Evaluation of Daniel Brandtner's Diploma Thesis

Satellite formation flight: optimal and cooperative control approaches

Writing as a **supervisor** I would state that mr. Brandtner started work on his Diploma Thesis in February 2018 under my supervision, studying the topic of satellite formation flight. In the course of his studies and research he successfully mastered the prerequisite elements of classical mechanics, orbital mechanics, and control theory; especially the advanced optimal and cooperative control methods. In those efforts mr. Btrandtner reached a level of competence and independence that enabled him to thoroughly investigate the various considered cases or orbital dynamics and to devise control designs to achieve the specified tasks.

The Diploma Thesis itself begins with modelling the orbital motion in Chapter 1, drawing from a rich body of literature on celestial mechanics. Mr. Brandtner systematically used Lagrangian models of uncontrolled and controlled orbital motion to describe the orbital dynamics around a single spherical body in different coordinate systems, appropriate to subsequent consideration of satellite formations. Those were then extended to include effects of the central-body oblatness as well as the presence of the second principal body. Mostly a circular Hill's model was considered for the latter purpose, but a more general elliptical Hill's model is also mentioned, which can be treated in a similar way.

Later chapters build on the models given in Chapter 1 to design first open-loop optimal control schemes in Chapter 2, and then the closed-loop cooperative controls in Chapter 3. Mr. Brandtner independently devised a numerical procedure for solving complicated, nonlinear, the two-point boundary value optimal control design problems, yielding a plethora of optimal controls effecting single-satellite orbit placement and orbit transfers between various uncontrolled orbits studied in Chapter 1. Those maneuvers take the least amount of fuel (control effort), in the L_2 norm sense. The orbits to which the transfers are achieved are, in fact, of some practical interest, either being the targets of past satellite missions, e.g. SOHO, or of missions planned in the near future. Those single-satellite transfers are applicable to formation flying by actuating each satellite independently. Optimal control methods are also applied to the entire formation, actuating all satellites together, effecting formation reconfigurations. Two special formations of particular importance were closer studied: the trailing formation and LISA triangular formation. The control problems solved utilizing the developed methods are indeed the ones recently identified as some of the key control challenges in deployment of satellite formations.

However, optimal controls, as designed in this Thesis, are open-loop protocols, hence they are sensitive to disturbances and possibly unmodelled dynamics. Such controls are usually precomputed so no easy on-the-flight corrections are possible later-on. For this reason, Chapter 3 brings the closed-loop cooperative controls, depending on distributed directed communications between individual satellites. These developments build on the state-of-the-art results in cooperative control and bring autonomous distributed algorithms that achieve the same, or similar, practically important goals as those achieved through the optimal control approach. The added benefits of the cooperative control are that it can run autonomously, avoiding the need for costly communication with the ground station, and that their feedback character imparts a degree of robustness to unavoidable perturbations and uncertainties; a feature helpful in the long-term formation keeping.

In summary; starting from rigorous classical mechanical modelling, through applying the advanced modern control theoretic methods, this Diploma Thesis brings intriguing solutions to challenging problems of current and future interest for satellite formation deployment. I addition to all presented results, mr. Brandtner independently drew correct conclusion on the, sometimes counterintuitive, nature of orbital maneuvers and systematically compared the performance of the devised control protocols.

For all these reason, I would propose the grade of **Excellent, A,** to be assigned for this Diploma Thesis.

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