Application of CFD-based efficient global optimization method to ship hull design

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Introduction

- Computational fluid dynamics (CFD) has become an invaluable tool for ship hull form optimization design.
- In the process of ship optimization design, the number of objective function (certain hydrodynamic performances to be improved) evaluations using high-fidelity numerical analysis solvers, is enormous but severely limited by computational time and cost, even with the aid of supercomputers.
- One alternative is to construct surrogate models based on finite sample points instead of direct numerical evaluations one by one.
- In this paper, The Efficient Global Optimization method (EGO) is used in ship optimization design based on our in-house solver OPTShip-SJTU.

Numerical methods

The EGO method mentioned herein is a Kriging-based global optimization method considering the uncertainty of the surrogate prediction. The key to the EGO method lies in balancing the need to fully exploit the surrogate model (by sampling where it is minimized) with the need to improve the accuracy of surrogate model (by sampling where prediction error may be high). The concept is expressed in the infill criterion of Expected Improvement (EI). The EI of optimization problem can be calculated as:

$$E\left[I(x)\right]=(f_{\min}-\hat{y})\Phi\left[(f_{\min}-\hat{y})/s\right]+s\phi\left[(f_{\min}-\hat{y})/s\right]$$

A simple flow chart of the EGO method applied for a simple mathematical function is shown in Fig. 1. The EGO method is added to our in-house solver OPTShip-SJTU for ship optimization design based on CFD.

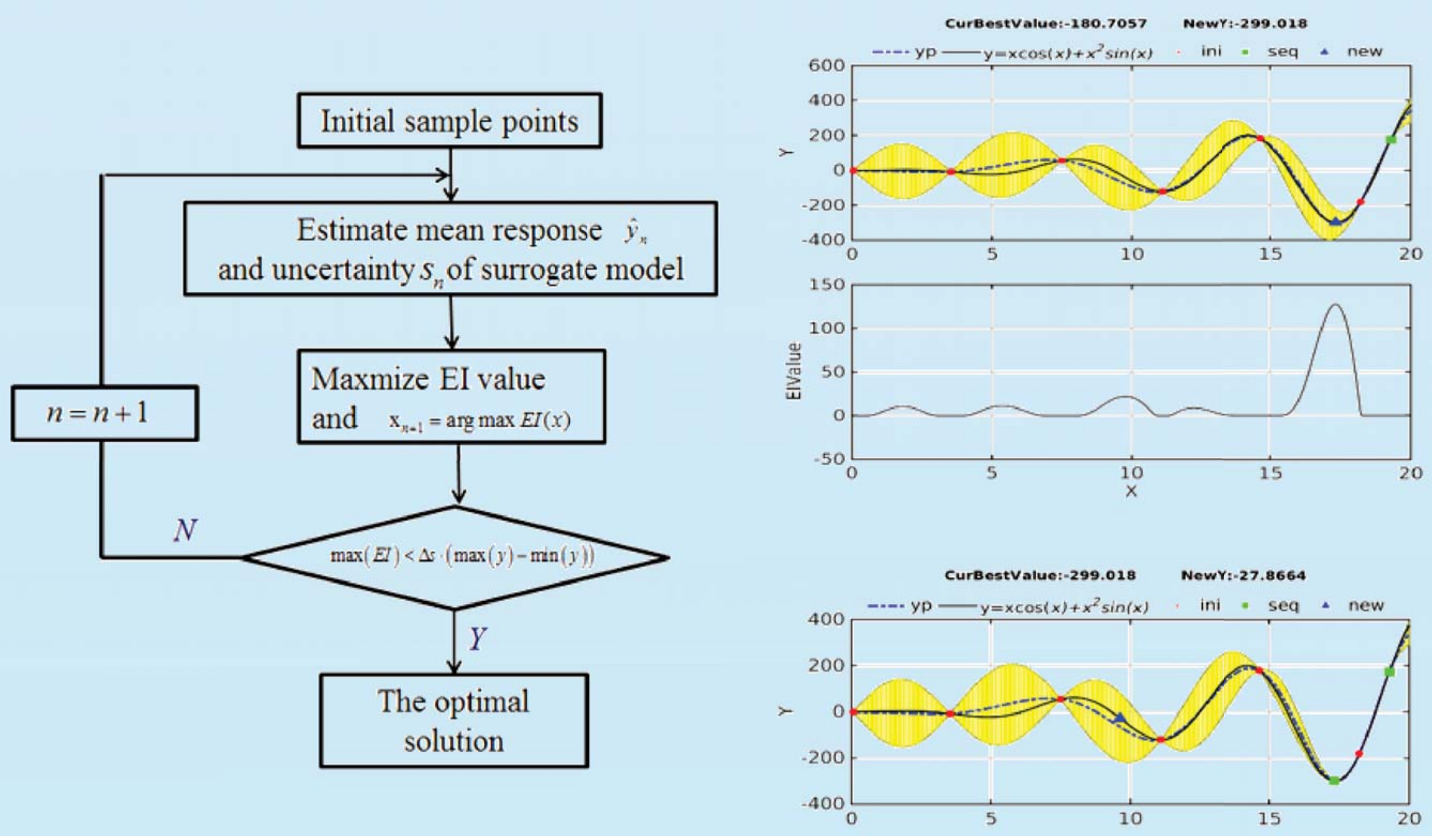

Figure 1: The flow chart of efficient global optimization: on the left, the steps are briefly described; on the right, an example is given (predetermined design points as red dots, the added new points as green squares and the next new point as a blue triangle).

Results

The EGO method is applied for ship optimization of Wigley to minimize the wave-making resistance in the calm water.

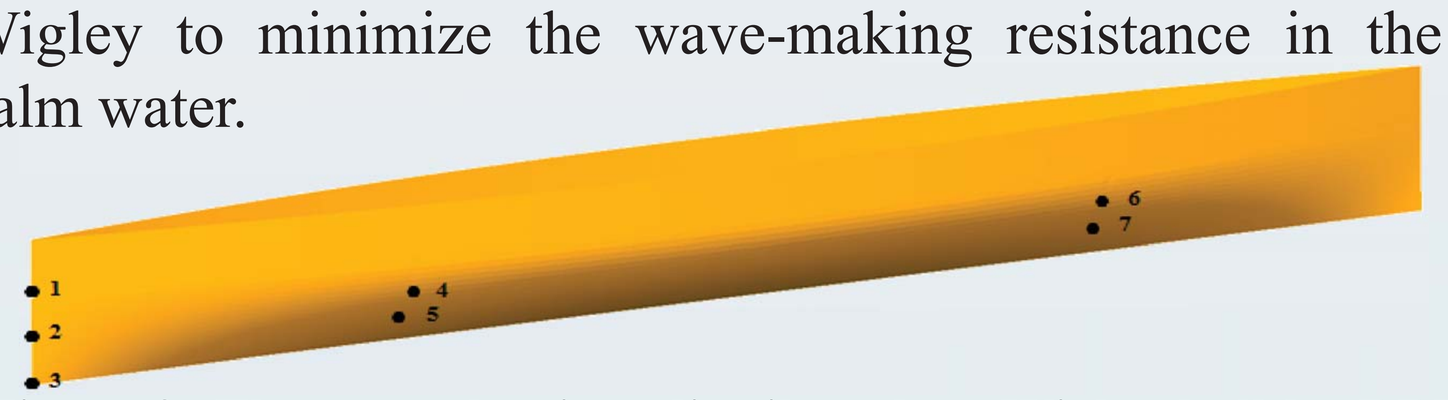

Figure 2: The control points distributed on Wigley hull by RBF method

It also starts with the classical Kriging surrogate model. A new design sample point is found through optimizing an infill criterion based on the surrogate model. This new design point is the next new ship directly evaluated by CFD method. The surrogate model will be rebuilt by the total sample points. This step of model reconstruction and generation of additional new design point is not iterated until a stop criterion is fulfilled. At last, the optimal ship will be obtained with the minimum wave-making resistance. The *Cw* converges to the minimum value, 1.046E-03, a larger reduction of 18.46% than the initial value. Details are shown in Fig. 3-6.

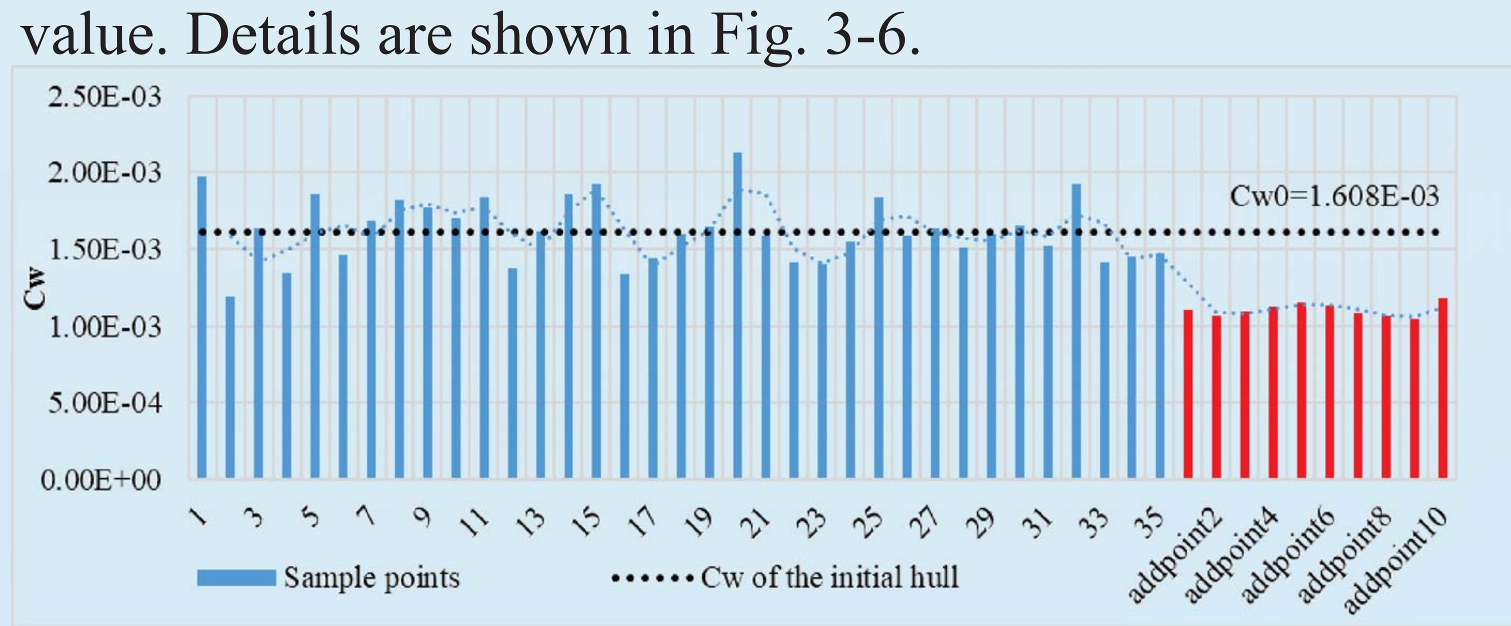

Figure 3: The initial sample hulls and the additional new hulls used in the EGO method

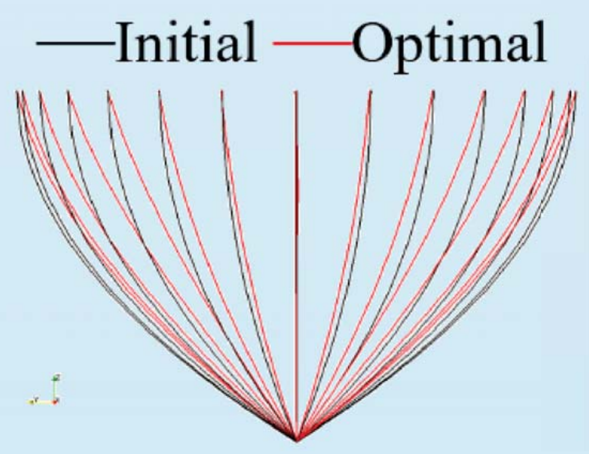

Figure 4: Comparisons of the body lines between the initial and optimal ships

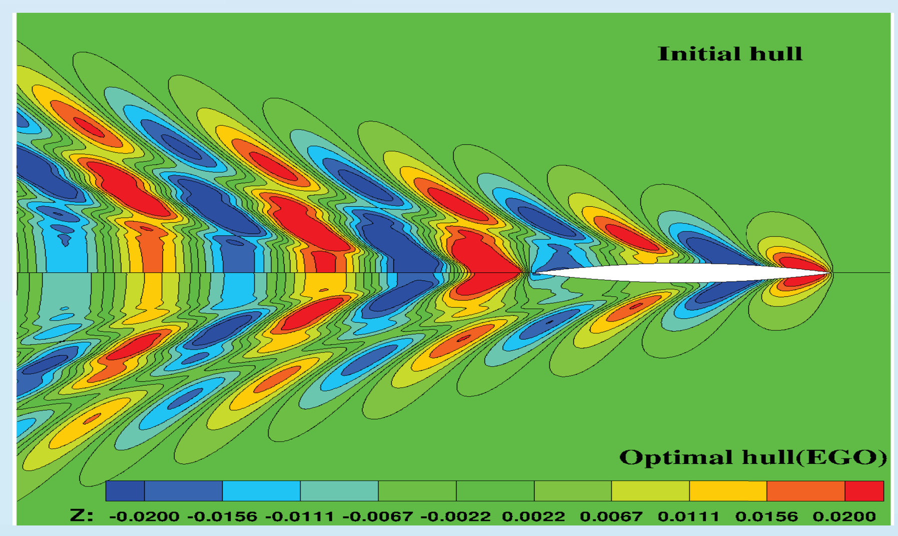

Figure 5: Comparison of free surface elevation between the initial and optimal ships

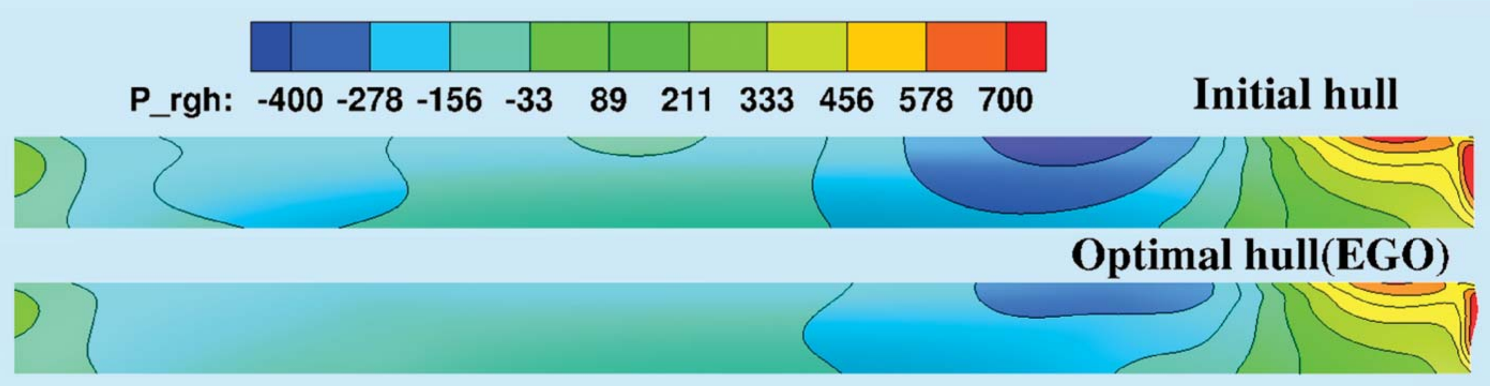

Figure 6: Comparison of pressure distribution between the initial and optimal hulls

Conclusions

This paper presents a Kriging-based global optimization method, efficient global optimization (EGO), different from the ordinary optimization method. It combines the surrogate modeling with the optimization algorithm. In the future, it will be used to the more complex ship optimization problem, such as the ship hull form design to improve comprehensive hydrodynamic performance, based on entire CFD.