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Hull surface modification for ship resistance performance optimization based on Delaunay triangulation

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ABSTRACT

Combining computational fluid dynamics and optimization techniques provides a significant method for automatic multi-scheme selection in hull form optimization, which can improve the design level of energy-efficient ships. This paper focuses on hull surface automatic modification and its application in hull form optimization. A new hull surface automatic modification method is proposed, based on the radial basis function interpolation method. Furthermore, Delaunay triangulation is applied in order to determine the support radius of the Wendland basic function. The developed hull form optimization tool is applied to the hydrodynamic design optimization of a Series 60 model, and model tests are carried out on the original and an optimised model at WHUT (Wuhan University of Technology) for validation. The numerical optimization and model tests results demonstrate that the proposed method can significantly improve optimization efficiency.

1. Introduction

The energy efficiency design index (EEDI) was proposed by IMO in 2009 (MEPC, 2009), and ship resistance performance optimization is an effective method for meeting the EEDI requirements. With the rapid development of computer technology and computational fluid dynamics (CFD), hull form optimization based on simulation has become a research hotspot. Harries et al., (2001), Peri and Campana (2003, 2005), Campana et al., (2006), Diez and Peri (2010), Li and Zhao (2011), Li (2012), Yang and Kim (2011), Yang et al. (2015b), and Tahara et al. (2004, 2006) have combined numerical simulation techniques and optimization algorithms, realised the integration of CAD and CFD, established a CFD-based hull form optimization platform, successfully completed the simulation optimization design of hull lines and obtained an optimal hull form with improved hydrodynamic performance. Xu and Wang (2001) traced the development of a classified optimization procedure consisting of five levels in order to complete the fine optimization of ship hull lines, and demonstrated that CFD code is applicable to the optimization of ship hull lines in terms of hull resistance performance. Abt et al. (2003) presented a parametric approach to modelling with the FRIENDSHIP-Modeler, as well as hydrodynamics with SHIPFLOW, for ship hull forms. Campana et al. (2003, 2004, and 2005) investigated a variable-fidelity approach for speeding up the optimization process using a free surface RANS in a multi-objective design problem. Tahara et al. (2004) employed a finite-difference gradient-based approach for stern and sonar dome optimization. Peri et al. (2004) introduced a design optimization method based on large-scale numerical simulations (simulation-based design, SBD) for complex engineering optimization problems involving highly computationally expensive objective functions and nonlinear constraints. Zhang et al. (2009) optimised the hull form with minimum wave-making resistance based on CFD, by combining the Rankine source method with nonlinear programming (NLP). Peri (2016) presented an approach for robust optimization of a bulk carrier's conceptual design, subject to uncertain operating and environmental conditions, and a particle swarm optimization algorithm was applied for the global minimisation process, minimising the expectation and standard deviation of the unit transportation cost. Since then, the feasibility of RDO based on actual operating ship data has been demonstrated. Grigoropoulos and Chalkias, (2010) proposed an improved scheme for hull form optimization with respect to calm water resistance and seakeeping. These authors also adopted the FRIENDSHIP-Modeler for hull form modelling and modification, as well as modeFRONTIER and EASYcodes to accomplish multi-objective optimization by means of evolutionary strategies. Yang and Kim, (2011) developed an efficient and effective hull surface modification technique for CFD-based hull form optimization in order to achieve both local and global hull form modifications by combining the two

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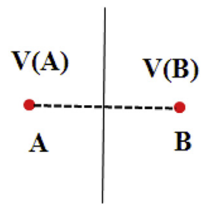

Fig. 1. Nearest area.

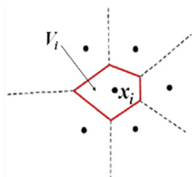

Fig. 2. Voronoi diagram.

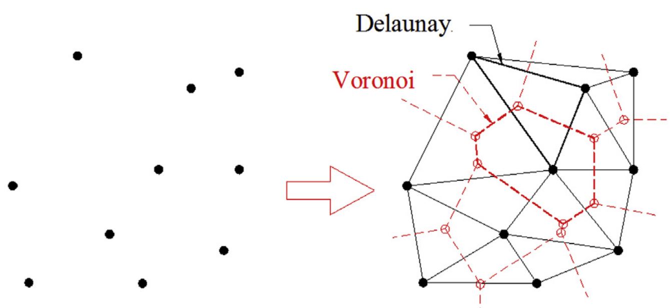

Fig. 3. Delaunay triangulation.

approaches. Kim et al. (2010) developed a new methodology for hydrodynamic optimization of a TriSWACH, which considers not only the side hull positions, but also their shape.

In order to satisfy the requirements of a ship's hydrodynamic performance, the hull form is somewhat complicated. When using a non-uniform rational B-spline (NURBS) to represent the hull surface accurately, the number of control points must be extremely large, which presents difficulties in hull surface modification. Therefore, several hull surface modification methods have been explored, and can be divided into two categories, as follows. 1) The fusion method based on the initial hull form (Tahara et al., 2006; Feng et al., 2010). This method can guarantee that the new hull surface is faired when the initial hull form is smooth. However, the limitation of this method is that it cannot consider the deformation of local hull lines. 2) Direct modification of the control points based on the Bezier patch and free-form deformation methods. This approach can be used for geometric reconstruction of the entire hull form, but the design variables are relatively more important and the control points must be carefully selected. Hull surface deformation is achieved using the initial ship's NURBS control points as design parameters in the above methods.

This study focuses on the hull surface modification method. A hull optimization tool is developed with the hull surface modification module. The enhanced hull optimization tool is applied to the resistance performance optimization of a Series 60 vessel, and model tests are carried out in order to verify the method's validity.

2. Hull surface modification method

The hull surface modification method plays a vital role in ship hydrodynamic performance optimization, and should meet the following requirements.

1) In order to save optimization time, hull surface modification should be achieved using few design parameters.
2) The modification range of the hull form should be sufficiently large.
3) The local modified hull surface should have a fairing connection with other parts of the hull surface.

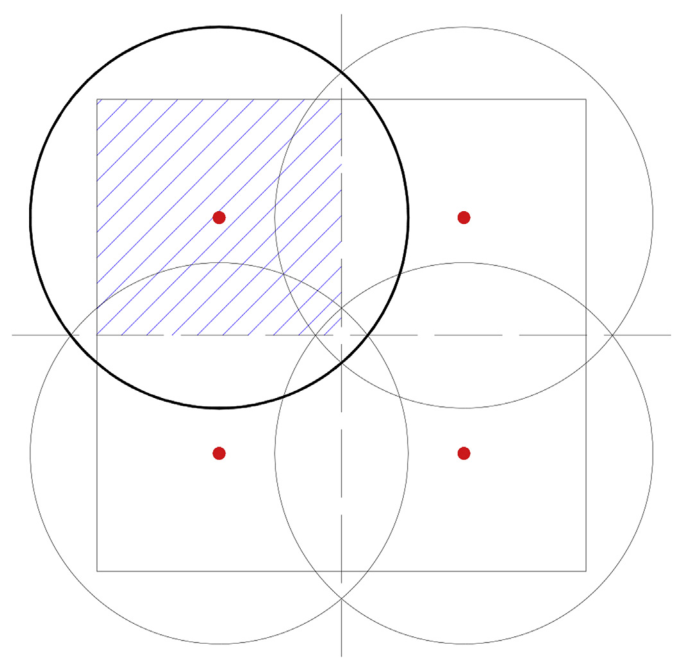

Fig. 5. Support radius area of 2D points set.

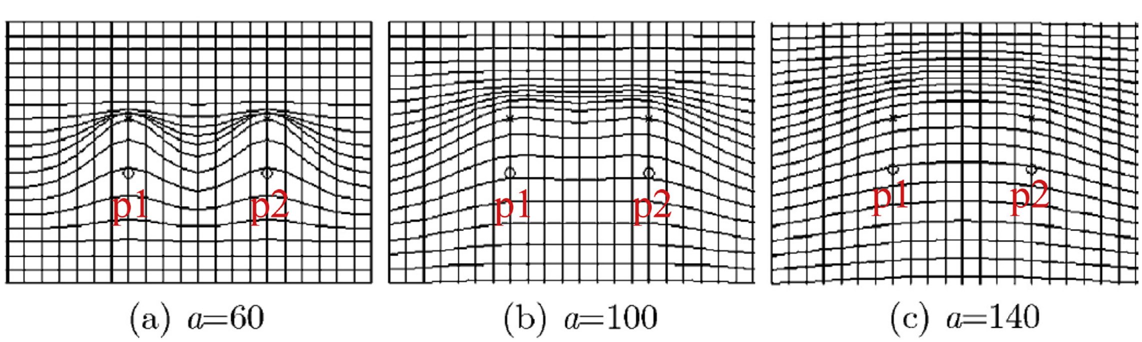

Fig. 4. Interpolation results of different support radiuses.