

Enabling DNN Uncertainty Onboard a Test Platform for Resource-Constrained Robots

S1.16

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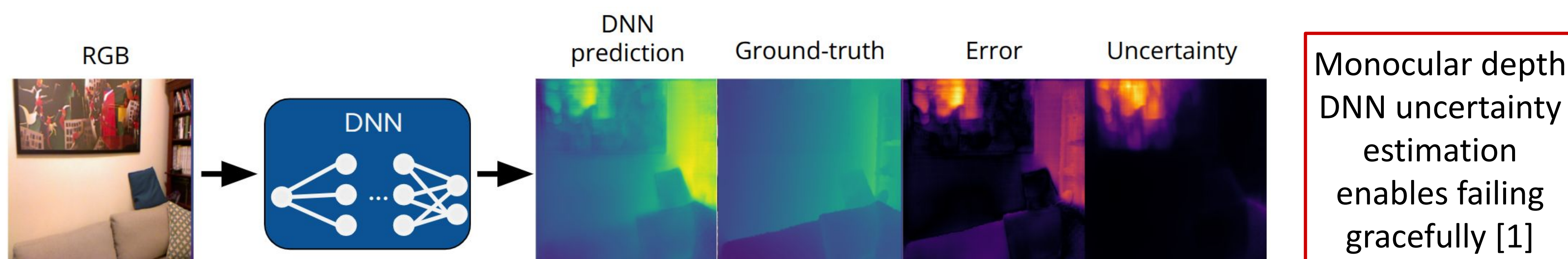
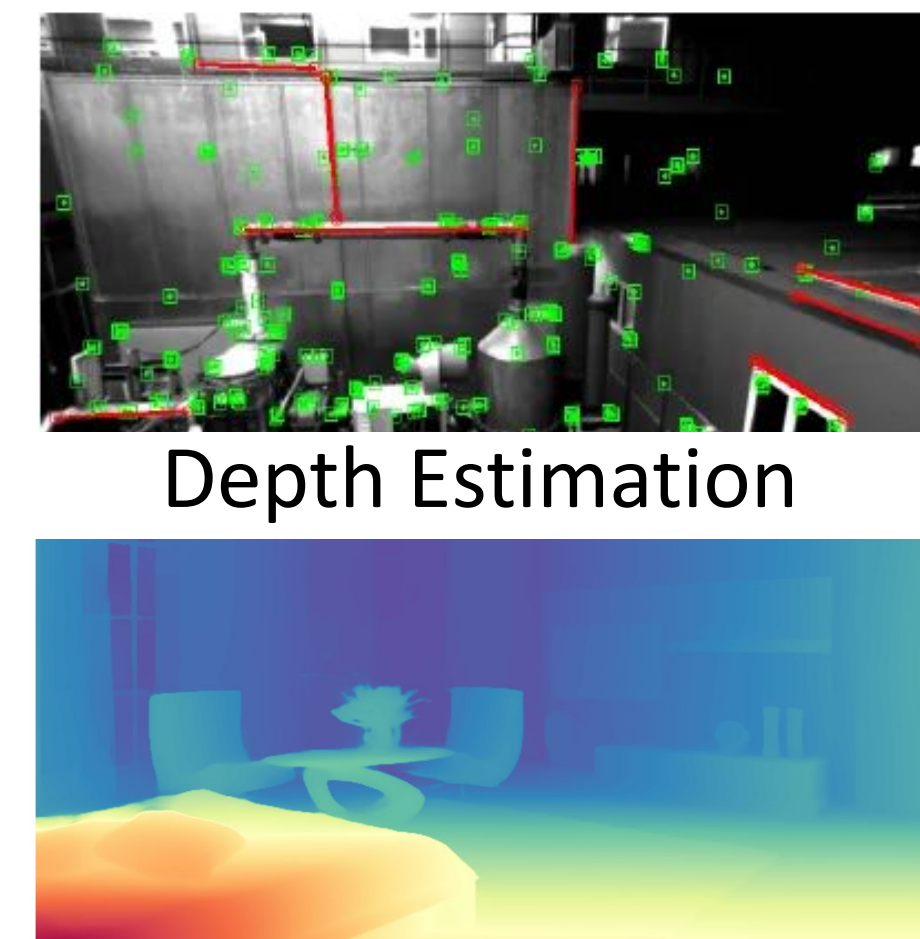
MARC2026:
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Motivation: Test Platform for Efficient Perception

Visual Perception on Small Robots:

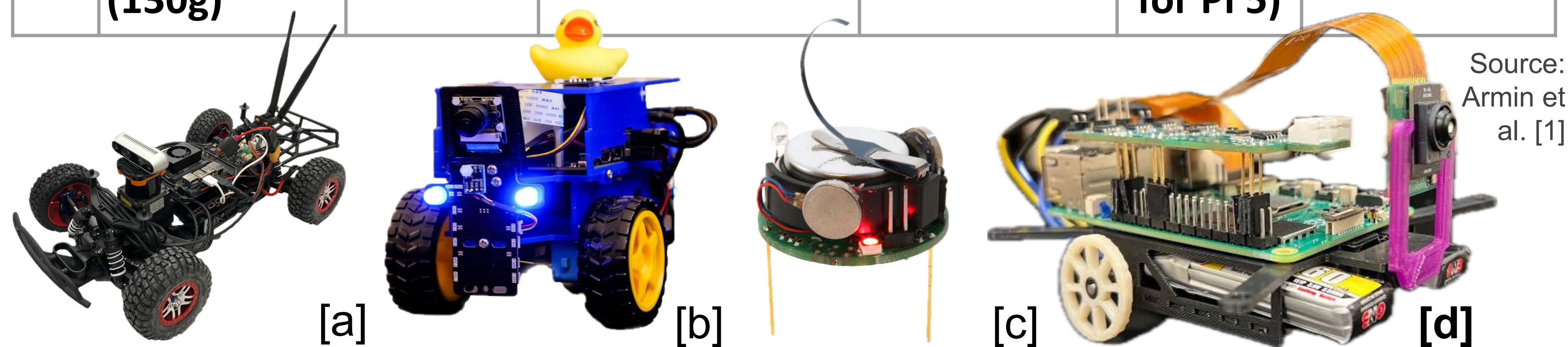
1. **Enables sensing of its environment** to answer questions like:
(1) Where am I? (2) What is around me?
2. Can be the most energy intensive autonomy task → **reduces mission duration on a battery**

Simultaneous Localization & Mapping (SLAM)



Uncertainty from Motion (UfM) algorithm reduces compute energy for DNN uncertainty estimation, but has only been tested on limited-scope datasets

Platform	Onboard Perception Capability			Power Usage	Real-time Power Monitoring
	Sensor	Compute	Algorithm		
[a] F1TENTH (4kg)	LiDAR + RGBD	NVIDIA Jetson TX2	SLAM + DNN	High 30W	✗
[b] Duckietown (1.8kg)	RGB Camera	NVIDIA Jetson Nano	SLAM + DNN	Med 15W	✗
[c] Kilogrid (16g)	IR Sensor	ATmega 328 microcontroller	Path Following	Very Low 0.1W	✗
[d] LEAN Minicar V2 (130g)	Sony IMX500	Raspberry Pi 5	DNN	Low 7W (6W for Pi 5)	✓

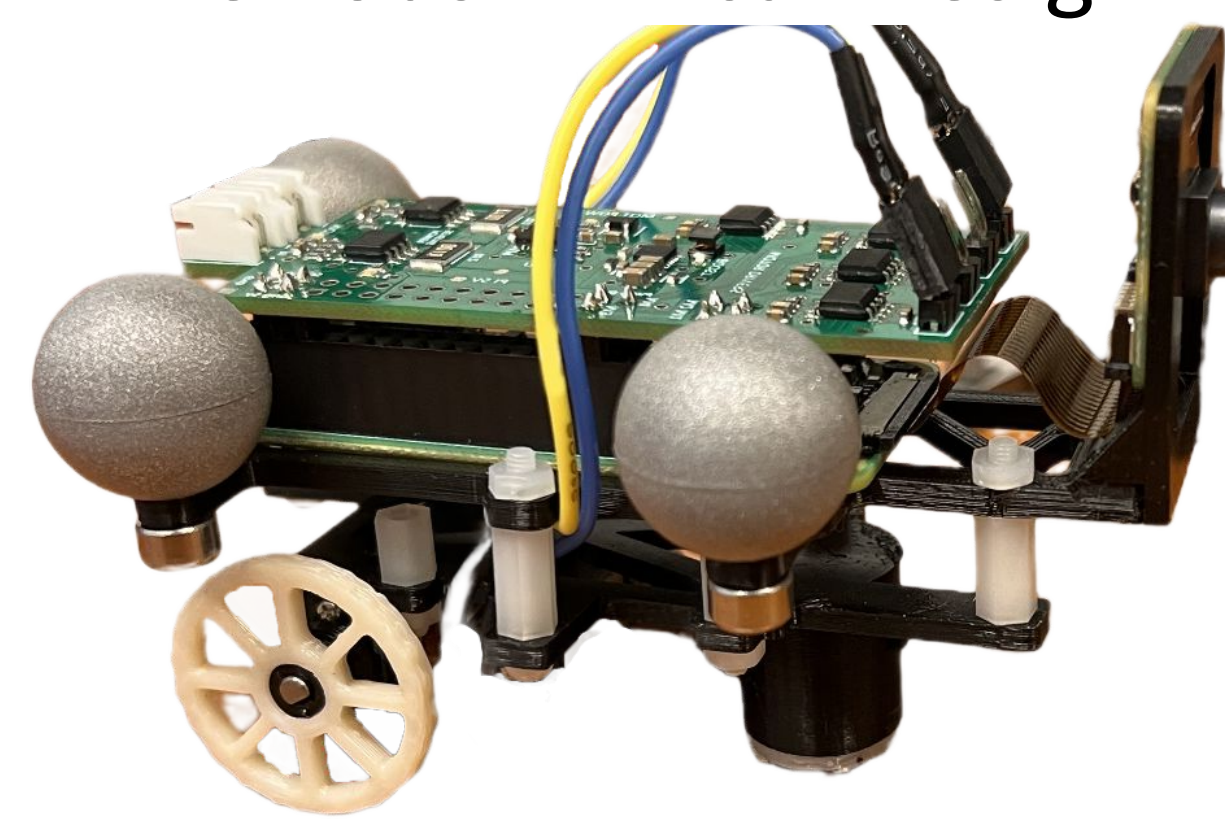


Goal: Demonstrate Uncertainty from Motion on real-world data by running (1) monocular depth estimation and (2) UfM concurrently onboard a small, low-energy test platform

Methodology: Refining LEAN Minicar

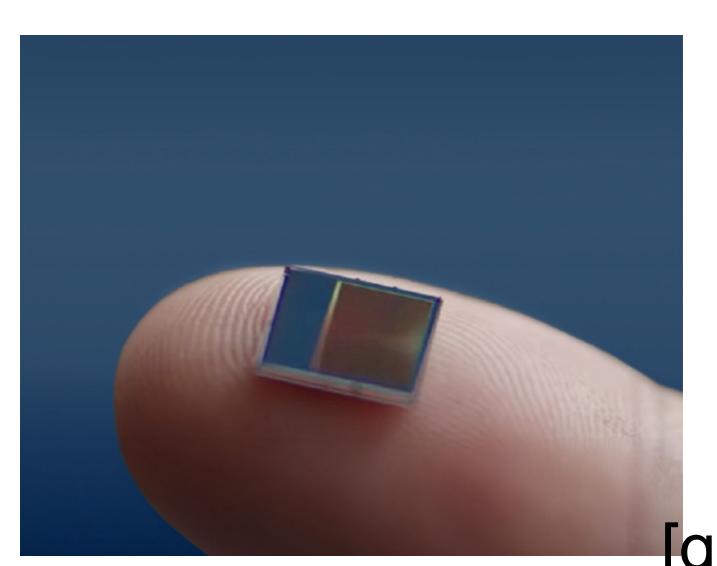
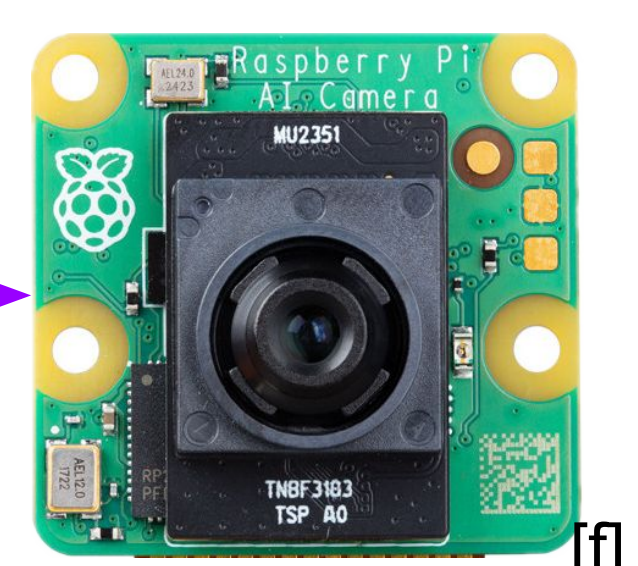
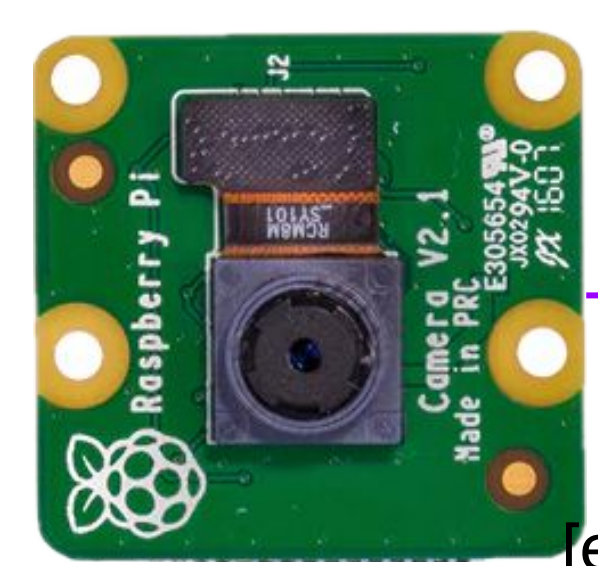
1. Equipped platform with Raspberry Pi 5 and Sony IMX500 (RGB camera + DNN accelerator)
2. Quantized FastDepth [3] DNN model from FP32 → W8A8 to fit IMX500's 8MB limit; 0.2% reduction in accuracy (59.8% → 59.6%)
3. Set up communication architecture via Robot Operating System (ROS) for lightweight communication and flexible integration with motion capture laboratory, offboard SLAM, etc.

Previous Minicar Design



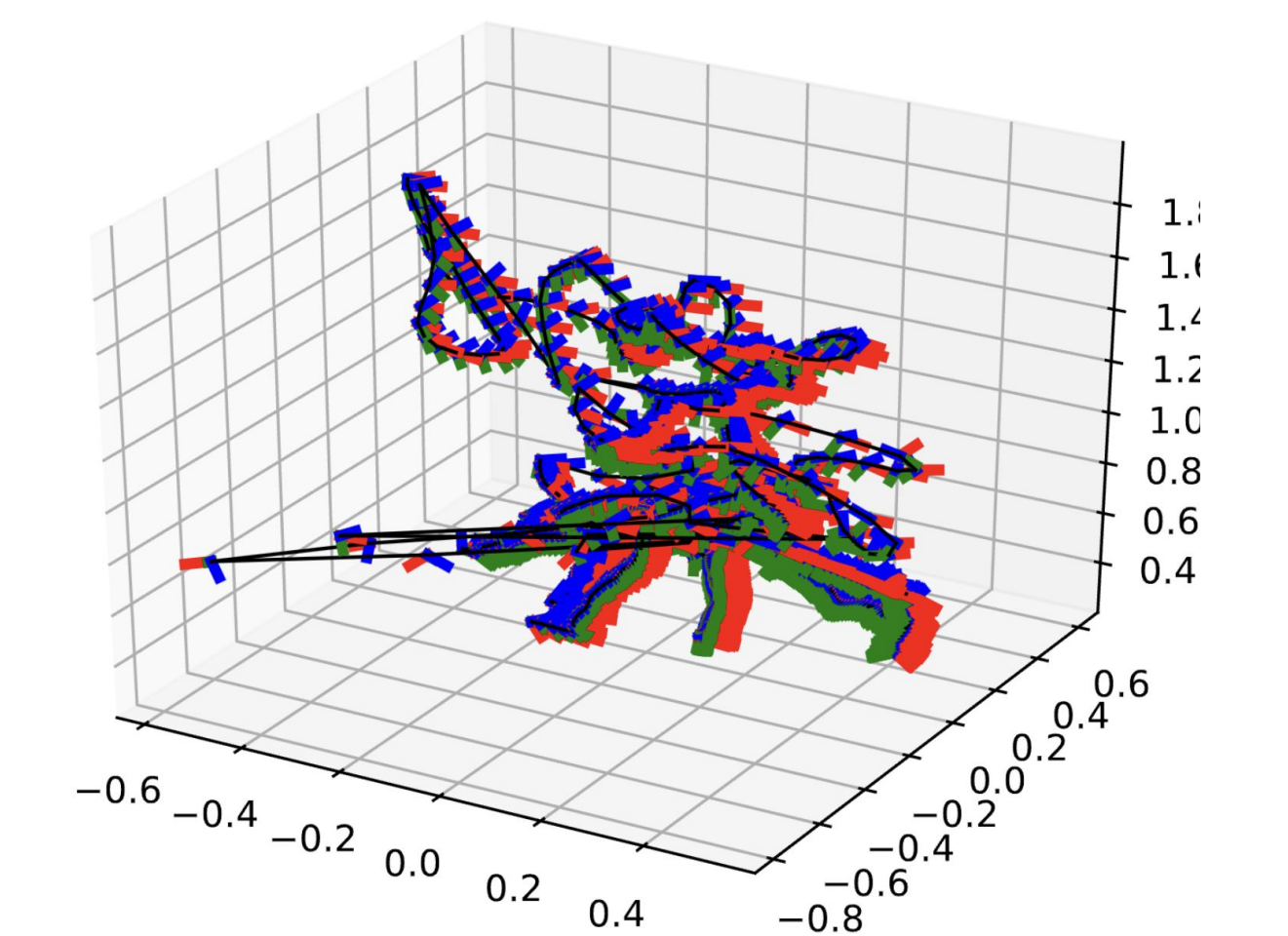
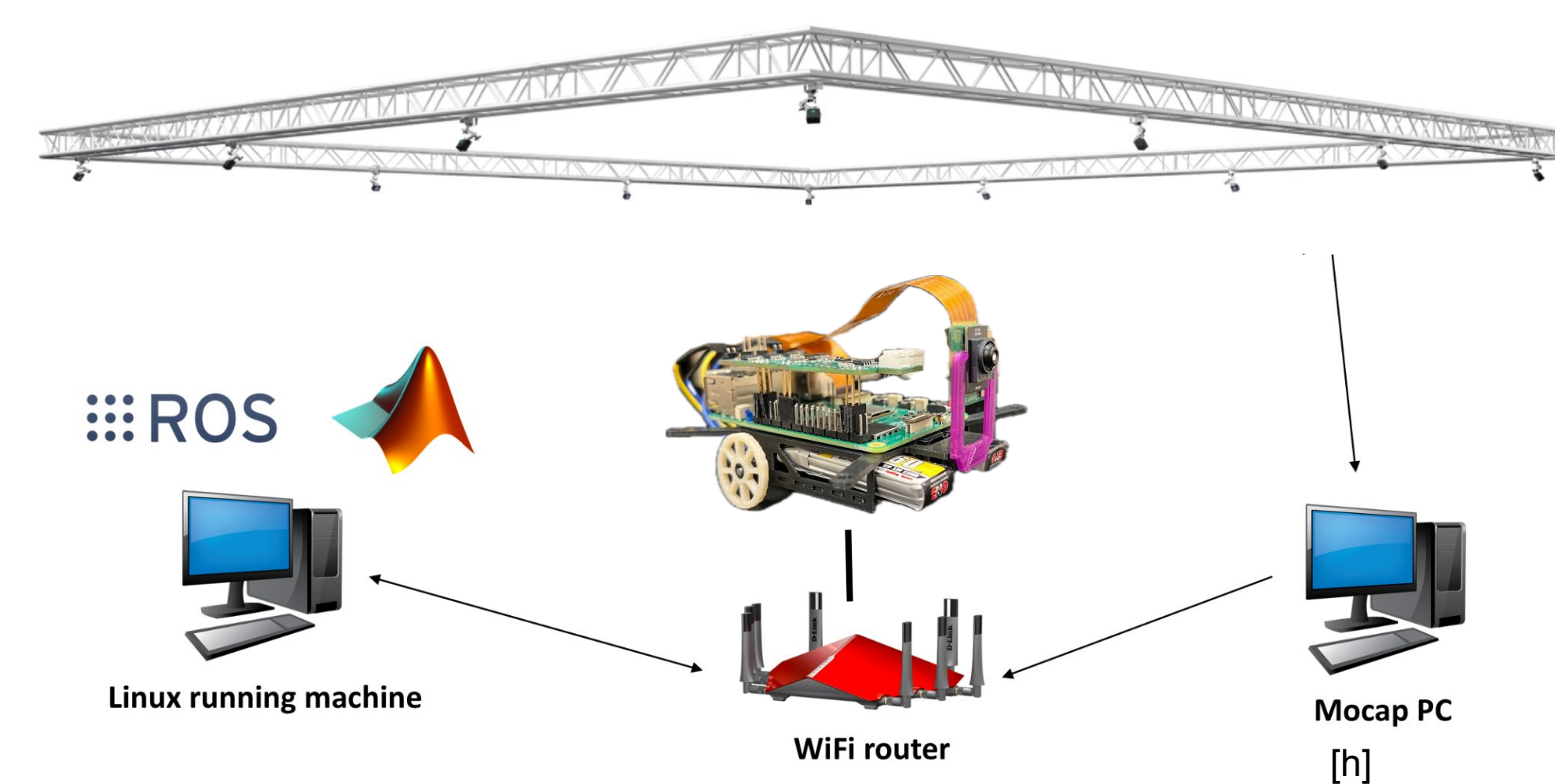
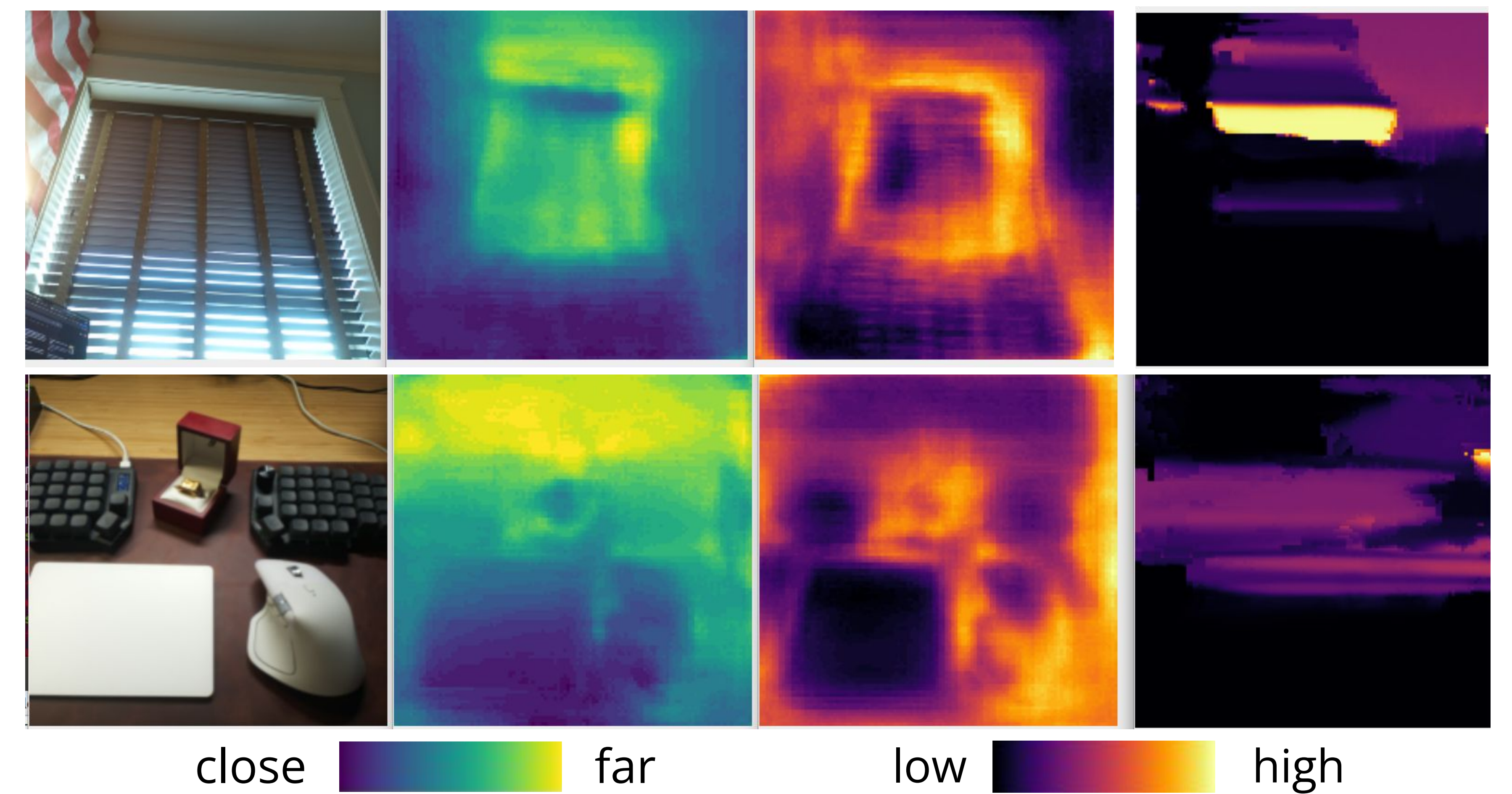
16MB FastDepth 32 Bit Floating Point

4MB FastDepth W8A8



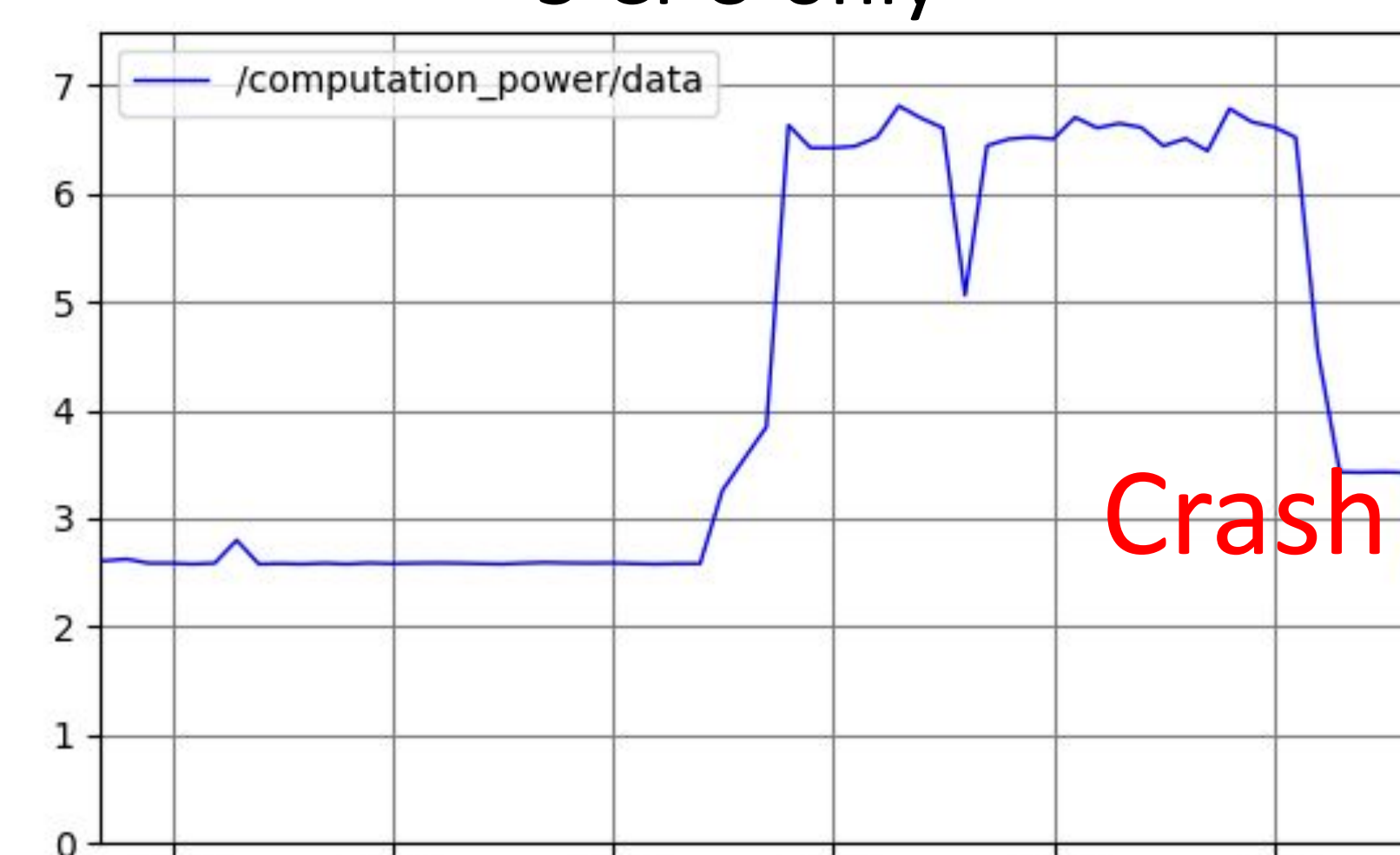
Results: New Perception Capabilities

Camera Onboard LEAN Minicar DNN Depth Data Uncertainty Uncertainty from Motion (UfM)



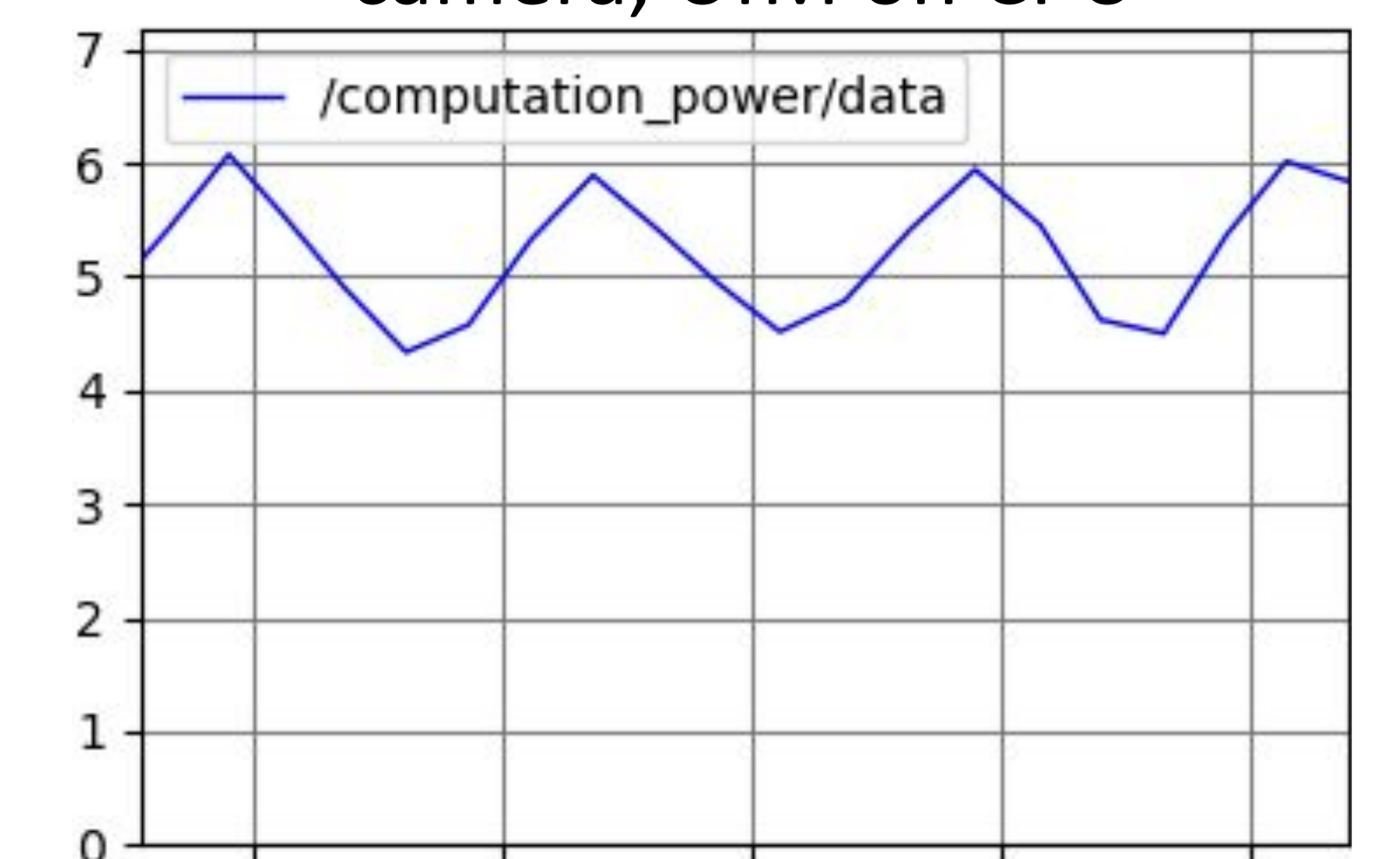
Performance + Energy Analysis: 4.7x Efficiency

Baseline: run DNN on Raspberry Pi 5 CPU only



7FPS → 140ms/depth prediction
60% CPU utilization
Avg power: 6.5 W
0.5 Joules/prediction

Ours: run DNN on Sony AI camera, UfM on CPU



28FPS → 36ms/depth prediction
12% CPU utilization
Avg. power: 5.5 W
0.1 Joules/prediction

Our updated LEAN Minicar runs the monocular depth DNN 4x faster using ~80% less energy and leaves our system with enough CPU resources to run and demonstrate DNN uncertainty estimation (UfM) in the real-world

Key Takeaways and Future Work

- Algorithm development for resource-constrained perception requires a resource-constrained test platform to demonstrate performance in the real-world
- LEAN Minicar supports running DNN depth estimation and uncertainty estimation concurrently by splitting workloads across the CPU and Sony AI Camera
- **Future work:**
 - Test perception algorithms on LEAN Minicar in the motion capture lab and in-the-wild
 - Integrate FPGA-in-the-loop for more flexible and custom hardware accelerators

[1] S. Sudhakar, V. Sze and S. Karaman, "Uncertainty from Motion for DNN Monocular Depth Estimation," 2022 International Conference on Robotics and Automation (ICRA), Philadelphia, PA, USA, 2022, pp. 8673-8679, doi: 10.1109/ICRA46639.2022.9812222.
[2] Mokhtarian, Armin, et al. "A survey on small-scale testbeds for connected and automated vehicles and robot swarms." arXiv preprint arXiv:2408.14199 (2024).
[3] Volk, D., Ma, F., Yang, T. J., Karaman, S., & Sze, V. (2019, May). FastDepth: Fast monocular depth estimation on embedded systems. In 2019 International Conference on Robotics and Automation (ICRA) (pp. 6101-6108). IEEE.
[4] https://f1tenth.readthedocs.io/en/stable/_images/f1tenth_NX.png [5] https://get.duckietown.com/cdn/shop/products/Duckiebot_DB21-J.jpg?v=1742903313 [6] https://robotsguide.com/robots/kilobot
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