Applied Soft Computing 13 (2013) 1781–1791

Contents lists available at SciVerse ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Artificial bee colony algorithm and pattern search hybridized for global optimization

Fei Kang*, Junjie Li, Haojin Li

Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:
Received 19 July 2012
Received in revised form
29 November 2012
Accepted 31 December 2012
Available online 10 January 2013

Keywords:
Artificial bee colony algorithm
Swarm intelligence
Memetic algorithm
Evolutionary computation
Global optimization

ABSTRACT

Artificial bee colony algorithm is one of the most recently proposed swarm intelligence based optimization algorithm. A memetic algorithm which combines Hooke–Jeeves pattern search with artificial bee colony algorithm is proposed for numerical global optimization. There are two alternative phases of the proposed algorithm: the exploration phase realized by artificial bee colony algorithm and the exploitation phase completed by pattern search. The proposed algorithm was tested on a comprehensive set of benchmark functions, encompassing a wide range of dimensionality. Results show that the new algorithm is promising in terms of convergence speed, solution accuracy and success rate. The performance of artificial bee colony algorithm is much improved by introducing a pattern search method, especially in handling functions having narrow curving valley, functions with high eccentric ellipse and some complex multimodal functions.

1. Introduction

Global optimization could be a very challenging task because many objective functions and real world problems are multimodal, highly non-linear, with steep and flat regions and irregularities [1], thus better optimization algorithms are always needed. Unconstrained global optimization problems can be formulated as

$$\min f(\boldsymbol{x}),\ \boldsymbol{x} = (x_1, x_2, \ldots, x_n) \quad (1)$$

where f: $\mathbf{R}^n \to \mathbf{R}$ is a real-valued objective function, $\boldsymbol{x} \in \mathbf{R}^n$, and n is the number of the parameters to be optimized.

With more complex systems arising in science and engineering fields often remained intractable to conventional mathematical and analytical methods, the research community has diverted their attention toward soft computing techniques to deal with various complex problems [2–4]. Evolutionary algorithms such as genetic algorithms [5], differential evolution [6] and particle swarm optimization (PSO) [7] are powerful tools for solving complex optimization problems. As extensions of evolutionary algorithms, memetic algorithms [8,9] have been developed to combine the advantage of evolutionary algorithms and some local search strategies. Such hybrids have been successfully applied to global optimization of numerical functions [5,10] and have been used to solve numerous real-world optimization problems [11,12].

Studies on swarm intelligence of honeybees for optimization problems are currently prevalent [13]. Artificial bee colony (ABC) algorithm is one of the newest global optimization techniques proposed by Karaboga and Basturk [14], inspired by the foraging behavior of honeybee swarms. It has received increasing interest from the optimization community due to its simplicity, wide applicability and outstanding performance. ABC methods that use chaotic maps as efficient alternatives to pseudorandom sequences were proposed by Alatas [15], and global-best-solution-guided ABC (GABC) was proposed by Zhu and Kwong [16]. Banharnsakun et al. [17] proposed a best-so-far selection ABC for numerical optimization and image registration. Gao and Liu [18] proposed an improved ABC algorithm inspired by differential evolution. Li et al. [19] proposed an ABC algorithm with the abilities of prediction and selection. The performance of ABC has already been compared with other optimization methods, such as GA, DE, and PSO [20,21]. The comparisons were made based on various numerical benchmark functions, which consist of unimodal and multimodal distributions. Results show that ABC can produce more optimal solutions and thus is more effective than the other methods in several sorts of engineering problems such as signal processing [22,23], parameter identification [24,25], clustering [26,27], image segmentation [28,29], leak detection [30], structure optimization [31] and geotechnical stability problems [32,33]. More extensive review of ABC can be seen in [34].

ABC has already been shown to be a promising global optimization algorithm. However, it still has some limitations in handling certain optimization problems [21]. Meanwhile, like

* Corresponding author. Tel.: +86 0411 84708516; fax: +86 0411 84708501.
E-mail addresses: kangfei2009@163.com, kangfei@dlut.edu.cn (F. Kang).

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http://dx.doi.org/10.1016/j.asoc.2012.12.025

most population-based algorithms, ABC takes a long time because of its stochastic nature. To improve the performance of ABC, a Hooke–Jeeves artificial bee colony (HABC) algorithm is proposed for global optimization of numerical functions. Compared to the algorithm proposed in [35], the HABC algorithm has only two more control parameters than ABC. The proposed algorithm retains the main steps of ABC and incorporates a pattern search based local search technique. ABC and pattern search have complementary advantages, and a hybrid of the two algorithms can result in a faster and more robust technique. The effect of control parameters for HABC was studied and efficiency of the new algorithm was tested on extensive functions.

The remainder of this paper is organized as follows. In Section 2, a concise presentation of ABC is provided. In Section 3, the proposed HABC algorithm is introduced. In Section 4, experimental results are presented. Conclusions are given in Section 5. Some test problems are listed in Appendix A.

2. Artificial bee colony algorithm

ABC is a population based optimization algorithm inspired by the honeybee foraging behavior. In ABC, there are three types of honeybees: employed bees, onlookers and scouts. The position of a food source represents a possible solution to the optimization problem and the profitability of a food source corresponds to the quality (fitness) of the associated solution. The number of employed bees is equal to the number of onlookers, and also equal to the number of food sources. Any food sources cannot be improved further in definite cycles will be replaced with a new food source by a scout bee.

At the beginning, an initial population contains NS solutions are generated randomly. Where $NS = NP/2$ is the number of food sources, and it is equal to the number of employed bees. NP is the population size. Each solution $\boldsymbol{x}_i$ ($i = 1, 2, \ldots, NS$) is an n-dimensional vector. Then, the honeybees perform cyclic search according to some specific rules.

To update feasible solutions, each employed bee selects a new candidate food source position. The choice is based on the neighborhood of the previously selected food source. A candidate solution $\boldsymbol{v}_i$ can be generated from the old solution $\boldsymbol{x}_i$ as

$$v_{ij} = x_{ij} + \phi_{ij}(x_{ij} - x_{kj}), \tag{2}$$

where $k \in \{1, 2, \ldots, NS\}$ and $j \in \{1, 2, \ldots, n\}$ are indexes chosen randomly; k has to be different from i; ϕ_{ij} is a uniformly distributed random number in the range $[-1, 1]$.

The candidate solution will be compared with the old one. If the new food source has equal or better quality than the previous source, the old one is replaced by the new one. Otherwise, the old one is retained. Employed bees will return to their hive and share the information of the food sources they have found with the onlooker bees.

In the next step, each onlooker bee selects one of the food sources depending on the fitness value. The probability p_i of a food source will be selected by an onlooker bee can be calculated as

$$p_i = \frac{fit_i}{\sum_{j=1}^{NS} fit_j}, \tag{3}$$

where fit_i is the fitness value of food source i, which is related to the objective function value of the food source.

The probability of a food source being selected by the onlooker bees increases as the fitness value of the food source increases. After the food source is selected, each onlooker bee finds a new candidate food source in the neighborhood of the selected one. The candidate food source can be calculated by Eq. (2). By evaluating the fitness of the candidate food source, the new food source is determined by greedy selection.

If a position cannot be improved further through *limit* cycles, then that food source is assumed to be abandoned. The corresponding employed bee becomes a scout, and the food source will be replaced with a new one found by the scout. *limit* is a predetermined number by the users. If the abandoned source is $\boldsymbol{x}_i$, the scout discovers a new food source as follows:

$$x_{ij} = x_{j\min} + rand[0, 1](x_{j\max} - x_{j\min}), \tag{4}$$

where $x_{j\min}$ and $x_{j\max}$ are lower and upper bounds of variable x_{ij}, $rand[0,1]$ is a uniformly distributed random number in the range [0,1].

The process will be repeated until the output of the objective function reaches a defined threshold value or the number of iteration equals a predefined maximum number of cycles. The main steps of ABC are shown in Fig. 1.

3. Hooke–Jeeves artificial bee colony algorithm

3.1. The modified Hooke–Jeeves method

Hooke–Jeeves pattern search method is a simple yet very effective optimization technique proposed by Hooke and Jeeves [36]. Today, it is still a popular tool for various optimization problems, especially for deterministic local search.

In the pattern search method, a combination of exploratory move and pattern move is made iteratively to search out the optimum solution for the problem. It starts with an exploratory move to determine an appropriate direction of search by considering one variable at a time along the individual coordinate directions in the neighborhood of a base point solution. Following the exploratory search, a pattern move is made to accelerate the search in the direction determined in the exploratory search. Exploratory searches and pattern moves are repeated until a termination criterion is met, as illustrated in Fig. 2.

The basic pattern search method is modified to accommodate the hybrid strategy. The main characteristics of the modified method are: (1) to accelerate the procedure, direct search takes advantage of its knowledge of the sign of its previous move in each of the directions; (2) different step sizes for different dimensions are used to adaptive to the scaling problems of different variables.

Assume $\boldsymbol{x}_0$ is the current solution (the base point), $f_{\min}$ is the current minimum value of the objective function, $\boldsymbol{\delta} = (\delta_1, \delta_2, \ldots, \delta_n)$ are the step sizes of n directions. $\boldsymbol{x}_1$ is a temporary vector to store the obtained point after exploratory move. The main steps of exploratory move are described in Fig. 3. Given two solutions $\boldsymbol{x}_0$ and $\boldsymbol{x}_1$ ($f(\boldsymbol{x}_1) < f(\boldsymbol{x}_0)$), the pattern move takes the step $\boldsymbol{x}_1 - \boldsymbol{x}_0$ from $\boldsymbol{x}_0$ as

$$\boldsymbol{x}_2 = \boldsymbol{x}_1 + (\boldsymbol{x}_1 - \boldsymbol{x}_0), \tag{5}$$

where $\boldsymbol{x}_2$ is the point obtained by pattern move. The pattern move is an aggressive attempt of the algorithm to exploit promising search directions because it exploits information gained from the search during previous successful iterations. The idea of pattern move is to investigate whether further progress is possible in the general direction $\boldsymbol{x}_1 - \boldsymbol{x}_0$ (since, if $f(\boldsymbol{x}_1) < f(\boldsymbol{x}_0)$, then $\boldsymbol{x}_1 - \boldsymbol{x}_0$ is clearly a promising direction) [37]. The main steps of the modified pattern search method are shown in Fig. 4. The variable s_a is adopted to judge when to stop the algorithm. The usually adopted value of step size reduction factor is $\rho = 0.5$.

3.2. The proposed hybrid artificial bee colony algorithm

The slightly modified pattern search is incorporated into ABC as a local exploitation tool. Meanwhile, to maintain the colony