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Sizing and Geometry Optimization of Truss Structures Using a Hybrid of Gravitational Search Algorithm and Cellular Automata

M. Dehghani[1], M. Mashayekhi[2,*], M. Sharifi[1]

[1] Civil Engineering Department, University of Qom, Qom, Iran.
[2] Civil Engineering Department, Vali-e-Asr University of Rafsanjan, Rafsanjan, Iran.

ABSTRACT: In this study, a new method is presented to solve the geometry and sizing optimization problems of truss structures using an effective hybrid of cellular automata (CA) and gravitational search algorithm (GSA), which is named the CA-GSA method. The basic of the GSA is the Newtonian Gravity and Motion laws. Due to the direct effect of all objects on each other and the lack of attention to elitist selection, this algorithm converges to a local optimum point. In this study, with the help of the CA method, masses are distributed in a finite cellular network, and each cell is only related to its neighbors. In the CA-GSA method, the laws of gravity and motion of masses in the GSA method are defined as the relationship factor of each cell to its neighboring ones. Therefore, the applied force on each mass is obtained from the resultant force of its top neighboring masses. The definition of these top neighboring masses and their applied force on the central mass add memory and elitist selection to the GSA algorithm, respectively. Another advantage of the new method is to update the cellular network after any local evolution, which makes it possible to achieve the optimal point using fewer analyzes. To investigate the usefulness of the proposed method, the CA-GSA method was used to solve the geometry and sizing optimization problems of four benchmark truss structures. The results of CA-GSA show the superiority and power of this algorithm in comparison with the methods introduced in the literature.

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1- Introduction

In this study, a new algorithm is presented using a hybrid of cellular automata (CA) and gravitational search algorithms (GSA). In which, by simulating each vector (representing an answer in the optimization problem) as a cell and defining the intercellular rules equivalent to the rules of the search algorithm, the advantages of the CA method have been exploited in the GSA algorithm. The CA method was first proposed by Wolfram in 1986 [1,2], which is derived from the process of repairing damaged bones. The GSA algorithm [3,4] is one of the algorithms that simulate a physical phenomenon in the world. To evaluate the usefulness of the proposed method, the CA-GSA method has been used to solve four benchmark size and geometry optimization of truss structures problems. The results of the numerical examples show the superiority and strength of the CA-GSA algorithm over other methods compared in this paper.

2- Geometry and size optimization problems formulation

Geometry and size optimization of truss structures is defined as follows [5]:

$$Minimize: w(X_A, X_G) = \sum_{i=1}^{ne} p_i A_i l_l \qquad (1)$$

$$Subject\ to: g_i^{\sigma}(X_A, X_G) = \frac{\sigma_i(X_A, X_G)}{\sigma_{i,all}} - 1 \le 0,\ i = 1,2,...,ne \qquad (2)$$

where w is the weight of the truss structure; X is the vector of design variables; ρ_i, A_i and g_i^{σ} are the material density, cross-sectional area, and length of the ith member, respectively; g_j^{σ} is the stress constraint; g_j^{d} is the displacement constraint of the jth node of the structure.

3- Modified cellular automata

According to the definitions provided, a set of $\langle Z^n, A, Y, \sigma \rangle$ is called cellular automata in which [5,6]:

The first element (Z^n), represents the number and the arrangement of the cells to each other. The second element (A), is the value or the content within each cell. The third element of (Y), is the arrangement of neighboring cells. For example, Fig. 1 shows the neighboring cells of each cell from the square grid and in the Moore neighborhood model.

The fourth element in CA is the rules for updating the internal values of cells or σ, which is a function of local transmission.

*Corresponding author's email:m.mashayekhi@vru.ac.ir

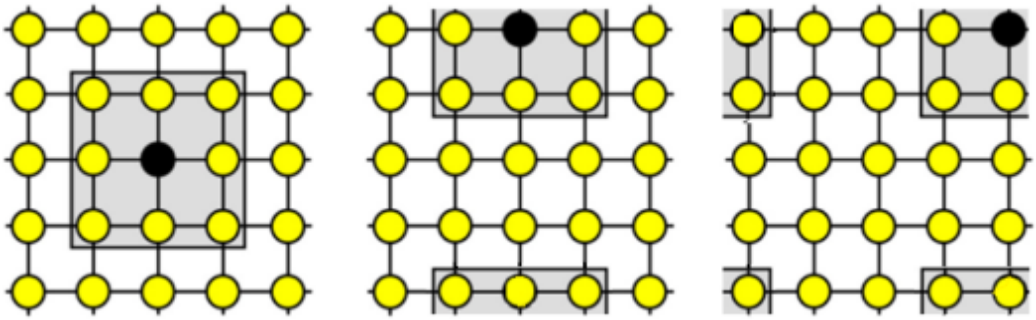

Fig. 1. Neighboring cells of a cell (central cells, corners, and edges) in the Moore neighborhood

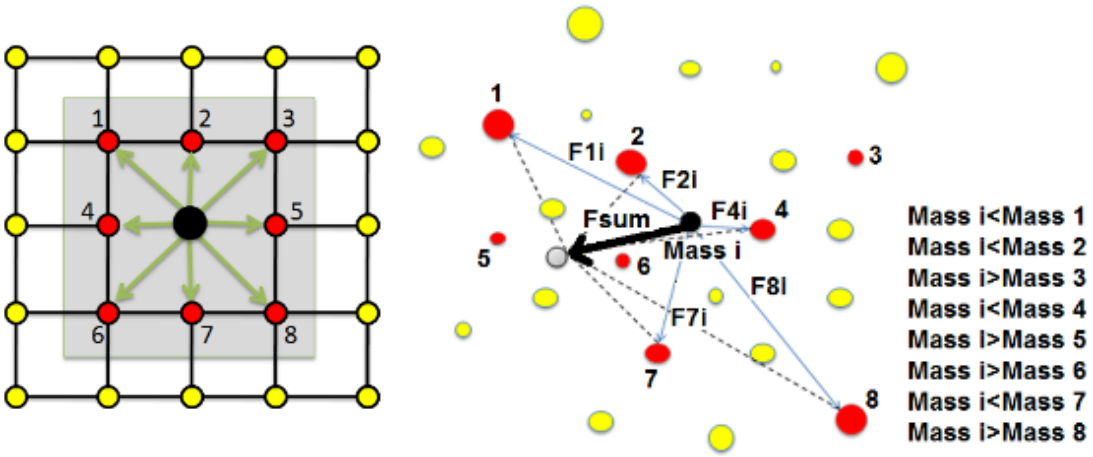

Fig. 2. (a) Neighborhood cell lattice with radius 1, (b) hows neighboring cells affect the central cell

4- A hybrid of cellular automata method with the laws of gravitational search algorithm (CA-GSA)

In the CA-GSA method, each cell is considered as a mass that is only affected by its neighboring cells (objects). Fig. 2 shows a random central mass and neighboring objects where arrows represent the effect of neighboring objects on the central mass. Fig. 2b shows the central mass and its neighboring objects among all the objects in the search space. The new position of the central cell mass is based on the resultant vector of the forces coming from all neighboring objects.

At the *t*th time, the force applied to the *l*th central cell by its 8 neighbors is defined as follows:

$$F_l^d(t) = G(t) \times \sum_{n=1}^{8} \left[\delta_n \times rand_n \times \frac{M_{pl}(t) \times M_{an}(t)}{R_{\ln}(t) + \varepsilon} (x_n^d(t) - x_l^d(t)) \right] \quad (3)$$

where M_{an} is the active gravitational mass of the neighboring cells, M_{pl} is the inactive gravitational mass of the *l*th central cell, δ_n is the assigned index to each cell (good or bad), $G(t)$ is the constant of gravity, ε is a small fixed number and *F* is the Euclidean distance between the *l*th and the *n*th particles [4].

The velocity and location of each particle are obtained as follows [4]:

$$v_{l,NEW}^d(t+1) = rand_l \times v_l^d(t+1) + a_l^d(t) \quad (4)$$

$$x_{l,NEW}^d(t+1) = x_l^d(t) + v_l^d(t+1) \quad (5)$$

$$v_l^d(t+1) = \begin{cases} v_{l,NEW}^d(t+1), if \ \Phi\left(x_{l,NEW}^d(t+1)\right) \le \Phi(x_l^d(t)) \\ v_l^d(t), otherwise, \end{cases} \quad (6)$$

$$x_l^d(t+1) = \begin{cases} x_{l,NEW}^d(t+1), if \ \Phi\left(x_{l,NEW}^d(t+1)\right) \le \Phi(x_l^d(t)) \\ x_l^d(t), otherwise, \end{cases} \quad (7)$$

In these relations, $rand_l$ is a random number with a uniform distribution in the range [1 and 0].

In summary, the CA-GSA optimization process includes the following steps:

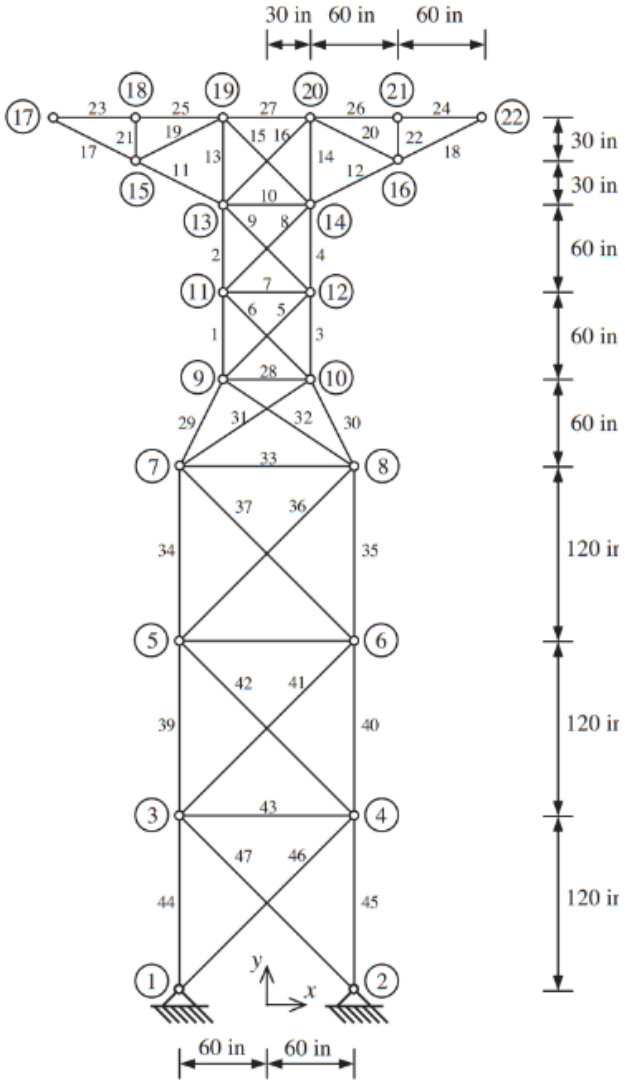

Fig. 3. Schematic view of the 47-member truss structure

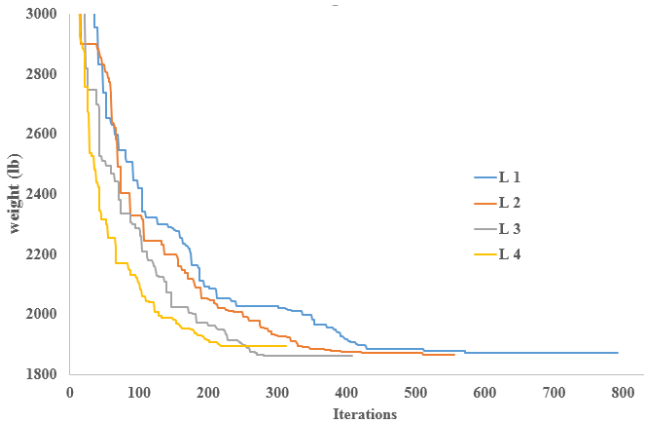

Fig. 4. Diagram of the convergence history of the 47-member

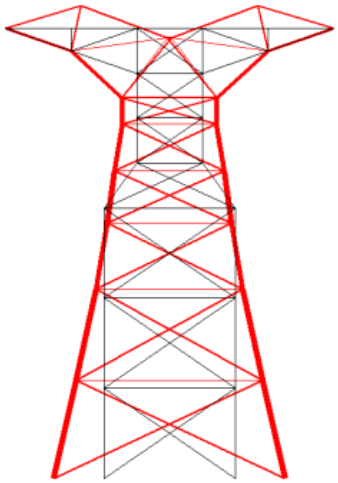

Fig. 5. The optimal 47-member truss

1- Creating a cellular lattice with L^2 dimensions
2- Random selection of the object's position in the search space with number L^2
3- Putting the position of the created objects in the cellular lattice
4- Determine the fitness of each particle based on its position
5- For each cell of the lattice:
- Selecting the *l*th central cell and its neighboring ones as N particles
- Appling the force of the neighbor's superior objects to the central cell

6- Determining the acceleration, velocity, and new location of the cell and its fitness
7- Repeating Steps 5-6 until the stopping criterion is satisfied.

5- Geometry and size optimization of the 47 member truss structure (example 4 of the main article)

The test problem is the layout optimization of the 47-bar tower for which Fig. 3 shows the initial configuration.

The tower is subject to the three independent loading conditions, and elements are grouped into 27 independent size variables [5,7]. The material density is 0.3 lb/in^3 and the modulus of elasticity is 3×10^4 ksi. Other specifications of this example can be found in the mentioned references.

The results of the CA-GSA algorithm for the 47-member truss structure including optimal final vector, structural weight, average weight of 20 different executions, error limiting range, and the number of structural analyzes required to achieve the best weight among 20 executions, are shown in Table 1. Among the various dimensions selected for the grid, the best dimension is L=7 with the best weight of 1862.9602 lb.

Figs. 4 and 5 show the diagram of the convergence history of the CA-GSA algorithm for the various values of the lattice dimensions and the optimal structure, respectively.

6- Conclusion

In this paper, a new hybrid optimization method (CA-GSA) is presented using the integration of the cellular automata method and GSA gravitational rules for geometry and size optimization of truss structures. To achieve this aim, after creating the initial random population in GSA, these primary objects are located in the CA grid, and to calculate the new position, each object is absorbed only by its neighboring ones in the CA lattice. To compare the efficiency of the CA-GSA, four benchmark optimization problems are presented and the results of three GSA, CA, and CA-GSA optimization methods are compared. The CA-GSA method uses different cellular lattices. To better compare the results the number of structural analyzes in each lattice is considered the same. From comparing their results, it is clear that the CA-GSA algorithm has converged to better answers in terms of minimum weights and their average. It also has a higher convergence rate than that of other optimization methods discussed in this paper. Also, the results of solved numerical examples show that in geometry and size optimizing of truss structures, values 5, 6, and 7 are suitable numbers for allocation to the *L* parameter.

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