Applied Soft Computing 59 (2017) 596–621

Contents lists available at ScienceDirect

Applied Soft Computing

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

A novel physical based meta-heuristic optimization method known as Lightning Attachment Procedure Optimization

A. Foroughi Nematollahi[a], A. Rahiminejad[b], B. Vahidi[a,*]

[a] Electrical Engineering Department, Amirkabir University of Technology, Tehran, 1591634311, Iran
[b] Department of Electrical and Computer Science, Esfarayen University of Technology, Esfarayen, North Khorasan, 9661998195, Iran

ARTICLE INFO

Article history:
Received 12 December 2016
Received in revised form 22 May 2017
Accepted 16 June 2017
Available online 21 June 2017

Keywords:
Meta-heuristic
Physical based
Optimization algorithm
Constrained optimization
Optimization

ABSTRACT

In this article, A novel nature-inspired optimization algorithm known as Lightning Attachment Procedure Optimization (LAPO) is proposed. The proposed approach mimics the lightning attachment procedure including the downward leader movement, the upward leader propagation, the unpredictable trajectory of lightning downward leader, and the branch fading feature of lightning. Final optimum result would be the lightning striking point. The proposed method is free from any parameter tuning and it is rarely stuck in the local optimum points. To evaluate the proposed algorithm, 29 mathematical benchmark functions are employed and the results are compared to those of 9 high quality well-known optimization methods The results of the proposed method are compared from different points of views, including quality of the results, convergence behavior, robustness, and CPU time consumption. Superiority and high quality performance of the proposed method are demonstrated through comparing the results. Moreover, the proposed method is also tested by five classical engineering design problems including tension/compression spring, welded beam, pressure vessel designs, Gear train design, and Cantilever beam design and a high constraint optimization problem known as Optimal Power Flow (OPF) which is a high constraint electrical engineering problem. The excellence performance of the proposed method in solving the problems with large number of constraints and also discrete optimization problems are also concluded from the results of the six engineering problem.

1. Introduction

Optimization refers to determination of the decision variables of a function so that the function would be in its minimum or maximum value. A majority of problems especially engineering ones are optimization problems in which the decision variables should be determined in a way that the systems operate in their best operation points. Since most engineering problems are non-linear, non-convex, and complicated, sophisticated methods are required to solve these problems optimally. This has resulted in excellence research in the area of optimization methods in recent years [1–3].

The early methods used for solving the optimization problems were the mathematical or numerical methods in which the decision variables are obtained by achieving the point at which the derivative is zero. However, solving the non-linear non-convex problems with lots of variables and constraints using these methods is almost impossible. Moreover, since there may be lots of local optimum points (at which the derivative is also zero), the numerical methods may be stuck at these local optimum points. In other words, there is no guarantee to find the best overall point of the problem using the numerical methods. Other specifications of these methods could be stated as need for initial guess, additional mathematical calculations, divergent issue, complicated implementation, difficult convergence for discrete types of optimization problem, etc. [4–6].

To overcome the drawbacks of numerical methods including derivative, complexity, and being trapped in local optimum points, a bunch of optimization methods known as meta-heuristics methods are introduced and developed in recent decades [7]. These methods, in which random operators are employed, are inspired by simple concepts. On one hand, using the random operators reduces the probability of being stuck in local optimum point. On the other hand, it increases diversity of the final results. Nevertheless, since the meta-heuristics methods 1-are simple methods which could be applied for both continuous and discrete functions, 2-do not need any additional complex mathematical operations such as deriva-

* Corresponding author at: Amirkabir University of Technology, 424 Hafez Ave., Tehran, 15916343111, Iran.
E-mail addresses: amin.forooghi@aut.ac.ir (A.F. Nematollahi), arahiminezhad@aut.ac.ir (A. Rahiminejad), bvahidi@yahoo.com, vahidi@aut.ac.ir (B. Vahidi).

http://dx.doi.org/10.1016/j.asoc.2017.06.033
1568-4946/

tive, and 3-rarely get stuck in local optimum points, they are used widely in different optimization problems.

for initial guess, additional mathematical calculations, divergent issue, complicated implementation, difficult convergence for discrete types of optimization problem, etc. [4–6].

To overcome the drawbacks of numerical methods including derivative, complexity, and trapping in local optimum points, a bunch of optimization methods known as meta-heuristics methods are introduced and developed in the recent decades [7]. These methods, in which random operators are employed, are inspired by simple concepts. In one side, using the random operators reduces the probability of being stuck in local optimum point. On the other side, it increases the diversity of final results. Nevertheless, since the meta-heuristics methods 1-are simple methods which could be applied for both continuous and discrete functions, 2-do not need any additional complex mathematical operations such as derivative, and 3-rarely get stuck in local optimum points, they are used widely in different optimization problems.

The meta-heuristic methods could be classified in two main categories

1. Single solution based methods in which a random solution is generated and improved until the best overall answer is obtained. Simulated Annealing (SA) [8] is one the most well-known single solution based methods.
2. Population based methods in which a set of solutions is generated randomly in the predefined search space. All the solutions are updated iteratively until the best answer is obtained among the population.

In the second group, each solution tries to find the local optimum point around itself based on the information interaction with the other solutions. Moreover, the solutions help others not to get stuck in the local optimum points. Since in these kinds of methods the whole search area is almost investigated, better results are achieved compared to the single solution based methods. Hence, they have attracted attentions of researchers recently.

The population based optimization methods are mostly inspired by the nature and could be categorized in 4 different categories.

1. Evolutionary algorithms: these methods simulate the evolution of the nature. The first generation is produced randomly and evolved gradually. The best answer would be the best solution among the whole population in the last iteration of evolution. Genetic Algorithm [9] is the first and most well-known meta-heuristic method which simulates the Darwin's theory of evolution. Evolution Strategy (ES) [10], Genetic Programming (GP) [11], and Biogeography-Based Optimizer (BBO) [12] are some other evolutionary methods.
2. Physical based optimization algorithm: in this kind of methods, the physical rules are employed for updating the solutions in each iteration. Charged System Search (CSS) [13], Central Force Optimization (CFO) [14], Artificial Chemical Reaction Optimization Algorithm (ACROA) [15], Black Hole (BH) algorithm [16], Ray Optimization (RO) algorithm [17], Small-World Optimization Algorithm (SWOA) [18], Galaxy-based Search Algorithm (GbSA) [19], Water Evaporation Optimization Algorithm [20], Multi-Verse Optimizer(MVO) [21] and Gravitational Search Algorithm(GSA) [22] are classified as the physical methods.
3. The third group is based on movement of a group of animals. This kind of methods mimic the social behavior of animals in order to enhance their knowledge of a goal such as food source. The most well-known method of this group is Particle Swarm Optimization (PSO) [23,24]. Wolf pack search algorithm [25], Cuckoo Search (CS) [26], Firefly Algorithm (FA) [27], Bird Mating Optimizer (BMO)[28], Monkey Search Algorithm (MSA) [29], Coral Reef Optimization Algorithm(CRO) [30,31], Artificial Bee Colony (ABC) algorithm[32], Antlion Optimization Algorithm(ALO) [33], Grey Wolf Optimization algorithm (GWO) [7], Moth-flame Optimization (MFO) algorithm [34], Whale Optimization Algorithm (WOA) [35], Dragonfly algorithm [36], Dolphin Echolocation (DE) [37], and Krill Herd (KH) [38] are some of other methods of this group.
4. The fourth group are the methods which simulate the human behavior. Teaching-Learning-Base Optimization (TLBO) [39] algorithm is one of the most well-known methods of this group which simulates the enhancing procedure of a class grade. The other methods which could be classified in this group are Harmony Search (HS) [40], Tabu Search [41–44], Group Search Optimizer (GSO) [45], Imperialist Competitive Algorithm (ICA) [46], League Championship Algorithm (LCA)[47,48], Firework Algorithm [49–51], Colliding Bodies Optimization (CBO) [52–54], Tug of War Optimization (TWO) [55], and Interior Search Algorithm (ISA) [56].

The optimization algorithms should be capable of searching all the search space. This refers to exploration. The high exploration methods are those with a large diversity of solutions in an iteration [57]. For instance, In GA [57], high probability of crossover causes more combination of individuals and it is the main mechanism for the exploration milestone. Moreover, the methods should enhance quality of the solutions in each iteration. This refers to exploitation which is the characteristics of a method in finding the local optimum point around a solution. The mechanism that brings GA exploitation is the mutation operators. Mutation causes slight random changes in the individuals and local search around the candidate solutions. It is obvious that these two characteristics are in contradiction to each other. In other words, high exploration means a large diversity of solutions which results in not obtaining the exact best global answer [58]. On the contrary, high exploitation may result in being trapped in local optimum point. Thus, a tradeoff should be established between these two features.

Although a large number of optimization algorithms are introduced in the literature, based on No-Free-Lunch (NFL) theorem [59], it cannot be claimed that an optimization algorithm could solve all the problems. In other words, a method may have acceptable results for some problems, but not for some others. Thus, new methods are introduced in order to solve a wider range of problems. This is the motivation of this study in which a new optimization method inspired by the attachment procedure of lightning is introduced. It should be mentioned that an optimization algorithm known as Lightning Search Algorithm (LSA) which is also inspired by lightning phenomena was proposed by Shareef et al., [60]. The inspiration of both LSA and proposed LAPO are the same; however, the view and the equations by which the solutions are updated, are completely different. In LSA the solutions are the atoms traveling through the atmosphere by their kinetic energy and ionizing the nearby space by collision with other molecules and atoms. In this method, only the downward movement of the ionized channel is considered. In the proposed LAPO, the solutions are the jumping points of the lightning. In this model both the upward and downward leader are considered. A full description of the proposed method is explained in Section 2. In order to distinguish the two methods, the results of the proposed LAPO for some benchmark functions are compared to those of LSA.

2. Lightning Attachment Procedure Optimization (LAPO)

In this section, the proposed algorithm and its inspiration are illustrated.