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Search group algorithm: A new metaheuristic method for the optimization of truss structures

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ABSTRACT

This paper presents a new metaheuristic optimization method, the Search Group Algorithm (SGA), to deal with the optimization of truss structures. The effectiveness of the SGA is demonstrated through a selection of benchmark problems taken from the literature. Special attention is given to problems that involve topology optimization, discrete design variables and/or natural frequency constraints due to the complexities that they present. As the main conclusion of these numerical experiments, the SGA was able to provide the lightest structures ever found for 5 of the 6 examples investigated, to the best of the authors' knowledge. Moreover, it was also able to improve the statistics of the independent runs of the algorithm in most cases. These results emphasize the capabilities of the SGA in this field and encourage its further development and application to real problems in engineering.

1. Introduction

Several types of real life structures may be modeled using truss elements such as roofs, bridges and transmission line towers, to name just a few. Due to the interest in designing economically competitive truss structures, optimization techniques have been developed and applied for this purpose. In the optimization of trusses, the designer has to deal with some peculiarities of this problem, such as non-linearity, non-convexity, existence of several local minima, presence of discrete and continuous design variables, and the variety of constraints that may be involved [1–4]. For example, a truss optimization problem may have displacement, stress, local buckling and natural frequency constraints. The latter, for instance, are highly nonlinear, non-convex and implicit with respect to the design variables [1].

Metaheuristic algorithms are usually well suited to handling these characteristics that may appear in a truss optimization problem. In fact, a large number of these algorithms have been widely applied for solving a variety of truss optimization problems. For example, classical metaheuristic algorithms such as Simulated Annealing [5,6], Genetic Algorithms [7,8], Particle Swarm Optimization [6,9–11], Harmony Search [12–14] and Ant Colony Optimization [15], were employed. For a comprehensive review of the optimization of truss structures using metaheuristics, the reader is referred to Saka [16,17], Lamberti and Pappalettere [18] and the references therein.

More recently, new metaheuristic algorithms have been developed and employed to solve this kind of problem, among which, we may cite: Big Bang–Big Crunch Algorithm [19], Ray Optimization [20], Imperialist Competitive Algorithm [21,22], Mine Blast Algorithm [23], Firefly Algorithm [24,25], Bat-Inspired Algorithm [26], Cuckoo Search Algorithm [27], Dolphin Echolocation [28], Teaching–Learning-Based Optimization [29], Chaotic swarming of particles [30], Colliding Bodies Optimization [31], to name just a few.

Metaheuristic algorithms must have two capabilities, exploration and exploitation, in order to be able to find reasonable solutions. Exploration may be described as the ability of the algorithm to find promising regions on the design domain, i.e. regions in which the optimal solution may be located. Exploitation is the ability of the algorithm to refine the solution on these promising regions, i.e. to pursue a local search on them. It is important for a metaheuristic algorithm maintaining an adequate balance between the exploration and exploitation tendencies in order to be competitive in terms of robustness and performance. The interested reader is referred to [32] for a study on the exploration and exploitation of metaheuristic algorithm on the optimization of truss structures. Indeed, this study suggested that for a good balance between exploration and exploitation the most desirable trend of variation of the diversity of the population is the one in

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which it has high values in the first iterations of the search to explore the design domain, and then, the diversity should gradually decrease as the iterations pass by to exploit promising regions where the global solution may be located.

In this context, a new metaheuristic optimization algorithm, the Search Group Algorithm (SGA), is developed in this paper and applied for the design of truss structures. The main goal of this algorithm is to be balanced in terms of exploration and exploitation of the design domain. Consequently, the SGA aims at providing better designs than other metaheuristics for the same computational cost. The effectiveness of the SGA is demonstrated through a selection of benchmark problems taken from the literature. Special attention is given to problems that involve topology optimization and natural frequency constraints [33–42] due to the complexities that they present. The first two problems consist in the size and size/shape optimization of truss structures with natural frequency constraints. The third and fourth problems include both continuous and discrete design variables dealing with the size/shape/topology optimization of trusses with displacement, stress and/or local buckling constraints. The last two examples deal with the size/topology optimization of trusses with displacement, stress, local buckling and natural frequency constraints. Finally, the ability of the SGA to provide a good balance between exploration and exploitation of the design domain is analyzed using

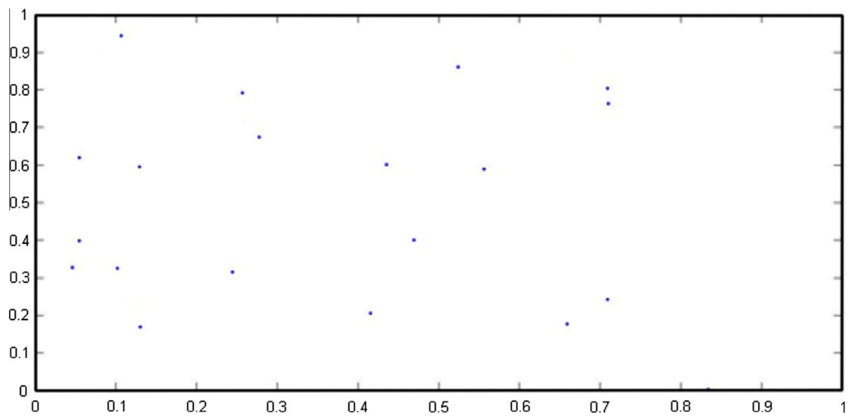

Fig. 1. Initial population randomly generated in a two dimensional domain.

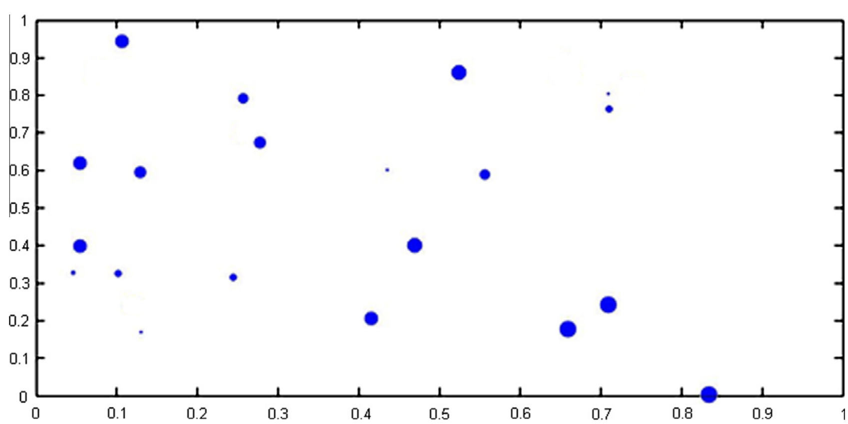

Fig. 2. Initial population: the bigger the circle is, the better the objective function of the individual is.

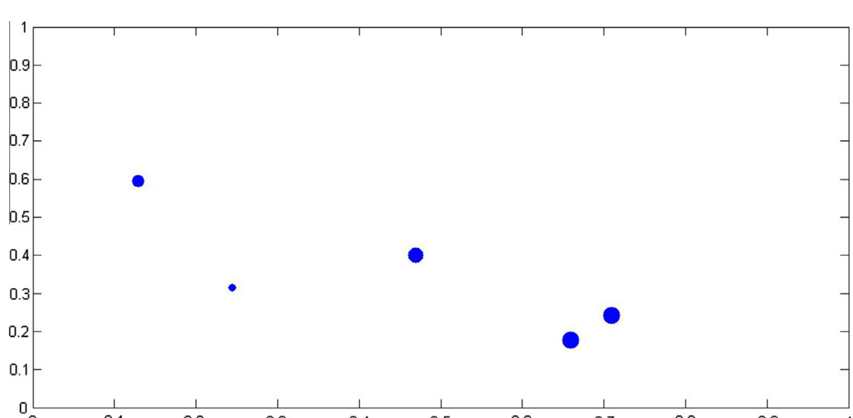

Fig. 3. Initial search group comprised by five members of the initial population.