National Aeronautics and Space Administration

Online Model Predictive Control for Under-Actuated Robotic Aerial Platforms

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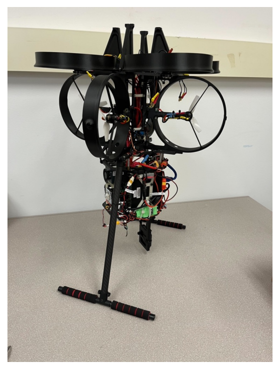
Program: FY22 SURP
Strategic Focus Area: Localization and Mobility

Objectives

The overall objective of this project is to develop and implement optimal control algorithms specifically relevant to under-actuated aerial platforms – including airships, blimps, balloons, and small drones – that can run on resource-constrained hardware (i.e. low bandwidth, power, and memory specifications). Under-actuated systems are inherently harder to control as there are fewer control inputs than degrees-of-freedom in the dynamics. Our goal is to test the algorithms and on a JPL-built zero-pressure autonomous balloon that exhibits many control challenges and may provide a useful platform for long-term aerial exploration in the atmospheres of Venus, Titan, and Mars.

Significance/Benefits to JPL and NASA

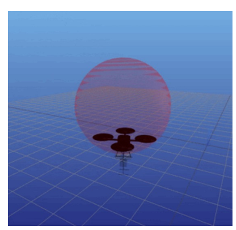
Many free-flying robotic space mission concepts employ highly constrained aerial mobility systems due to power, weight and deployment strategy and environment constraints. These constraints can result in underactuated designs that cannot be sufficiently controlled by typical feedback control strategies. JPL can more readily apply such designs to unique mission concepts by further developing an online predictive control capability for underactuated aerial robots. Such a capability would provide more capable free-flying robotic space mission concepts, such as low-altitude planetary aerobot (blimp) explorers, jumping and bouncing robots (e.g. Hedgehog or Tensegrity designs) and unique rotorcraft. Predictive control strategies would also enable landing site selection and accuracy as well as better resource utilization throughout missions.

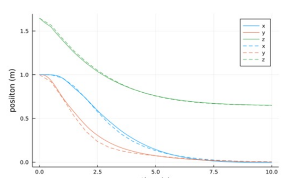


Blimp gondola hardware developed at JPL (left) and quadrotor hardware developed at CMU under test (right). Both platforms support low-level testing of control algorithms at high sample rates in a motion capture laboratory at CMU.

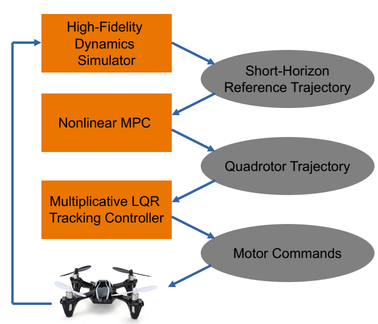
Approach and Results

A state-of-the-art solver algorithm has been developed that improves on standard methods for trajectory optimization by a factor of 10-100x in speed and efficiency. This algorithm has been implemented in both Julia and C++, and is lightweight enough to run on resource-constrained platforms such as a Raspberry Pi or Nvidia Jetson. The algorithm also natively accounts for the group structure of 3D rotations, which improves robustness and performance for rigid-body systems. To test this algorithm on hardware, we are performing experiments on quadrotors and a JPL-built blimp platform. We are also developing dynamics-emulation capabilities based on our algorithm to allow the quadrotor to behave dynamically like the blimp (or another vehicle) for hardware-in-the-loop testing.





(top) Plot of the spatial trajectory of a quadrotor (solid lines) emulating a blimp (dashed lines). (Bot) A screenshot of the simulator superimposing the blimp on top of a quadrotor. The nonlinear MPC controller with a 6-second horizon can run at about 25 Hz on an Nvidia Jetson Nano computer.



High-level framework for performing dynamic emulation onboard the quadrotor. The quadrotor's natural dynamics can effectively be replaced by another aerial vehicle for hardware-in-the-loop testing.

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Publications:

Jackson, Brian E., et al. "ALTRO-C: A Fast Solver for Conic Model-Predictive Control." International Conference on Robotics and Automation (ICRA), Xi'an, China. 2021.

Howell, Taylor A., Brian E. Jackson, and Zachary Manchester. "Altro: A fast solver for constrained trajectory optimization." 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2019.

Jackson, Brian E., Kevin Tracy, and Zachary Manchester. "Planning with attitude." IEEE Robotics and Automation Letters 6.3 (2021): 5658-5664.

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