PhD Position in Analysis of Aerospace Control Systems
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PhD: Enhanced probabilistic tools to improve verification and validation of space control systems

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Abstract

Current validation and verification (V&V) activities in aerospace industry mostly rely on time-consuming simulation-based tools. These classical Monte-Carlo approaches have been widely used for decades to assess performance of AOCS/GNC systems containing multiple uncertain parameters. They are able to quantify the probability of sufficiently frequent phenomena, but they may fail in detecting rare but critical combinations of parameters. As the complexity of modern space systems increases, this limitation plays an ever-increasing role. In recent years, model-based worst-case analysis methods have reached a good level of maturity. Without the need of simulations, these tools can fully explore the space of all possible combinations of uncertain parameters and provide guaranteed mathematical bounds on robust stability margins and worst-case performance levels. Problematic parameter configurations, identified using these methods, can be used to guide the final Monte-Carlo campaigns, thereby drastically shortening the standard V&V process. A limitation of classical model-based worst-case analysis methods is that they assume the uncertain parameters can take any value within a given range with equal probability. The probability of occurrence of a worst-case parameter combination is thus not measured. A system design can therefore be rejected based on a very rare and extremely unlikely scenario. The proposed idea aims to fill this gap by considering a richer set of probability distributions in the uncertain parameters and measuring the likelihood that a given problematic scenario will occur. It will also demonstrate on a realistic benchmark problem how to integrate the resulting tools in a typical aerospace V&V scenario and to significantly accelerate the system design. The objective is to provide the end user with a deep understanding of the way uncertainty at component level can propagate to a probabilistic outcome at system level.

State of the art

Monte-Carlo simulations [1], [2] are the preferred validation means in the space industry. They are able to quantify the probability of sufficiently frequent phenomena, but they are generally time-consuming, provide only soft bounds [3] and may fail in detecting rare but nevertheless critical events. Less expensive deterministic and simulation-free alternatives exist and have reached a good level of maturity, as is the case for μ-analysis [4], [5], [6]. But unlike Monte Carlo simulations, if worst-case scenarios are no longer missed, their probability of occurrence is also not measured, which can invalidate an AOCS on the basis of very rare and therefore extremely unlikely events [7], [8], [9].

Research to fill the gap between these two approaches is still at a very early stage and only few practical tools are available, although this issue was identified 20 years ago by [10]. This is all the more surprising since the validation process currently accounts for up to 80% of the AOCS total development time, and is becoming longer as the space missions become increasingly complex. In this context, the proposed PhD will build on the work of [11], [9], [12], [7], [13] on probabilistic μ-analysis to develop new cheap and reliable tools to improve the characterization of rare but nonetheless possible events, so as to tighten the aforementioned V&V analysis gap. Connections with other promising probabilistic approaches such as uncertainty quantification [14] and randomized algorithms [15] will also be investigated. The work initiated in [16] will finally be pursued to apply these tools to challenging spacecraft control problems and show how they can be integrated into the traditional AOCS V&V cycle, so as to improve the current industrial standard and fasten the validation process.

Background

The space industry usually carries out intensive simulation campaigns to validate spacecraft control architectures. But this is very time-consuming and can sometimes be unreliable. Less expensive deterministic alternatives have been developed since the 1980s. One of the most famous is μ-analysis, which has emerged as the preferred robustness analysis tool for uncertain dynamical systems within the control community. But its use remains rather limited in the industry. A common criticism is the lack of quantitative measures on the likelihood occurrence of the identified worst-cases. Therefore, the guaranteed robustness margins and performance levels are often too conservative , and the associated worst-case configurations can correspond to situations that are unlikely to occur in practice. Filling the gap between simulation-based methods and deterministic optimization-based approaches is thus a major need relayed by many engineers and researchers. The proposed PhD thesis falls within this context.

On the one hand, control systems Verification and Validation (V&V) has been among ONERA's main research topics for more than 20 years. Current studies under ESA contract constitute the state-of-the-art on probabilistic model-based V&V techniques but are still at an early stage in their development. On the other hand, modeling and control of complex space systems have been at the heart of ISAE's activities for a very long time as well. Both entities have published several dozen papers in leading journals and conferences on these topics. In addition, there is a long-standing collaboration and a proven scientific complementary between ONERA and ISAE, which has resulted in numerous joint research activities with ESA.

Candidate Profile

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.

Fundings

This PhD is an *ESA Co-funded Research* project (for more information `https://www.esa.int/About_Us/Careers_at_ESA/ESA_Co-funded_Research`).

Conditions of employment

A full-time employment for three years, including:

- A gross monthly salary and benefits in accordance to the ONERA standard
- Receiving institution: ONERA (Toulouse, France), Department *Traitement de l'Information et Systémes*
- A visiting research period at ESTEC (Noordwijk, The Netherlands)
- Access to ESTEC laboratories: researchers are able to use ESTEC facilities

Candidates are expected to start around October 2021.

Application

All applications should be compressed (.zip, 5MB max.) and submitted by email to the addresses below, including:

- Cover letter including a statement of purpose and previous experiences
- Detailed curriculum vitae
- Course grades transcripts
- Contact information of two references

Applications will be received until **May 15-th, 2021**. Interviews will be held shortly thereafter.
For more information regarding this position, please contact:

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