Advanced Guidance and Autopilot Design for Autonomous Lunar Soft-Landing

Thesis Abstract

Aiming towards the development of a long-term lunar research base for scientific exploration of futuristic objectives, soft-landing on the Moon has gained renewed interest worldwide. This work focuses on optimal guidance and autopilot design for multiphase autonomous soft-landing on the lunar surface. The objective of the guidance design is to translate the spacecraft from a parking-orbit towards the designated landing site with a near-zero touchdown velocity. In the process of the development, three different guidance methods that are capable of onboard implementation are explored. In this context, the Model predictive static programming (MPSP) based optimal guidance design has been carried out for the multi-constraint soft-landing mission. The MPSP is a computationally efficient numerical guidance algorithm which requires an initial guess control solution to iterate. In order to obtain a good guess history, an inverse polynomial based explicit guidance is formulated in a nonlinear guidance framework. Next, a minimum jerk based explicit guidance law with a re-targeting feature is proposed for the critical terminal descent phase of soft-landing. Various bottlenecks of existing guidance laws such as guaranteed ground collision avoidance, initial continuity of guidance command in between successive phases, the terminal vertical orientation of spacecraft, and tuning difficulties like time-to-go selection are comprehensively addressed. Formulations of different guidance methods along with detailed simulation studies are presented.

The second part of this thesis focuses on autopilot design. In order to realize the guidance command with actuator units, a nonlinear dynamic inversion based autopilot design has been carried out with a six degree of freedom spacecraft model. The spacecraft is composed of two sets of thrust engines as actuator units. The translational motion of spacecraft is driven by primary thrusters which are throttleable. The rotational motion is driven by a set of eight Reaction control system (RCS) thrusters, which operate in on-off (switching) mode. An exhaustive search-based optimization for the selection of actuation of RCS thruster is presented. The proposed thruster selection logic embeds the physical limitations like minimum on time of RCS thrusters. To incorporate sufficient robustness against unknown perturbations due to various possible modeling errors, vehicle integration difficulties, manufacturing errors, inaccurate prediction of mass and CG variations, etc. a detailed closed-loop autopilot design with neuro-adaptive augmented control law has been presented. In order to address the nonlinear coupled translational and rotational motion of the lunar module in an integrated framework, the partial integrated guidance and control (PIGC) design has been carried out. The PIGC design, which operates in a two-loop structure, combines the benefits of both integrated guidance and control as well as conventional three-loop guidance and autopilot philosophies and it reduces the transient effects of the overall design. Moreover, the MPSP based PIGC design in an optimal control framework minimizes the required body-rate demands and thereby leading to control effective solution in terms of torque requirements. The effectiveness of the proposed autopilot designs is demonstrated with a detailed realistic simulation of the multiphase landing scenario.