Efficient constraint multi-objective optimization with applications in ship design

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Summary

Constraint multi-objective optimization with a restriction to the number of allowed function evaluations is a challenging topic. This thesis proposes a solution for constraint multi-objective optimization problems, with a special emphasis on its application in the ship design industry. It distinguishes itself by abandoning traditional design methodologies by introducing a more holistic, computational framework that uses efficient global optimization for complex design challenges. These algorithms are intended to help naval architects deal with these design challenges, where competing objectives such as cost, efficiency, environmental impact, and safety must be balanced while the constraints imposed by physics and regulations should be satisfied. This shift is facilitated by advancements in computational power and simulation technologies, enabling designers to explore more of the design space efficiently.

Central to this research is the development and application of efficient constraint multi-objective optimization algorithms that are capable of identifying the feasible Pareto frontier of computationally expensive problems. The proposed algorithms do so by exploiting surrogates for the computationally expensive functions, while the computationally inexpensive functions are used directly when searching for promising solutions that jointly have a large hypervolume contribution. Because of the use of the introduced multi-point acquisition function, the expensive evaluation of the solutions can be done in parallel. This research provides a comprehensive examination of these algorithms on a diverse set of benchmark problems and compares them with other state-of-the-art algorithms. After empirically proving the success, the algorithms are deployed and used to solve ship design optimization problems.

This thesis also highlights the importance of the early design phase, arguing that decisions made during this stage have a significant impact on the ship's lifecycle costs and performance. By integrating multi-objective optimization techniques early in the design process, the designers can make more informed decisions that lead to more cost-effective, efficient, and environmentally friendly vessels. This approach not only enhances the sustainability of ship designs but also aligns with the broader industry trend towards greener and more sustainable maritime operations.

The practical applications of these optimization techniques are demonstrated with a series of case studies. These case studies not only validate the effectiveness of the algorithms in real-world scenarios but also provide valuable insights into the challenges and opportunities associated with their implementation. Through these practical examples, the research bridges the gap between theory and practice, offering a compelling argument for the adoption of optimization techniques in ship design.

Looking toward the future, several areas for further research are identified, including the need for more efficient algorithms that can handle mixed integer optimization problems. It also calls for a broader application of these techniques beyond ship design, the use of the proposed algorithms can be interesting to other engineering disciplines faced with similar multi-objective optimization problems.

In conclusion, the research presented in this dissertation represents a significant contribution to the field of multi-objective optimization and naval architecture. By advancing the state of the art in multi-objective optimization and demonstrating its practical applications in ship design, the research paves the way for more innovative, sustainable, and cost-effective design solutions. This work not only enhances our understanding of the complexities involved in ship design but also offers a blueprint for the future of maritime engineering, where computational optimization techniques play a central role in addressing the industry's most pressing challenges.