National Aeronautics and Space Administration

Online Model Predictive Control for Under-Actuated Robotic Aerial Platforms (SP20014)

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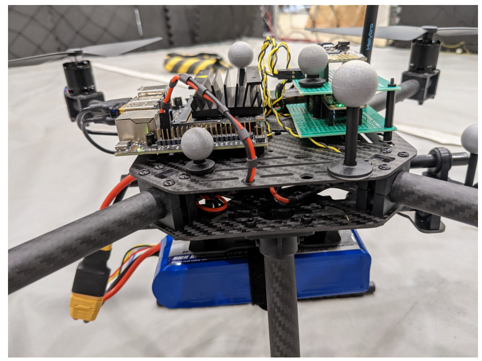
Program: FY21 SURP   Strategic Focus Area: Localization and Mobility

Objectives

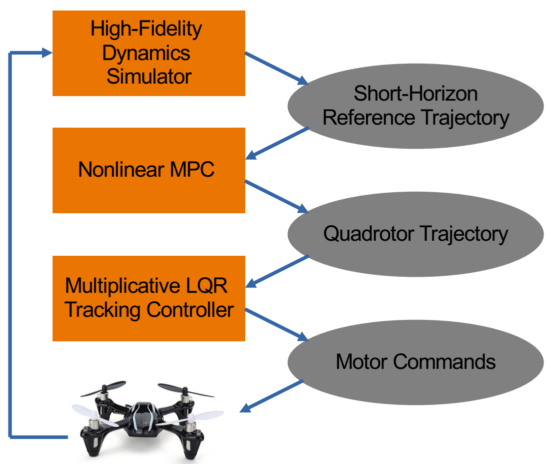
The objective of the overall project is to develop and implement optimal control algorithms specifically relevant to under- actuated aerial platforms – including airships, blimps, balloons, and small drones – that can run on resource-constrained hardware (i.e. low bandwidth, power, and memory specifications).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

Approach and Results

A state-of-the-art algorithm has been developed that improves on standard methods for trajectory optimization by a factor of 10-100x. 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. This algorithm also natively accounts for the group structure of 3D rotations, which improves robustness and performance for systems of one or more rigid bodies. To test this algorithm on hardware, we are developing custom quadrotor and accessing low-level control commands. Using an adaptation of the algorithm developed, we will also be able to use this platform to emulate the dynamics of other aerospace vehicles, such as blimps operating on other planets.

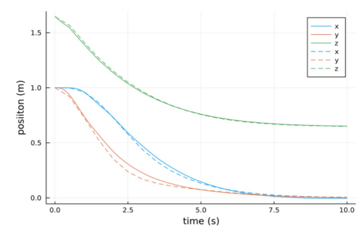


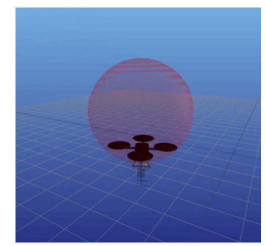
(above) Custom quadrotor hardware developed by CMU. This open-source hardware platform exposes an easy-to-use API for sending low-level control commands to the motors.
(below) High-level framework for using the quadrotor above to emulate other system dynamics.



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.





(above left) Plot of the spatial trajectory of a quadrotor (solid lines) emulating a blimp (dashed lines).
(above right) 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.

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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