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Optimum Structural Design of Space Trusses using Genetic Algorithms and a Particle Swarm Optimization Algorithm

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Introduction

In the past two decades, a number of optimization algorithms have been used in structural design optimization, ranging from gradient-based mathematical algorithms to probabilistic-based search algorithms, for addressing global non-convex optimization problems. Many probabilistic-based algorithms have been inspired by natural phenomena, such as Evolutionary Programming (EP), Genetic Algorithms (GA), Evolution Strategies (ES), among others. Recently, a family of optimization methods has been developed based on the simulation of social interactions among members of a specific species. One of these methods is the Particle Swarm Optimization (PSO) method that is based on the behavior reflected in flocks of birds, bees and fish that adjust their physical movements to avoid predators and seek for food.

Methods

The GA is based on the biological principle of natural selection and the survival of the fittest, as dictated by the theory of evolution. First, a population of random solutions is generated and ranked according to their fitness by an evaluation (objective) function. Each candidate solution is called an individual and the aspects of each solution are its chromosomes. Some of the individuals are stochastically selected for reproduction, where a higher fitness ranking increases the chance of an individual being selected. The offspring of the next generation of individuals come from recombination (cross-over) of the parents and therefore carry their chromosomes, while in every generation there is also a small chance that mutation in some of the chromosomes of the individuals will occur, in order to increase the diversity of the initial genetic pool. The offspring and some of the parents will form the next generation which in turn will be ranked by the evaluation function and reproduce.

The PSO Method is based on the simulation of social behavior within a population. In PSO, as in GA, a population of potential solutions is considered and utilized to search within the design space. However, its members do not reproduce but rather communicate with each other their knowledge of solutions in order to reach the optimum. Each “particle”, “flies” through the multi-dimensional design space, with a certain velocity vector for each iteration. It performs a search in its vicinity for an optimum position, specified by the evaluation function, and after each iteration it adjusts its movement according to its previous velocity, its own experience of the best position (personal best) as well as the experience of whole swarm or the members of its neighborhood (global best).

Results

GA and PSO methods are applied in single-objective, continuous, constrained structural engineering optimization problems where the aim is to minimize the weight of the structure under the constraints of maximum allowable nodal displacements and maximum allowable values of stresses. Two steel truss structures are considered, a 25-bar plane truss and a 72-bar space truss. The constraints are checked by performing a Finite Element analysis for every candidate optimum design. For each method, the performance, functionality and effect of different setting parameters are studied. After a fine tuning of the parameters of each method, their respective results are compared to each other as well as to results of other methods from the literature. The comparison is done with regard to the speed of convergence, in terms of number of objective function evaluations, and accuracy of the solution.

Conclusion

The GA and the PSO have similarities and share a number of common characteristics. The conceptual difference lies in the definition of the two methods, which in PSO is given in a social context, instead of the biological context for the GA case. Unlike the GA, PSO has no genetic operators such as crossover and mutation, as the particles improve their fitness by altering their position in the design space, according to a velocity vector updated in each iteration. The main objective of the study was to examine the behavior of the two methods in engineering optimization problems of steel structures and compare them to each other for the two benchmark test examples. It can be concluded that both methods were able to produce optimization solutions of high quality. On the other hand, the performance of PSO was found superior in both test examples, as the PSO was able to arrive to the optimum more quickly, requiring less objective function evaluations.