

An Open-Source LiDAR and Monocular Off-Road Autonomous Navigation Stack

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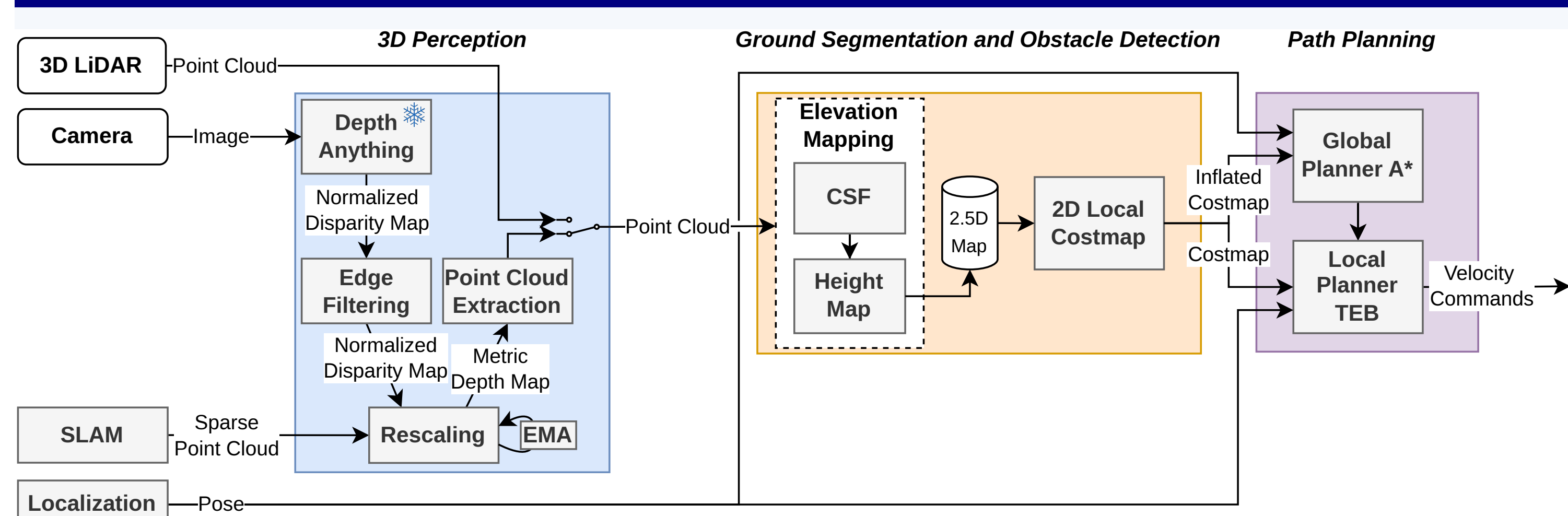
Motivation

- ▶ Off-road autonomous navigation requires reliable 3D perception under challenging terrain, vegetation, and lighting conditions.
- ▶ **LiDAR** provides accurate geometry but is **costly, power-hungry** ($\sim 20\text{ W}$ vs. $\sim 2\text{ W}$ for cameras), and easily detectable in the context of defense.
- ▶ **Stereo cams** struggle with low-texture regions, glare, and limited depth range.
- ▶ **Monocular depth estimation** via foundation models offers a lightweight alternative, but integration into off-road navigation stacks remains **unexplored**.

Contributions

1. A **ready-to-use open-source stack** for off-road reactive navigation
2. Integration of **monocular depth estimation** for 3D perception,
3. **Extensive experiments** on our navigation stack on real and simulated environments

Navigation Stack

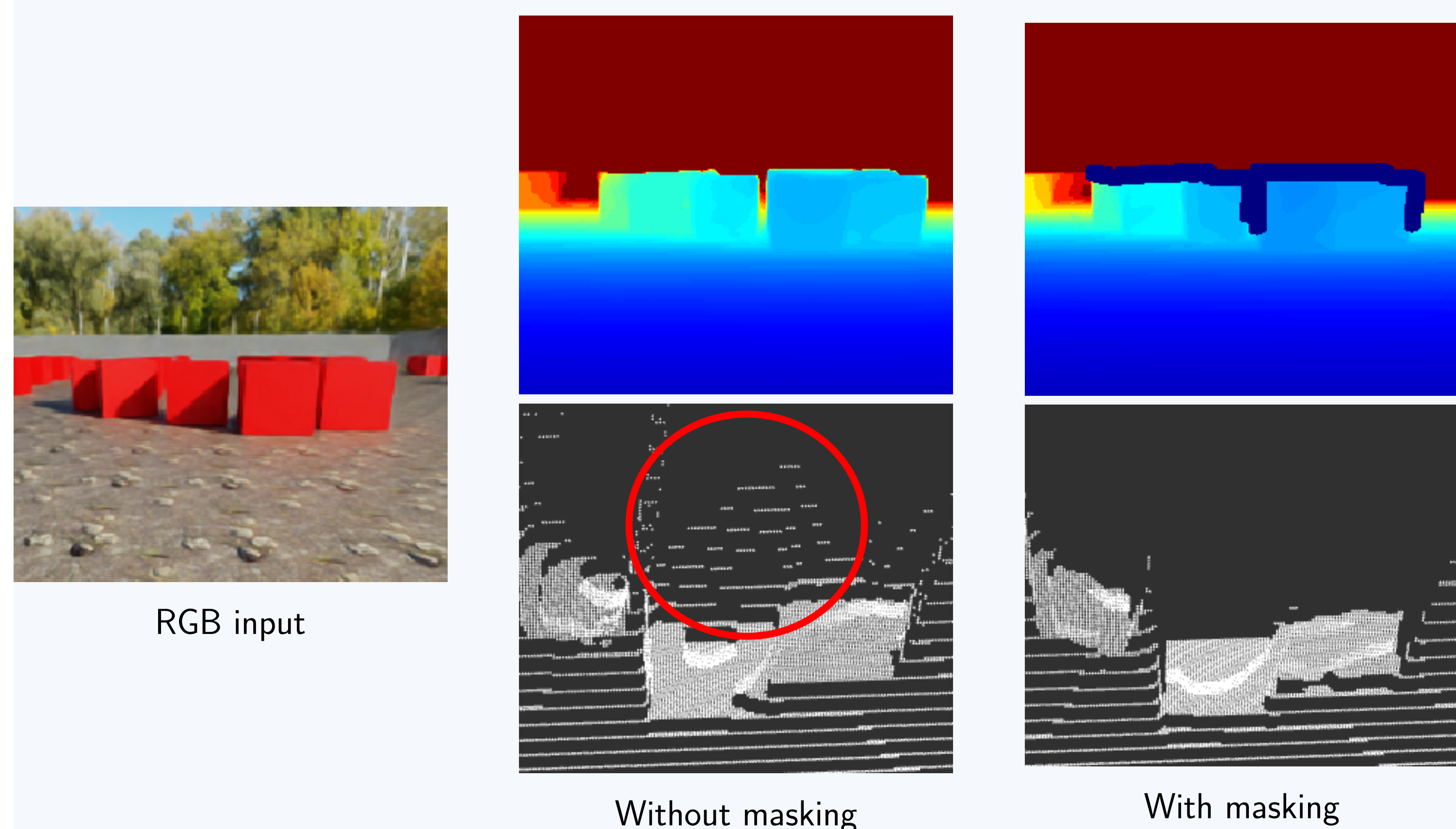


1. **3D Perception**: LiDAR point cloud or monocular depth (Depth Anything V2) rescaled with sparse VINS-Mono measurements
2. **Ground Segmentation**: Cloth Simulation Filter (CSF) $\rightarrow$ 2.5D elevation map $\rightarrow$ binary costmap
3. **Path Planning**: A* global planner + TEB local planner $\rightarrow$ velocity commands

Monocular Depth: Edge Masking & Temporal Smoothing

Edge Masking:

- ▶ Blurry depth borders $\rightarrow$ **phantom obstacles** blocking the robot
- ▶ Sobel filter on disparity map detects depth discontinuity edges
- ▶ Pixels within 5 px of edges are masked out



Temporal Smoothing:

- ▶ Exponential moving average on scale/shift $\hat{s}$ to mitigate SLAM instabilities:
$$\hat{s}_t = \alpha \hat{s}_{t-1} + (1 - \alpha) \hat{s}_t, \quad \alpha = 0.8$$

Experimental Setup



Real-world platform

Simulated platform

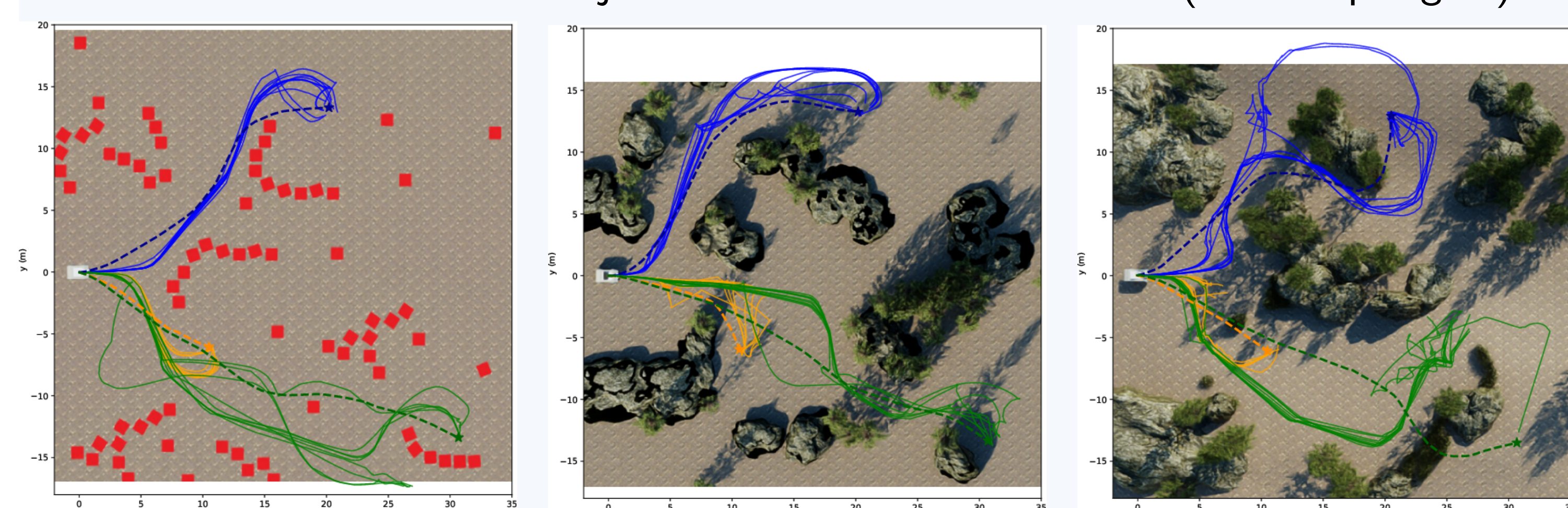
Hardware: Barakuda robot (Shark Robotics) with Ouster Dome 128-ch LiDAR, ZED2i camera, SBG IMU + dual GNSS, Jetson AGX Orin 64 GB.

Simulation: 3 Isaac Sim environments (easy / medium / hard) with goals at 10, 20, 30 m. 10 runs per goal for all 3 environments (**90 runs** per config).

Real-world: 3 scenarios (easy / medium / hard) and 3 runs each (**9 runs** per config).

Results

Simulation – Mono-VINS trajectories across 3 environments (10 runs per goal):

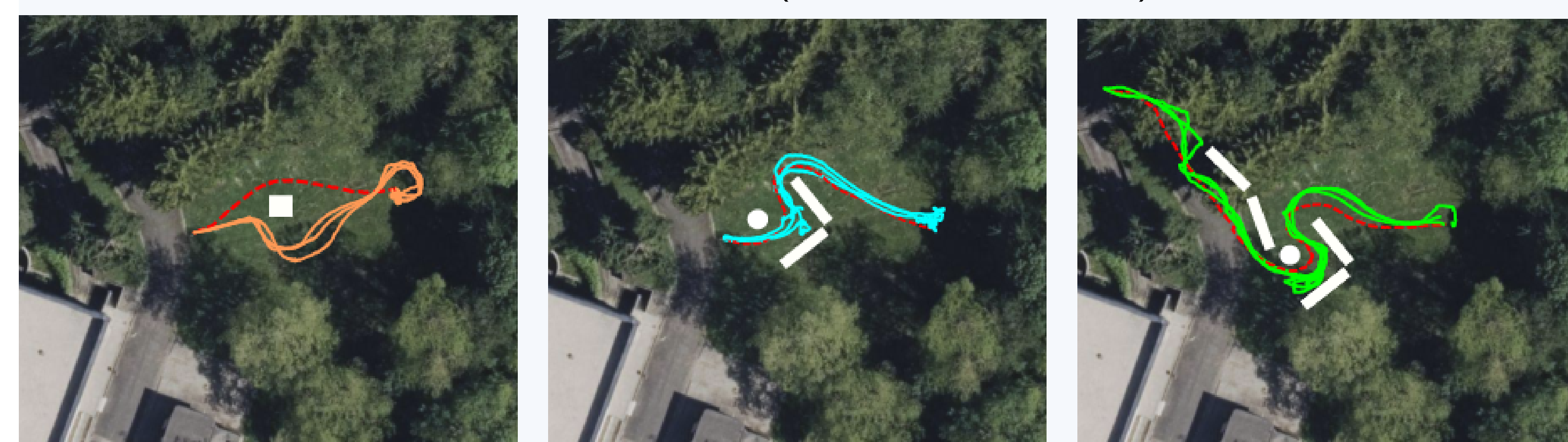


Easy Medium Hard

	10 m goal			20 m goal			30 m goal		
	SR	SPL	DR	SR	SPL	DR	SR	SPL	DR
LiDAR (sim-tuned)	0.80	0.58	0.92	0.63	0.53	0.76	0.73	0.57	0.84
LiDAR (real-params)	0.70	0.47	0.87	0.57	0.44	0.74	0.67	0.51	0.80
Mono-VINS (STCD)	0.77	0.57	0.89	0.97	0.75	0.98	0.43	0.35	0.73

- ▶ Success Rate (SR), Success weighted by Path Length (SPL), Distance Ratio (DR).
- ▶ Mono-VINS: **97% SR at 20 m** (vs. 63% LiDAR sim-tuned)
- ▶ Performance drops at 30 m in hard env. due to dense high grass

Real-World – Mono-VINS trajectories (3 runs per scenario):



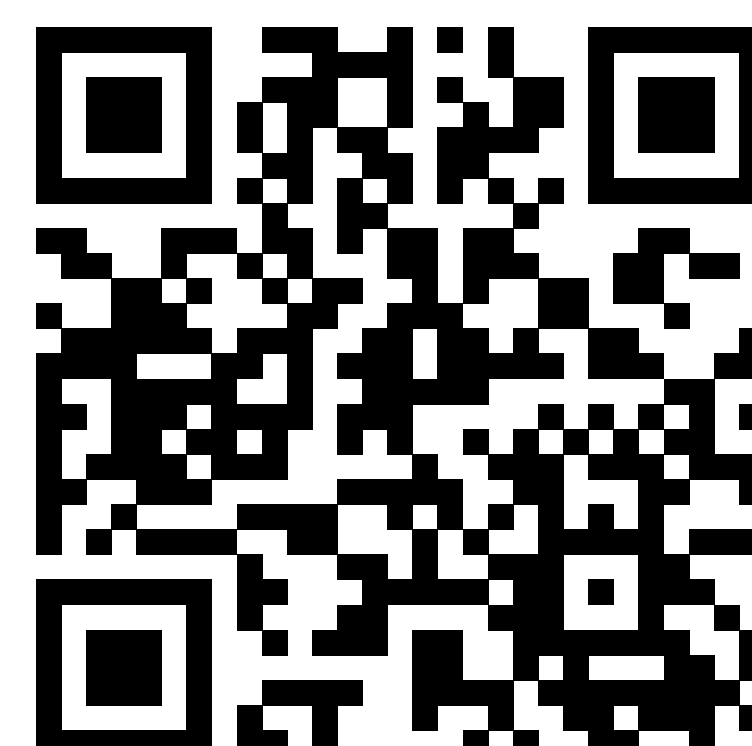
Easy Medium Hard

	Easy			Medium			Hard			Average		
	SR	SPL	DR	SR	SPL	DR	SR	SPL	DR	SR	SPL	DR
LiDAR	1.0	0.73	1.0	1.0	0.68	1.0	1.0	0.67	1.0	1.0	0.69	1.0
Mono-VINS	1.0	0.51	1.0	1.0	0.63	1.0	1.0	0.63	1.0	1.0	0.59	1.0

- ▶ **100% success rate** for both LiDAR and monocular in all scenarios
- ▶ Monocular SPL slightly lower (0.59 vs. 0.69) due to longer processing chain

Conclusion & Future Work

- ▶ Foundation-model-based monocular depth can be a **viable, low-cost LiDAR alternative** for off-road navigation
- ▶ **Open-source** navigation stack + simulation environments released for reproducible benchmarking
- ▶ **Future work**: traversability classification for high grass, negative obstacle handling, ROS2 migration



Project page – arXiv and GitHub