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Enriched Imperialist Competitive Algorithm for system identification of magneto-rheological dampers

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ABSTRACT

In the current research, the imperialist competitive algorithm is dramatically enhanced and a new optimization method dubbed as Enriched Imperialist Competitive Algorithm (EICA) is effectively introduced to deal with high non-linear optimization problems. To conduct a close examination of its functionality and efficacy, the proposed metaheuristic optimization approach is actively employed to sort out the parameter identification of two different types of hysteretic Bouc–Wen models which are simulating the non-linear behavior of MR dampers. Two types of experimental data are used for the optimization problems to minutely examine the robustness of the proposed EICA. The obtained results self-evidently demonstrate the high adaptability of EICA to suitably get to the bottom of such non-linear and hysteretic problems.

1. Introduction

As the knowledge in a certain physical problem expands, it is tried to find and include more determining factors to achieve a more accurate simulation of empirical observation. Therefore, the simplified mathematical models are increasingly replaced by the complex models which are accompanied by high-dimensional and non-differential mathematical problems. Conventional mathematical programming methods (e.g. linear programming, homogeneous linear programming, integer programming, dynamic programming, and even non-linear programming) fail to correctly address the parameter identification of systems with high inherent non-linearity and a big number of parameters. Metaheuristic optimization methods have been alternatively utilized to desirably fit the intricate factual behavior of various physical systems to their corresponding high non-linear mathematical models. However, high non-differential characteristics, discrete experimental data and difficulty of estimating a reasonable starting point for parameters' search cumulatively make the “system identification” problems to remain a challenging task.

The Bouc–Wen model is a hysteretic non-linear mechanical model in which system's response is related to the system's input through a first order non-linear differential equation containing a number of unknown parameters. By adjusting these parameters to their optimal values, it is feasible to predict the factual behavior of one hysteretic physical system under any arbitrary input excitations. Charalampakis et al. [1,2] successfully used a hybrid Evolutionary Algorithm (EA) and Particle Swarm Optimization (PSO) approaches to find the optimal set of Bouc–Wen model parameters for producing the experimentally obtained hysteretic behavior of a steel cantilever beam. Meiying and Xiaodong [3] examined and validated the effectiveness of the PSO estimating parameter characteristics of Bouc–Wen model for experimental data. Kwok et al.

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[4,5] applied the Genetic Algorithm (GA) to identify the Bouc–Wen relations modeling hysteretic non-linear behavior of MR dampers. Liu et al. [6] and Talatahari et al. [7] also utilized the Simulated Annealing algorithm (SA) and the Charged System Search (CSS) [8–10] respectively to optimally find the Bouc–Wen model parameters of MR dampers. Also, Talatahari et al. proposed a hybrid algorithm for solving this problem in [11].

The purpose of the current paper is to effectively improve the so-called Imperialist Competitive Algorithm (ICA) [12–15] and submit a novel optimization method called as Enriched Imperialist Algorithm (EICA); which could be successfully used for high non-linear optimization problems. Herein, to provide a merit investigation on the efficacy of the proposed approach dealing with high non-linear problems, it is employed to find the optimal parameters of the various types of hysteretic Bouc–Wen models predicting extreme non-linear demeanor of MR fluid dampers. MR dampers are a kind of semi-active energy-dissipating devices that provide controllable damping forces by reforming the magnitude of the applied magnetic field (input voltage). These dampers are actively engaged to mitigate the vibrational responses of civil structures [16–19] and mechanical systems [20–25].

2. Problem formulation

In order to obtain the optimal values of the parameters, a proper objective function shall be determined and engaged by the optimization algorithm. The normalized mean square error (MSE) of the predicted response time history $\hat{f}(t_i|\mathbf{p})$ (for any obtained parameters' vector $\mathbf{p}$) in comparison with the experimentally obtained response history $f(t_i)$ at each time step t_i is usually considered as the objective function to be minimized. The discrete–time objective function can be expressed as

$$OF(\mathbf{p}) = \frac{\sum_{i=1}^{N}\left(f(t_i) - \hat{f}(t_i|\mathbf{p})\right)^2}{N\sigma_f^2} \tag{1}$$

in which $\mathbf{p}$ is the vector of model's parameters; σ_f^2 is the variance of experimental response time history; Σ represents the summation of the its subsequent term (N discrete values); and N is the number of experimental data employed in the optimization process. It should be noticed that the optimization problem involves the minimization of the objective function when the parameters vector is varied between the following side constraints:

$$\mathbf{p_{min}} \le \mathbf{p} \le \mathbf{p_{max}} \tag{2}$$

where $\mathbf{p_{min}}$ and $\mathbf{p_{max}}$ are the vectors which include the lower and upper bounds of the model parameters, respectively.

3. Outline of the optimization method

3.1. A concise overview of original Imperialist Competitive Algorithm

The ICA simulates the social political process of imperialism and imperialistic competition. The agents of this algorithm are called “countries”. There are two types of countries; some of the best countries (in optimization terminology, countries with lower cost) are selected to be the “imperialist” states and the remaining countries form the “colonies” of these imperialists. All the colonies of initial countries are divided among the imperialists based on their “power”. The power of each country is inversely proportional to its cost. The imperialist states together with their colonies form some “empires”.

After forming initial empires, the colonies in each empire start moving toward their relevant imperialist country. This movement is a simple model of assimilation policy which was pursued by some of the imperialist states. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. This fact is modeled by defining the total power of an empire as the power of the imperialist country plus a percentage of mean power of its colonies.

Then the imperialistic competition begins among all the empires. Any empire that is not able to succeed in this competition and cannot increase its power (or at least prevent losing its power) will be eliminated from the competition.

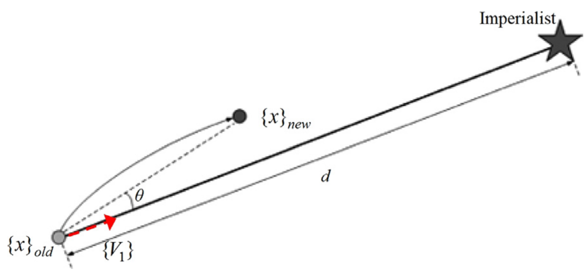

Fig. 1. Movement of colonies to its new location in the original ICA.