodes, the cross-sectional areas of the 25 members are divided into 8 groups as shown in Table 3, the allowable displacement of each node in three directions is $\pm 0.35\text{in}(\pm 0.00889\text{m})$, the stress limitation for each member is equal to $\pm 40000\text{psi}(\pm 275.79\text{MPa})$. The load cases applied to 25-bar truss are described in Table 4. The number of design variables is equal 30, which are selected from the set $S=[0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.8, 3.0, 3.2, 3.4](\text{in}^2)$. The calculation parameters of the collaborative algorithm are referenced in Table 1, and the comparison of optimal design results in Table 5, the iterative convergence process of the object function value is shown in Fig.6.

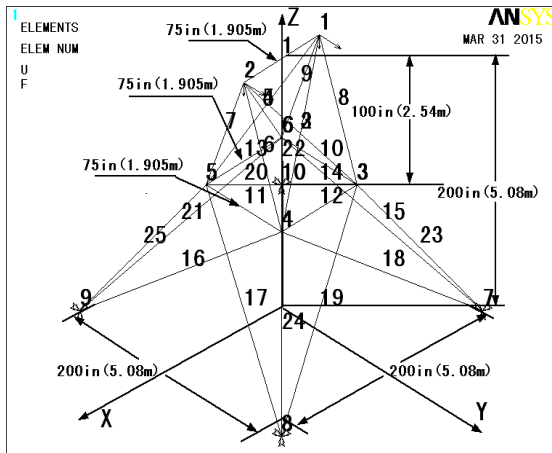


Fig. 5 25-bar spatial truss

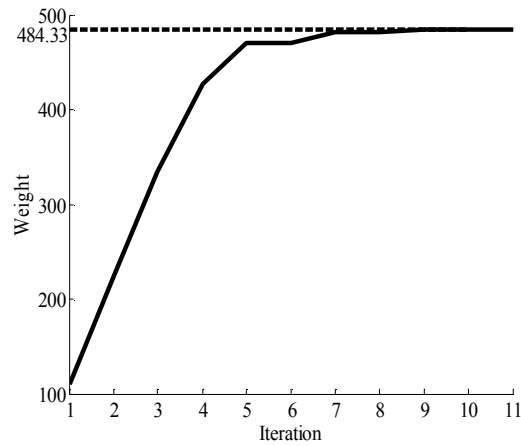


Fig. 6 25-bar truss iterative convergence process

Table 3 Grouping of 25-bar spatial truss

Groups	Node Number	Groups	Node Number
1	1-2	5	3-4,5-6 ,
2	1-4,2-3,1-5,2-6	6	3-10,6-7,4-9,5-8
3	2-5,2-4,1-3,1-6	7	3-8,4-7,6-9,5-10
4	3-6,4-5	8	3-7,4-8,5-9,6-10

Table 4 Load cases for the 25-bar spatial truss

Node	Px	Py	Pz
1	1K	10K	-5K
2	0	10k	-5K
3	0.5k	0	0
6	0.6k	0	0

Table 5 Comparison of results for the 25-bar spatial truss

Variables		A1	A2	A3	A4	A5	A6	A7	A8	Weight
Area	Rajeev[7]	0.1	1.8	2.3	0.2	0.1	0.8	1.8	3.0	546.01
	Galante[8]	0.1	0.5	3.4	0.1	1.5	0.9	0.6	3.4	486.29
	Tang[2]	0.1	0.6	3.4	0.1	1.6	0.9	0.5	3.4	485.77
	Present	0.1	0.4	3.4	0.1	2.2	1.0	0.4	3.4	484.33

As shown in table 5, the optimal result of 25-bar is 484.33 lb, which is better than other papers. The average value of this paper is 484.94 lb, which is 1.27% lighter than paper [2]. The result further illustrates the algorithm used in this paper has higher search efficiency and higher accuracy.

Conclusions

In this paper, the collaborative computation using improved genetic algorithm and ANSYS based on Lagrange multiplier method is proposed to deal with the structure optimization with discrete variables. The results of truss structure optimization show the collaborative algorithm is feasible in our research. It is applied in truss structures optimization with discrete variables has good global search capability. Compared with others, the results of truss structures optimization are reliable and it can obtain higher accuracy and better solution. The collaborative algorithm provides a viable way to solve the problem of complex optimization design of structure.

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