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DEVELOPMENT OF AN INTEGRATED FRAMEWORK FOR PERCEPTION, PLANNING AND CONTROL OF SPACE MISSIONS

Abstract

Space environments are hard to simulate, due to highly dynamic and ambiguous operating conditions like luminous intensity variations, micro vibrations, inter-planetary surfaces with craters, hills etc. As new space missions are becoming multi-objective and complex, the perception, planning and control requirements of these missions are getting stringent. To demonstrate reliability and robustness of mission aspects, the simulation and validation framework also needs to be physically accurate and multidisciplinary. Existing implementations target single application end-use with less integration features for new requirements like space robotics and machine learning. Hence there is a need for an integrated framework with novel capabilities for the development of perception, planning and control modules of future space missions.

The paper presents the implementation details and simulation results of an end-to-end framework for space missions, which can be adaptable from interplanetary rovers to dexterous in-space manipulation applications. MuJoCo based physics accurate simulation environment with OpenGL rendering in Python forms the core of the framework. A sensor suite consisting of vision sensors, range sensors, and inertial measurement units (IMU) along with actuator models of joints, thrusters and momentum exchange devices are integrated directly to the physics. Critical sensor requirements like field of view (FoV), pixel resolution, range limits, luminosity conditions as well as actuator requirements are finalized based on the framework simulations. State-of-the-art deep learning-based perception algorithms (object detection) as well as geometric algorithms (relative pose estimation using fiducial markers) are interfaced to the framework extending its capabilities.

For demonstrating perception application, the framework is used to generate space relevant image dataset for object detection. Preliminary results of detection inference of space objects of interest generated using the dataset will be presented. Multiple space mission scenarios viz a) Lunar rover navigation (on uniform surface and on surface with hill/craters); b) In-space manipulation and c) Rendezvous-docking (direct and obstacle avoidance in presence of debris) are created using the framework. Constrained optimization-based trajectory generation is implemented for the above-mentioned scenarios for capability demonstration and results will be presented. Expansion capability of the framework is demonstrated for environment rendering using bio-inspired sensors (event cameras) as well as neuromorphic implementation of object detection. Future capabilities will include integration of photo-realistic scenario creation, estimation filters and learning based planning and control algorithms.