Towards Zero Domain Gap: A Comprehensive Study of Realistic LiDAR Simulation for Autonomy Testing

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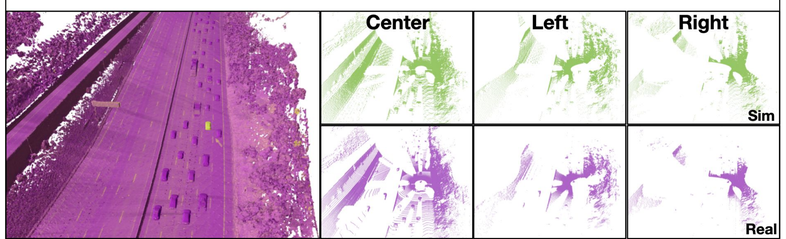
https://waabi.ai/LiDAR-DG/

Motivation: Realistic End-to-End Simulation

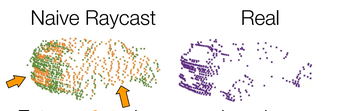
- **Simulation** is critical for scalable self-driving development
- **End-to-end** analysis is necessary, but needs **sensor input**
- Sensor simulation **realism** is challenging to measure
- Main contributions:
  1. novel methodology for evaluating a simulator's domain gap
  2. analysis of what is relevant for realistic LiDAR simulation



(Left) Example reconstructed digital twin used in our analyses.
(Right) Simulated and Real LiDARs.

LiDAR Simulation Components

(A) Pulse Effects

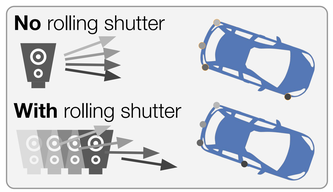


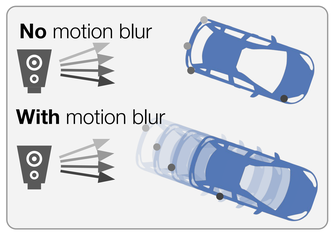
Extra **points** increase domain gap.

Secondary echoes around object boundaries need to be modelled.

Ghost reflections may also impact the autonomy system.

(B) Temporal Effects





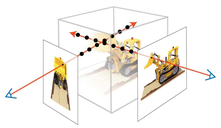
(C) Asset Fidelity

CAD Models

vs.

LiDAR Aggregation

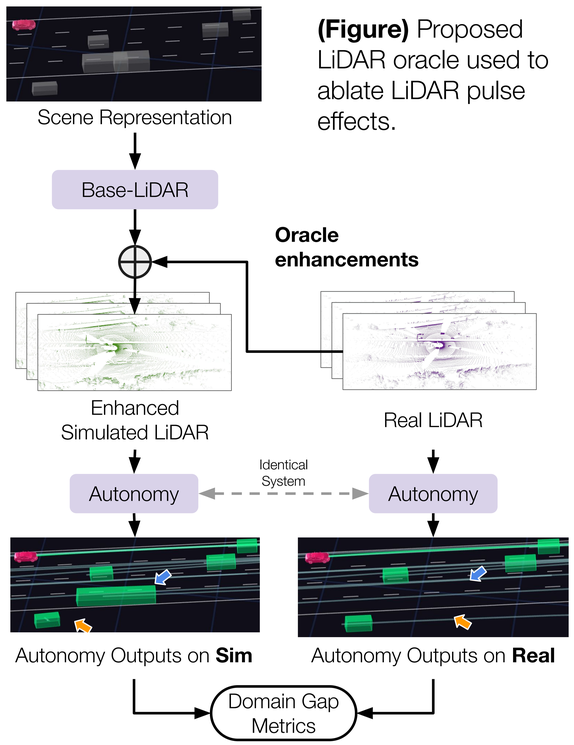
vs.



Neural Rendering

Analysis Methodology

- **Paired setting:** real data + re-simulated data
- **(A) Pulse effects:** Selectively transfer real LiDAR effects (e.g. dropped rays) using **oracles**
- **(B) Temporal effects:** Ablated from the base raycasting engine
- **(C) Asset fidelity:** Also ablated from the engine.



(Figure) Proposed LiDAR oracle used to ablate LiDAR pulse effects.

Results: LiDAR Phenomena

#	DropP	AddE	AddP	ModP	Prediction minADE ↓	Planning PD@5s ↓
1					1.74	3.22
2	✓				1.87	3.30
3		✓			1.58	2.71
4			✓		1.43	3.21
5		✓	✓		1.35	2.50
6				[0, 200]	0.98	1.80
7	✓		✓		1.46	3.22
8	✓			[0, 200]	**0.42**	**0.92**
9			✓	[0, 200]	0.93	1.69
10		✓	✓	[0, 200]	0.93	1.69
oracle	✓	✓	✓	✓	0.00	0.00

Prediction minADE = min absolute displacement error
Planning PD = plan divergence, L2 error between output waypoints

- Four **oracles**
  - **DropP** drops extra points
  - **AddE** adds secondary echoes
  - **AddP** adds all missing points
  - **ModP** adjusts existing points
- Key results
  - Dropping points alone isn't helpful
  - Modeling dropped points should be coupled with better geometry
  - Multi-echoes are important to model

Summary & Outlook

(A) Pulse Phenomena

- Secondary returns should not be ignored
- Future LiDAR rendering approaches need to model unreturned rays
- Material modeling should be coupled with better geometry for best results

(B) Temporal Effects

- Motion blur more important than rolling shutter
- Rolling shutter less important as simulator output is always compensated, and autonomy expects motion-compensated input

(C) Asset Fidelity

- Off-the-shelf + reconstructed assets is best
- Off-road background is surprisingly important for realism