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Parallel Genetic Algorithm with Population - based Sampling Approach to Discrete Optimization Under Uncertainty

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Abstract

The optimization of composite laminates using ply orientation angle as a discrete variable provides an example to demonstrate an approach for discrete optimization under uncertainty. The use of ply orientation angles as continuous design variables becomes a non-viable approach from a manufacturing perspective. Optimization under uncertainty accounts for design variables and external parameters or factors with probabilistic distributions instead of fixed deterministic values; it enables problem formulations that might maximize or minimize an expected value while satisfying constraints using probabilities. For discrete optimization under uncertainty, a Monte Carlo sampling approach enables high-accuracy estimation of expectations but it also results in high computational expense. The genetic algorithm with a population-based sampling technique enables optimization with discrete variables at a lower computational expense than using Monte Carlo sampling for every fitness evaluation. Population-based sampling uses fewer samples in the exploratory phase of the GA and a larger number of samples when ‘good designs’ start emerging over the generations. This sampling technique therefore reduces the computational effort spent on ‘poor designs’ found in the initial phase of the algorithm. The expected value of the fitness function and constraints of the designs in each generation are calculated in parallel to facilitate reduced wall-clock time. These fitness values are stored in a global array and updated with increase in sample size throughout the run. A customized stopping criterion is also developed for the GA with population-based sampling. The stopping criterion requires that the design with the minimum expected fitness value to have at least 99% constraint satisfaction and to have accumulated at least10000 samples. The average change in expected fitness values in the last ten consecutive generations is also monitored.

The optimization problem used to demonstrate further developments of the GA with population-based sampling aims to reduce the expected weight of the composite laminate while treating the laminate’s fiber volume fraction and externally applied loads as uncertain quantities following normal distributions. The square fiber model is implemented to construct the stiffness matrix of the laminate with a fiber volume fraction sample. The constraints enforced include the probability of satisfying the Tsai-Hill failure criterion and the maximum strain limit. The calculations to establish the expected values of constraints and fitness values use the Classical Laminate Theory. The parallel fitness analyses are implemented via the Matlab Parallel Computing Toolbox and the Distributed Server Toolbox. The results from a deterministic optimization, optimization under uncertainty using Monte Carlo sampling and population – based sampling are studied. Also, the effectiveness of running the fitness analyses in parallel and the sampling scheme in parallel are investigated.