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NETWORKED AND DISTRIBUTED COOPERATIVE ATTITUDE CONTROL OF FRACTIONATED SMALL SATELLITES

Abstract

In recent years modular satellite architectures have become more and more prevalent, thanks to their many advantages in comparison with mission-tailored single use architectures. Fractionated satellite architectures go even further by increasing the subsystem autonomy and interconnectivity even more, e.g. by going from a wired satellite harness to a wireless one. A fractionated architecture allows the use and control of still functional submodules in an otherwise broken satellite (e.g. in case the central OBDH system has failed). If the OBDH of a fractionated satellite in an earth observing formation fails, the other satellites in the formation could take direct control of the broken satellite's attitude control subsystem and therefore the original mission objective could still be continued. However, this approach imposes different challenges to the satellites. First, the failure in a subsystem has to be detected and a subsystem for replacing the faulty one, has to be selected and assigned. In a changing formation topology, it might be necessary to dynamically adapt the assignment, because the quality of the inter-satellite links might vary. Second, if for example closed-loop control is performed via wireless connection links, the communication channel properties (like transmission and processing delays, packet losses, etc.) have to be taken into account in the controller design. This paper presents solutions for both described problems. The solution of the first problem requires regular intra-satellite communication e.g. via alive messages to recognize failures in subsystems. For the selection of the responsible satellite/subsystem to take over the functionality of the defect one, a distributed auction method is proposed, where each satellite votes depending on its state and capabilities. For the second problem of control via communication links, we propose a networked control approach based on Lyapunov Model-Predictive Control (MPC) methodology. As demonstration example, MPC is adapted and applied to a coordinated attitude tracking problem based on a typical attitude model of a nano-satellite in LEO. Transmission channel model definition is also based on typical nano-satellites in close proximity with intra-satellite low-power wireless connected submodules and inter-satellite UHF connections. Using a high-fidelity communication and attitude-dynamic simulation, a comparison of stability and mission performance of a cooperative tracking scenario is made with the broken satellite's attitude being controlled by a non-networked MPC from another satellite and by the broken satellite's attitude being controlled by a networked MPC from another satellite. Figures of merit for stability and performance are presented.