

## AOCS Advanced V&V: Advanced Uncertainty Propagation for AOCS Verification and Validation Performances

The goal of this internship is the assessment, the selection, and the implementation of advanced methodologies and techniques for AOCS V&V activities, potentially improving the state-of-practice.

### Background and Topic:

The state-of-practice for the Attitude and Orbit Control System (AOCS) Verification & Validation (V&V) entails the analysis of both frequency and time domain requirements. The aim of these analyses is to assess how variations and uncertainties in the different elements of the control loop (see Figure 1) impact the performance of the system, and to verify that the system performance indicators meet the prescribed requirements over the entire operational life time.

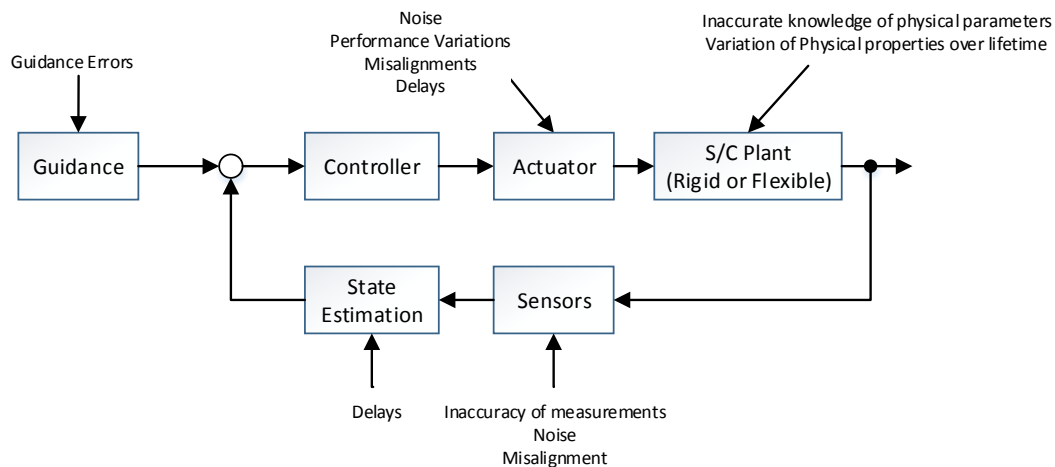


Figure 1: Closed-Loop Model for Verification and Validation.

To this end, in the current industrial applications, traditional methodologies for the AOCS V&V are employed. Such methodologies are either based on probabilistic approaches, e.g. Monte-Carlo analysis campaigns, or on deterministic ones, e.g. the definition of a set of limit values for uncertain parameters characterizing the design.

Despite being very practical in showing the design sensitiveness to parametric variations, the standard V&V approaches have many disadvantages. Among them, the majorly limiting aspects are: (i) the need of relying on massive amounts of computationally expensive simulation runs, potentially to be repeated multiple times across the project phases, (ii) the lack of a guaranteed proof about the conservatism of the analysis results and the adopted parameter space, and (iii) a potential inapplicability when the problem dimension is high.

To overcome these limitations, the adoption of advanced uncertainty propagation techniques, in combination with more traditional approaches, has been explored in the field of system design V&V. Such a combined approach was mainly aiming at:

- quickly identifying performance violation cases or worst-cases behaviours of the system under analysis, as well as identifying the impact of the uncertain parameters with respect to properly defined system behaviours and requirements;

- increasing the confidence in the obtained results, even when adopting simplified models of the system under analysis;
- enhancing the V&V analyses feasibility by improving the applicability of standard methodologies to more complex scenarios.

Examples of advanced uncertainty propagation techniques proposed in the literature include *Optimization-Based Analysis* [1], *Polynomial Chaos Expansion* [2-6], *Unscented Transform* [7], and *Gaussian Mixture Models* [8-9].

#### **Job Requirements:**

- Relevant Master Degree, with a focus on mathematics, numerical methods, optimisation and control engineering topics;
- High proficiency in Matlab/Simulink and C/C++;
- Basic knowledge of optimisation algorithms and techniques;
- English proficiency;
- Independent and self-driven candidate, with proven capability to work on schedule;
- Previous team-work experience in highly-demanding projects.

#### **References:**

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- [3] B. A. Jones, A. Doostan, G. H. Born, *Nonlinear Propagation of Orbit Uncertainty Using Non-Intrusive Polynomial Chaos*, Journal of Guidance, Control and Dynamics, Vol. 36, No. 2, pp. 430-444
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- [6] D. Xiu and G. E. Karniadakis, *The Wiener-Askey Polynomial Chaos for Stochastic Differential Equations*, SIAM Journal of Scientific Computing, Vol. 24, No. 2, pp. 619-644, 2002
- [7] E. A. Wan and R. van der Merwe, *The Unscented Kalman Filter for Nonlinear Estimation*, 2002
- [8] K. De Mars, R. H. Bishop, M. K. Jah, *Entropy-Based Approach for Uncertainty Propagation of Nonlinear Dynamical Systems*, Journal of Guidance, Control, and Dynamics, Vol. 36, No. 4, pp. 1047-1057, July-August 2013
- [9] G. Terejanu, P. Singla, T. Singh, P. D. Scott, *Uncertainty Propagation for Nonlinear Dynamic Systems using Gaussian Mixture Models*, Journal of Guidance, Control and Dynamics, Vol. 31, No. 6, pp. 1623-1633, Nov.-Dec. 2008

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