Reliability-Based MOGA Design Optimization Using Probabilistic Response Surface Method and Bayesian Neural Network

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ABSTRACT

In this paper, an effective optimization approach, which integrated the probabilistic surrogate model, non-dominated sorting genetic algorithm, and reliability index method, is proposed to multi-objective reliability-based design optimization. To reduce the computational cost and improve the efficiency of the optimization process, the problem can be surrogated by probabilistic response surface method and Bayesian neural network as high fidelity metamodel with statistical modelling method. After verification through the simulation results on numerical test problem, these techniques have been applied to engineering problem in optimizing simultaneously multi-performances or objective functions subject to reliability constraints.

CCS CONCEPTS

• **Mathematics of computing** → Probabilistic algorithms; • **Theory of computation** → Mathematical optimization

KEYWORDS

Multi-objective optimization, Reliability based design optimization (RBDO), Reliability index, Evolutionary algorithms, Non-dominated sorting genetic algorithm, Probabilistic response surface method (PRSM), Bayesian neural network (BNN)

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1 INTRODUCTION

For accurate design optimization, it is important to consider uncertainty using an estimation process for the scatter acting on the component, especially in hierarchical structure problem. For the approximate model, the design of experiments is conducted, various types of metamodels such as polynomial equations, neural network, Kriging are being used. In this respect, a sequential statistical modeling (SSM) technique can be used for the estimation of appropriate distribution and parameters reflected in the optimization process [1].

Deterministic design optimization (DDO) is a commonly used approximate optimization technique; however, this technique considers only a single fixed value and does not reflect the uncertainty and tolerance of design variables. To minimize or maximizes all objective functions that are usually conflict concurrently, some compromise and trade-off must be done. The goal of this study is to find the Pareto front which consists of Pareto optimal solution sets and a set of all these non-dominated solutions. To solve the problems consists of enhancing the concept of reliability based design optimization (RBDO) considering several objectives subject to reliability constraints, surrogate model based multi-objective reliability-based design optimization (MORBDO) is formulated as shown in Fig. 1.

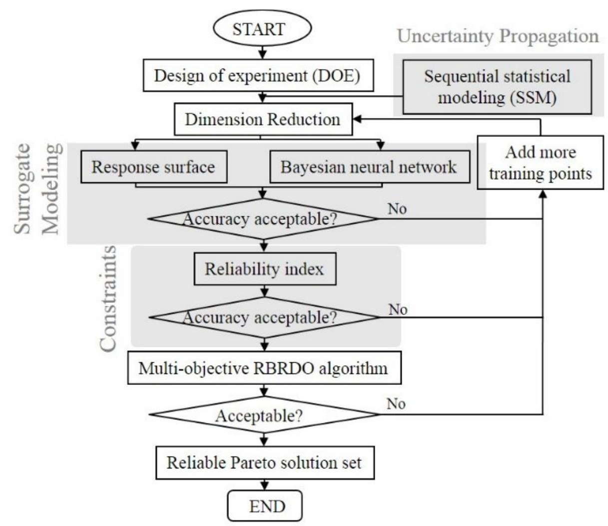

Figure 1: Research flowchart

2 OPTIMIZATION TECHNIQUES

2.1 High-Fidelity Metamodeling

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To reduce the computational cost and improve the efficiency of the optimization process, probabilistic response surface method (PRSM) and Bayesian neural network (BNN) have been developed in solving optimization problem as a surrogate model. PRSM reflects the variables as distributions in order to develop the existing methods based on the polynomial equation and take into account the inherent uncertainty. BNN is also used to deal with the sources of parameter uncertainty by updating its weights according to a Bayes inference used to train it [2].

As a statistical approach based on design of experiments for stochastic design, SSM is combined to optimize the design responses in the case of simultaneous variations of its design variables. The uncertainty propagation effect of input variables is quantified through SSM, and the estimated distribution shape and parameter of the best-fit distribution are entered as standard deviation of input variables. The accuracy of using these two metamodel techniques is verified.

2.2 Multi-Objective Reliability Based Design Optimization

The implemented algorithm combines the efficient NSGA-II algorithm developed by Deb *et al*. [3] to carry out the multi-objective optimization and a first order reliability method (FORM) to compute the probabilistic constraints.

In the constrained multi-objective optimization, NAGA-II is able to maintain a better spread of solutions and converge better in the obtained nondominated front compared to other elitist multi-objective evolutionary algorithms (MOEAs). Probabilistic constraints are evaluated by most probable point (MPP) based FORM. As the representative MPP based FORM techniques, there are reliability index approach (RIA) using a gradient based optimization named Hasofer-Line-Rackwitz-Fiessler (HL-RF) method to compute the reliability indexes and performance measure approach (PMA) using an advanced mean value (AMV) method [4,5]. The probability measure is converted into a performance measure for an inverse reliability analysis in the inner loop, which consists in searching for the point with minimum performance on the target reliability surface.

In order to verify the MORBDO technique, the following numerical problem is solved, and Pareto front is represented in the Fig. 2. Where, population size is 200 and generations is 100 in NSGA-II [6].

$$
\begin{array}{ll}
\text{Minimize} & f_1 = x \\
\text{Minimize} & f_2 = \dfrac{1+y}{x} \\
\text{Subject to} & y + 9x - 6 \geq 0, \\
& -y + 9x - 1 \geq 0, \\
& 0.1 \leq x \leq 1, 0 \leq y \leq 5
\end{array}
\qquad (1)
$$

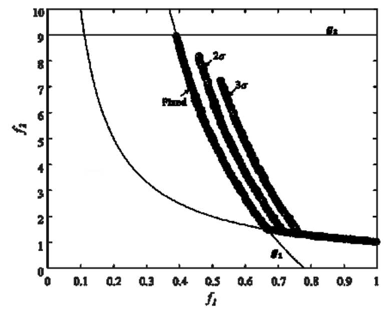

Figure 2: Trade-off frontiers of multi-objective for different reliability index

3 CONCLUSIONS

In summary, the numerical result shows that the optimal front of deterministic solution lies on constraint, and the MORBDO solutions is obtained from inside the feasible region as the reliability index increases. Additionally, through its application to the engineering problem, the integration of SSM technique with response surface design called as PRSM and BNN has proven to be a metamodel-based MORBDO with high fidelity accuracy for predicting the response.

As further research, other metaheuristics algorithms such as multi-objective particle swarm optimization and other sampling techniques are considered.

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