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Colliding bodies optimization: A novel meta-heuristic method

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ABSTRACT

This paper presents a novel efficient meta-heuristic optimization algorithm called Colliding Bodies Optimization (CBO). This algorithm is based on one-dimensional collisions between bodies, with each agent solution being considered as an object or body with mass. After a collision of two moving bodies having specified masses and velocities, these bodies are separated with new velocities. This collision causes the agents to move toward better positions in the search space. CBO utilizes simple formulation to find minimum or maximum of functions and does not depend on any internal parameter. Numerical results show that CBO is competitive with other meta-heuristics.

1. Introduction

Methods of optimization can be divided into two general categories: 1. Mathematical methods such as quasi-Newton (QN) and dynamic programming (DP) [1]; 2. Meta-heuristic algorithms such as Genetic algorithms (GA) [2], Particle swarm optimization (PSO) [3], Ant colony optimization (ACO) [4], Big bang-big crunch (BB-BC) [5], Charged system search (CSS) [6], Ray optimization (RO) [7], Democratic PSO [8], Dolphin echolocation (DE) [9], Mine blast (MB) [10].

Mathematical algorithms are hard to apply and time-consuming in some optimization problems. Furthermore, they require a good starting point to successfully converge to the optimum and may be trapped in local optima [11].

Meta-heuristic algorithms try to solve optimization problems. The implementation of these algorithms can computationally be performed in a variety of ways. They often have many different variable representations and other settings that must be defined. These include the definition or representation of the solution, mechanisms for changing, developing, or producing new solutions to the problem under study, and methods for evaluating a solution's fitness or efficiency. Once a meta-heuristic algorithm is developed, a tuning process is often required to evaluate different experimental options and settings that can be manipulated by the user in order to optimize convergence behavior in terms of the algorithm's ability to find near optimal solution. A meta-heuristic algorithm is usually tuned for a specific set of problems. However, one of the nice features of efficient meta-heuristic algorithms is their applicability to a wide range of problems [6].

The main goal of this paper is introduce a new and simple optimization algorithm based on the collision between objects, which is called Colliding Bodies Optimization (CBO). The present paper is organized as follows: In Section 2, we describe the laws of collision between two bodies. In Section 3, the new method is presented. Three well-studied engineering design problems and two structural design examples are studied in Section 4. Conclusions are derived in Section 5.

2. The collision between two bodies

Collisions between bodies are governed by the laws of momentum and energy. When a collision occurs in an isolated system (Fig. 1), the total momentum of the system of objects is conserved. Provided that there are no net external forces acting upon the objects, the momentum of all objects before the collision equals the momentum of all objects after the collision.

The conservation of the total momentum demands that the total momentum before the collision is the same as the total momentum after the collision, and can be expressed by the following equation:

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

Likewise, the conservation of the total kinetic energy is expressed as:

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

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

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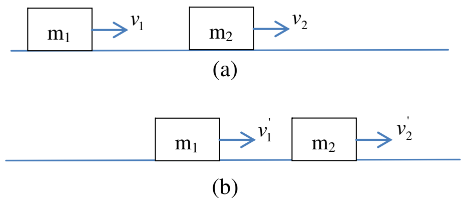

Fig. 1. The collision between two bodies. (a) Before the collision and (b) after the collision.

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 the impact [12].

The formulas for the velocities after a one-dimensional collision are:

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

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

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

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

According to the coefficient of restitution, there are two special cases of any collision as follows:

(1) A perfectly elastic collision is defined as the one in which there is no loss of kinetic energy in the collision ($Q = 0$ and $\varepsilon = 1$). 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 will be converted to other forms of energy. In this case, coefficient of restitution does not equal to one ($Q \neq 0$ & $\varepsilon \leqslant 1$). In this case, after collision the velocity of separation is low.

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

3. The CBO algorithm

3.1. Theory

The main objective of the present study is to formulate a new simple and efficient meta-heuristic algorithm which is called Colliding Bodies Optimization (CBO). 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 and (ii) to push stationary objects towards better positions. After the collision, new positions of colliding bodies are updated based on new velocity by using the collision laws as discussed in Section 2.

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:

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

where x_i^0 determines the initial value vector of the ith CB. $x_{\min}$ and $x_{\max}$ are the minimum and the maximum allowable values vectors of variables; $rand$ is a random number in the interval [0, 1]; and n is the number of CBs.

2. The magnitude of the body mass for each CB is defined as:

$$m_k = \frac{\frac{1}{fit(k)}}{\sum_{i=1}^{n} \frac{1}{fit(i)}}, \quad k = 1, 2, \ldots, n \tag{7}$$

where $fit(i)$ represents the objective function value of the agent i; n is the population size. It seems that a CB with good values exerts a larger mass than the bad ones. Also, for maximization, the objective function $fit(i)$ will be replaced by $\frac{1}{fit(i)}$.

3. The arrangement of the CBs objective function values is performed in ascending order (Fig. 2a). The sorted CBs are equally divided into two groups:
   - The lower half of CBs (stationary CBs); These CBs are good agents which are stationary and the velocity of these bodies before collision is zero. Thus:

$$v_i = 0, \quad i = 1, \ldots, \frac{n}{2} \tag{8}$$

   - The upper half of CBs (moving CBs): These CBs move toward the lower half. Then, according to Fig. 2b, the better and worse CBs, i.e. agents with upper fitness value, of each group will collide together. The change of the body position represents the velocity of these bodies before collision as:

$$v_i = x_i - x_{i-\frac{n}{2}}, \quad i = \frac{n}{2} + 1, \ldots, n \tag{9}$$

Where, v_i and x_i are the velocity and position vector of the ith CB in this group, respectively; $x_{i-\frac{n}{2}}$ is the ith CB pair position of x_i in the previous group.

4. After the collision, the velocities of the colliding bodies in each group are evaluated utilizing Eqs. (3) and (4), and the velocity before collision. The velocity of each moving CBs after the collision is obtained by:

$$v'_i = \frac{(m_i - \varepsilon m_{i-\frac{n}{2}})v_i}{m_i + m_{i-\frac{n}{2}}}, \quad i = \frac{n}{2} + 1, \ldots, n \tag{10}$$

where v_i and v'_i are the velocity of the ith moving CB before and after the collision, respectively; m_i is mass of the ith CB; $m_{i-\frac{n}{2}}$ is mass

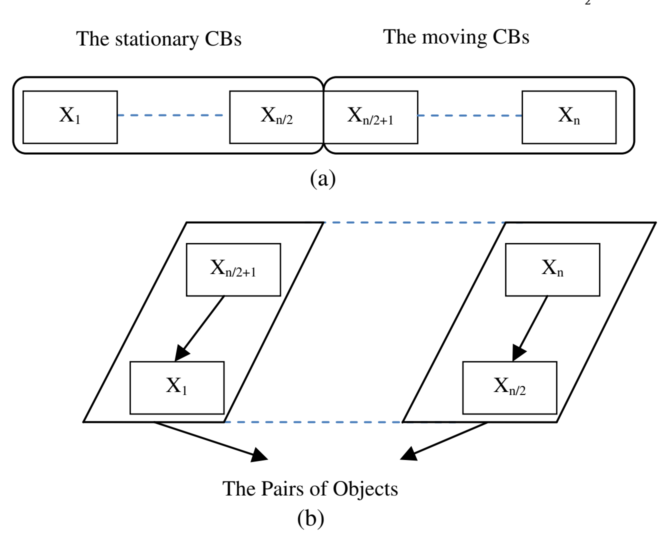

Fig. 2. (a) CBs sorted in increasing order and (b) colliding object pairs.