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Deimos Experience, Insight and Perspective on Space Control R&D

Augusto Caramagno, Luis Felipe Peñín, Andrés Marcos

The GNC group at Deimos Space has actively worked in the last few years in the direction of GNC technological developments for formation flying (FF), rendezvous (RDV), entry-descent-and-landing (EDL) and autonomous GNC systems were a plethora of guidance and control techniques have been used for modeling, design and analysis: including nonlinear dynamic inversion (NDI), linear fractional transformations (LFT), linear parameter varying (LPV), structured singular value (μ) and classical approaches.

In this talk, an overview of Deimos past and present control projects and team experience will be given highlighting the lessons learnt and challenges faced during our work and concluding with a technological roadmap summarizing Deimos view on future research and development activities.

Deimos believes there is a need to develop modeling methods capable of producing traceable models that connect the highest-fidelity nonlinear models down to the simplest-to-use design models. The current industrial approach of applying numerical methods (to obtain linear, time, invariant state-space models) is very limited for the future and more challenging space missions due to the loss of design insight, which results in a shift in the design process to *ad hoc* analysis in order to verify and validate the resulting controllers. Furthermore, if a controller is not cleared there are no direct methods to use the analysis results to improve the design and typically a new model, and controller, must be developed (with the impact this has on project cost and time overruns). Additionally, it cannot be sufficiently stressed that in order for any modeling method to be successfully transferred to control researchers in Industry and Academia, well-developed and easy to use software tools must support them. Europe has taken a decisive world-lead in recent years thanks to the efforts made by research/academic/industrial groups in developing tools capable of obtaining reduced-order, but exact, LFT models (the paradigm in robust modeling, control and analysis). Much is still needed to consolidate this leading position, especially noting that these modelling software tools have been developed and applied to aircraft and thus, they must be examined and tailored to the specific requirements and objectives of space missions.

The need for advances in control design approaches arise again from the issues being faced in some of the current and future space missions. As an example, Deimos has identified several control law issues for the high-speed atmospheric re-entry problem of future human-rated or automated missions: simplicity of the implemented control law (to allow astronaut emergency maneuvering and simplify training & monitoring), robust and safe margins (to account for the increased mission uncertainty), augmented fault tolerance characteristics relying in functional approaches (to allow reduction of hardware and weight while maintaining required safety and autonomy objectives), and combination of advanced robust guidance and control techniques (to simplify implementation while satisfying the more demanding robustness and fault tolerance requirements).

Finally, with respect to analytical advances, Deimos perceives that development of currently available analysis approaches to include robustness, worst-case and fault characteristics is also a key direction. This development includes both, research on the necessary tools for such analyses and on the most appropriate way to present the information obtained. More importantly, it also means development of approaches to transform the resulting handling & flying requirements into mathematical objectives (e.g. constraints and cost functions) in a form ready for Space GNC design. The use of recently established aeronautical robust and worst-case analysis techniques, which have shown great promise in dealing with the nonlinear demands of high-performance aircraft systems, seems to be a very plausible starting point. For example: linear/nonlinear robust analysis techniques such as the structure singular value μ, LFT modelling techniques, and the more advanced integral-quadratic-constraints (IQC) and LPV analysis techniques could open up the possibility of more specialized analyses (allowing for a combination of time-domain and frequency-domain uncertainty characterizations and covering much more general types, ranging from time-invariant parametric to time-varying dynamic and non-linear).