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Water cycle algorithm with evaporation rate for solving constrained and unconstrained optimization problems

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ABSTRACT

This paper presents a modified version of the water cycle algorithm (WCA). The fundamental concepts and ideas which underlie the WCA are inspired based on the observation of water cycle process and how rivers and streams flow to the sea. New concept of evaporation rate for different rivers and streams is defined so called evaporation rate based WCA (ER-WCA), which offers improvement in search. Furthermore, the evaporation condition is also applied for streams that directly flow to sea based on the new approach. The ER-WCA shows a better balance between exploration and exploitation phases compared to the standard WCA. It is shown that the ER-WCA offers high potential in finding all global optima of multimodal and benchmark functions. The WCA and ER-WCA are tested using several multimodal benchmark functions and the obtained optimization results show that in most cases the ER-WCA converges to the global solution faster and offers more accurate results than the WCA and other considered optimizers. Based on the performance of ER-WCA on a number of well-known benchmark functions, the efficiency of the proposed method with respect to the number of function evaluations (computational effort) and accuracy of function value are represented.

1. Introduction

Among optimization methods, metaheuristic algorithms have proved their potentials in finding near optimal solutions to real life problems where exact methods may not reach the optimum solution within a reasonable computational time, especially, when the global minimum is surrounded by many local minima. The concepts of such optimizer are usually motivated by observing natural phenomena. Genetic algorithms (GAs), simulated annealing (SA), particle swarm optimization (PSO), ant colony optimization (ACO), and so forth are based on natural phenomena.

The GAs is inspired by the genetic process of biological organisms [1]. After many generations, natural populations evolve according to the principles of natural selections (i.e., survival of the fittest). In the GAs, a candidate solution is considered as a set of factors. Each design variable is symbolized by a gene. Combining the genes, a chromosome (an individual) is created which denotes a potential solution.

During the reproduction phase, the individuals are selected from the population and recombined. Parents are randomly chosen from the population using a scheme which favors the fitter individuals. By randomly selecting two parents, their chromosomes are recombined; using crossover and mutation mechanisms. For the exploration purposes, mutation is applied to some individuals, to guarantee population diversity [2]. The GAs with floating-point representation (GAF) consists of three genetic operators (selection, crossover, and mutation). Details of the GAF operators are given in the literature [3–5].

The PSO is a computation technique for solving optimization problems introduced by Kennedy and Eberhart [6]. The PSO is based on individual improvement copped with population cooperation and competition. Researchers have discovered that the synchrony of animal's behavior is through maintaining optimal distances among individual members and their neighbors [7].

Artificial bee colony (ABC) introduced by Karaboga [8] is encouraged by the behavior of honey bees when seeking for food source. Also, the ACO was inspired by the foraging behavior of real ants [9]. This behavior aids ants to find the shortest path between food sources and their nest. This performance of real ant colonies is considered in artificial ant colonies for tackling optimization problems [10,11].

The origins of SA lay in the analogy of optimization and a physical annealing process [12]. In physics, annealing is a thermal process for obtaining low-energy states of a solid in a heat bath. The idea behind the grenade explosion method (GEM) is based on observation of a grenade explosion, in which the thrown pieces of shrapnel destruct the objects near the explosion location [13].

Geem et al. [14] developed the harmony search (HS) algorithm motivated by 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 resembled to local and global search schemes in optimization methods [15].

Bacterial foraging optimization (BFO) is based on the foraging (i.e. searching food) strategy of *Escherichia coli* bacteria [16]. In the BFO, the optimization uses the advantages of chemo-taxis, swarming, reproduction, elimination, and dispersal events to reach global minima.

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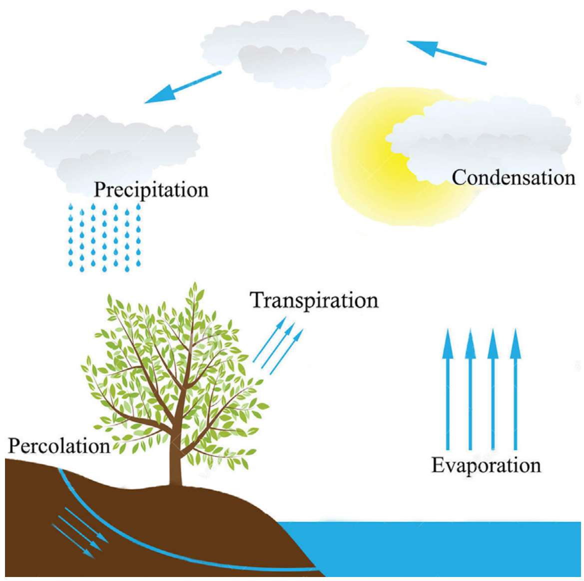

Fig. 1. A schematic view of the hydrologic cycle (water cycle process).

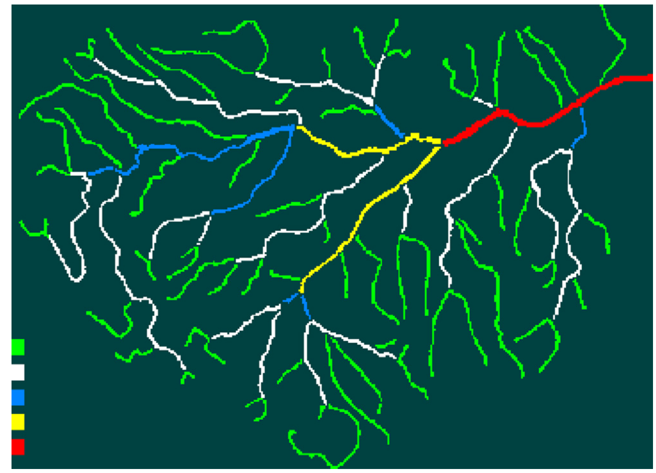

Fig. 2. Schematic diagram of streams having different orders flowing to a river. (For interpretation of the references to color in text, the reader is referred to the web version of the article.)
Adopted from U.S. Geological Service.

Shuffled complex evolution algorithm (SCE-UA) is a global optimization algorithm developed to evolve the traditional best parameter set and its underlying posterior distribution within a single optimization run [17,18].

Modified shuffled complex evolution algorithm (MSCE) has been utilized in the differential evolution (DE) to be used with the adaptation of the downhill simplex. The DE, a population-based optimizer, shows an overall superiority for a wide range of benchmark functions [19–21]. The DE combines simple operators such as recombination, mutation, and selection to progress from a randomly generated initial population.

This paper presents a modified version of water cycle algorithm (WCA) for optimizing continuous problems so called evaporation rate based WCA (ER-WCA). The WCA is based on the observation of water cycle process and how rivers and streams flow to the sea as in nature [22].

This paper is organized as follows. In Section 2, the proposed modified method and its concepts are introduced in detail. Validation of the ER-WCA is given in Section 3. In this section several unconstrained and constrained benchmark functions have been examined using the ER-WCA as follows:

1. The obtained optimization results have been compared with other reported optimizers in terms of number of function evaluations (NFEs) and function value.
2. Finding the global minimum among several local minimums (multimodal functions), and,
3. Finding all the global minima of functions having several global minima.
4. Finding the optimal feasible solutions of nonlinear constrained and engineering problems.

Finally, conclusions are drawn in Section 4.

2. The modified water cycle algorithm

2.1. Inspired idea

The idea of the WCA is inspired by nature and based on the observation of water cycle process and how rivers and streams flow downhill toward the sea in nature [22]. To further clarify, some basics of how rivers are created and water travels down to the sea are provided as follows.

A river, or a stream, is formed whenever water moves downhill from one place to another. This means that most rivers are formed high up in the mountains, where snow from the winter or ancient glaciers is melting.

Fig. 1 is a schematic view of the water cycle process, so called the hydrologic cycle. Water in rivers is evaporated, while plants discharge (transpire) water through photosynthesis process. The evaporated water is carried into the air to produce clouds which then condenses in the colder weather. Afterwards, the water returns to earth in the form of rain. This natural procedure is known as the hydrologic cycle [23].

Fig. 2 is a schematic diagram of how streams having deferent orders flow to the river. The smallest river branches are the small streams where the rivers begin to form. These tiny streams are called first-order streams (shown in Fig. 2 in green colors).

A second-order stream (shown in Fig. 2 in white colors) is produced when two first-order streams are joined. A third-order stream is formed where two second-order streams join, (shown in Fig. 2 in blue colors), and such process continues until the river flows out into the sea [24]. Finally, all of the rivers flow to the sea (i.e., the most downhill place).

2.2. Proposed evaporation rate based WCA

In the WCA, it is assumed that there are some rain or precipitation phenomena. Streams are created using the water from the rain. The WCA is a population-based algorithm; therefore, an initial population of designs variables (i.e., streams) is randomly generated between upper (UB) and lower (LB) bounds. The best individual, classified in terms of having the minimum cost function (or maximum fitness), is chosen as the sea.

Then, a number of good individuals (i.e., cost function values close to the current best solution) are chosen as rivers, while all other streams are called streams which flow to rivers and sea. In an N dimensional optimization problem, a stream is an array of $1 \times N$. This array is defined as follows:

$$\text{A Candidate stream} = [x_1, x_2, x_3, \cdots, x_N], \quad (1)$$

where N is the number of design variables (i.e., problem dimension). To initiate an optimization algorithm, an initial population demonstrating a matrix of individuals of size $N_{pop} \times N$ is created.