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NEW IMPLICIT NEIGHBORING OPTIMAL GUIDANCE AND ATTITUDE CONTROL FOR THREE-DIMENSIONAL LUNAR ASCENT

Abstract

Recently, several Countries have shown an increasing interest toward robotic or human missions to the Moon. Ascent path and orbit injection represent a crucial issue for a lunar module, because the dynamical conditions at injection affect the subsequent phases of spaceflight. This research proposes the original combination of two techniques applied to lunar ascent modules, i.e. (i) the variable-time-domain neighboring optimal guidance (VTD-NOG), and (ii) a constrained proportional-derivative (CPD) attitude control algorithm. VTD-NOG belongs to the class of feedback implicit guidance approaches, aimed at maintaining the spacecraft sufficiently close to the reference trajectory. This is an optimal path that satisfies the second-order sufficient conditions for optimality. A fundamental original feature of VTD-NOG is the use of a normalized time scale, with the favorable consequence that the gain matrices remain finite for the entire time of flight. The updating formula for the time-to-go and the guidance termination criterion derive from the natural extension of the accessory optimization problem associated with the original optimal control problem. This extension leads also to obtaining new equations for the sweep method, which yield all the time-varying gain matrices. VTD-NOG identifies the trajectory corrections by assuming a thrust direction always aligned with the longitudinal axis of the spacecraft. However, this assumption represents an approximation, and the attitude control system must maintain the actual spacecraft orientation sufficiently close to this thrust alignment condition. To do this, the attitude control system uses thrust vector control and side jet system. A proportional-derivative (PD) control action, in conjunction with the nonsingular Euler parameters, is initially employed. Through the selection of sufficiently large gains, the integrated guidance and control system is proven to be capable of providing accurate orbit injection. However, increasing further the PD gains leads to unacceptable peaks of the rates of the control inputs, especially during the first seconds of flight. This circumstance puts limits on the gains, which in turn limit the precision of orbit injection. Thus, CPD introduces an appropriate saturation action that constrains the rates of the control inputs to feasible upper bounds. The numerical results unequivocally demonstrate that the joint use of VTD-NOG and CPD represents an accurate and effective methodology for guidance and control of three-dimensional lunar ascent and orbit injection. Due to their generality, the combined use of these two techniques can be applied to guidance and control of aerospace vehicles employed in a wide variety of mission scenarios.