Design Optimization of Ship Propellers by Means of Advanced Metamodel-Assisted Evolution Strategies

Michael T. M. Emmerich*, Jochen Hundemer*, Mihai-Christian Varcol* and Moustafa Abdel-Maksoud*

*Institute for Ship Technology and Transportation.
University of Duisburg-Essen, 47048 Duisburg, Germany
Email to: varcol@nav.uni-duisburg.de - Web page: http://www.uni-duisburg.de/IST/willkommen.html

*Leiden Institute for Advanced Computer Science.
Niels Bohrweg 1, 2333-CA Leiden NL
Email to : emmerich@liacs.nl - Web page: www.liacs.nl/~emmerich

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ABSTRACT

The design of ship propellers is a challenging design optimization task in the field of ship propulsion technology. Nowadays, potential solvers can predict the performance of a propeller design with a high accuracy. This performance of a ship propeller can be seen as a function of its resulting efficiency, torque coefficients, thrust coefficients, and cavitation, all of which can be computed by potential flow numerical solvers within one time consuming simulation that, depending on the input variables, takes several minutes up to hours for one evaluation by the simulation software. The simulator, an implementation of a First-Order Potential-based Panel Method, uses this method to calculate the hydrodynamic performance of any given propeller at a given advance coefficient. Furthermore the area where pressure lies below the vapor pressure is calculated to evaluate the magnitude of cavitation.

The parameterization of a propeller is another challenging task. Different parameterized spline curves are used to describe characteristics of the 3-D shape of a propeller. Among others these shape characteristics are the pitch, the skew, the rake, cord length, the thickness and the camber. The number of parameters multiplies with the number of shape characteristics, because each of the characteristics is described by means of a spline curve. The propeller is described in this parametric manner, so that it can be modified easily in order to create variants. Simple parameterizations can already come along with 25 design variables, whereby only 2 dimensional splines are considered in such cases.

In the studies presented in this paper a nonlinear optimization software was coupled to an analysis method for ship propellers [5] in order to develop designs of improved performance. Besides problems caused by the high dimensionality and the nonlinearity of the function, a particular challenge was to deal with the high computation time.

In order to tackle non-linear, high dimensional functions evolution strategies are one of the most favourable choices. An alleged drawback of these strategies is that they need a large number of evaluations to approach an optimum with high accuracy. Thus, in the presence of time consuming objective function evaluations, measures have to be taken to accelerate search. One of these measures is to use parallel evaluations. Evolution strategies generate a set of variants in
each iteration (generation) that can be evaluated concurrently. Hence, the parallelization of ES can be done in a straightforward manner by simultaneously evaluating variants. Though the overall optimization time can be decreased by a linear factor, the total computational cost does not reduce by employing parallel function evaluations.

Recently, it has been proven that the evolutionary algorithms [6, 7], and in particular evolution strategies [3], can be significantly accelerated by using metamodels. The principle of such metamodel-assisted evolution strategies is to generate a surplus of variants in each iteration and reduce it to a subset by means of an approximation model that is learned from previous evaluations.

Given a set of evaluated design points in a high dimensional search space, a metamodel can predict the response at design points that have not yet been evaluated. The prediction routines used here are called Kriging [4] and stem from geostatistics. By means of Kriging models not only the response can be predicted but also the uncertainty of a response prediction is provided by means of the parameters (standard deviation) of a Gaussian distribution describing the possibility of other outcomes. This information can be used to make the optimization algorithm more reliable and prevent the convergence to false optima. Various measures for doing so have been developed by the authors.

In this paper different methods are compared of how to accelerate evolution strategies by means of metamodels on artificial test problems similar to the time consuming evaluation function. A promising strategy is then used to optimize the real application problem on a parallel computer cluster. For the last step problem specific adaptations of the metamodel-assisted evolution strategies (MAES) are discussed.

Figure A:

![Figure A](image)

The first results obtaineded with a parallel MAES for the design of ship propellers are remarkable and far beyond our expectations. The figures [A] and [B] illustrate these results.

Figure B:
In Figure [A] we see the geometry of a propeller before and during optimisation (the best candidate solution from a total budget of 1000 exact evaluations). The surface has become smaller and the efficiency has increased. Figure [B] shows the change of the propeller blade parameters, here the pitch and the chord length over the propeller radius. The shrink of the propeller dimensions as shown in Figure [A] corresponds to the smaller chord length parameter during optimisation. Obviously the MAES varies the pitch parameter in order to improve the performance.

A comparison between three different strategies will be given in the full paper. It was obtained, that the MAES-strategies outperform the pure ES variants. The best results are obtained using a mixture of preselection methods, i.e. 2% of the preselected individuals are chosen via MSE-criteria, whereas 8% are chosen using the approximation of the simulator function provided by the Kriging algorithm.

As a conclusion, we state that among many other fields [1, 2], for the field of ship engineering the MAES seems to be a very valuable tool that opens up perspectives for new ways of exploring the design space for the engineer.
REFERENCES


