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Research paper

An enhanced honey bee mating optimization algorithm for design of side sway steel frames

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ABSTRACT

Honeybee mating is a swarm-based meta-heuristic optimization method where the search algorithm is inspired by the process of mating in honeybees. In this paper, a new improved algorithm is proposed which performs remarkably better than the basic honeybee mating optimization process and is very competitive with other meta-heuristic optimization algorithms reported in the literature. The new algorithm, termed as enhanced honey bee mating optimization (EHBMO) algorithm, uses the concept of giving weight to distant candidates which are slightly less feasible than the current local candidates but may hold information about the location of global optima further afield. The robustness of the algorithm in terms of both solution quality and computational cost is proven by solving four design optimization problems of side sway steel frames.

1. Introduction

In discrete structural optimization problems, design variables are selected from a pre-defined set of sections. Due to the computational difficulties entailed by classical mathematical optimization methods, in recent years, meta-heuristic optimization algorithms have received a great deal of attention. The basic concept of meta-heuristic algorithms is imitation of natural phenomena. These phenomena may include the biological evolutionary process (such as the evolutionary algorithm [1] and the genetic algorithm [2–4]), swarm intelligence (such as ant colony [5], school fishing and bird flocking [6] and honeybee mating [7]), and the physical annealing process (e.g., simulated annealing [8]).

In most structural optimization problems, the weight of the structure *W(x)* must be minimized under strength and displacement constraints. In the objective function formulation, $\varphi(x)= W(x)(1+\kappa C)^{\varepsilon}$ (C is the penalty function value and κ and ε are penalty parameters given by the user), the weight of the structure is penalized based on its constraint violation. The objective function value is called the fitness of the structure to evaluate the quality of a trial design.

One major drawback of the basic meta-heuristic optimization algorithms is that the solution may become trapped in some local optima from which it cannot escape. To overcome this problem and to solve more complicated optimization problems, however, more powerful meta-heuristic algorithms are needed. To this end, in recent years some researchers have worked on improving the existing algorithms by overcoming some of their drawbacks, others have hybridized two or more of the existing algorithms by combining their strong and complementary features and some researchers have worked on developing new meta-heuristic algorithms based on other natural or physical phenomena. Comprehensive reviews on new developments in meta-heuristic optimization approaches for engineering problems are given by Saka [9], Lamberti and Pappalettere [10] and Saka and Doğan [11].

Over the last decade, meta-heuristic algorithms based on swarm intelligence, particularly those modeling the behavior of social insects, such as ants and bees, have been the subject of much attention in solving discrete structural design optimization problems. Honeybees are among the most frequently studied social insects. Honeybee mating optimization (HBMO) is a swarm-based approach to optimization. Abbass [12,13] developed an algorithm based on the honeybee marriage process. Bozorg Haddad and Afshar [7] also applied honeybee mating algorithm to a single reservoir optimization problem with discrete decision variables. Later, Bozorg Haddad et al. [14] applied the same algorithm to three benchmark mathematical problems.

Similar to other basic meta-heuristic algorithms, the HBMO algorithm may fall trapped in local optima, preventing it from increasing its search space to locate the global optimum. In the present study, a distance factor is introduced which gives added credence to distant candidates which are slightly less feasible than the current local candidates with the aim of increasing the search space. In the proposed modification to the algorithm, termed the enhanced honey-bee mating optimization (EHBMO), to introduce

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the distance factor the movement of broods toward the queen is modified. In the following, after presenting an overview of the basic HBMO algorithm, the proposed EHBMO algorithm is first described and then applied to optimum design of a number of benchmark side-sway frames. The optimization results are then compared with those obtained from some other meta-heuristic optimization solutions available in the literature so that the performance of the proposed algorithm can be evaluated.

2. Honey-bee mating optimization algorithm

A typical honeybee colony consists of a single or a number of long-living queens, several hundred drones and several thousand workers. Only the queen bee is fed the 'royal jelly'. This nourishing substance makes the queen bee bigger than any other bee in the hive. The drones' task is to provide the queen with some sperms. After the mating process, the drones die. Workers are specialized in brood care. Broods arise either from fertilized or unfertilized eggs. The former represents potential queens or workers, whereas, the latter represent prospective drones. The queen(s) mate during their mating flights far from the nest. During the mating flight the drones follow the queen and the lucky ones mate with her in the air in a probabilistic manner. In each mating, sperm accumulates in the spermatheca to form the genetic pool of the colony. Each time a queen lays fertilized eggs, she randomly retrieves a mixture of the sperm accumulated in the spermatheca to fertilize the egg [12]. At the start of the flight, the queen is initialized with some energy content and returns to her nest when the energy is within some threshold.

In developing the optimization algorithm each worker may be represented as a heuristic function which acts to improve and/or take care of a set of broods. Using an annealing function, the probability of a drone mating with a queen may be expressed as follows [15]:

$$Prob(Q, D) = e^{-\frac{\Delta(f)}{S(t)}} \quad (1)$$

where, *Prob(Q, D)* is the probability of drone *D* mating with the queen *Q;* $\Delta(f)$ is the absolute difference between the fitness of *D* (i.e. $f_{(D)}$) and the fitness of *Q* (i.e. $f_{(Q)}$) and *S(t)* is the speed of the queen at time *t*. It is worth noting that the probability of mating is high when either the queen is still at the beginning of her mating flight, therefore her speed is high, or when the fitness of the drone is as good as the queen's. Unlike Simulated Annealing [8], the probability of Eq. (1) is not compared with any other thresholds, since the mating probability in every single flight depends only on the queen's speed and energy and energy of a drone. The random decrease in the queen's speed and energy keeps the stochastic essence of the algorithm. After each transition in space, the queen's speed and energy decrease according to the following equations:

$$\mathrm{S(t+1)} = \alpha \times \mathrm{S(t)} \quad (2)$$

$$\mathrm{E(t+1)} = \mathrm{E(t)} - \gamma \quad (3)$$

where, α is a factor ϵ [0,1] and γ is the amount of energy (*E(t)*) reduction after each transition. The value of γ is given to the algorithm. In this study, the queen's energy content in each flight is a random value ϵ [0, 1] and γ is chosen as 0.01 for all design examples. EHBMO convergence is sensitive to the value of γ, since energy content plays the role of a termination criterion in every mating flight. Larger values for γ may terminate the flights with an incomplete spermathecal, while smaller values may slow the convergence.

Each queen is characterized with a genotype, speed, energy, and a pre-defined spermatheca capacity. Therefore, before each mating flight the speed and energy of the queen are randomly initialized. In the algorithm, a drone is represented by a genotype and a genotype marker. Because all drones are naturally haploid, a genotype marker may be employed to randomly mark half of the genes, leaving the other half unmarked. In this case, only the unmarked genes are those that form a sperm to be randomly used in the mating process [15].

In each mating flight (cross-over) the drones (structures) that succeed to mate with the queen (the best structure) are kept in the spermathecal (a set of structures that are developing towards the optimum structure) to be used to produce and improve broods. The maximum number of drones (trial structures) that can be kept in spermathecal is called "Max Sperm".

The improvement to the brood's genotype is carried out by the workers which represent a set of different heuristics. The rate of improvement in the brood's genotype, defines its fitness value. A brood is constructed by copying some of the drone's genes into the brood genotype and the genes from the queen's genome form the rest. The fitness of the resulting genotype is determined by evaluating the value of the objective function of the brood genotype and/or its normalized value. It should be noted that a brood has only one genotype. The HBMO algorithm includes the following main steps:

1. After generating a random initial population, the initial queen (best member) starts her mating flight, whereby she selects drones probabilistically to form the spermatheca (list of drones). A drone is then randomly selected from the list for the creation of broods.
2. New broods (trial solutions) are created by crossing the drone's genotypes with those of the queen.
3. Workers (heuristics) are used to conduct local search on broods (trial solutions).
4. Workers' fitness is evaluated, based on the amount of improvement achieved on broods.
5. The weaker queens are replaced by the fitter broods.

Every time the fitness of a drone or brood or queen (generally a structure) is calculated, one structural analysis is done. In each flight, the number of structural analyses depends on the number of bees being evaluated i.e. the number of drones flying to the queen and the broods, etc. the number of analyses in each flight decreases throughout the search.

Detailed description of the HBMO algorithm can be found in [12,15].

3. Enhanced honey bee mating optimization algorithm (EHBMO)

Most basic meta-heuristic optimization algorithms act well in solving simple problems. When it comes to the more complicated problems with large search spaces, however, more robust algorithms are needed. Complicated problems may have many local optima and also some regions containing multiple nearby local optima, termed 'multiple local optima regions' in their search space. In order to understand the proposed enhanced algorithm, a brief review of the basic HBMO algorithm was presented above. As it was mentioned, after randomly generating the initial population, the best member is chosen as the initial queen. In the first mating flight, the selected qualified drones mate with the queen to produce broods. Creation of these first broods is directly affected by the queen. In the next step, the workers must improve the quality of the broods by performing something similar to the mutation process in GA. The improvement procedure is aimed at moving the broods gradually closer to the queen using the queen as an influencing agent.