Advanced Robust Strategies for Attitude Control of Spacecraft

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Abstract: Attitude control system (ACS) design is a crucial task for any spacecraft mission. In the last couple of decades, various nonlinear control theories have been developed and extensively employed to design attitude control laws with the primary objective of achieving the desired attitude or time-varying reference trajectory. While designing the attitude control, an ideal ACS must withstand the challenges of model uncertainties, external disturbances (including gravitational force), modal vibrations, actuator faults, input saturation. Moreover, an efficient controller must also provide features like higher accuracy, faster convergence, lesser energy consumption, invariance against uncertainties and faults, feasibility under a constraint network. With the background of above-mentioned challenges, this thesis proposes consolidated attitude control methods aiming to achieve the desired attitude. Meanwhile, the proposed controllers also provide robustness against various uncertainties, alleviation of chattering, minimum use of communication resources, energy efficiency, anti-unwinding design, parameter optimization.

The sliding mode control (SMC) is a well-known robust nonlinear control strategy. However, the primary limitation of a classical SMC is the occurrence of chattering in input, which may propagate into the system and destabilize the system performance. Therefore, in this thesis, the problem of chattering is alleviated by employing three different approaches. The first strategy explores the finite-time disturbance observer (DO) with advanced SMC schemes. The next approach employs the adaptive higher order SMC with parameter optimization. The third methodology uses an alternative to the SMC by exploring the artificial time delay-based estimation with state feedback control. These three distinct attitude control strategies overcome/reduce the high-frequency component from the input and successfully achieve the desired system response. These proposed techniques render satisfactory performance, and the control laws are updated on a continuous-time framework. This means the control input is executed digitally using a numerical method with a significantly small periodic sampling time. However, these techniques provide unsatisfactory performance if the wireless communication channel (between the controller module and the actuator) has a limited data transmission rate. Consequently, alternative aperiodic control update schemes are needed to reduce the rate of control input updates through the wireless network, which minimizes the computational burden on the onboard processors.

This thesis investigates two concepts under a constraint network, i.e., quantization technique and event trigger (ET) approach, along with the invariant control methods for attitude regulation of spacecraft. In this regard, an adaptive feedback control with an input hysteresis quantizer is employed to achieve a satisfactory response with a minimum usage of control updates. Besides, the proposed ET scheme is investigated with different robust strategies (i.e., high gain and adaptive SMC) under constrained wireless networks. Moreover, a finite time DO with a dynamic ET technique is also proposed to tackle the input chattering and constraint network problems.

The proposed strategies are theoretically investigated by the Lyapunov stability theory and the state trajectories convergence analysis. Furthermore, the efficacy of the proposed schemes is assessed and compared with state-of-the-art through numerical analysis.

Keywords: Spacecraft attitude control, sliding mode control, Lyapunov theory, finite-time convergence, disturbance observer, metaheuristic technique, artificial time delay estimation, constraint network, event-trigger technique, hysteresis quantizer.