Robust Optimal Control of High-Performance Aerospace Systems

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Real-Time Optimal Control

Motivation – control of fast dynamical systems:
- Non-linear dynamics
- System subject to disturbances and modeling error
- Operational constraints (e.g., state and control)
- Want to minimize some cost function objective

Objectives – robust optimal control:
- Finite time reachability of goal configuration
- Minimal incurred cost
- Efficient implementation on hardware

Application: UAV Carrier Landing

- Current capability limited to supervised flight in favorable weather and sea conditions
- No explicit guarantees on robustness or performance, especially in adverse conditions
- Our solution: use RMPC with non-linear predictive models for the UAV and ship’s motion

Robust Model Predictive Control (RMPC)

Key Challenges:
- Optimization over closed-loop policies
- Minimize conservatism that plagues robust control
- Fast implementation

Solution approach:
- Recursively solve a receding finite-horizon version of the problem ignoring disturbances
- Implement a portion of the resulting control sequence and an auxiliary feedback law to stay close to the predicted state (invariant set)

Application: Drag-free Spacecraft

- Detection of gravitational waves, geodesy, aeronomy
- Non-linear high-dimensional coupled dynamics
- Stringent precision requirements: $10^{-12}$ ms$^{-2}/\sqrt{Hz}$ within [0.01, 1] Hz
- Strict constraints on control
- Strict hardware limitations

Conclusions

Key result: Robust MPC using contraction theory is an efficient and tractable approach for optimally and safely controlling fast dynamical systems.

Detailed results:
- Preliminary paper on RMPC using Contraction theory [Singh, Pavone, Slotine, CDC ’16, submitted]
- High-fidelity modeling and robust control synthesis for a Drag-free microsatellite using $H_\infty$ – optimization [Singh, D’Amico, Pavone, ISSFD ’15]

Current research directions:
- Investigating more complex state manifolds for dynamical system
- Implementation on quadrotor system
- Merging with state-of-the-art motion planning techniques for online re-planning with multiple robots in a shared environment

Supported by the Stanford Graduate Fellowship