

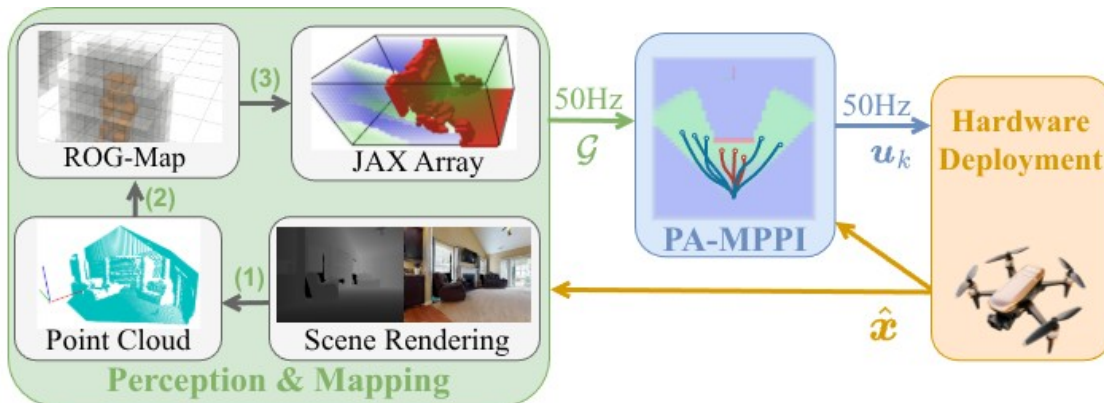
PA-MPPI: Occupancy-Aware MPPI for Safe Quadrotor Navigation

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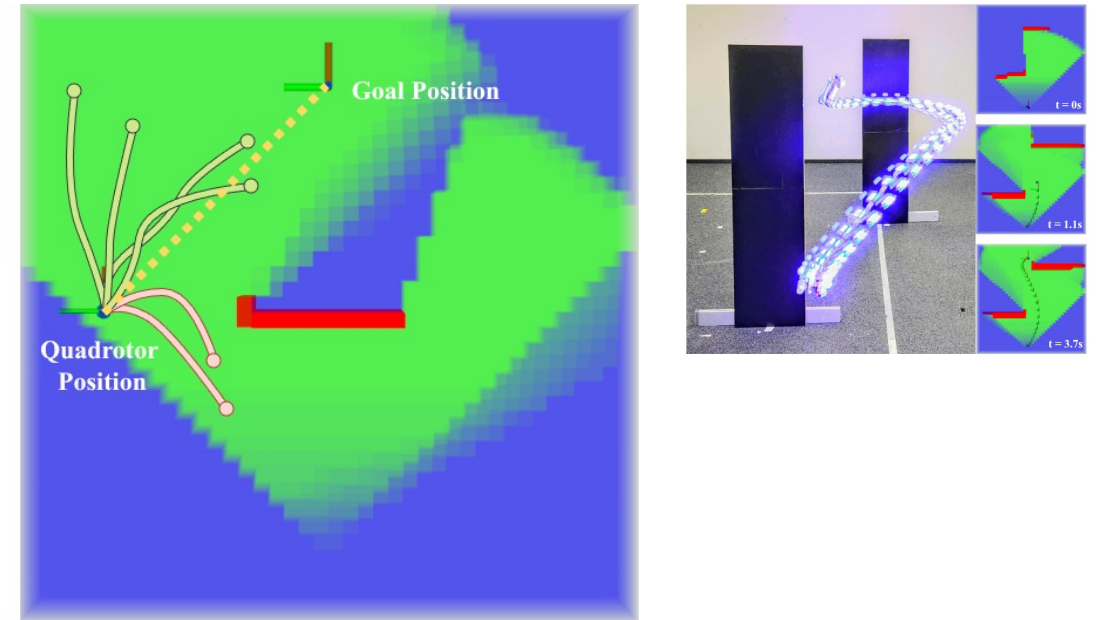
Key Idea

- Embed occupancy reasoning directly into MPPI cost function
- Three-state map: free / occupied / unknown
- Ray-tracing rewards unknown frontiers toward goal
- No external planner or reference trajectory needed

System Architecture



Perception Cost



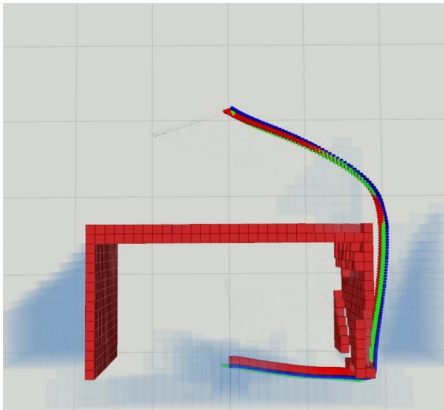
- Ray cast toward goal through occupancy grid
- Unknown voxel hit $\rightarrow$ negative cost (explore!)
- Occupied voxel hit $\rightarrow$ positive penalty (avoid)
- Free line of sight $\rightarrow$ go straight to goal

Results: Matching SUPER with Less Energy, No Per-Scene Tuning

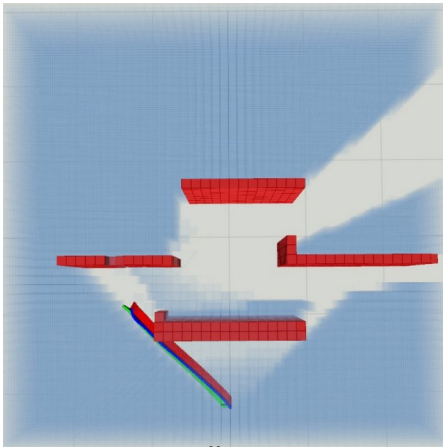
Navigation Performance (hardest config, 100% success for both)

Scene	Method	Time (s)	Avg Vel (m/s)	Energy (J)
C-wall	SUPER	6.00±0.84	1.08±0.03	286.8±42
	PA-MPPI	5.14±0.22	1.14±0.06	249.5±9
4-Wall	SUPER	7.57±0.99	0.72±0.07	364.3±50
	PA-MPPI	5.78±0.23	1.05±0.07	281.7±11

Test Scenes (occupancy maps)



C-wall scene



4-wall scene

Up to 34% less energy

Fixed hyperparameters across all scenes
(SUPER tuned per scene)

50 Hz on laptop GPU

JAX + NVIDIA A1000 (6 GB)
Hardware-in-the-loop validated

Foundation Model Integration

PA-MPPI as safety filter for NoMaD:
grounds collision-prone 2D waypoints in 3D occupancy

Based on: Zhai, Reiter, Scaramuzza. "PA-MPPI: Perception-Aware MPPI for Quadrotor Navigation in Unknown Environments" IEEE RA-L 2026