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A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice

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Abstract

Most engineering optimization algorithms are based on numerical linear and nonlinear programming methods that require substantial gradient information and usually seek to improve the solution in the neighborhood of a starting point. These algorithms, however, reveal a limited approach to complicated real-world optimization problems. If there is more than one local optimum in the problem, the result may depend on the selection of an initial point, and the obtained optimal solution may not necessarily be the global optimum. This paper describes a new harmony search (HS) meta-heuristic algorithm-based approach for engineering optimization problems with continuous design variables. This recently developed HS algorithm is conceptualized using the musical process of searching for a perfect state of harmony. It uses a stochastic random search instead of a gradient search so that derivative information is unnecessary. Various engineering optimization problems, including mathematical function minimization and structural engineering optimization problems, are presented to demonstrate the effectiveness and robustness of the HS algorithm. The results indicate that the proposed approach is a powerful search and optimization technique that may yield better solutions to engineering problems than those obtained using current algorithms.

Keywords: Harmony search; Heuristic algorithm; Continuous design variables; Mathematical function minimization; Structural engineering optimization

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1. Introduction

Over the last four decades, a large number of algorithms have been developed to solve various engineering optimization problems. Most of these algorithms are based on numerical linear and nonlinear programming methods that require substantial gradient information and usually seek to improve the solution in the neighborhood of a starting point. These numerical optimization algorithms provide a useful strategy to obtain the global optimum in simple and ideal models. Many real-world engineering optimization problems, however, are very complex in nature and quite difficult to solve using these algorithms. If there is more than one local optimum in the problem, the result may depend on the selection of an initial point, and the obtained optimal solution may not necessarily be the global optimum. Furthermore, the gradient search may become difficult and unstable when the objective function and constraints have multiple or sharp peaks.

The computational drawbacks of existing numerical methods have forced researchers to rely on meta-heuristic algorithms based on simulations to solve engineering optimization problems. The common factor in meta-heuristic algorithms is that they combine rules and randomness to imitate natural phenomena. These phenomena include the biological evolutionary process (e.g., the evolutionary algorithm proposed by Fogel et al. [1], De Jong [2], and Koza [3] and the genetic algorithm (GA) proposed by Holland [4] and Goldberg [5]), animal behavior (e.g., tabu search proposed by Glover [6]), and the physical annealing process (e.g., simulated annealing proposed by Kirkpatrick et al. [7]). In the last decade, these meta-heuristic algorithms, especially GA-based methods have been studied by many researchers to solve various engineering optimization problems. The GA was originally proposed by Holland [4] and further developed by Goldberg [5] and by others. It is a global search algorithm that is based on concepts from natural genetics and the Darwinian survival-of-the-fittest code. Meta-heuristic algorithm-based engineering optimization methods, including GA-based methods, have occasionally overcome several deficiencies of conventional numerical methods. To solve difficult and complicated real-world optimization problems, however, new heuristic and more powerful algorithms based on analogies with natural or artificial phenomena must be explored.

Recently, Geem et al. [8] developed a new harmony search (HS) meta-heuristic algorithm that was conceptualized using the musical process of searching for a perfect state of harmony. The harmony in music is analogous to the optimization solution vector, and the musician's improvisations are analogous to local and global search schemes in optimization techniques. The HS algorithm does not require initial values for the decision variables. Furthermore, instead of a gradient search, the HS algorithm uses a stochastic random search that is based on the harmony memory considering rate and the pitch adjusting rate (defined in harmony search meta-heuristic algorithm section) so that derivative information is unnecessary. Compared to earlier meta-heuristic optimization algorithms, the HS algorithm imposes fewer mathematical requirements and can be easily adopted for various types of engineering optimization problems.

In this study, we describe a brief overview of existing meta-heuristic algorithms and a new HS meta-heuristic algorithm-based approach for engineering optimization problems with continuous design variables. Various standard benchmark engineering optimization examples including function minimization problems and structural optimization problems from the literature are also presented to demonstrate the effectiveness and robustness of the HS meta-heuristic algorithm method.

2. A brief overview of existing meta-heuristic algorithms

Since the 1970s, many meta-heuristic algorithms that combine rules and randomness imitating natural phenomena have been devised to overcome the computational drawbacks of existing numerical algorithms (i.e., complex derivatives, sensitivity to initial values, and the large amount of enumeration memory