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PROPOSITION DE SUJET DE THESE

Intitulé : Advances in probabilistic µ-analysis for robust certification of aerospace control systems

Référence : **TIS-DTIS-2020-44**
(à rappeler dans toute correspondance)

Début de la thèse : October 2020	**Date limite de candidature :** May 2020

Mots clés

Control laws validation, probabilistic µ-analysis, Monte Carlo simulations, aerospace control systems

Profil et compétences recherchées

Students from engineering schools and top universities, with a good knowledge in control theory, linear algebra, aerospace systems and Matlab/Simulink software, as well as a very good English level.

Présentation du projet doctoral, contexte et objectif

Novel lightweight materials and deployable structures make it possible to launch new spacecraft architectures in Space and to perform a wide variety of on-orbit services, such as mirror assembly, on-orbit refueling, debris capture or satellite repair. This requires to design very efficient and highly optimized Attitude and Orbit Control Systems (AOCS), which can deal with the interactions between the flexible elements of the spacecraft structure (solar panels, booms, robotic arms, antennas, mirrors) and numerous internal/external perturbations. The latter can indeed magnify the natural resonance of the structure and make it difficult to meet the challenging pointing performance requirements demanded by the future Science and Earth observation missions. In this context, the AOCS design problem demands not only a good control architecture, but also adequate analysis and validation methods to assess the mission risk and ensure a good trade-off between stability and performance in the face of all admissible combinations of uncertainties arising from an unavoidable misknowledge of the system.

The current industrial standard for performance verification and validation is the Monte Carlo (MC) approach. It is a rather simple statistical technique based on random sampling of the various uncertain parameters of the system and time-domain simulations. However, MC methods require intensive computational effort and can only provide soft bounds on the system performance. This means that they do not directly provide an exact probability that a given requirement is satisfied, but they only establish that the probability is achieved within a specified accuracy and a specified confidence probability. Moreover, rare events cannot be effectively detected even if a very large number of simulations are carried out. Less expensive deterministic alternatives have been developed since the 1980s, so as to compute guaranteed (hard) robustness margins and to identify worst-case parametric configurations without any time-domain simulation. This is typically the case of µ-analysis, which has emerged as the preferred robustness analysis tool for uncertain dynamical systems within the control community. In contrast, its use remains rather limited in the industry. A common criticism for its use in clearance and certification processes is the lack of quantitative measures on the likelihood occurrence of the identified worst-cases. Therefore, the resulting robustness margins are often too conservative because of the implicit assumption that each of the uncertain parameters in the model has uniform probability distribution, and the associated worst-case configurations can correspond to situations that are unlikely to occur in practice.

This PhD thesis falls within this context and aims at filling the gap between MC methods (able to quantify sufficiently frequent phenomena) and worst-case µ-analysis (relevant for extremely rare events). This is a major need relayed by many engineers and researchers. Probabilistic methods appear to be the most appropriate. In this context, the ambition is to develop new probabilistic validation tools which combine the advantages of both MC and µ approaches, so as to improve the characterization of rare but nonetheless possible events. The ultimate goal is to improve the current industrial standard and to fasten the validation process, which currently accounts for 80% of the AOCS total development time in the space industry. Beyond control laws validation, the integration of probabilistic validation methods into the design process will also be studied, so as to better optimize certain controller gains. The ambition is to shorten the development time by alleviating the tedious iterative process between design and validation, and to better handle the trade-off between robustness margins and performance levels.

All theoretical advances will be validated on different benchmarks that stimulate the current research interest on Space systems. In particular, the topic of on-orbit servicing will be addressed through the imperative need to improve Space traffic/collision management and to facilitate deep space exploration. The first contribution in this area will be to provide a step forward to the state-of-art in Space rendezvous missions analysis. Then, on-orbit refueling will be considered. This is a challenging task, which implies that the AOCS of both the chaser and the target spacecraft guarantee the stability and performance requirements in the presence of numerous system uncertainties during the refueling operation, with the added difficulty that the inertia is time-varying.

Collaborations envisagées

Co-supervision by Francesco Sanfedino from the Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)

Possible mobility of a few months at the European Space Agency (ESA)

Laboratoire d'accueil à l'ONERA

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