Harmony Search for Multiple Dam Scheduling

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INTRODUCTION

The dam is the wall that holds the water in, and the operation of multiple dams is complicated decision-making process as an optimization problem (Oliveira & Loucks, 1997). Traditionally researchers have used mathematical optimization techniques with linear programming (LP) or dynamic programming (DP) formulation to find the schedule.

However, most of the mathematical models are valid only for simplified dam systems. Accordingly, during the past decade, some meta-heuristic techniques, such as genetic algorithm (GA) and simulated annealing (SA), have gathered great attention among dam researchers (Chen, 2003) (Esat & Hall, 1994) (Wardlaw & Sharif, 1999) (Kim, Heo & Jeong, 2006) (Teegavarapu & Simonovic, 2002).

Lately, another metaheuristic algorithm, harmony search (HS), has been developed (Geem, Kim & Loganathan, 2001) (Geem, 2006a) and applied to various artificial intelligent problems, such as music composition (Geem & Choi, 2007) and Sudoku puzzle (Geem, 2007).

The HS algorithm has been also applied to various engineering problems such as structural design (Lee & Geem, 2004), water network design (Geem, 2006b), soil stability analysis (Li, Chi & Chu, 2006), satellite heat pipe design (Geem & Hwangbo, 2006), offshore structure design (Ryu, Duggal, Heyl & Geem, 2007), grillage system design (Erdal & Saka, 2006), and hydrologic parameter estimation (Kim, Geem & Kim, 2001). The HS algorithm could be a competent alternative to existing metaheuristics such as GA because the former overcame the drawback (such as building block theory) of the latter (Geem, 2006a).

To test the ability of the HS algorithm in multiple dam operation problem, this article introduces a HS model, and applies it to a benchmark system, then compares the results with those of the GA model previously developed.

BACKGROUND

Before this study, various researchers have tackled the dam scheduling problem using phenomenon-inspired techniques.

Esat and Hall (1994) introduced a GA model to the dam operation. They compared GA with the discrete differential dynamic programming (DDDP) technique. GA could overcome the drawback of DDDP which requires exponentially increased computing burden. Oliveira and Loucks (1997) proposed practical dam operating policies using enhanced GA (real-code chromosome, elitism, and arithmetic crossover). Wardlaw and Sharif (1999) tried another enhanced GA schemes and concluded that the best GA model for dam operation can be composed of real-value coding, tournament selection, uniform crossover, and modified uniform mutation. Chen (2003) developed a real-coded GA model for the long-term dam operation, and Kim et al. (2006) applied an enhanced multi-objective GA, named NSGA-II, to the real-world multiple dam system. Teegavarapu and Simonovic (2002) used another metaheuristic algorithm, simulated annealing (SA), to solve the dam operation problem.

Although several metaheuristic algorithms have been already applied to the dam scheduling problem, the recently-developed HS algorithm was not applied to the problem before. Thus, this article deals with the HS algorithm's pioneering application to the problem.

HARMONY SEARCH MODEL AND APPLICATION

This article presents two major parts. The first part explains the structure of the HS model; and the second part applies the HS model to a bench-mark problem.

Dam Scheduling Model Using HS

The HS model has the following formulation for the multiple dam scheduling.

Maximize the benefits obtained by hydropower generation and irrigation

Subject to the following constraints:

1. **Range of Water Release**: the amount of water release in each dam should locate between minimum and maximum amounts.
2. **Range of Dam Storage**: the amount of dam storage in each dam should locate between minimum and maximum amounts.
3. **Water Continuity**: the amount of dam storage in next stage should be the summation of the amount in current stage, the amount of inflow, and the amount of water release.

The HS algorithm starts with filling random scheduling vectors in the harmony memory (HM). The structure of HM for the dam scheduling is as follows:

$$\begin{bmatrix} R_1^1 & R_2^1 & \cdots & R_N^1 & \bigg| & Z(\mathbf{R}^1) \\ R_1^2 & R_2^2 & \cdots & R_N^2 & \bigg| & Z(\mathbf{R}^2) \\ \vdots & \cdots & \cdots & \cdots & \bigg| & \vdots \\ R_1^{HMS} & R_2^{HMS} & \cdots & R_N^{HMS} & \bigg| & Z(\mathbf{R}^{HMS}) \end{bmatrix}$$

$$(1)$$

Each row stands for each solution vector, and each column stands for each decision variable (water release amount in each stage and each dam). At the end of each row, the objective function value locates. HMS (harmony memory size) is the number of solution vectors is HM.

Based on the initial HM, a new scheduling can be generated with the following function:

$$R_i^{NEW} \leftarrow \begin{cases} R_i, R_i^{MIN} \leq R_i \leq R_i^{MAX} & \text{w.p.} \quad p_1 \\ R_i(k) \in \{R_i^1, R_i^2, ..., R_i^{HMS}\} & \text{w.p.} \quad p_2 \\ R_i(k) + \Delta & \text{w.p.} \quad p_3 \\ R_i(k) - \Delta & \text{w.p.} \quad p_4 \end{cases}$$

$$(2)$$

where R_i^{NEW} is a new water release amount for decision variable i; the first row in the right hand side means that the new amount is chosen randomly from the total range; the second row means that the new amount is chosen from the HM; the third and fourth rows means that the new amount is certain unit (Δ) higher or lower

than the original amount $R_i(k)$ obtained from the HM. The summation of probability is equal to one ($p_1 + p_2 + p_3 + p_4 = 1$).

If the newly-generated vector, $\mathbf{R}^{NEW}$, is better than the worst harmony in the HM in terms of objective function, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

If the HS model reaches MaxImp (maximum number of function evaluations), computation is terminated. Otherwise, another new harmony (= vector) is generated by considering one of three above-mentioned mechanisms.

Applying HS to a Benchmark Problem

The HS model was applied to a popular multiple dam system as shown in Figure 1 (Wardlaw & Sharif, 1999).

The problem has 12 two-hour operating periods, and only dam 4 has irrigation benefit because outflows of other dams are not directed to farms. The range of water releases is as follows:

$$0.0 \leq R_1 \leq 3, \, 0.0 \leq R_2, R_3 \leq 4, \, 0.0 \leq R_4 \leq 7 \qquad (3)$$

The range of dam storages is as follows:

Figure 1. Schematic of four dam system
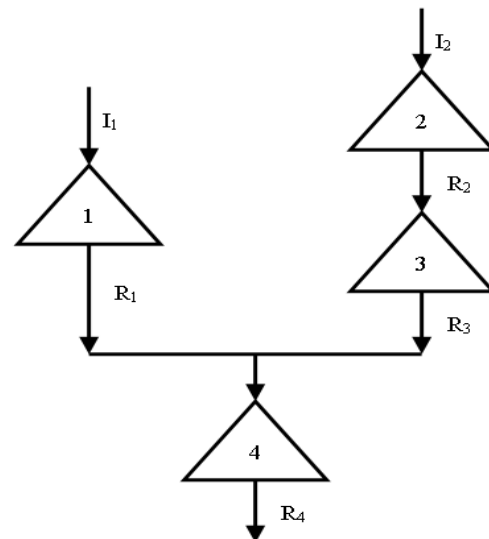
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