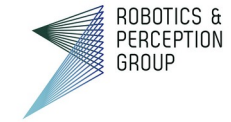


Multi-Fidelity Predictive Control for Unconventional Aerial Robots



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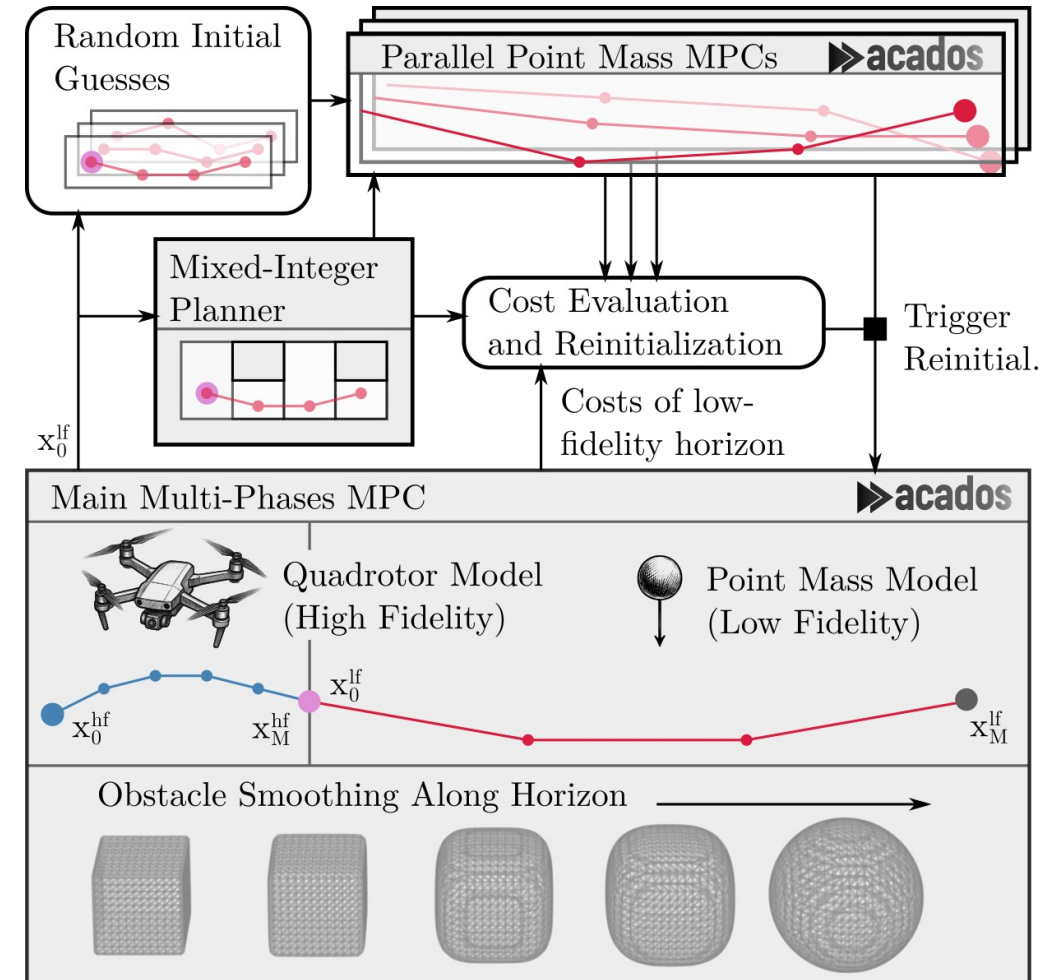
Motivation

- Unconventional morphologies (compliant joints, flexible arms) improve resilience but require complex, expensive models
- High-fidelity MPC across full horizon: computationally infeasible
- Key idea: stack multiple model phases along the MPC horizon
- High fidelity near current state for fast dynamics and constraints, low-fidelity surrogates for long-range planning



Morphy: compliant quadrotor with passive spring-damper joints [Petrís et al., 2024]

Multi-Phase MPC Architecture



Two-phase MPC with parallel solvers and progressive obstacle smoothing [Reiter et al., 2025]

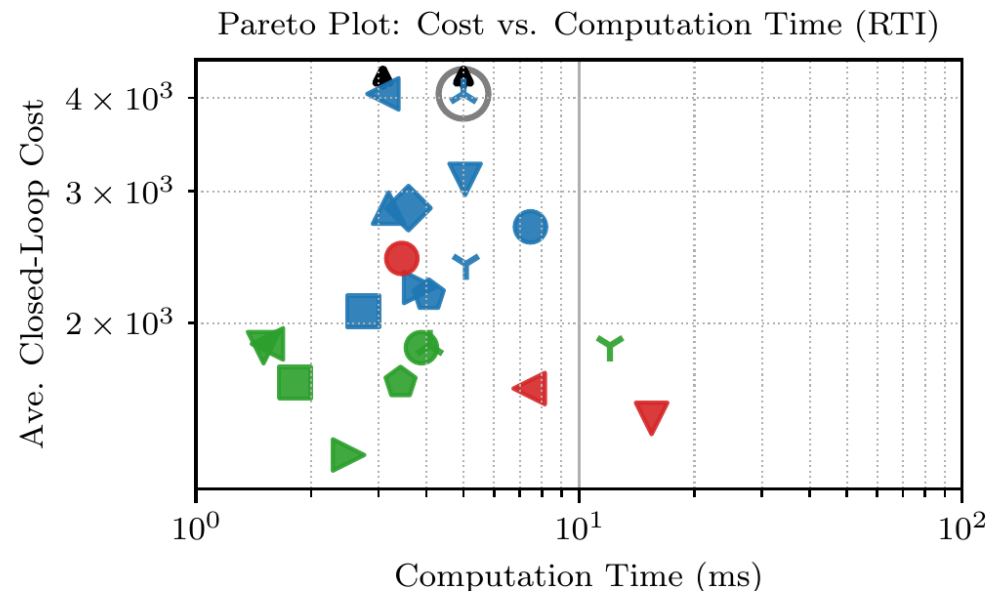
Unified Planning and Control for High-Speed Flight (2 Phases)

Two-phase formulation: 17-state rigid-body model (short horizon) + point-mass surrogate (long horizon)

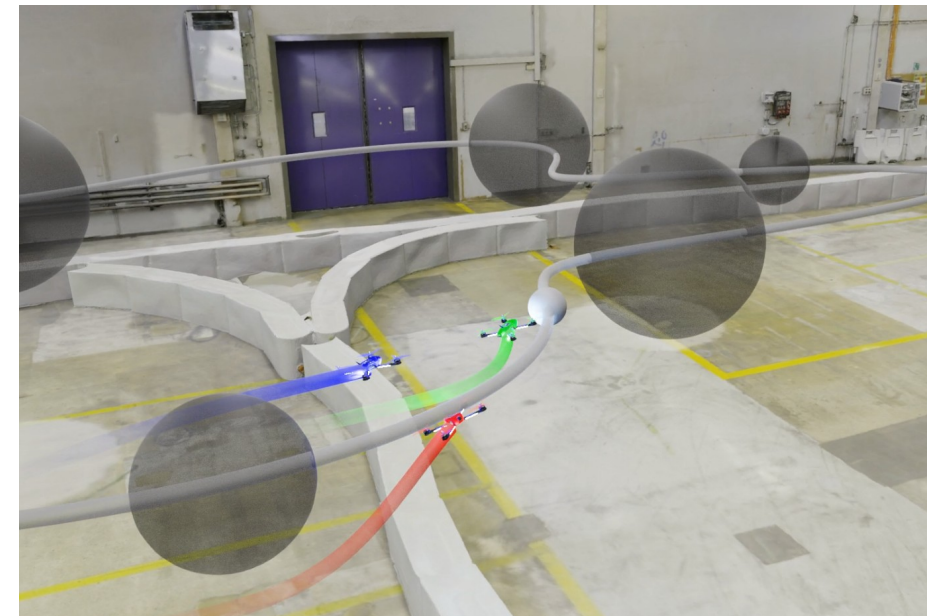


Real-World Experiments

- Multi-phase: 0.83 m mean error (34 obstacles, figure-8 track)
- Standard MPC: 3.33 m — 4× worse under same compute budget
- Hierarchical baseline: 1.83 m — 2.2× worse
- Up to 75% lower closed-loop cost across all tested scenarios



Pareto front: combined multi-phase (green) dominates hierarchical (blue) and standard MPC (red)



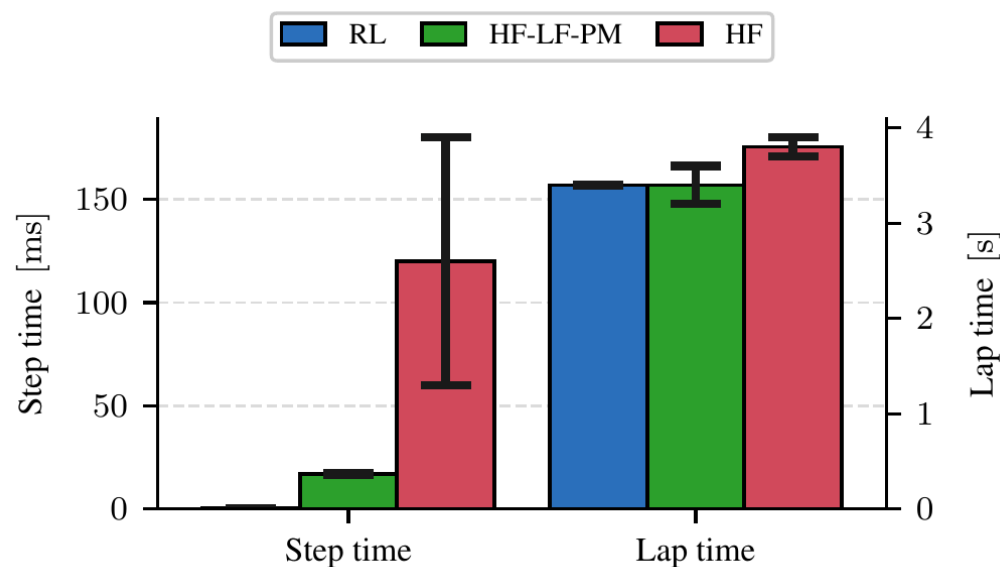
Real-world obstacle-rich tracking with multi-phase MPC [Reiter et al., 2025]

Multi-Phase Contouring Control for a Flexible-Joint Drone (3 Phases)

Three-phase formulation: flexible-joint DAE (short) + rigid-body surrogate (mid) + point-mass surrogate (long horizon)

Computation Time and Lap Performance

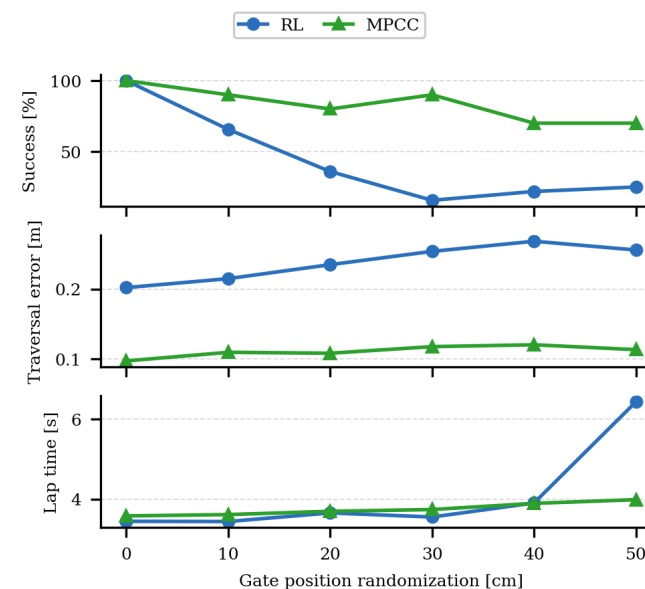
- Step time: 17.0 ± 0.2 ms (3-phase) vs. 120 ± 60 ms (single HF)
- 7× faster — enables real-time control on complex morphology
- Lap time: 3.4 s vs. 3.8 s (single HF) — faster and more stable
- Only multi-phase MPC achieved stable real-time flight



Step time and lap time: RL vs. multi-phase (HF-LF-PM) vs. single high-fidelity [Pettiti et al., 2026]

Robustness Under Domain Randomization

- Multi-phase MPCC: >70% success at 50 cm gate perturbation
- RL drops to ~30% — sensitive to distribution shift
- MPCC: consistently lower traversal error at all randomization levels
- Physics-based fidelity scheduling generalizes better than learned policies



Robustness: MPCC vs. RL under increasing gate randomization [Pettiti et al., 2026]