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IN-SPACE DEMONSTRATIONS OF CARGO TRANSPORTATION WITH DECENTRALIZED MODEL PREDICTIVE CONTROL

Abstract

Recent developments in space activity, including the soaring interest around the globe in in-space servicing, assembly, and manufacturing (ISAM) missions, have highlighted the need for future automated space transportation. In many ISAM applications, it is economical and effective for multiple cooperative satellites to perform transport functions, such as moving a large piece of cargo. Safe, efficient, and effective control algorithms are needed for these cooperative transport spacecraft.

In the context of fuel-optimal space trajectories, Model Predictive Control (MPC) is a well-established method with mature theory developed over decades. Cooperative space transport governed by decentralized MPC (DMPC) is profoundly attractive, as the framework can leverage constraint satisfaction for employing safe close proximity operation, among other advantages.

Mass uncertainty poses a significant challenge in the cargo transportation problem, as the non-linear attitude dynamics tend to dominate when mass is distributed over larger distances. Linearization of the dynamics with Taylor expansion limits accuracy to small neighborhoods around equilibrium points, making this control problem cumbersome to tackle.

This work presents an in-space demonstration of a novel DMPC framework based on a leader-follower formation control strategy for an unknown cargo transportation problem using two robots. No prior knowledge of the mass of the cargo transported is considered; however, bounded uncertainty of the mass is assumed. A quaternion feedback controller is employed in a distributed fashion in such a way that a Lyapunov function is manifested in terms of the rotational measurements reaching asymptotic stability.

A proof of concept of the proposed algorithm is demonstrated using the Astrobee free-flyer robots on-board the International Space Station (ISS). The experimental setup consists of two Astrobee robots attached to a stowage locker. The torque limit of the robots was less than the torque demand for the stability of the system. The proposed framework is designed to overcome the common torque limitation that prevails in small-scale robots for cooperative cargo handling scenarios. The aforementioned DMPC framework was tested in ROS/Gazebo simulations and in the NASA Ames Research Center granite lab, and then demonstrated in space on the ISS using the Astrobee robots. The simulation and experimental results show the efficacy of the proposed framework in the presence of bounded localization errors, communication delays, and bounded parameter uncertainties.