Project Page

A Monte Carlo Rendering Framework for Simulating Optical Heterodyne Detection

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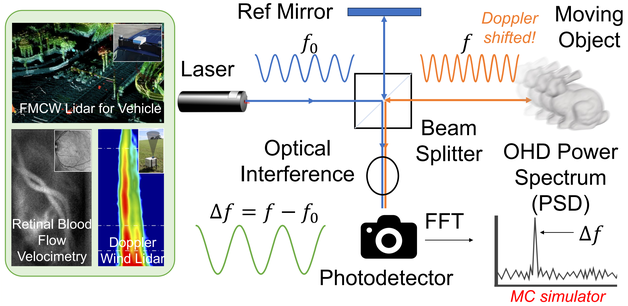
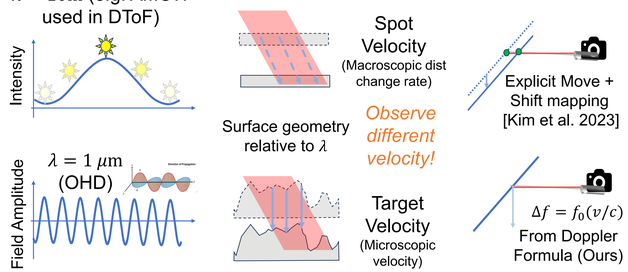
1. Optical Heterodyne Detection



A broad range of imaging systems—including FMCW LiDAR, blood flow velocimetry, and wind Doppler lidar—can be understood within the unified framework of optical heterodyne detection (OHD). We developed a scalable Monte Carlo (MC) simulator that accurately models multipath effect in complex OHD scenarios. The key idea is to express the OHD measurement as a path integral, enabling the use of existing physically based light transport techniques.

2. Field (OHD) vs Intensity (DToF) Doppler



3. Proposed Monte Carlo Simulation

(1) OHD Path Integral

$$S_{\text{AC}}(\omega) = \eta_{\text{h}} \int_{\mathcal{P}} f(\bar{\mathbf{x}})\delta\big(\omega - \omega(\bar{\mathbf{x}})\big)\,\mathrm{d}\mu(\bar{\mathbf{x}})$$

$\omega(\bar{\mathbf{x}})$ is calculated from path length, velocity

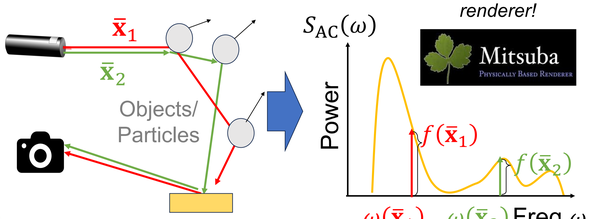
OHD Power Spectrum | Heterodyne efficiency (constant) | Path Domain | radiometric path throughput | path frequency

Transient Path Integral [Jarabo et al. 2014]

$$I(t) = \int_{\mathcal{P}} f(\bar{\mathbf{x}})\delta\big(t - t(\bar{\mathbf{x}})\big)\,\mathrm{d}\mu(\bar{\mathbf{x}})$$

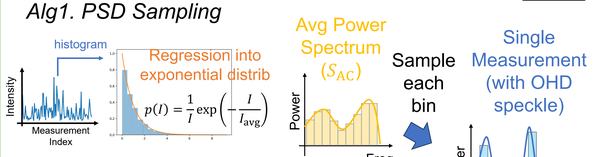
$t(\bar{\mathbf{x}})$ is calculated from path length

(2) OHD Monte Carlo Simulation

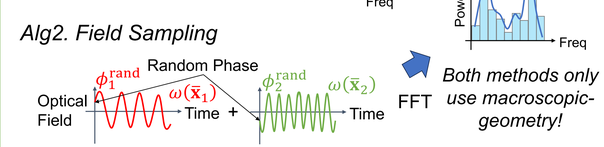


4. OHD Speckle Simulation

Alg1. PSD Sampling

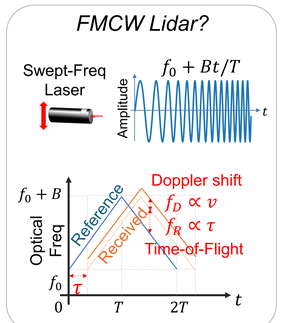


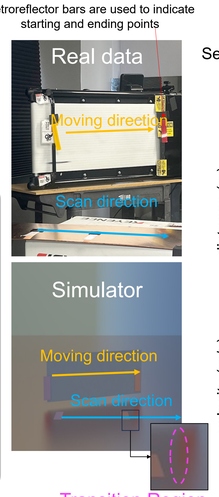
Alg2. Field Sampling

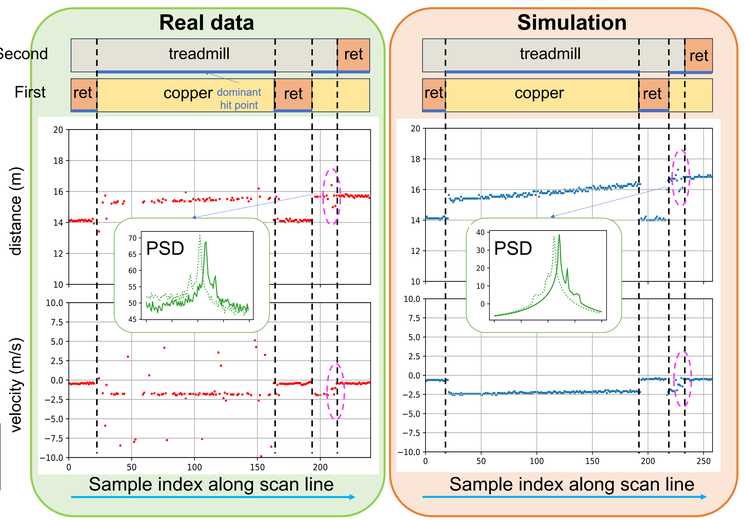


5. Applications

(1) FMCW Lidar on a Glossy Surface

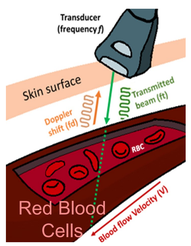


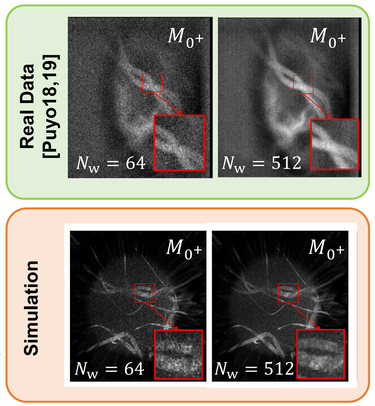




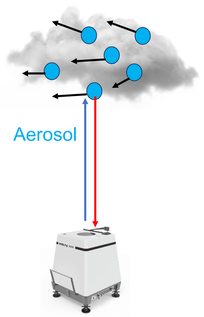
(2) Laser Doppler Velocimetry

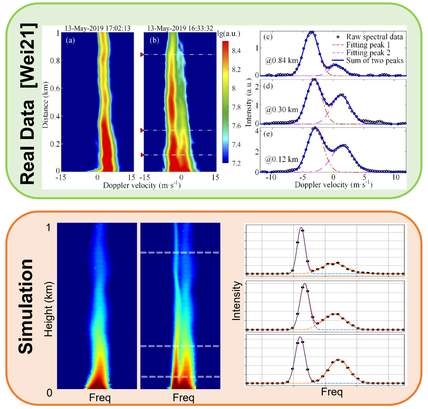
N_{w} : number of FFT windows





(3) Coherent Wind Doppler Lidar





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[3] Felix Heide, Wolfgang Heidrich, Matthias Hullin, and Gordon Wetzstein. 2015. Doppler Time-of-Flight Imaging. ACM Transactions on Graphics (Proceedings of SIGGRAPH) 34, 4 (2015).
[4] Juhyeon Kim, Wojciech Jarosz, Ioannis Gkioulekas, and Adithya Pediredla. 2023. Doppler Time-of-Flight Rendering. ACM Transactions on Graphics (TOG) 42, 6 (2023), 1–18.
[5] Adrian Jarabo, Julio Marco, Adolfo Munoz, Raul Buisan, Wojciech Jarosz, and Diego Gutierrez. 2014. A Framework for Transient Rendering. ACM Transactions on Graphics (Proceedings of SIGGRAPH Asia) 33, 6 (Nov. 2014), 177:1–177:10.
[6] DH Dolan. 2009. What does “velocity” interferometry really measure?. In AIP Conference Proceedings, Vol. 1195. American Institute of Physics, 589–594

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