Information Sciences 181 (2011) 4515–4538

Contents lists available at ScienceDirect

Information Sciences

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

Self-adaptive learning based particle swarm optimization

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ARTICLE INFO

Article history:
Available online 24 July 2010

Keywords:
Particle swarm
Self-adaptive learning
Numerical optimization
Economic load dispatch
Power system

ABSTRACT

Particle swarm optimization (PSO) is a population-based stochastic search technique for solving optimization problems over continuous space, which has been proven to be efficient and effective in wide applications in scientific and engineering domains. However, the universality of current PSO variants, i.e., their ability to achieve good performance on a variety of different fitness landscapes, is still unsatisfying. For many practical problems, where the fitness landscapes are usually unknown, employing a trial-and-error scheme to search for the most suitable PSO variant is computationally expensive. Therefore, it is necessary to develop a more adaptive and robust PSO version to provide users a black-box tool for various application problems. In this paper, we propose a self-adaptive learning based PSO (SLPSO) to make up the above demerits. SLPSO simultaneously adopts four PSO based search strategies. A probability model is used to describe the probability of a strategy being used to update a particle. The model is self-adaptively improved according to the strategies' ability of generating better quality solutions in the past generations. In order to evaluate the performance of SLPSO, we compare it with eight state-of-the-art PSO variants on 26 numerical optimization problems with different characteristics such as uni-modality, multi-modality, rotation, ill-condition, mis-scale and noise. The experimental results clearly verify the advantages of SLPSO. Moreover, a practical engineering problem, the economic load dispatch problem of power systems (ELD), is used to further evaluate SLPSO. Compared with the previous effective ELD evolutionary algorithms, SLPSO can update the best solution records.

1. Introduction

Inspired by the concerted actions of flocks of birds, shoals of fish, and swarms of insects searching for food, Kennedy and Eberhart originally proposed particle swarm optimization (PSO) in the mid-1990s [23,24]. As an important branch of swarm intelligence, PSO has attracted public attention from the research community and has been successfully implemented in various scientific and engineering applications, such as mixed discrete nonlinear programming [38], nearest neighborhood classification [8], receive-diversity-aided STBC systems [30], software development [9], Value-at-Risk based fuzzy random facility location models [60] and economic load dispatch in power systems [45]. These applications can be uniformly formulated as D-dimensional optimization problems over continuous space:

$$\begin{aligned} &\text{minimize } f(x), \\ &\text{where } x = [x_1, x_2, \ldots, x_D]. \end{aligned} \tag{1}$$

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0020-0255/$ - see front matter
doi:10.1016/j.ins.2010.07.013

Generally speaking, the features of PSOs in dealing with global optimization problems include the improved capability of solving complex problems, high convergence speed and good generality for different problems. These advantages promoted the use of PSO in many engineering applications [16,55]. In the recent years, several state-of-the-art PSO variants have been proposed, such as fully informed PSO (FIPS-PSO) [36], fitness-distance-ratio based PSO (FDR-PSO) [41], cooperative based PSO (CPSO) [4], efficient population utilization strategy based PSO (EPUS-PSO) [19], and comprehensive learning PSO (CLPSO) [28] to name a few.

Although many variants of PSO have been proposed, the universality and robustness, i.e., the effectiveness of one algorithm in dealing with diverse problems with different characteristics, is still unsatisfying. Generally speaking, the success of PSO in solving one specific problem crucially depends on the choice of suitable strategies, foremost the selection of the velocity updating method. For example, CLPSO [28] is specifically designed for complex multi-modal problems, but the convergence speed of CLPSO on uni-modal problems and relatively simple multi-modal problems is much lower than of the other variants. The PSO variants with high convergence speed, on the other hand, are always prone to shrink towards some local optima in a few generations [19,28]. Therefore, it can be concluded that the conflict between exploration and exploitation is very intense in present PSO variants. Besides, it has been observed that the performance of previous PSO variants on ill-conditioned problems is very poor [19,28,36,41], even when the problems are uni-modal, such as the rotated versions of the classical Schwefel 2.21 problem $f_4(x) = \max |z_i|$ and Rochenbrock problem. The reason for this behavior may be that the velocities of particles in these PSO variants are difficult to be adapted to the narrow valleys towards the global optimum of these problems without losing diversity. However, practical scientific and engineering problems may have any kind of fitness landscape, and furthermore, their structure is usually not known or cannot be analyzed efficiently beforehand. Naturally, employing a trial-and-error scheme to search for a most suitable PSO variant for a specific application problem is one possible approach to handle this problem, but the computational cost of this scheme is usually too high [43]. Therefore, from the perspective of engineering practitioners, it is necessary and urgent to develop a more robust and more effective PSO version that can cope with various problems without resetting the strategies and parameters respectively.

In the previous research of optimization techniques, the scheme of simultaneously using multiple offspring creation strategies from one or more different algorithms has been studied by a number of works [33,34,43,44,46,54,58,59]. In these works, it has been proven that applying multiple strategies or methods in one algorithmic framework is useful for algorithm to obtain good performance on different kinds of problems. In this paper, two new PSO velocity updating strategies, the difference-based velocity updating strategy (DbV) and the estimation-based velocity updating strategy (EbV), are proposed to make up the demerits of PSO on ill-conditioned problems, and to accelerate the convergence on many uni-modal problems, respectively. Then, a self-adaptive learning framework is used to probabilistically steer four PSO velocity updating strategies with different features in parallel to optimize problems with different fitness landscapes. The purpose of using self-adaptive learning framework is to adaptively give preference to appropriate strategies on different problems and at different stages of the optimization process based on the feedback of the quality of solutions generated by them. The fundamental idea of tuning the strategies' contribution proportionally to their previous performance is similar to that of [43,59]. Instead of directly assigning absolute shares of the population to the different strategies according to their effectiveness [44,43,59], SLPSO uses execution probabilities to stochastically determine which strategy is adopted to update the current particle. Besides, instead of using relatively fixed execution probabilities during the whole optimization procedure [54], SLPSO uses a gradual updating mechanism based on a given learning rate to adaptively update the execution probabilities based on the feedback of previous optimization procedure. In order to comprehensively evaluate the performance of SLPSO, we conduct function optimization experiments on 26 numerical optimization problems with different characteristics, such as uni-modality, multi-modality, rotation, ill-condition, mis-scale, and noise. The performance of SLPSO is compared with eight state-of-the-art PSO variants. The experimental results clearly validate the efficiency and effectiveness of SLPSO on diverse problems. Besides, in order to benchmark the robustness of SLPSO on practical engineering problems, we applied it to solve the economic load dispatch problem of power system (ELD). Its performance is compared with that of the optimization algorithms known to be most effective in the ELD domain. The best solution records for several ELD benchmark instances are updated by SLPSO.

The remainder of this paper is structured as follows: In the next section, the original PSO is introduced. Then, a literature review on PSO algorithms is presented by categorizing their features according to three aspects. For each classification aspect, the differences between SLPSO and the previous works are discussed. In Section 3, the DbV and EbV strategies are proposed. In Section 4, the new algorithm SLPSO is proposed and then, the search behaviors of PSO, SLPSO, and CLPSO are analyzed by investigating their search range. Experimental results on function optimization are shown and discussed in the fifth section and in Section 6, the experimental results on large scale ELD problems are presented. Finally, the contributions of this paper are summarized and the future work is outlined in Section 7.

2. Previous work related to PSO

PSO is a population-based, stochastic optimization algorithm based on the idea of a swarm moving over a given landscape. The algorithm adaptively updates the velocities and positions of the members of the swarm by learning from the good experiences. Unlike many other evolutionary algorithms [2,63,67], no mutation or crossover operators are used. In original PSO, the velocity V_i^d and position X_i^d of the dth dimension of the ith particle are updated as follows [23]: