Harmony Search for Structural Design

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ABSTRACT

Various algorithms have been developed and applied to structural optimization, in which cross-sectional areas of structure members are assumed to be continuous. In most cases of practical structure designs, however, decision variables (cross-sectional areas) are discrete. This paper proposes a combinatorial optimization model for structural design using a new nature-inspired algorithm, harmony search (HS). HS is also compared to genetic algorithms through a standard truss example. Numerical results reveal that the proposed HS is a powerful search algorithm for combinatorial structure optimization.

Categories and Subject Descriptors

F.2.2 [**Analysis of Algorithms and Problem Complexity**]: Numerical Algorithms and Problems – *Computations on discrete structures*

General Terms

Algorithms, Design, Theory

Keywords

Harmony Search, Structural Design, Combinatorial Optimization

1. INTRODUCTION

Traditionally, many gradient-based mathematical algorithms have been developed to solve structural optimization problems [1]. These algorithms assume that decision variables (cross-sectional areas) are continuous by nature. However, in most cases of practical structure designs, the values of decision variables have to be chosen from a list of discrete values. Thus, structural optimization problem becomes a combinatorial problem where discrete design values are efficiently allocated to decision variables.

Over the past decade, in order to overcome the computational drawbacks of mathematical algorithms, evolutionary or meta-heuristic algorithms such as genetic algorithm (GA) and simulated annealing have been devised and applied to optimal design of discrete structural system. Especially, the GA-based discrete optimization models have been vigorously studied by many researchers [2-8]. However, seeking more powerful, effective and robust algorithm is still a major concern to structural engineers.

The major purpose of this paper is to introduce a new nature-inspired algorithm, harmony search (HS) for combinatorial structure optimization. The recently-developed HS algorithm was conceptualized using musical improvisation process of searching for a perfect state of harmony, and successfully applied to various benchmark and real-world optimization problems [9-11]. Thus, the HS provides a possibility of success in combinatorial structure optimization problem.

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2. HARMONY SEARCH ALGORITHM

2.1 Step 1: Initialize Problem

In Step 1, the discrete optimization problem is specified as follows:

$$\textit{Minimize}\ f(\mathbf{x})\ \textit{s.t.}\ x_i \in \mathbf{X}_i,\ i = 1,2,...,N \tag{1}$$

where $\mathbf{X}_i$ is the set of possible candidate values for each decision variable, that is, $\mathbf{X}_i = \{x_i(1),\ x_i(2),\ \ldots,\ x_i(K_i - 1),\ x_i(K_i)\}$ for discrete decision variables.

2.2 Step 2: Initialize Harmony Memory

In Step 2, harmony memory (HM) matrix shown in Equation 2 is randomly filled with as many solution vectors as harmony memory size (HMS).

$$\begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \cdots & \cdots & \cdots & \cdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \begin{matrix} \Rightarrow & f(\boldsymbol{x}^1) \\ \Rightarrow & f(\boldsymbol{x}^2) \\ \Rightarrow & \vdots \\ \Rightarrow & f(\boldsymbol{x}^{HMS-1}) \\ \Rightarrow & f(\boldsymbol{x}^{HMS}) \end{matrix} \tag{2}$$

2.3 Step 3: Improvise New Harmony

In Step 3, a new harmony vector, $\boldsymbol{x}' = (x_1', x_2', ..., x_N')$ is improvised. There are three rules to choose one value for each decision variable: memory consideration, pitch adjustment, and random selection.

In memory consideration, the value of the first decision variable (x_1') can be chosen from any discrete value in the specified HM range $\{x_1^1,\ x_1^2,\ \cdots,\ x_1^{HMS-1},\ x_1^{HMS}\}$ with the probability of HMCR which varies between 0 and 1. Values of the other decision variables (x_i') can be chosen in the same manner. However, there is still a chance where the new value can be randomly chosen from a set of entire possible values with the probability of (1-HMCR).

$$x_i' \leftarrow \begin{cases} x_i' \in \{x_i^1, x_i^2, \ldots, x_i^{HMS}\} & w.p. \quad HMCR \\ x_i' \in \boldsymbol{X}_i & w.p. \quad (1\text{-}HMCR) \end{cases} \tag{3}$$

Any component of the new harmony vector, whose value was chosen from the HM, is then examined to determine whether it should be pitch-adjusted. This operation uses pitch adjusting parameter (PAR) that sets the rate of pitch-adjustment decision as follows:

$$\text{Pitch adjustment for } x_i' \leftarrow \begin{cases} Yes & w.p. \quad PAR \\ No & w.p. \quad (1-PAR) \end{cases} \tag{4}$$

If the pitch adjustment decision for x_i' is Yes, x_i' is replaced with $x_i(k)$ (the k^{th} element in $\mathbf{X}_i$), and the pitch-adjusted value of $x_i(k)$ becomes

$$x_i' \leftarrow x_i(k \pm 1) \tag{5}$$

The algorithm chooses -1 or 1 for the neighboring index m with the same probability.

2.4 Step 4: Update Harmony Memory

If the new harmony $\mathbf{x}' = (x_1', x_2', ..., x_N')$ is better than the worst harmony in the HM in terms of objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

2.5 Step 5: Check Termination Criterion

In Step 5, the computation is terminated when the termination criterion is satisfied. Otherwise, Steps 3 and 4 are repeated.

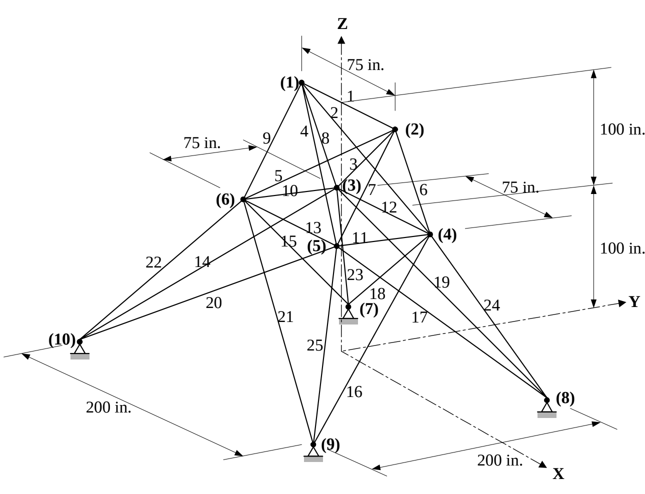

Figure 1. 25-member Transmission Tower Truss

3. 25-MEMBER TRUSS EXAMPLE

The HS-based structural optimization model is applied to a 25-member transmission tower truss, shown in Figure 1, which has been optimized by many researchers [2, 6-7].

HS ran five times with different algorithm parameters (HMS = 10 ~ 50; HMCR = 0.7 ~ 0.95; and PAR = 0.2 ~ 0.5), and obtained minimal weight of 484.85 lb while Rajeev and Krishnamoorthy [2] obtained 546.01 lb, Wu and Chow [6] 486.29 lb, and Camp et al. [7] 485.05 lb.

4. CONCLUSIONS

Recently-developed HS algorithm was successfully applied to a combinatorial structure optimization with discrete decision variables. The results showed that the proposed algorithm is potentially a powerful search and optimization technique in terms of best solutions and convergence history.

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