Hull Form Optimization Using Bayesian Optimization Framework

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ABSTRACT

In this paper, a data-driven shape optimization approach is proposed for ship hull form optimization. To avoid the time-consuming evaluation of ships via a viscous flow solver, we developed a Machine-Learning (ML) based model that predicts the hull’s hydrodynamic performance. For this purpose, a Bayesian optimization framework is developed and applied to OPTShip-SJTU, an existing ship optimization solver. Among them, the CFD method is used to calculate ship performance, and the Radial Basis Function (RBF) method is adopted for hull surface deformation. To improve the efficiency of hull form optimization, the surrogate model is used to approximate the CFD simulation. Unlike the traditional static approximation models used in the process of hull form optimization, a dynamic approximation model based on expected improvement is proposed. The adaptive balance parameter is taken in the parallel efficient optimization (PEGO) algorithm to make a tradeoff between exploitation and exploration. The Optimal Latin hypercube algorithm is used as the method of design of experiments. The Krigeing model is employed as the surrogate hull. Wigley ship is used to demonstrate the proposed optimization framework. Lines of the ship are determined and optimization results of the resistance show the effectiveness of the proposed method.

KEY WORDS: OPTShip-SJTU Solver; dynamic approximation model; parallel efficient global optimization algorithm (PEGO); Wigley; resistance

INTRODUCTION

Ship is a significant tool for humans to explore and exploit the ocean. Design of a ship is so complex that multiple performances should be considered, especially hydrodynamic performance which includes maneuverability, rapidity, and seakeeping. In the process of ship design, rapidity is the main concern. Besides, the resistance of ship is an essential aspect that reflects the ship’s rapidity performance. Reducing the resistance of ships becomes more and more challenging, which can be achieved by optimizing the ship hull lines. Changes in hull lines can also affect other ship properties, such as seakeeping performance and maneuverability. Noteworthy, how to obtain the best hull form is the main concern in the design stage. With the development of computer technology, Computer Fluid Dynamics (CFD) based on viscous theory has been widely applied to hydrodynamic problems. As a result, simulation-based design (SBD) technology has been widely applied to hull form optimization in the past decades.

Based on SBD technology, scholars at home and abroad have conducted a lot of research and obtained good results. Peri, Rossetti and Campana (2001) modified a tanker ship by using the Bézier patch. Three different algorithms which included Conjugate Gradient (CG), Steepest Descent (SD) and Sequential Quadratic Programming (SQP) were used to optimize its total resistance and wave amplitude. Peri and Campana (2003) performed a local reconstruction of the sonar cover of DTMB5415 based on the Bezier polynomial surface method and optimized the total drag coefficient when Fr=0.41. The results showed that the total drag coefficient of the optimized ship model was reduced by 6%. Lin, Yang and Guan (2019) used six cross-sectional area curve parameters of Small Waterplane Area Twin Hull (SWATH) as design variables. The optimal Latin hypercube sampling (OLHS) method was employed to obtain 40 sample data. After hydrodynamic evaluation, the Krigeing model was constructed, and the optimal ship type was obtained by using Multi-Island Genetic Algorithm. The results showed that the total resistance of the optimal hull was reduced by 28.9% compared with the parent ship. Wang, Chen and Feng (2021) selected 9 parameters of deep-sea aquaculture vessels as design variables and applied 60 sample data which were obtained by uniform sampling method to construct radial basis network surrogate model. The optimization results showed that the total drag coefficient and the non-uniformity of wake flow of the optimal vessel were reduced by 1.67% and 17.12%, under the structural draft and 2.59% and 4.04%, under the ballast draft, respectively. Liu, Zhao and Wan (2022) optimized the resistance and propeller wake distortion of Japan Bulk Carrier (JBC) based on the in-house solver OPTShip-SJTU considering the interaction between hull and propeller. The Free-Form Deformation (FFD) method was applied to modify the stern shape of JBC. 30 sample points were obtained by using the Optimized Latin Hypercube Sampling Method (OLHS). The Kriging model was constructed to reduce the computation cost. The optimal results obtained by using the multi-objective genetic algorithm (NSGA-II) showed that it was necessary to consider the propeller effect in the