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A hybrid particle swarm optimizer with sine cosine acceleration coefficients

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ABSTRACT

Particle swarm optimization (PSO) has been widely used to solve complex global optimization tasks due to its implementation simplicity and inexpensive computational overhead. However, PSO has premature convergence, is easily trapped in the local optimum solution and is ineffective in balancing exploration and exploitation, especially in complex multi-peak search functions. To overcome the shortcomings of PSO, a hybrid particle swarm optimizer with sine cosine acceleration coefficients (H-PSO-SCAC) is proposed to solve these problems. It is verified by the application of twelve numerical optimization problems. In H-PSO-SCAC, we make the following improvements: First, we introduce sine cosine acceleration coefficients (SCAC) to efficiently control the local search and convergence to the global optimum solution. Second, opposition-based learning (OBL) is adopted to initialize the population. Additionally, we utilize a sine map to adjust the inertia weight ω. Finally, we propose a modified position update formula. Experimental results show that, in the majority of cases, the H-PSO-SCAC approach is capable of efficiently solving numerical optimization tasks and outperforms the existing similar population-based algorithms and PSO variants proposed in recent years. Therefore, the H-PSO-SCAC algorithm is successfully employed as a novel optimization strategy.

1. Introduction

With the increase in the level of industrialization and the development of artificial intelligence technology, stochastic optimization approaches [3,11] have attracted the attention of technical staff and managers over the past two decades. Optimization refers to the process of searching all the reasonable solutions to determine the optimal solution based on the parameters of a given system to minimize or maximize its output [30]. Optimization tasks are frequently applied in many scientific fields such as engineering design [4], chemistry [14], economics [31], pattern recognition [40] and information theory [48]. In recent years, an increasing number of complex optimization problems have emerged. It is difficult to solve these problems by relying solely on traditional optimization algorithms. Therefore, it is necessary to propose new optimization algorithms. Inspired by the biological and physical phenomena of nature, researchers have proposed a series of intelligent algorithms. Particle swarm optimization (PSO) [23], biogeography-based optimization (BBO) [41], krill herd (KH) algorithm [15], ant colony optimization (ACO) [8], artificial bee colony (ABC) [24], gravitational search algorithm (GSA) [38] and sine cosine algorithm (SCA) [30] are all the well-known paradigms of these intelligence algorithms. These optimization approaches have been adopted by researchers to date and are well suited to solve optimization tasks within various fields such as

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function optimization [5], feature selection [13], electric transmission systems [18], network attacks [25] and artificial neural networks [26].

The particle swarm optimizer, inspired by the social behaviors of the individuals in flocks of birds, is a nature-inspired and swarm optimization algorithm. Similar to other meta-heuristic swarm intelligent algorithms, PSO begins with the random initialization of population positions in the search range. However, unlike other population-based algorithms, PSO searches for an optimum solution by simply tuning its flying trajectory based on its own best location and its neighborhood's best location at each period [6]. Because of its implementation simplicity and high efficiency, the PSO approach has become a widely accepted optimization method and has been successfully applied to many real-world optimization tasks [7,9]. The particle swarm optimizer has the disadvantages of lacking diversity and premature convergence. To overcome these problems, variants of PSO have been proposed in the literature, such as orthogonal learning PSO (OLPSO) [49], comprehensive learning PSO (CLPSO) [27], levy flight PSO (LFPSO) [16], time varying acceleration coefficients PSO (TVACPSO) [19] and dynamic multi-swarm PSO (DMS-PSO) [50]. These modified PSO variants have improved search performances over the original PSO. To strengthen the global search performance of PSO and overcome the deficiency of premature convergence, we present a hybrid particle swarm optimizer with sine cosine acceleration coefficients (H-PSO-SCAC) utilizing a new optimization strategy.

In this paper, we propose three modifications to the PSO approach: Initially, we introduce sine cosine acceleration coefficients to avoid premature convergence in the early part of the optimization process and to enhance convergence accuracy at the end of the search stage, which is called PSO-SCAC. The simulation results of twelve numerical functions (seven unimodal and five multimodal functions) show that the PSO-SCAC algorithm has better search accuracy and faster search speed than the PSO and PSO-TVAC methods. Additionally, we apply opposition-based learning (OBL) to initialize the population. Meanwhile, the sine map is used to adjust the inertia weight ω and a new modified formula is proposed to update the next generation population position. These three modifications to PSO will be referred to as H-PSO. Finally, we combine H-PSO with SCAC as a new population search strategy for the PSO concept, which is called H-PSO-SCAC. Again, twelve numerical optimization problems are adopted to verify the performance of H-PSO-SCAC. We establish three group contrast experiments. First, we compare H-PSO-SCAC with H-PSO and the original PSO. Experimental results show that H-PSO-SCAC has better convergence accuracy and a stronger ability to escape local solutions than the original PSO for the majority of test functions, while the H-PSO-SCAC shows better search performance than H-PSO in the majority of cases. Second, the H-PSO-SCAC approach is compared with state-of-art optimization algorithms (ABC, KH, BBO, SCA and GSA). The simulation results show that the H-PSO-SCAC method provides better search results in almost all test functions and it is more stable as well. Third, the H-PSO-SCAC approach is compared with other PSO variants. The results indicate that the H-PSO-SCAC approach outperforms other PSO variants for the majority of numerical functions. In summary, through the above three experiments it can be seen that H-PSO-SCAC has shown a very high search performance on numerical optimization problems. Therefore, the H-PSO-SCAC algorithm should be employed as a novel optimization strategy.

The remainder of this paper is organized as follows: Section 2 summarizes previous related works. In Section 3, we describe the proposed new algorithms (PSO-SCAC, H-PSO and H-PSO-SCAC) that have an extremely strong ability to escape the local optimal solution and have high convergence accuracy. Section 4 describes experimental settings and simulation strategies for numerical function testing. The simulation results and discussions are shown in Section 5. Finally, the paper provides a summary and recommendations for future work in Section 6.

2. Review of previous work

2.1. Particle swarm optimizer

Inspired by the social behaviors of the individuals in flocks of birds, PSO is a nature-inspired and global optimization technique originally developed by Kennedy and Eberhart in the mid-1990s [23]. The PSO algorithm is becoming very popular due to its simplicity, efficiency and ability to quickly and reasonably converge on global optimum solutions. In the simulation, either the best global individual or the best local particle will influence the behavior of each particle in the population. In the original PSO algorithm, a particle represents a potential solution.

When searching in the D-dimensional space, each particle i has a position vector $\boldsymbol{X_i^d} = [x_{i1}, x_{i2}, \cdots, x_{iD}]$ and a velocity vector $\boldsymbol{V_i^d} = [v_{i1}, v_{i2}, \cdots, v_{iD}]$ to calculate its current state, where D is the dimensions of the solution space. Moreover, particle i will retain its personal previous best position vector $\boldsymbol{pbest_i} = [pbest_i^1, pbest_i^2, \cdots, pbest_i^D]$. The best position discovered by the entire population is denoted as $\boldsymbol{gbest} = [gbest^1, gbest^2, \cdots, gbest^D]$. The position $\boldsymbol{X_i^d}$ and velocity $\boldsymbol{V_i^d}$ are initialized randomly and updates to the D-dimension of the i particle. The process are calculated as follows:

$$V_i^d = V_i^d + c_1 \times r_1 \times (pbest_i^d - X_i^d) + c_2 \times r_2 \times (gbest^d - X_i^d) \tag{1}$$

$$X_i^d = X_i^d + V_i^d \tag{2}$$

where c_1 and c_2 are the acceleration parameters which are set to 2.0 commonly and r_1 and r_2 are two uniform distributed values in the range [0,1].