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Accurate and efficient BEM modelling of squat and bank effects in navigation channels and inland water ways

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Safe and efficient navigation of large ships in shallow and confined water is a challenge. New container ships are enlarged to increase fuel efficiency and offshore installation vessels are larger to accommodate as many wind turbine parts as possible. Often these ships must navigate shallow and confined fjords or navigation channels to reach inland ports. We must ensure safe, predictable, and efficient navigation in these shallow and confined waters, and protect the marine environment in coastal areas. Safety is assessed by maritime engineering analysis tools and maintained by training of maritime officers in maritime simulators.

In order to address the challenges, we are developing new numerical tools for prediction of squat, bank effects and ship to ship interaction. Our goal is to accurately calculate the hydrodynamic interaction forces and moments on ships in real-time in maritime training simulators. Ships navigating in coastal and inland waterways are sailing relatively slow, hence both the length- and depth-based Froude numbers are small (< 0.2), and the well-known double body model gives a valid approximation of the hydrodynamic ship flow. We are using the state-of-the-art boundary element model π-BEM [1] to solve the double body potential flow problem. π-BEM has higher order polynomial elements, numerical quadrature for singular integrals, adaptive multi resolution quadrilateral mesh generation directly on the ships CAD geometry, fast multipole optimization of matrix vector products and MPI parallelization. We have extended the π-BEM by streamlined pre-processing of the CAD geometry, developed new error-estimators for the adaptive multiresolution, developed numerical methods for calculation of flow separation along geometrical edges, compared squat prediction and bank effects with experiments for the ship models KCS and KVLCC2 [2].

Recently we developed a novel bathymetry model that, based on a point set including coastlines, depth contours and soundings from electronic sea charts and high-resolution soundings in the navigation channels, generates a fair bathymetry surface. Using a multiresolution quadtree subdivision of the point set, we assign two-dimensional Bezier polynomials (up to 5^{th} order) to each element. The polynomial coefficients are found by weighted least squares (WLS) fit to the point set, minimization of the bathymetry surfaces bending energy, a minimal energy surface (MES), and point, tangent, and curvature continuity constraints between the quadrilateral elements. This is a bounded (seabed is required to be lower than the sea level) optimization problem with two objective functions and equality constraints. By reformulation into an optimization problem for the MES, with negative value of the gradient of the WLS functional squared as inequality constraints and the inter element continuity equality constraints, we can solve it using the barrier-based primal-dual interior point algorithm. The resulting bathymetry model is saved as a CAD model and imported in our BEM model for accurate calculation of squat and bank effects. At the conference we present comparison of bank forces and moments between our BEM model and model experiments and assessment of navigation limits in the Limfjord in Northern Denmark.

[1] Nicola Giuliani and Andrea Mola and Luca Heltai, "π-BEM: A flexible parallel implementation for adaptive, geometry aware, and high order boundary element methods", *Advances in Engineering Software* 121 (2018): 39-58

[2] Ole Lindberg and Ole Vilmann, "Accurate and efficient simulation tools for squat prediction and hydrodynamic interaction effects", In proceedings: *6th MASHCON International Conference on Ship Manoeuvring in Shallow and Confined Water with special focus on port manoeuvres,* 2022.