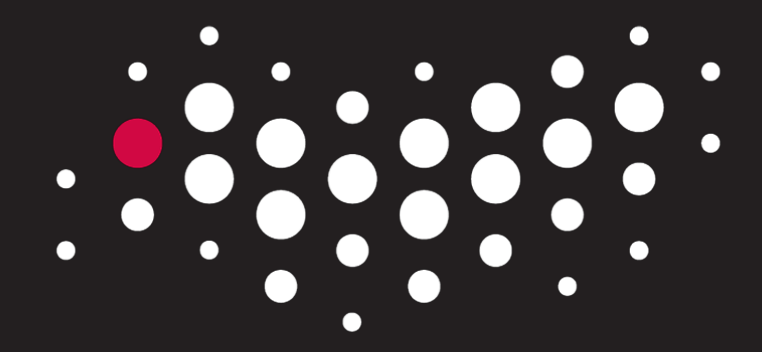


A practical GPU-accelerated method for the simulation of naval objects on irregular waves

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Previous Work

There are several approaches to simulating floating bodies (floaters). Some of them, which are precise and acceptable for naval object design, utilize finite-element methods (FEM) [1], smooth-particle hydrodynamics (SPH) [2], but suffer from extremely high computational cost. Other approaches are faster but limited by less dimensions of freedom [3], or aimed at solving particular problem [4]. However, there are a lot of applications such as simulators and video games where a precise solution is not critical. But even such applications require plausible motion of such objects that satisfy and perceptible relation between body naval object shape, weight and waves. More over, such methods should be numerically stable for most cases and have predictable and scalable performance. Some of these approaches is presented here [5], [6] and here [7].

Objective

The method of simulating floating bodies has to meet the following requirements:

1. Handling multiple floating objects.
2. Handling arbitrary hull shapes.
3. Good scalability.
4. Should work with real wave spectra.

Proposed Method: Mathematical Section

Consider a naval object to be a rigid body with six degrees of freedom and added mass. The total force \mathbf{F} and torque \mathbf{T} acting on a floating body could be expressed as follows.

$$m\ddot{\mathbf{p}} = \mathbf{F} \quad \mathbf{T}\ddot{\mathbf{q}} = \mathbf{M} \quad (1)$$

where \mathbf{p} object position and \mathbf{q} object rotation. For floating naval object right part of equations (1) can be rewritten as follows:

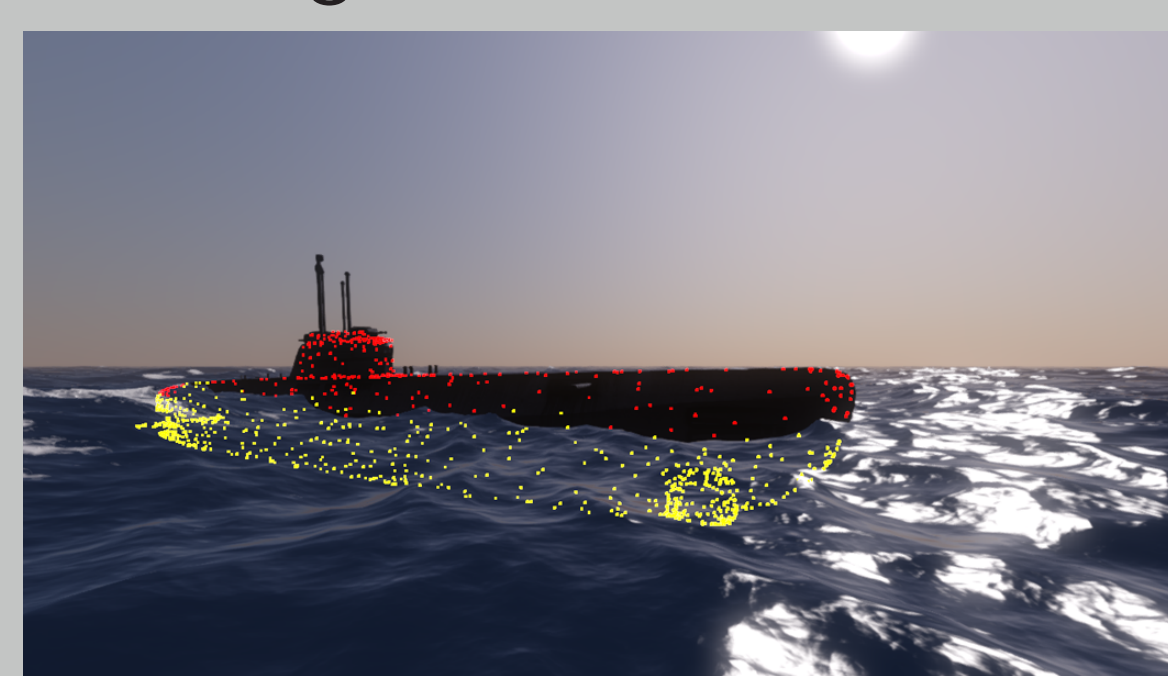
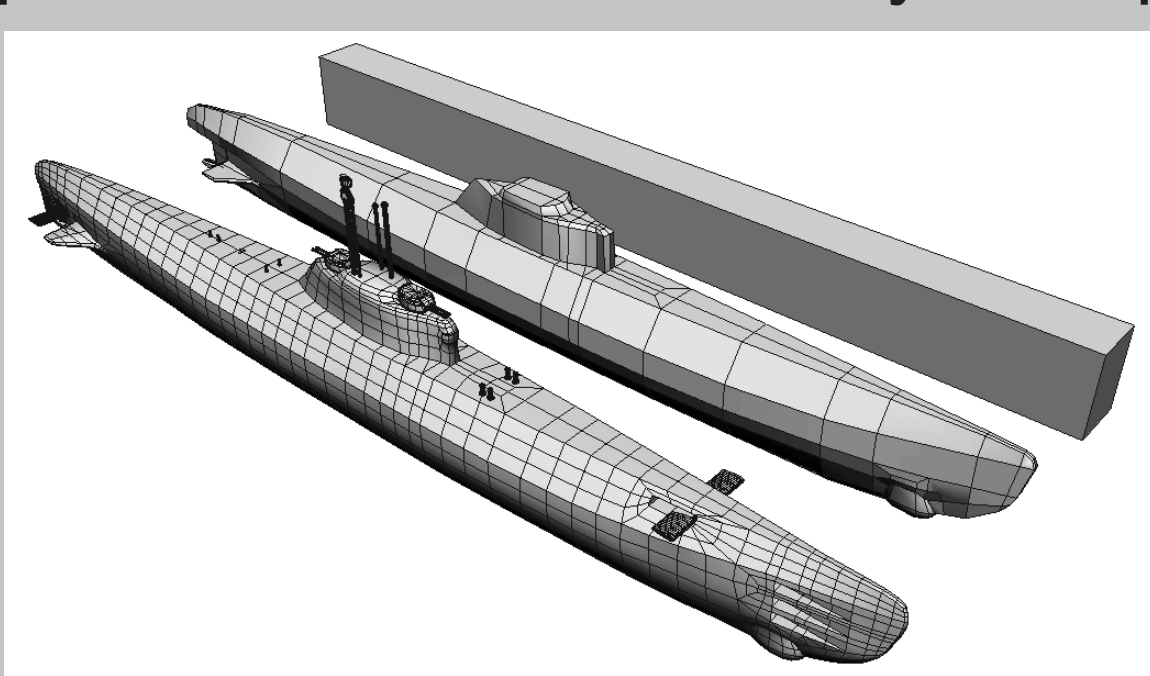
$$\mathbf{F} = \iint_{\Phi} p\mathbf{n}d\sigma + D \quad \mathbf{T} = \iint_{\Phi} (p\mathbf{n}) \times (\mathbf{r} - \mathbf{p}) d\sigma \quad (2)$$

where Φ — submerged surface of naval object, D — naval object weight, p — static and dynamic water pressure, \mathbf{n} — surface normal, \mathbf{r} — radius-vector of each point on submerged surface of naval object, m — mass of naval object (including added masses), \mathbf{J} — inertia of naval object (including added inertia).

Proposed Method: Force Integration

Analytical integration of (2) is impossible for arbitrary hull shapes and an arbitrary sea surface. The solution is to divide the submerged hull surface into small surface elements [7], but fixed regular or random discreet dividing will lead to non-compensated forces and constant drift especially on silent water. To avoid this effect, we uniformly (within triangles) place several hundred random points on the naval object hull at each simulation step. Each point represents a surface element with a particular area and normal. Surface elements are considered to be so small that a change of pressure or force along these elements is negligible.

The left figure shows input meshes for rendering (lower left) for force integration (middle) and for collisions (upper right). The right figure shows point distribution where yellow points are submerged.



To compute force acting on each surface element, we determine whether each element is submerged. If the element is submerged, we obtain wave height and water velocity at the centre of the element and the absolute velocity of this element. We compute the hydrostatic force from the wave height above a given point.

To obtain water height-, offset- and velocity fields we use a fast Fourier transform [8] with Pierson-Moskowitz spectra [9].

Proposed Method: Drag and Lift Forces

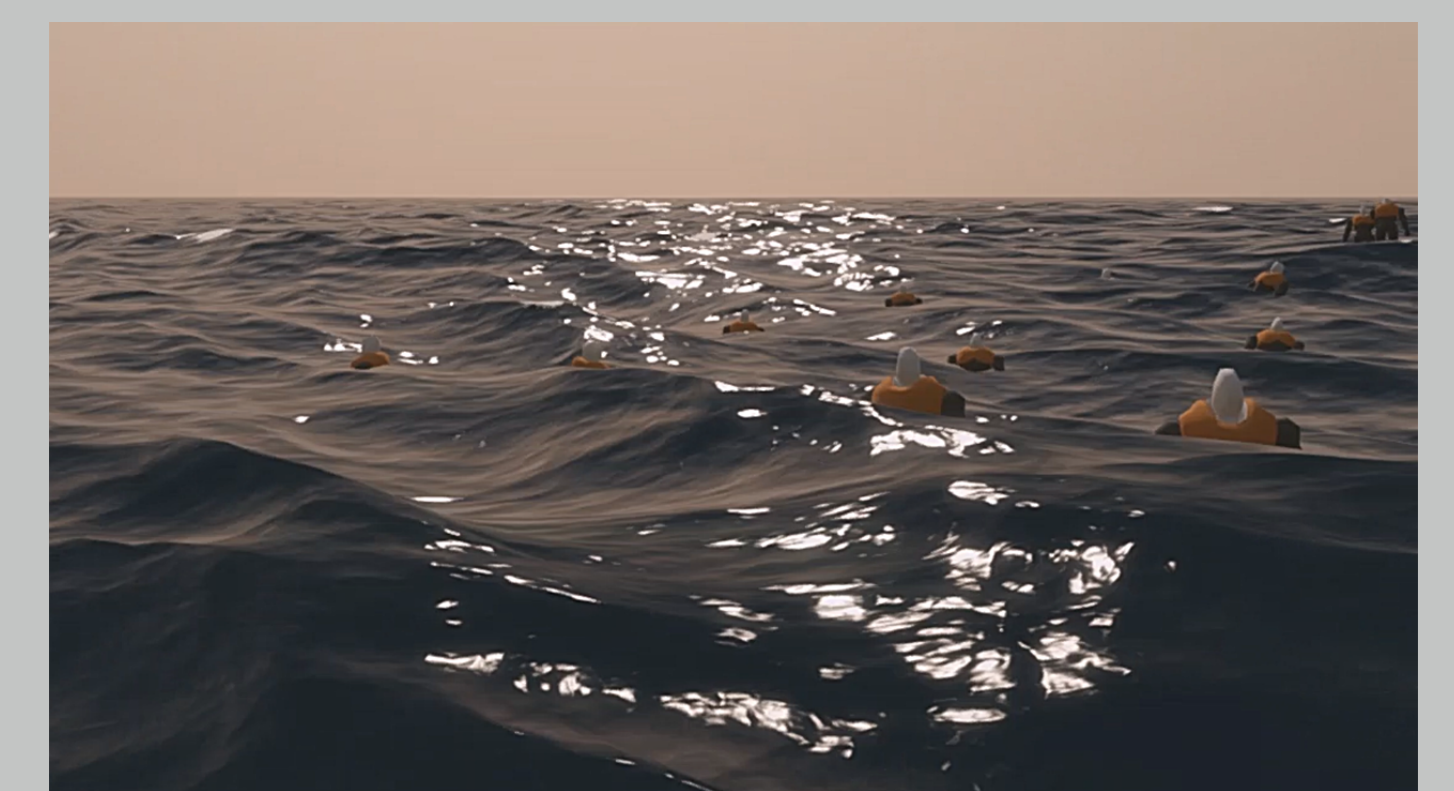
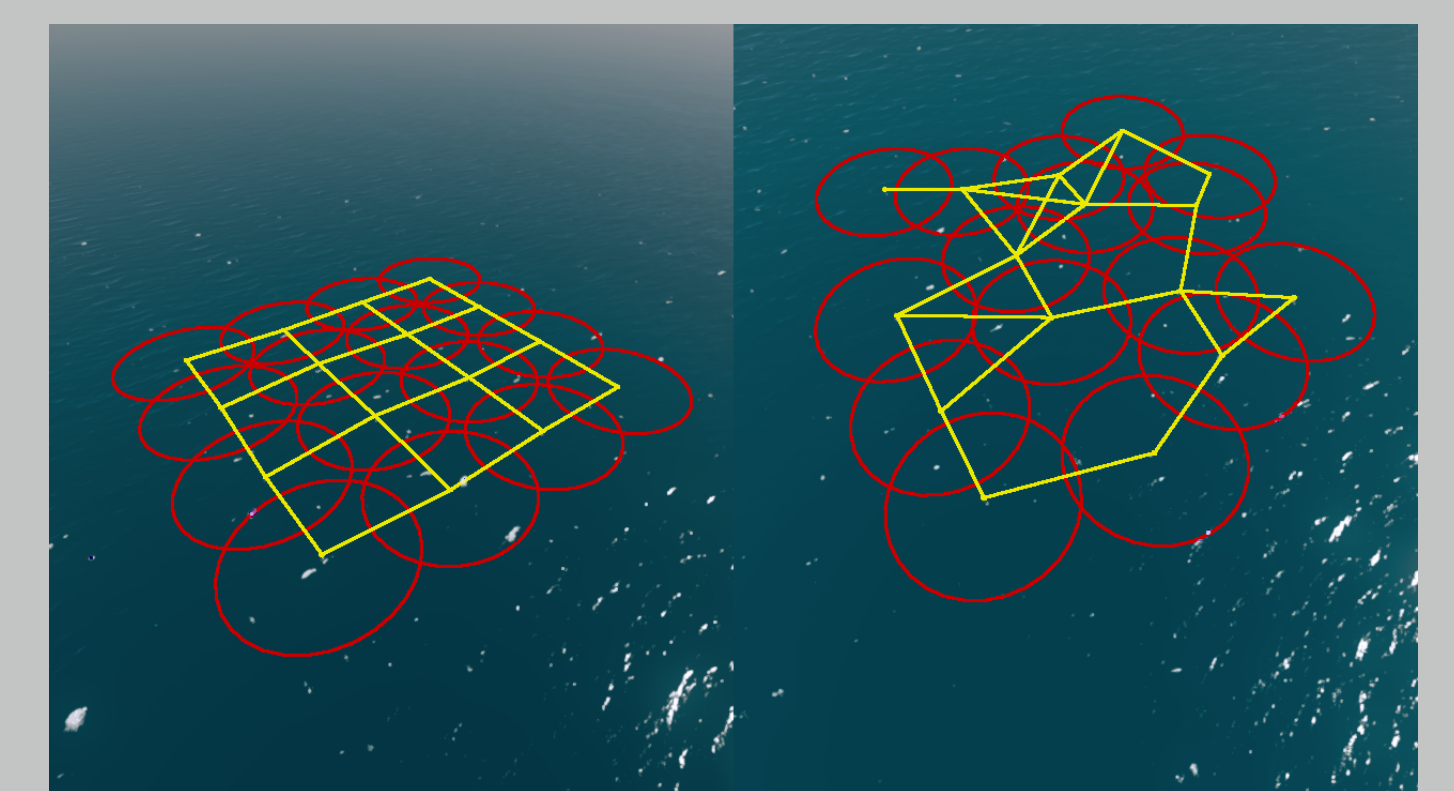
The hydrodynamic force is computed as the sum of the drag (\mathbf{F}_{drag}) and lift (\mathbf{F}_{lift}) forces acting on given surface element. Drag and lift forces are computed as follows (3).

$$\mathbf{F}_{drag} = \frac{1}{2}\rho C_{drag} S \mathbf{u}^2 \quad \mathbf{F}_{lift} = \frac{1}{2}\rho C_{lift} S \mathbf{u}^2 \quad (3)$$

Where ρ — water density, \mathbf{u} — incoming flow velocity, S — surface element area. Coefficients C_{drag} and C_{lift} depend on the angle α between surface element normal and negated velocity vector. We assume $C_{drag} = a \cos(\alpha) + b$ and $C_{lift} = c \sin(2\alpha)$. Coefficients a , b and c could be found by experiment. For our simulations we choose $a = c = 1$ and $b = 0.1$ that provides believable motion damping.

Applications

1. Carrier landing simulation.
2. Cargo loss search and rescue simulation.
3. Evolution of buoy network grid simulation.
4. Search and rescue operation simulation for shipwreck victims.



Conclusion

1. The proposed method has linear scalability and does not depend on the number of floating bodies.
2. The proposed method efficiently handles large objects like ships and vessels, as well as small ones, like buoys or naval mines.

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