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Advanced satellite attitude control strategies under actuation constraints and multiple sources of disturbance

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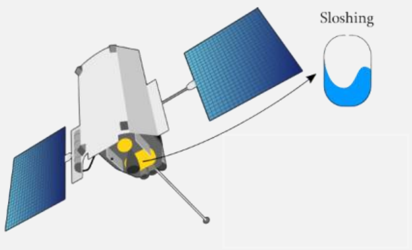
Context

In a scenario of highly autonomous geostationary satellites, with self-assembly and self-maintenance capabilities, **fuel slosh dynamics** and **actuators constraints** represent an undeniable risk of performance and stability degradation for the satellite attitude control system. While passive fuel slosh damping solutions and suboptimal techniques to prevent the actuators saturation exist by their own, an **optimal unique active control solution** is lacking and of great interest in the space industry for weight, cost and complexity of manufacturing reduction.



Methods

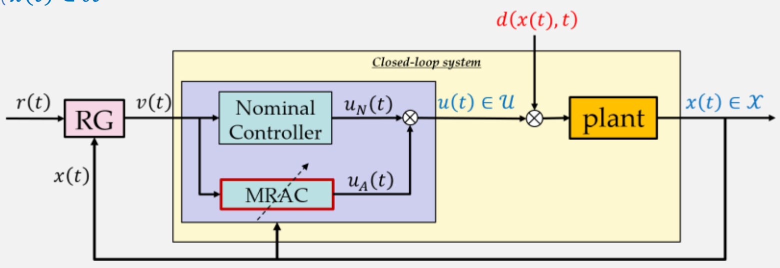
- **Fuel slosh dynamics** → Unmodelled dynamics $d(x(t),t)$ → **Model Reference *Adaptive* Control** (MRAC)
- **Actuator Constraints** → Predictive Control s.t. $\begin{cases} u(t) \in \mathcal{U} \\ x(t) \in \mathcal{X} \end{cases}$ → Robust **Reference Governor** (RG)

RG working principle

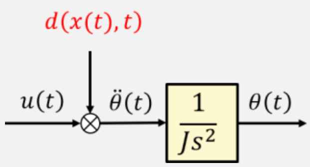
***Predict** the closed-loop trajectories and, accordingly, **slow down** the system to guarantee constraints enforcement by modifying $r(t)$ into $v(t)$ via solving an **optimization problem** at each time step.*

RG properties

- *No interaction with the stability properties of the closed-loop system,*
- *Low computational cost.*



Simulation Results : *MRAC performance guarantees-based RG for constrained uncertain systems [1]*



Uncertainty

$d(x(t),t) = W^T(t)\sigma(x(t))$
- $W(t) = [5, -2, -10\sin(t)]$
- $\sigma(x(t)) = [\theta(t), \dot{\theta}(t), 1]^T$

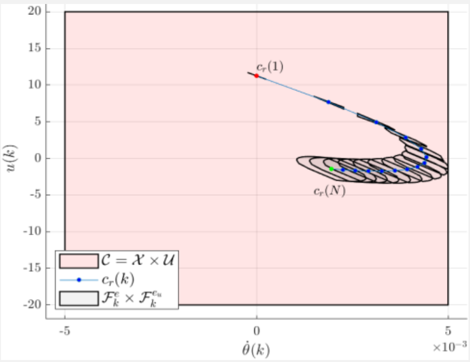
Constraints

- $|\dot{\theta}(t)| \leq \dot{\theta}_{max} = 1\text{deg} \cdot s^{-1}$
- $|u(t)| \leq u_{max} = 20N \cdot \text{m}$

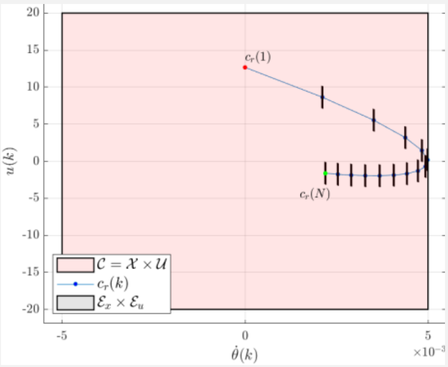
Objective

Track $r(t) = 0.3491\text{rad}$

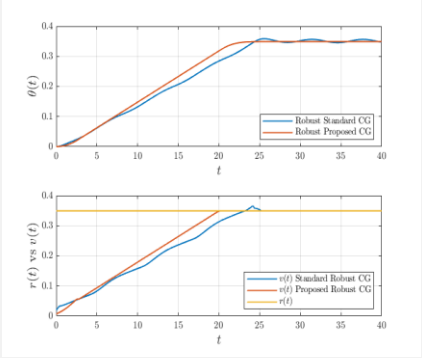
Standard Robust RG prediction



MRAC-based RG prediction



Results



*In the **standard Robust RG prediction**, the uncertainty propagates along the prediction horizon (black sets are growing) and a conservative constraints enforcement is required.*

*With the **proposed solution**, thanks to the MRAC performance guarantees:*

- *Precise **uncertainty compensation**,*
- ***Limited conservatism** while satisfying constraints* → *faster convergence to $r(t)$.*

Perspectives

- Advanced MRAC solutions to completely decouple the performance bounds from the knowledge of the uncertainty.
- Experimental Validation.

Reference

*[1] Guido Magnani, Alex dos Reis de Souza, Mario Cassaro, Jean-Marc Biannic, Helene Evain, Laurent Burlion, **Command governor-based adaptive control for constrained linear systems in presence of unmodelled dynamics**, 2023 American Control Conference (ACC).*

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