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GUIDANCE AND CONTROL FOR SPACECRAFT AUTONOMOUS LANDING ON SMALL PLANETARY BODIES

Abstract

Landing on small planetary bodies, such as asteroids, comets and moons has proven to be a crucial step towards a more complete understanding of their physical and chemical characteristics, which is in turn essential for identification of resources and a deeper understanding of their origin and formation. Landing on such bodies, however, is very challenging due to their hazardous terrains and irregular shape and gravity field. This environment leads to complex and uncertain landing dynamics, bringing the need for a robust Guidance, Navigation and Control (GNC) system to make reliable and safe landing on such bodies feasible.

The paper focuses on the development of a robust guidance and control scheme for landing on small planetary bodies. The guidance algorithm is based on propellant-optimal trajectory generation via Convex Optimization. A Nonlinear Dynamic Inversion (NDI) controller is then investigated for trajectory tracking of the spacecraft. The system is designed to be robust against the uncertainties, disturbances and errors associated with landing in such environments.

Since these remote bodies are located at long distances from Earth, the use of remote landing control becomes impractical, therefore, the guidance and control scheme presented here are designed to function online and as part of an autonomous landing concept which includes Terrain Relative Navigation (TRN) and Hazard Detection and Avoidance (HDA) to guarantee that the spacecraft can safely navigate through hazards and be guided and controlled to a safe landing site.

The TRN and HDA algorithms rely on instruments such as optical sensors and scanning LiDARs for detection of surface features and hazards, therefore, the pointing requirements of these sensors need to be taken into account, making the attitude control of the spacecraft a crucial component of the landing. For this reason, the system presented here is based on coupled orbital and attitude dynamics of the lander spacecraft. The trajectory is therefore generated and controlled to guarantee not only precise landing, but also, the required attitude constraints for the TRN and HDA functions.

The first section of the paper presents the coupled orbit-attitude dynamics model of the spacecraft, the model for the microgravity environment of the small body and models for the disturbances and uncertainties. The second part of the paper presents an overview of the GNC system, followed by details on the guidance and control algorithms. Results are then shown to illustrate the performance and robustness of the system in the presence of disturbances and uncertainties.