Computers and Structures 195 (2018) 99–112

Contents lists available at ScienceDirect

Computers and Structures

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

An adaptive hybrid evolutionary firefly algorithm for shape and size optimization of truss structures with frequency constraints

Qui X. Lieu, Dieu T.T. Do, Jaehong Lee *

Department of Architectural Engineering, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul 05006, Republic of Korea

ARTICLE INFO

Article history:
Received 6 March 2017
Accepted 12 June 2017

Keywords:
Adaptive hybrid evolutionary firefly algorithm (AHEFA)
Differential evolution (DE)
Firefly algorithm (FA)
Elitist technique
Truss structures
Frequency constraints

ABSTRACT

This paper presents a novel adaptive hybrid evolutionary firefly algorithm (AHEFA) for shape and size optimization of truss structures under multiple frequency constraints. This algorithm is a hybridization of the differential evolution (DE) algorithm and the firefly algorithm (FA). An automatically adapted parameter is utilized to select an appropriate mutation scheme for an effective trade-off between the global and local search abilities. An elitist technique is applied to the selection phase to choose the best individuals. Accordingly, the convergence rate is significantly improved with the high solution accuracy. Six numerical examples are examined for the validity of the present algorithm.

1. Introduction

Since the pioneering paper on shape and size optimization problems of truss structures with multiple frequency constraints was published by Bellagamba and Yang [1], researches in this field have been rapidly developed and have attracted many scientists all over the world during over the past decades. For instance, an optimality algorithm based on uniform Lagrangian density for resizing and a scaling procedure to locate the constraint boundary were used by Grandhi and Venkayya [2]. Wang et al. [3] developed an optimality criterion under a single constraint based on differentiation of the Lagrangian function. The finite element force method associated with the sequential quadratic programming (SQP) approach was delivered by Sedaghati et al. [4,5]. Wei et al. [6] proposed the niche hybrid parallel genetic algorithm (NHPGA) to save the computational cost and enhance the solution accuracy. Gomes [7] employed the particle swarm optimization (PSO) algorithm for simultaneous shape and size optimization problems of truss structures with multiple frequency constraints. Miguel and Fadel Miguel [8] utilized the harmony search (HS) and the firefly algorithm (FA) for addressing this type of problems. Based on a hybridization of the enhanced charged system search (CSS) and the big bang-big crunch (BBBC) approaches with trap recognition capability, Kaveh and Zolghadr [9] suggested the so-called CSS-BBBC algorithm. Subsequently, these authors also additionally proposed the democratic PSO [10], the cyclical parthenogenesis algorithm (CPA) [11] and the tug of war optimization (TWO) [12]. The hybrid optimality criterion (OC) and genetic algorithm (GA) method for solving such problems were reported by Zuo et al. [13]. Khatibinia and Naseralavi [14] introduced the orthogonal multi-gravitational search algorithm (OMGSA). Kaveh and Ghazaan [15] combined the aging leader and challengers (ALC) with the PSO to produce a novel algorithm named the ALC-PSO. By integrating the harmony search-based mechanism into the ALC-PSO, the new so-called HALC-PSO was also exhibited by the above authors. More recently, Tejani et al. [16] proposed an adaptive symbiotic organisms search (SOS) algorithm. Ho-Huu et al. [17] suggested another variant of the DE named the roulette wheel selection-elitist-differential evolution (ReDE). An improved evolution (IDE) algorithm was released by Ho-Huu et al. [18] as well. Farshchin et al. successfully developed the multi-class teaching–learning-based optimization (MC-TLBO) [19] and the school-based optimization (SBO) [20], and so on.

As indicated in [2], natural frequencies and constraints of the foregoing optimization problems are highly nonlinear, non-convex and greatly sensitive to shape changes and member sizes of truss structures. Mode shapes and corresponding obtained frequencies may switch during the optimization process, and this causes many difficulties for the convergence. Therefore, a proper optimization algorithm utilized to solve such problems is really

---

* Corresponding author.
E-mail addresses: lieuxuanqui@gmail.com (Q.X. Lieu), thanhdieu0801@gmail.com (D.T.T. Do), jhlee@sejong.ac.kr (J. Lee).

https://doi.org/10.1016/j.compstruc.2017.06.016
0045-7949/

essential. Obviously, restricted applications of gradient-based algorithms could be recognized due to their disadvantages. In particular, these methods always require sensitivity analyses relating to derivatives of the objective function and constraints with regard to each of design variables whose performances are relatively complex and expensive, even impossible in many cases. Moreover, local optimum solutions may be trapped if a given set of initial values in a specified search space is not chosen carefully. For these shortcomings, non-gradient-based algorithms, known as metaheuristic approaches, have been rapidly developed and have received much considerable attention of many researchers. These algorithms use stochastic searching techniques to randomly select potential solutions within a predetermined search space, and thus they are completely free from sensitivity analyses and almost demand less mathematical analyses. Consequently, these approaches are easy to perform and very robust in finding global optimal solutions for optimization problems concerning highly nonlinear and non-convex properties. However, the computational cost of the search process is fairly expensive and often time-consuming as an optimal solution must be looked for over the entire search space without any definite directions. Additionally, the stochastic searching techniques differently defined in each method are also one of the key factors that affect the solution accuracy.

Among non-gradient-based optimization methods, differential evolution (DE) algorithm which was first developed by Storn and Price [21] is one of the commonly used nature-inspired population-based approaches. This algorithm has been broadly applied to a wide range of disciplines due to its effectiveness and robustness in searching a global optimal solution in continuous spaces. A large number of its variants have been introduced later to improve several drawbacks relating to the computational speed, convergence properties and the optimal solution accuracy [22–28]. Another highly effective way to improve the DE is to combine it with other available optimization algorithms for benefiting from the synergy and overcoming individual drawbacks of each of hybridized original algorithms. Accordingly, many hybrid DE methods have been developed by mixing it with other global search approaches like GA [29,30], HS [31], biogeography-based optimization (BBO) [32], gradient based real-coded population-based incremental learning (RCPBIL) algorithm [33], ant colony optimization (ACO) [34], bacterial foraging-based optimization (BFO) [35], PSO [36], invasive weed optimization (IWO) [37], simulated annealing (SA) [38,39], covariance matrix adaptation evolutionary strategies (CMA-ES) [40,41], fireworks algorithm (FWA) [42], gravitational search algorithm (GSA) [43], and artificial bee colony (ABC) algorithm [44], etc. Some other hybrid approaches of the DE integrated with local search methods could be found in [45–48]. For a more detailed discussion, the interested reader should refer to a comprehensive review of the DE particularly surveyed by Das et al. [49].

As one of the alternative population-based algorithms, Yang [50–52] developed a new approach named the firefly algorithm (FA). As stated by the author, the method can be considered as a generalization to the PSO, DE, and SA algorithms by setting its some parameters with specific values. The above three algorithms are thus only special cases of the FA. Consequently, the FA inherits the advantages of all those algorithms and can perform effectively. Indeed, this approach has captured the attention of many researchers and been successfully applied to the hardest optimization problems [53]. The interested readers are encouraged to consult the above references for a more detailed description of the algorithm as well as its applications. Although the FA is of the above good features, the computational cost of the FA is still relatively expensive since its searching technique is also metaheuristic like the classical DE and other non-gradient-based methods. For improvements, some hybrid firefly algorithms have been proposed by blending with other methods, i.e. the Lévy flight search [54], GA [55,56], ant colony [57], DE [58,59] and so forth, with an essential aim that such hybrid algorithms will outperform in terms of the solution accuracy and convergence rate from their collaborations.

Although all the aforementioned works have been extensively applied to various optimization problems in many engineering and scientific areas with fairly prominent achievements [53,49], hybrid algorithms in the framework of the DE and the FA that have the ability to improve the convergence speed for the reduction of computational cost and time-consuming process as well as to enhance the solution accuracy appear to be very limited apart from two researches of Abdullah et al. [58,59]. These authors proposed the so-called hybrid evolutionary firefly algorithm (HEFA) for the evaluation of nonlinear biological model parameters. In that algorithm, the population obtained in the previous generation is sorted according to the fitness and then divided into two sub-populations, i.e. potential and weak ones. The mutation operator “rand/1” in the DE is applied to the weak sub-population to enhance the solution search capability while the other is substantially implemented in the manner of the FA. All the rest of the procedure absolutely follows the FA without any other integrations of the DE. Although results showed that this algorithm requires less computation time than the PSO, FA and Nelder-Mead for finding good solutions, its convergence to the optimal solution still demands a highly large number of finite element (FE) analyses that will lead to the increase of the computational cost. Furthermore, its validation to shape and size optimization problems of truss structures with multiple frequency constraints has still not been examined yet so far. Therefore, this work is executed to deal with the afore-discussed issues.

In this study, a novel adaptive hybrid evolutionary firefly algorithm (AHEFA) as a hybridization of the DE method and the FA is proposed for the improvement on the convergence speed and the solution accuracy. An automatically adapted parameter computed from the deviation of objective function between the best individual and the whole population in the previous generation is utilized to select an appropriate mutation scheme for the performance in the mutation phase. The balance between the global exploration and local exploitation abilities is hence enhanced effectively. Accordingly, the convergence speed and the accuracy of achieved optimal solutions are improved considerably. Furthermore, an elitist technique is employed for the selection phase to choose a new population for the next generation containing the best individuals from the mixture of the target and trial individuals. This technique helps to speed up the convergence rate of the proposed algorithm as well. The validity of the AHEFA is then confirmed by testing for shape and size optimization problems of truss structures with multiple frequency constraints. Optimal results attained by the proposed method are compared with those given by other algorithms in the literature.

The remainder of this article is constructed as follows. The statement of shape and size optimization problem of truss structures with multiple frequency constraints is built up in Section 2. A detailed discussion of the DE approach, the FA, and the proposed AHEFA is provided in Section 3. Section 4 presents six most widely investigated benchmark numerical examples to illustrate the effectiveness and robustness of the AHEFA. Finally, Section 5 ends with conclusions.

2. Problem statement

For optimization problems of truss structures under multiple frequency constraints, the aim is to design member sizes or/and the shape of the structure so that its weight is minimized. In which, member cross-sectional areas or/and nodal coordinates are consid-