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Colliding Bodies Optimization method for optimum design of truss structures with continuous variables

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ABSTRACT

In recent years, the importance of economical considerations in the field of structures has motivated many researchers to propose new methods for minimizing the weight of the structures. In this paper, a new and simple optimization algorithm is presented to solve weight optimization of truss structures with continuous variables. The Colliding Bodies Optimization (CBO) is an algorithm based on one-dimensional collisions between two bodies, where each agent solution is modeled as the body. After a collision of two moving bodies, having specified masses and velocities, these are separated and moved to new positions with new velocities. This process is repeated until a termination criterion is satisfied and the optimum CB is found. Comparison of the results of the CBO with those of some previous studies, demonstrate its capability in solving the present optimization problems.

1. Introduction

Optimal design of structures is performed using different optimization algorithms in the last decade. These algorithms are convenient to use by the practicing engineers to find the minimum weight of structures. These methods can be divided into two general categories: (i) Gradient-based methods. (ii) Stochastic meta-heuristic algorithms.

The most commonly used optimization techniques are gradient-based algorithms which utilize gradient information to search the solution space near an initial starting point. In general, gradient-based methods converge faster and can obtain solutions with higher accuracy compared to stochastic approaches. However, the acquisition of gradient information can be either costly or even impossible to obtain the minima. Furthermore, a good starting point is vital for a successful execution of these methods. In many optimization problems, prohibited zones, side limits and non-smooth or non-convex functions should be taken into consideration. As a result, these non-convex optimization problems cannot easily be solved by these methods. Therefore many new evolutionary algorithms are developed for structural optimization. Some efforts on the optimal design of structures have focused on utilizing meta-heuristic algorithms. One can list some of these as: Genetic algorithms [1], Evolution Strategies [2], Simulated Annealing [3], Particle Swarm Optimization [4], Ant Colony Optimization [5], Harmony Search [6], Big Bang–Big Crunch [7], Charged System Search [8], Ray Optimization [9], Democratic Particle Swarm Optimization [10], Bat Optimization [11], and Dolphin Echolocation method [12], among many others.

Recently, an efficient and simple continuous optimization algorithm, so-called Colliding Bodies Optimization (CBO), for optimization problems, is developed by the present authors that utilizes simple formulation, and it requires no parameter tuning [13]. This algorithm can be considered as a multi-agent method, where each agent is a colliding body (CB). In CBO, each CB is considered as an object with a specified mass and velocity before the collision. After collision occurs, each CB moves to a new position according to the new velocity. This process is repeated until a termination criterion is satisfied and the optimum CB is found.

This paper considers: (i) The CBO algorithm is introduced for optimization of continuous problems. (ii) A comprehensive study of sizing optimization for truss structures is presented. The examples are chosen from the literature to verify the effectiveness of the algorithm. These examples are as follows: a 25-member spatial truss with 8 design variables, a 72-member spatial truss with 16 design variables, a 582-member space truss tower with 32 design variables, a 37-member plane truss bridge with 16 design variables, and a 68-member plane truss bridge with 4, 8 and 12 design variables. All the structures are optimized for minimum weight with CBO algorithm, and a comparison is carried out in terms of the best optimum solutions and their convergence rates in a predefined number of analyses. The results indicate that the proposed algorithm is very competitive with other state-of-the-art metaheuristic methods.

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The remainder of this paper is organized as follows: In Section 2, the new method is briefly presented. Three well-studied engineering design problems and one structural design examples are studied in Section 3. Conclusions are derived in Section 4.

2. Colliding Bodies Optimization

Nature has always been a major source of inspiration to engineers and natural philosophers and many meta-heuristic approaches are inspired by solutions that nature herself seems to have chosen for hard problems [8]. The collision is also a natural occurrence, which it happens between objects, bodies, cars, etc. The idea of the proposed algorithm is based on observation of a collision between two objects in one-dimension; in which one object collide with other object and they moves toward minimum energy level.

2.1. Collision laws

In physics, collisions between bodies are governed by: (i) laws of momentum and (ii) laws of energy. When a collision occurs in an isolated system, Fig. 1, the total momentum and energy of the system of objects is conserved.

The conservation of the total momentum requires the total momentum before the collision to be the same as the total momentum after the collision, and can be expressed as:

$$m_1 v_1 + m_2 v_2 = m_1 v'_1 + m_2 v'_2 \tag{1}$$

Likewise, the conservation of the total kinetic energy is expressed by

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2 + Q \tag{2}$$

where v_1 is the initial velocity of the first object before impact, v_2 is the initial velocity of the second object before impact, v'_1 is the final velocity of the first object after impact, v'_2 is the final velocity of the second object after impact, m_1 is the mass of the first object, m_2 is the mass of the second object, and Q is the loss of kinetic energy due to impact [14].

The velocities after a one-dimensional collision can be obtained as:

$$v'_1 = \frac{(m_1 - \varepsilon m_2) v_1 + (m_2 + \varepsilon m_2) v_2}{m_1 + m_2} \tag{3}$$

$$v'_2 = \frac{(m_2 - \varepsilon m_1) v_2 + (m_1 + \varepsilon m_1) v_1}{m_1 + m_2} \tag{4}$$

where ε is the coefficient of restitution (COR) of two colliding bodies, defined as the ratio of relative velocity of separation to relative velocity of approach:

$$\varepsilon = \frac{|v'_2 - v'_1|}{|v_2 - v_1|} = \frac{v'}{v} \tag{5}$$

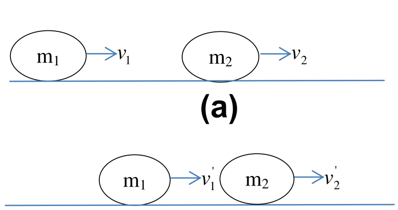

Fig. 1. The collision between two bodies. (a) Before the collision. (b) After the collision.

According to the coefficient of restitution, two special cases of collision can be considered as:

(1) A perfectly elastic collision is defined as the one in which there is no loss of kinetic energy in the collision ($Q = 0 \;\; \& \;\; \varepsilon = 1$). In reality, any macroscopic collision between objects will convert some kinetic energy to internal energy and other forms of energy. In this case, after collision the velocity of separation is high.
(2) An inelastic collision is the one in which part of the kinetic energy is changed to some other form of energy in the collision. Momentum is conserved in inelastic collisions (as it is for elastic collisions), but one cannot track the kinetic energy through the collision since some of it is converted to other forms of energy. In this case, coefficient of restitution does not equal to one ($Q \neq 0 \;\; \& \;\; \varepsilon \leqslant 1$). Here, after collision the velocity of separation is low.

For most of the real objects, ε is between 0 and 1.

2.2. The CBO algorithm

The main concern of the present study is to extend the application of the recently developed meta-heuristic algorithm, so-called Colliding Bodies Optimization, to optimal design of truss structures. In CBO, each solution candidate X_i containing a number of variables (i.e. $X_i = \{X_{i,j}\}$) is considered as a colliding body (CB). The massed objects are composed of two main equal groups; i.e. stationary and moving objects, where the moving objects move to follow stationary objects and a collision occurs between pairs of objects. This is done for two purposes: (i) to improve the positions of moving objects; (ii) to push stationary objects towards better positions. After the collision, the new positions of the colliding bodies are updated based on the new velocity by using the collision laws as discussed in Section 2.1.

The CBO procedure can briefly be outlined as follows:

(1) The initial positions of CBs are determined with random initialization of a population of individuals in the search space:

$$x_i^0 = x_{\min} + rand(x_{\max} - x_{\min}), \quad i = 1, 2, \ldots, n \tag{6}$$

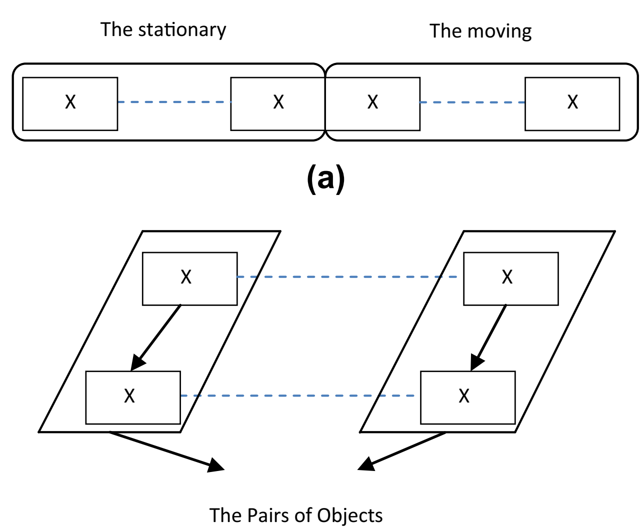

Fig. 2. (a) The sorted CBs in an increasing order. (b) The pairs of objects for the collision.