Real Time GPU-Based Maritime Scenes Simulation

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GTC2012 - S0053
Introduction and background

Technical presentation
- 3D surface
- Mesh generation
- Surface illumination and atmospheric propagation
- Rendering effects
- Workflow
- Interaction with boats
- Performances

Demo

Future - Work in progress
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The ALYOTECH group
- Software service company
- 1900 employees worldwide
- Major sites in Canada, Europe, North Africa and Middle East

The Scientific Software Department
- Located in France
- Modeling, simulation and software development
- 40 engineers in computer science & physics
- 6 PhDs.

GPU expertise
- Rendering (OpenGL, OpenSceneGraph, Unity, OpenInventor, VTK)
- Computing (CUDA, OpenCL)
Background

Goal
- Provide a real time visible, IR and radar simulation of a marine scene
- Civil and military market:
  - Sensor design (Maritime surveillance, Offshore platform protection, pollution detection),
  - Search and Rescue mission preparation,
  - Training, marketing

MERCUDA
- 2007-2011: first CUDA development, sea surface simulation demo
- ALYOTECH investment

Sea clutter
- 2009-2011: radar sea clutter simulation software
- French Research Institute for Exploration of the Sea (IFREMER) partnership
- French MoD funding

NEMO
- 2012-2014: Real time multi-spectral marine scene simulation product development
- 75% ALYOTECH investment
- 25% French public funding to support SMEs innovation
Mixing rendering and computing
- On the same chip
- Huge memory bandwidth thanks to CUDA (OpenCL) / OpenGL interoperability

GPU computing
- Intensive use of CUDA / OpenCL

GPU rendering
- First version: OpenGL + GLSL
- Now: OpenSceneGraph + GLSL
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Sea surface

- Sea surface as a height field
- Spectrum approach
  - iFFT to transform back to spatial domain
  - Pros
    - Oceanography state-of-the-art spectrums
    - Very fast
  - Cons
    - No interaction with objects
    - No interaction with boundaries
- Use of cuFFT
Sea surface generation

- **2 spectrums: LF and HF**
  - **Set up with:**
    - Wind sea (Jonswap, Elfouhaily): fetch, wind speed, depth
    - Optional swell: direction, wavelength, amplitude
  - **Benefits:**
    - Covering full wavelength range [0.2m; 300m]
    - Limited computation time

- **For each spectrum**
  - **At T0:**
    - Generation from analytical 2-D wave power spectrum \( \Rightarrow \) Mean spectrum
    - Multiply by a complex Gaussian noise \( \Rightarrow \) T0 spectrum (instantaneous realization of the mean spectrum)
  - **At each time step T:**
    - Phase shifting \( \Rightarrow \) T spectrum
    - iFFT \( \Rightarrow \) T periodic height map
Sea surface generation

- 2 height maps generated:
  - 512x512 pixels resolution
  - High frequency (0.2 m. ~ 8 in.)
  - Low frequency x16 (3.2 m. ~ 10 ft.)

- Can generate an infinite open surface:
  - Summing HF and LF
  - Repeated pattern width:
    - 512 pixels at 3.2m (1.6km ~ 1 mile)
Goal: getting asymmetry between flatter troughs and sharper crests

Choppy wave model:
- Horizontal displacement computing
- Height map (regular grid) => point cloud
Goal: getting asymmetry between flatter troughs and sharper crests

Choppy wave model:
- Horizontal displacement computing
- Height map (regular grid) => point cloud

At each time step
- Generation of X and Y displacements spectrums from Z spectrum (HF & LF)
- 6 iFFTs -> $X_{LF}$, $Y_{LF}$, $Y_{LF}$, $X_{HF}$, $Y_{HF}$, $Y_{HF}$ displacement grids

Can generate an infinite open surface
- Summing HF and LF displacements for each axis
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Mesh generation

➢ At each time step

   • Plane regular grid - multi scale mesh (10 levels of details)
     o 1.5 $10^6$ facets
   • For each vertex:
     o Computing reference position in HF and LF displacement grids
     o Adding displacements to initial vertex position
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Multi-spectral simulator

- Physically consistent
- Visible (RGB)
- Infrared (Luminance)
  - MW-IR \( \lambda = [2 \, \mu\text{m}, 5 \, \mu\text{m}] \)
  - LW-IR \( \lambda = [8 \, \mu\text{m}, 12 \, \mu\text{m}] \)

Scene illumination
- Partially cloudy sky illumination
- Global illumination by the sun

Surface reflection
- Pre-computed blurred sky domes
- Direct solar reflection
Cloudy sky illumination

- **Pre-computed sky domes**
  - SKYGEN - ALYOTECH product
  - Computes multi-spectral cloudy sky radiance and illumination domes
  - Visible and Infrared
  - MODTRAN based algorithms
Sky dome surface reflection

- Set of sky domes (generated for different roughnesses)
  - roughness = unresolved waves in the facet (slope standard deviation of unresolved waves)
  - Each sky dome corresponds to the original SKYGEN dome reflected on a rough surface
- Compute each mesh facet roughness
- Benefits
  - Handles different sea states
  - Handles different facet sizes in the multi-scale mesh

Roughness=0

Roughness=1

Roughness=4
Sun illumination

- **Sky**
  - Sun seen as a pin light
  - In addition to the cloudy sky dome

- **Sea surface**
  - Direct solar reflection
  - In addition to the sky dome surface reflection
  - Computed at run time
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Other rendering effects

- Local roughness modification (oil slick)
Other rendering effects

- An atmospheric propagation based on MODTRAN, used together with a dedicated fast band-integration scheme.
Other rendering effects

- A white caps model based on each facet vertical acceleration
Other rendering effects

- An optional tone mapping rendering (work in progress)
  - Based on real time statistical computing on the HDR image

- Currently implemented:
  - Filmic tone mapping
  - Global average tone mapping
  - S-curve tone mapping

Normalized Gamma LUT

Filmic tone mapping

S-curve tone mapping
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Sea parameters:
- Wind speed
- Fetch
- ...

Workflow

T0 Plane Mesh
Sky domes (original and blurred domes)
Direct solar illumination

PHASE SHIFT

CUDA
OpenGL

Displacements
Z Grid
Y Grid
X Grid

T Spectrums
Z
Y
X

Vertex shader
Fragment shader
Textures
PBOs
Pin light

T0 Z Spectrum

iFFT

5/10/2012
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Interaction with boats

- No access to the generated mesh
  - Sea height computed from HF/LF displacement grids

- Boat behavior:
  - Nutshell
  - Transfer function (work in progress)
  - PDE resolution (small boats)

- Wakes
  - Kelvin wake
  - Particles
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- **Surface generation:**
  - 6 iFFT 512x512

- **Mesh generation:**
  - 0.8 $10^6$ vertices
  - 1.5 $10^6$ facets
  - Computing the 3D displacement of each vertex at each frame

- **Sea surface illumination**
  - Physically consistent illumination model of each pixel (1920x1080)

- **Performances**
  - Matlab + OpenGL: ~ 1 frame per minute
  - Cuda + OpenGL: ~ 25 frames per second (Full HD)
    - Fragment shader consumes more than 50% of the total time


NVIDIA GeForce GTX 580
DEMO
Use GPU computing to generate the mesh (instead of OpenGL)
  - Simplify sea-objects interaction computing

Fully OpenCL compatible version
  - Same binaries able to address both Cuda and OpenCL platforms

Dynamic sky domes
  - Depending on the camera position and the current time

Coupling with weather prediction model
  - Computing sea parameters from weather model outputs

Towards a product: NEMO
  - Coupling with existing EM simulation (ALYOTECH SeaClutter)
  - Multi spectral (Visible/IR/Radar) and multi sensor marine scenes simulator
Contacts

- Website (Fr)
  - http://www.alyotech.fr/ist_intro

- Videos
  - http://www.youtube.com/watch?v=sf6EVn2Zgk4 (electro-optics)
  - http://www.youtube.com/watch?v=yEPBf6VJC2U (EM SeaClutter)

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