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An accelerated water evaporation optimization formulation for discrete optimization of skeletal structures

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ABSTRACT

Water Evaporation Optimization (WEO) is a recently developed physics-based metaheuristic algorithm that mimics the well-known rules governing the evaporation process of water molecules from a solid surface with different wettability. In the WEO algorithm, molecules are updated globally and locally respectively in two independent sequential phases: monolayer and droplet evaporation phases. In this study, the computational cost of the WEO is improved through the simultaneous utilizing of both phases. The new formulation is tested on classical discrete optimization problems achieving a significant enhancement in convergence rate compared to the basic WEO.

1. Introduction

Efficient metaheuristic optimization algorithms are developed to overcome the drawbacks of some traditional methods in highly nonlinear engineering optimization problems with high complexity, high dimension and multi-modal design spaces and gain increasing popularity nowadays [1]. Performance assessment of a metaheuristic algorithm may be used by solution quality, computational effort, and robustness [2] directly affected by its two contradictory criteria: exploration of the search space (diversification) and exploitation of the best solutions found (intensification).

A novel metaheuristic algorithm, imitating the evaporation process of a tiny amount of water molecules adhered on a solid surface with different wettability has been developed very recently and named Water Evaporation Optimization (WEO) [3]. WEO was successfully utilized in real parameter optimization [3], and continuous structural optimization problems [4] presenting: (1) competitive behavior with other algorithms in terms of accuracy and robustness; (2) advantages over other algorithms in the aspect of parameter tuning (except population size, other parameters are set based on the molecular dynamics); and (3) imposing a rational number of physically rules leads to significantly good convergence behavior and simple algorithmic structure. In structural optimization problems, high computational cost of the algorithm has been found to be the only drawback of the algorithm. In view of this, the present study will propose an accelerated version of WEO potentially able to solve multidisciplinary and engineering optimization problems regardless of the type of optimization problem at hand.

The basic WEO is initialized with a population of random designs, named water molecules that are updated through an iterative process to search the optimum. Updating is governed by evaporation rules based on molecular dynamic simulations results obtained for evaporation process of water molecules from a solid surface with different wettability. The candidate solutions are updated globally and locally in two independent sequential phases: monolayer and droplet evaporation phases. Rules driving each phase are in a good agreement with the local and global search ability of the algorithm. In this study, it is shown that the WEO can be improved to reduce computational cost by simultaneous utilizing of both phases.

The improvement to WEO hence involves a simultaneous use of both phases. Two scenarios are developed for considering simultaneous evaporation phases based on the (1) water molecules distance and (2) objective function value of molecules. The effects of these enhancements are tested in very classical discrete structural optimization problems. The first scenario which is developed from the physics of water evaporation phenomena is efficient in enhancing the convergence rate. Although the second scenario (which is developed greedily) also is efficient, the first scenario is accepted and developed in this study in view of its physical interpretation and higher performance.

The article is organized as follows. Section 2 outlines the basic WEO algorithm. Section 3 deals with developing of accelerated version of WEO with mixed phases. Section 4 discusses the perfor-

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mance of the new formulation of WEO in discrete structural optimization problems. Finally, conclusion is given in Section 5.

2. Basic Water Evaporation Optimization (WEO) algorithm

Evaporation of water restricted on the surface of solid materials is the inspiration basis of WEO which is different from the water evaporation of bulk surface. This type of water evaporation is essential in the macroscopic world such as the water loss through the surface of soil [5]. Wang et al. [6] presented Molecular Dynamics (MD) simulations on the evaporation of water from a solid substrate with different surface wettability. MD simulations were carried out by adhering nano-scale water aggregation in a neutral substrate which is chargeable. By varying the value of charge ($0\ e \leqslant q \leqslant 0.7\ e$), a substrate with tunable surface wettability can be obtained. It is found that as the surface changed from hydrophobicity ($q < 0.4$ e) to hydrophility ($q \geqslant 0.4$ e), the evaporation speed did not show a monotonically decrease from intuition, but increased first, and then decreased after reached a maximum value. Fig. 1 depicts the MD simulation method, (a) Side view of the initial system (the upward arrow denoted the accelerating region); (b) snapshot of water on the substrate with low wettability (the water molecules accumulate into the form of a sessile spherical cap with a contact angle θ to the surface); (c) snapshot of water on the substrate with high wettability (the adhered water forms a flat single-layer molecule sheet), and (d) theoretical topology of water molecules with respect to substrate wettability used for MD simulations.

Considering MD simulation results from end to the beginning a fine analogy can be found between this type of water evaporation phenomena and a population based metaheuristic algorithm. This analogy led us to developing the basic WEO algorithm [3,4], depicted in Fig. 2.

Water molecules and substrate with decreasing wettability are considered as algorithm individuals and search space, respectively. Decreasing the surface wettability reforms the water aggregation from a monolayer to a sessile droplet. Similarly, mutual positions of individuals in the design space change as the search process progresses. Decreasing q from 0.7 e to 0.0 e can represent the reduction of the objective function for a minimization problem. Evaporation flux variation is considered as the most appropriate measure for updating the algorithm individuals which is in a good agreement with the local and global search ability.

Evaporation flux reaches its maximum around $q = 0.4$ e. This situation is considered in the basic WEO [3] until the algorithm reaches the middle of the optimization process. In the other words, basic WEO updates the individuals in two independent sequential phases: monolayer and droplet evaporation phases. These two phases were explained in detail in [3]. In each phase the correspon-

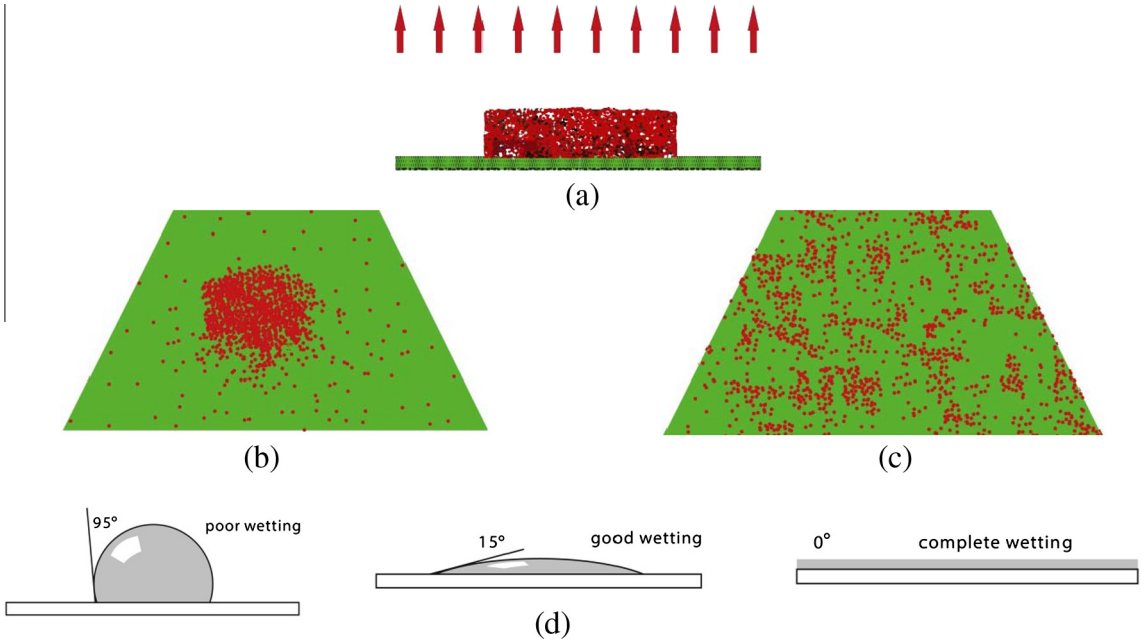

Fig. 1. (a) Side view of the initial system; (b) snapshot of water on the substrate with low wettability (q = 0 e); (c) snapshot of water on the substrate with high wettability (q = 0.7 e); and (d) theoretical topology of water molecules with respect to substrate wettability used for MD simulations.

Water molecules	~	Algorithm individuals
Substrate with decreasing wettability	~	Search space with different objective function values
Water aggregation reforms from a monolayer to a sessile droplet with decreasing the surface wettability	~	Change mutual positions of individuals as the algorithm progresses
Decreasing q from 0.7 e to 0.0	~	Decreasing the objective function value
$q = 0.4$ e	~	The algorithm reaches the middle of the optimization process
Evaporation in two phases (Monolayer and droplet) with different evaporation flux	~	Global and local search ability of the algorithm

Fig. 2. Analogy between water evaporation from a solid surface and a population based metaheuristic algorithm.