OceanSim: A GPU-Accelerated Underwater Robot Perception Simulation Framework

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Abstract & Background

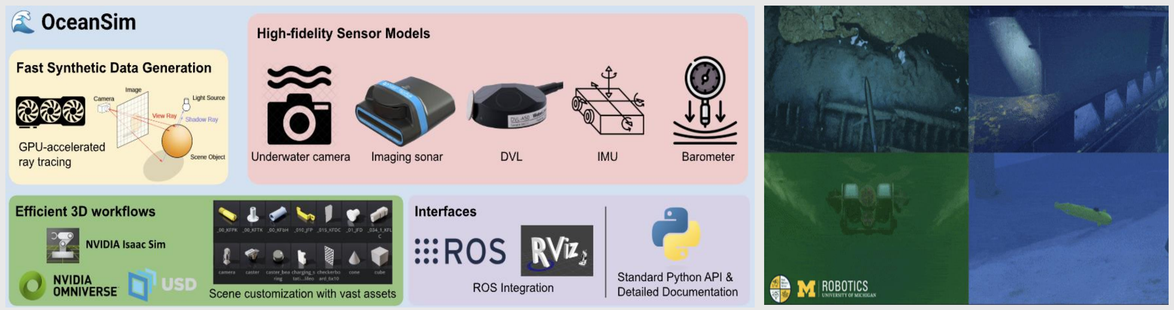

Figure 1. OceanSim is a high-performance simulator built for GPU-accelerated synthetic data generation with high-fidelity sensor models.

This project introduces a real-time, physics-informed side-scan sonar sensor into *OceanSim*, an underwater robotics simulator developed by the FRoG Lab at the University of Michigan. Built on NVIDIA Isaac Sim, OceanSim provides a high-fidelity environment for testing autonomous systems without the cost and risk of field deployment.

Introduction

- Underwater field testing is expensive, risky, and complex, limiting rapid development of autonomous systems.
- Side-scan sonar (SSS) is critical for tasks like seafloor mapping but is rarely available in robotics simulators.
- **Goal:** Develop and integrate a physics-informed side-scan sonar sensor into OceanSim to enable realistic simulation of underwater autonomy.

Methodology

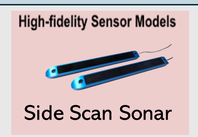

Figure 2. Adding SSS to high-fidelity sensor models

- Ray Tracing & Binning
  - Cast rays to collect data
  - Bin intensity into 1D strips
- Compute & Normalize Intensity

$$I_{sonar} = A_r \left(-\frac{\vec{v}_{in}}{|\vec{v}_{in}|} \cdot \frac{\vec{v}_n}{|\vec{v}_n|} \right) e^{-\alpha d}$$

v_{in}: incident ray vector, v_n: queried normal vector, α: attenuation coefficient, d: distance to the query point, A_r: acoustic reflectance

- Visualization
  - Warp kernel to stack rows & create scrolling display

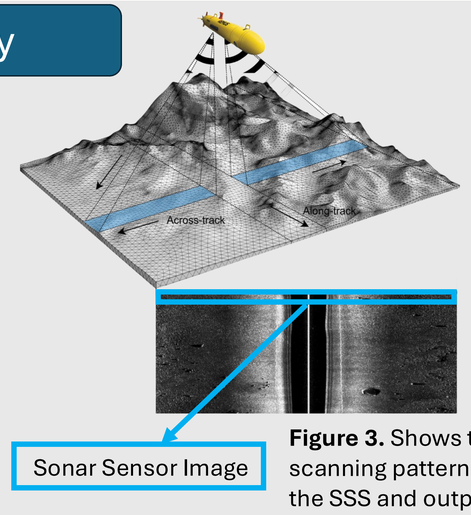

Figure 3. Shows the scanning pattern of the SSS and output.

Results

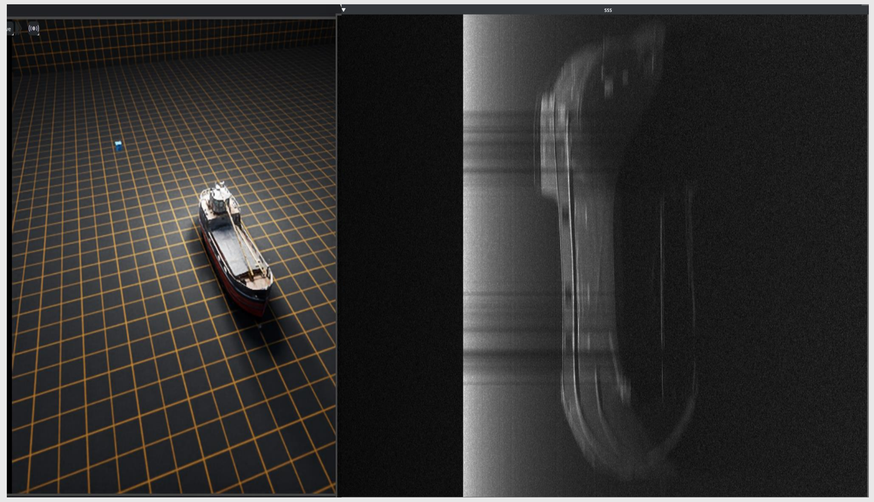

Figure 4. IsaacSim environment featuring the robot and shipwreck and displaying the real-time scan's waterfall output.

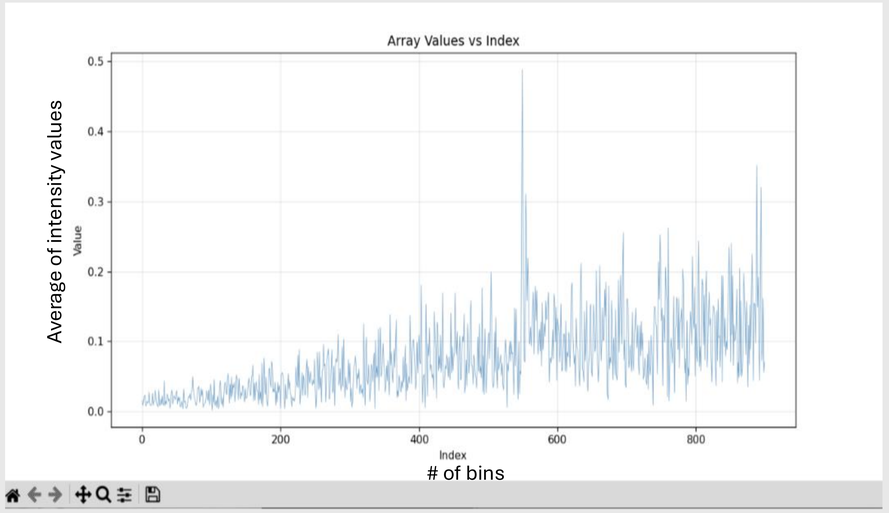

Figure 5. Average of intensity values vs. # of bins to illustrate the brightness of the output, meaning which bins the intensity values are falling into.

Frame rate of approximately 20 FPS, optimized for ray cast count and resolution to balance performance and visual sharpness.

References

[1] Le Hoang, Thanh & Phung, Son & Chapple, Philip & Bouzerdoum, Abdesselam & Ritz, Christian & Tran, Le Chung. (2020). Deep Gabor Neural Network for Automatic Detection of Mine-Like Objects in Sonar Imagery. IEEE Access. PP. 1-1. https://ieeexplore.ieee.org/document/9095329

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[3] Nvidia, "Nvidia omniverse, Nvidia Isaac Sim, Nvidia Warp Documentation" [Online]. https://docs.isaacsim.omniverse.nvidia.com/latest/index.html, https://nvidia.github.io/warp/