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Artificial Bee Colony algorithm for optimization of truss structures

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ABSTRACT

The main goal of the structural optimization is to minimize the weight of structures while satisfying all design requirements imposed by design codes. In this paper, the Artificial Bee Colony algorithm with an adaptive penalty function approach (ABC-AP) is proposed to minimize the weight of truss structures. The ABC algorithm is swarm intelligence based optimization technique inspired by the intelligent foraging behavior of honeybees. Five truss examples with fixed-geometry and up to 200 elements were studied to verify that the ABC algorithm is an effective optimization algorithm in the creation of an optimal design for truss structures. The results of the ABC-AP compared with results of other optimization algorithms from the literature show that this algorithm is a powerful search and optimization technique for structural design.

1. Introduction

Over the last 60 years, a number of optimization techniques have been developed and used in the structural optimization [1,2]. These techniques can be broadly divided into two groups: (i) gradient based and (ii) direct search (stochastic or non-gradient based). Since there are known difficulties in the application of gradient-based techniques in structural optimization problems, direct search techniques have gained popularity in recent years [2–7]. Direct search techniques explore the design space by generating a number of successive solutions to guide the algorithm to an optimal design. Genetic algorithms [8–12], simulated annealing algorithms [13–16] evolutionary programming [17] and evolutionary strategies [18] are the most notable direct search optimization techniques used in the solution of engineering problems. The main characteristic of these algorithms is the imitation of biological and physical events by evolving a good enough or near-optimal solution over a number of successive iterations. These techniques do not require the evaluation of gradients of objective and constraint functions, but they do require a significant amount of computer power. In the past, such techniques were considered impractical for design use due to the limitations of earlier computers. Recent advancements in computer hardware, especially in memory size and the speed of personnel computers make direct search techniques more feasible and practical.

More recently, another branch of biologically inspired algorithms have attracted the attention of researchers all over the world. Algorithms belonging to this field imitate the collective behavior of a group of social insects (for example, bees, termites, ants and wasps) to solve complex optimization problems. These social insects live closely together in their nest and divide up the various tasks within the colony, such as foraging, nest building and defense. Each member of the colony performs their own tasks by interacting or communicating directly or indirectly in their local environment. Even when one or more individuals fail to carry out their task, the group as whole can still perform their tasks [19,20]. The process of the division of labor among insects is believed to be more effective than individual action performed by an individual insect. These collective and adaptive behaviors of simple insects have been used by researchers to develop new optimization algorithms, known as swarm-based optimization algorithms. Particle swarm optimization [21–24] and ant colony optimization algorithms [25,26] are well known swarm-based algorithms and are already employed to solve structural optimization problems. On the hand, bee-inspired algorithms have not yet been employed to solve structural engineering optimization problems. The main objective of this paper is to propose a bee-based algorithm for the optimum design of planer and space trusses consisting of continuous design variables and to evaluate the performance of the algorithm by comparing the results of the algorithm with those of other optimization techniques. Also, modifications that have been made to implement the algorithm to the structural optimization are described.

The bee-inspired optimization algorithms are based on either a crude imitation of their mating process or their foraging behaviors. The algorithms based on the biological process of their

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reproduction are generally used in the combinatorial optimization problems while algorithms based on the foraging behavior of honeybees are used for various types of optimization problems. The Bee Colony Optimization [27,28], Virtual Bee [29], Bee [30,31] and Artificial Bee Colony [32–35] are some of the algorithms based on mimicking the foraging behavior of honeybee swarms. Although all bee algorithms share some common features, they do have some different characteristics.

The Bee Colony Optimization (BCO) algorithm developed by Teodorovic and co-workers [27,28] was used to solve the traveling salesman problem and a number of other numerical examples. In addition, they presented some potential application areas of the BCO algorithm in transportation and traffic engineering problems. Teodorovic [27] also stated that the BCO algorithm based on Swarm Intelligence principles gave encouraging results for its use in solving complex engineering problems. Yang [29] proposed the Virtual Bee Algorithm (VBA) and demonstrated how it could solve two-dimensional numerical problems. Based on his findings, Yang stated that VBA was usually as effective as genetic algorithms and could, in some cases, optimize more effectively than a conventional algorithm due to the parallelism of the multiple agents.

The Bee Algorithm (BA) originally proposed by Pham et al. [30,31] is used for solving unconstrained function optimization problems and training multi-layered perceptron networks to recognize different patterns in control charts. They claimed that the BA generally gives better results than the genetic algorithm and the ant colony algorithm, when compared with the BA in terms of speed of optimization and accuracy of the results. However, one of the drawbacks of the BA is the number of parameters that must be tuned before executing the algorithm.

Karaboga and Basturk [32–34] proposed the Artificial Bee Colony (ABC) algorithm. They used the ABC algorithm to solve unconstrained and constrained function optimization problems. The performance of the ABC algorithm was compared to that of differential evaluation, particle swarm optimization and an evolutionary algorithm. Karaboga and Basturk declared that the ABC algorithm when compared with differential evaluation, particle swarm optimization and an evolutionary algorithm performed better and could be effectively employed to solve engineering problems. Recently, Singh [35] used the ABC algorithm to solve the leaf-constrained minimum spanning tree discrete optimization problems. He compared the ABC algorithm with three other metaheuristic algorithms, namely the genetic algorithm, ant colony optimization algorithm and tabu search algorithm. Singh stated that the results of the new ABC algorithm outperforms all the other approaches and provides quality solutions in shorter time.

Since the ABC algorithm has been shown to perform well, it was selected for use in the present study for truss optimization with some deviations. Similar to other direct search algorithms, the ABC is an unconstrained optimization algorithm. To accommodate the inclusion of constraints, Karaboga and Basturk [33] proposed the Deb's selection mechanism. In this work, the self-adaptive penalty function approach is used to find a way of incorporating constraints in order to improve the ABC algorithm. Although only the size optimization of truss structures is considered in this study, it is believed that the ABC optimization algorithm can also be used for the topology and shape optimization of other types of structures.

The remainder of this paper is arranged as follows: Section 2 briefly presents the characteristics of the structural optimization problems. In Section 3, the natural forging behavior of real bees is described, Section 4 describes the modeling of foraging behavior of artificial bees, the constraint handling procedure included in the ABC algorithm is given in Section 5. The pseudo-code of ABC-AP algorithm is presented in detail in Section 6. The analysis of standard test problems to demonstrate the effectiveness of the algorithm in finding the optimal solution is given in Section 7. Finally, Section 8 presents the conclusions.

2. The presentation of the structural optimization problem

Many problems in engineering have multiple solutions and selecting the appropriate one can be a major task. In sizing optimization problems, the major task is to find an optimal cross-section of the elements of a system by minimizing the weight of the structure. This is expressed mathematically as:

$$\text{Minimize } W(\vec{A}) = \sum_{j=1}^{n} A_j L_j \rho_j \tag{1}$$

where A_j, L_j, and ρ_j are the cross-sectional area, length and unit weight of jth truss member, respectively; $W(\vec{A})$ is the weight of truss which is minimized; n is the total number of members. The vector $\vec{A}$ represents element cross-section vector that is selected between lower A^l and upper A^u bounds. Eq. (1) is subjected to the following normalized constraints:

$$s_{m,l}(\vec{A}) = \frac{\sigma_{m,l}}{\sigma_{m,allowed}} - 1 \le 0, \quad m = 1, 2, \ldots, n \tag{2}$$

$$b_{m,l}(\vec{A}) = \frac{\lambda_{m,l}}{\lambda_{m,allowed}} - 1 \le 0, \quad m = 1, 2, \ldots, n \tag{3}$$

$$d_{k,l}(\vec{A}) = \frac{u_{k,l}}{u_{k,allowed}} - 1 \le 0, \quad k = 1, 2, \ldots, n_n \tag{4}$$

where $s_{m,l}$, $b_{m,l}$, and $d_{k,l}$ are respectively, the element stress, element buckling and nodal displacement constraint functions; $\sigma_{m,l}$ and $\lambda_{m,l}$ are the stress and the slenderness ratio of mth member due to the loading condition l; $\sigma_{m,allowed}$ and $\lambda_{m,allowed}$ are the allowable axial stress and allowable slenderness ration for mth member, respectively; $u_{k,allowed}$ and $u_{k,l}$ are the allowable displacement and nodal displacement of kth degrees of freedom due to the loading condition l, respectively; n_n is the number of restricted displacements. All the normalized constraint functions are activated when the violated constraints have values larger than zero.

3. The behavior of real honeybees in their natural environment

Honeybees live in social units called colonies, depending on the time of year a typical colony includes a single queen, thousands of semi-sterile female workers and a few thousand males (drones). Adult workers are responsible for executing all the tasks associated with colony living such as; processing and storing food, cleaning cells, feeding larvae (nursing behavior), secreting wax and constructing combs, and guarding the entrance [36]. When the female bees are about 3 weeks old, they begin foraging, cease performing most tasks within the hive and usually remain foragers for the rest of their lives [37]. Foragers are able to utilize a large number of flower nectar (food sources) in multiple directions up to 12 km from the hive, but mostly they fly within a 3 km radius [30].

In a colony, the female bees start the foraging process by randomly searching for the promising flower patches. After finding a food source, the bee loads up with nectar then returns to the hive and unloads her nectar. Then, she may inform her nest mates about her findings through the movements known as the "waggle dance." This dance gives three pieces of information regarding the flower patch; the direction in which it can be found, distance from the hive and quality rating [20,28,31]. In a decentralized but intelligent fashion, some of the bees decide to follow their nest mates who have performed the waggle dance; others, to maximize their nectar intake, search for the food source without following the dancers. This means that each bee can follow one of three options