Accelerating real-time ship motion simulations using general purpose GPU computations

I. Petriakov   I. Gankevich   A. Degtyarev

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Virtual testbed project

Global goal: Decision support system that analyses data from ships in sea, models the environment and predicts (and prevents) dangerous situations.

Current goal: Real-time simulation environment for ships with visualisation.

Key features:
- Real-time. We have 16–33 ms to compute everything.
- Realistic marine objects. We load ships from IGES files.
- Arbitrary-amplitude ocean waves (work-in-progress).

Project timeline (2018)

Aug   Sep   Dec

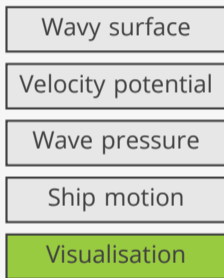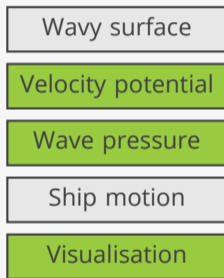| Wavy surface |
| Velocity potential |
| Wave pressure |
| Ship motion |
| Visualisation |

No copying, but slow.

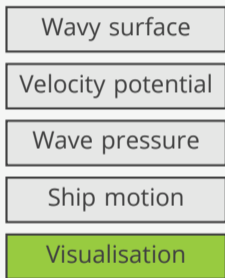CPU GPU

Project timeline (2018)

Aug	Sep	Dec

Aug:
- Wavy surface
- Velocity potential
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Sep:
- Wavy surface
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- Wave pressure
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Faster, but a lot of copying (30 FPS).

CPU GPU

Project timeline (2018)
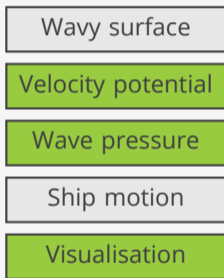
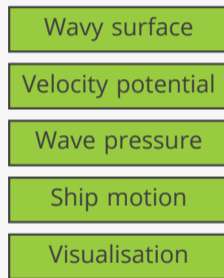| Aug	Sep	Dec
Wavy surface	Wavy surface	Wavy surface
Velocity potential	Velocity potential	Velocity potential
Wave pressure	Wave pressure	Wave pressure
Ship motion	Ship motion	Ship motion
Visualisation	Visualisation	Visualisation
No copying, but slow.	Faster, but a lot of copying (30 FPS).	Expected to be much faster with no copying.

CPU GPU

The anatomy of a frame

Linear models

Geometric transforma-
tions, transcendental
functions, derivatives

Runge—Khutta—Fehlberg

Wavy
surface → Velocity
potential → Wetted
panels → Wave
pressure → Ship
motion → Visualisation

Convolution
($4\times$FFT), derivatives

The anatomy of a frame

Linear models

Geometric transformations, transcendental functions, derivatives

Runge—Khutta—Fehlberg

| Wavy surface | → | Velocity potential | → | Wetted panels | → | Wave pressure | → | Ship motion | → | Visualisation |

Convolution (4×FFT), derivatives

FPS	One frame, ms	One stage, ms
60	16	5
30	33	11

Velocity potential equations

$$\nabla^2 \phi = 0 \qquad \text{continuity equation}$$

$$\phi_t + \frac{1}{2}|\vec{v}|^2 + g\zeta = -\frac{p}{\rho} \qquad \text{dynamic BC for } z = \zeta(x, y, t)$$

$$D\zeta = \nabla\phi \cdot \vec{n} \qquad \text{kinematic BC for } z = \zeta(x, y, t)$$

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$$\zeta_t = \underbrace{\left(\frac{\zeta_x}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} - \zeta_x \right)}_{f_1} \phi_x + \underbrace{\left(\frac{\zeta_y}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}} - \zeta_y \right)}_{f_2} \phi_y - \underbrace{\frac{1}{\sqrt{1 + \zeta_x^2 + \zeta_y^2}}}_{f_3} \phi_z$$

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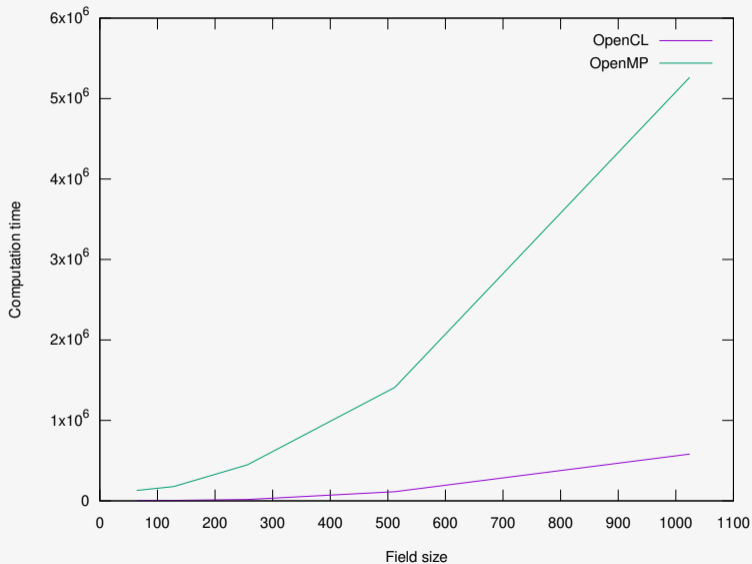
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Solution:

$$\phi(x,y,z,t) = \mathcal{W}_2(x,y,z) * \frac{\zeta_t(x,y,t)}{F(f_1,f_2,f_3)}$$

Velocity potential field computation performance

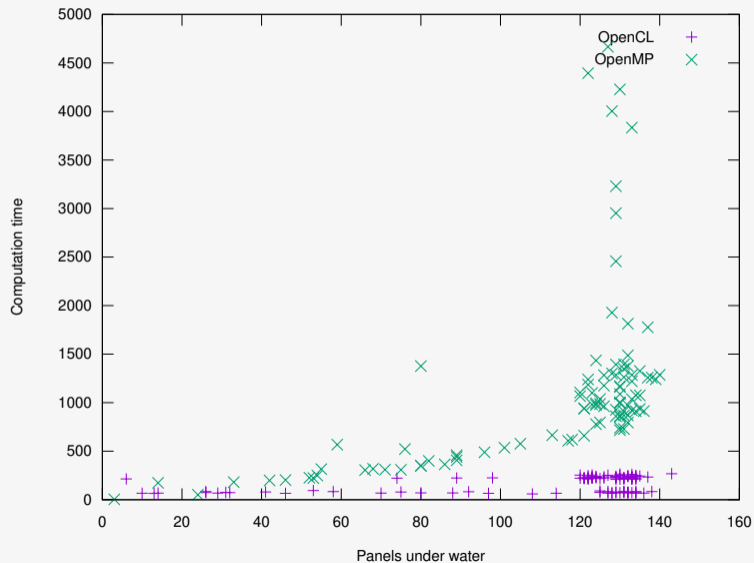| CPU | AMD FX-8370 |
| GPU | GeForce GTX 1060 6GB |
| OS | Fedora 28 |

Wave pressure

Pressure:
$$p(x, y, z, t) = -\rho\phi_t - \rho\frac{1}{2}\left(\phi_x^2 + \phi_y^2 + \phi_z^2\right) - \rho g z$$

Pressure force:
$$F(x, y, z, t) = -pS\vec{n}$$

Pressure computation performance

CPU	AMD FX-8370
GPU	GeForce GTX 1060 6GB
OS	Fedora 28

Thank you for attention!