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【論文の内容の要旨】

(Summary of dissertation)

Developing a highly efficient optimization methodology is critical for the design process in the aerospace arena because an aeronautical design is usually complicated and expensive. In addition, design problems often have several objectives for simultaneous consideration. To increase the performance of the optimization methodology, an efficient global optimization (EGO) was developed. The EGO needs to be further improved via an exploratory method, such as a genetic algorithm (GA) and surrogate methods.

This thesis begins with reviews and the development of a GA using an exploratory method for real-world design problems. Focusing on the distribution of the population, the GA with a multi-modal distribution crossover method (MMDX) was proposed to consider the skewness of the distribution of parent candidates. The proposed crossover method creates four segments from four selected parents, of which two segments are bounded by selected parents and two are bounded by one parent and another segment. After defining these segments, four offspring are generated. This study considers the application of a proposed optimization method for the real-world problem of creating a multi-objective airfoil design using a class-shape function transformation (CST)parameterization, which is of an aerodynamic shape, to investigate the effectiveness of the algorithm. The exploration results were compared with the results

of blend crossover (BLX) and unimodal normal distribution crossover (UNDX) algorithms with regard to maintaining the diversity of solutions. The comparison results showed that the developed algorithm obtained solutions that were superior to those obtained by the BLX and UNDX algorithms. This is a beneficial feature for real-world problems.

Next, a multi-fidelity optimization technique based on an efficient global optimization method using a multi-fidelity approach was investigated for solving real-world design problems. In the proposed approach, a multi-fidelity surrogate model was developed for evaluating local deviation using the Kriging method and for constructing a global model using a radial basis function. The expected improvement (EI) was computed based on the uncertainty of the developed model, which was evaluated using the Kriging method, to determine additional samples to improve the model and EGO. The proposed multi-fidelity approach was investigated by solving mathematical test problems whose results were compared with those of the ordinary Kriging-based EGO that uses a single-fidelity approach and the co-Kriging-method-based EGO. The proposed method obtained better solutions than the other two. It was applied to the aerodynamic design optimization of helicopter blades for hovering to maximize blade efficiency. The shapes of the helicopter blades were designed by changing their twist angle distribution. The performance of the optimal shape obtained using the proposed method was almost equal to that obtained using high-fidelity evaluation based on single-fidelity optimization by an ordinary Kriging. The results of the proposed method were compared with that of a co-Kriging-based multi-fidelity approach. The accuracy of the proposed method was the highest, while the total number of high-fidelity evaluation runs required to obtain a converged solution was the lowest.

Finally, the method was expanded to solve multi-fidelity/multi-objective problems. An expected hypervolume improvement (EHVI) was used as an index to find additional samples for the optimization process. EHVI was computed based on the model's uncertainty to determine additional samples as well as the EI. First, the proposed approach was applied to two-objective optimization test functions. Then, it was applied to airfoil design optimizations that have two- and three-objective functions, namely, minimization of aerodynamic drag and maximization of airfoil thickness at the trailing edge for the two-objective problem and minimization of aerodynamic drag at cruising speed, maximization of airfoil thickness at the trailing edge, and maximization of lift at low speeds assuming a landing attitude for the three-objective problem. A panel method was used to apply the low-fidelity inviscid aerodynamic force. A Reynolds-averaged Navier–Stokes simulation was applied for high-fidelity aerodynamics in conjunction with a high-cost approach. For comparison, multi-objective optimization was applied using only a Kriging model with a high-fidelity solver. The design results indicate that the non-dominated solutions of the proposed method achieve greater data diversity than the optimal solutions of the Kriging method. Moreover, the proposed method has a smaller error than the Kriging method with the single-fidelity approach.