Anti-Windup Compensator Approach to Nanosatellite Fault Tolerant Architecture - SSC20-WP1-30

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Overview

- Anti-windup (AW) compensator in this study is designed to work with control systems experiencing actuator saturation. While working with an existing controller, the AW compensator prevents degradation in performance during saturation and enhances the system to perform optimally after saturation [1]. In addition, the fault tolerant capability of a proposed integrated fault tolerant architecture is studied with the AW compensator.
- The model of ESTCube-2 nanosatellite is used to simulate results and numerically analyze the performance of the proposed method. ESTCube-2 is a three-unit CubeSat aimed at an in-orbit demonstration of the plasma brake and the electric solar wind sail (E-Sail) [2].

AIM

- Design an integrated AW fault-tolerant controller.
- The proposed method must ensure global asymptotic stability of the nonlinear system.

Satellite Model

The equation below represents the satellite mathematical model with Reaction Wheels (RW) as actuator

- $$J\dot{\omega}_i = T_d + T_c - \omega_i^{\times}(J\omega_i + H)$$
- $H = [h_1\ h_2\ h_3]^T$ is the angular momentum of the wheel
- T_d is the sum of disturbance torques acting on the satellite.
- T_c is the applied control input torque.
- $J\dot{\omega}_i$ is the rate of angular momentum $\dot{h}$ in inertial reference frame.
- $\omega_i^{\times}$ is the skew symmetric representation of the angular velocity in inertial reference frame.
- Proposed FTC is designed based on this model with angular momentum of the wheel.

Fault Tolerant Control Architecture

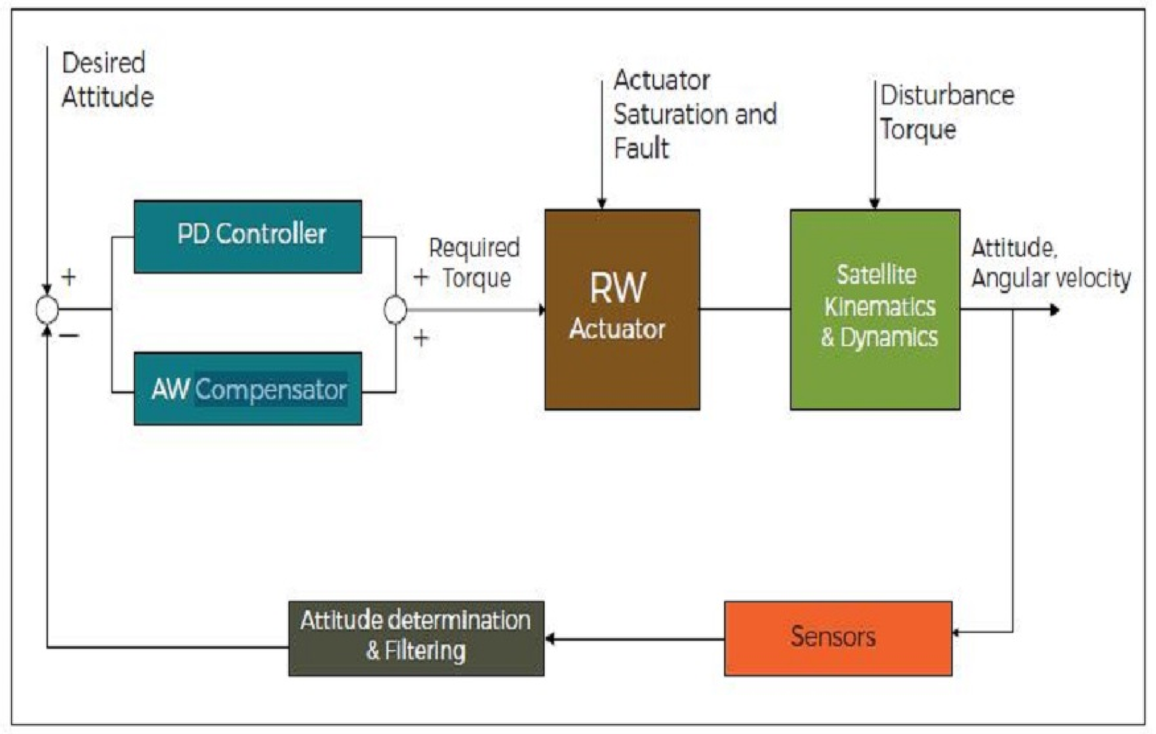

Figure: Proposed Fault-Tolerant Control Method

ESTCube-2 Artist impression

Anti-Windup Structure

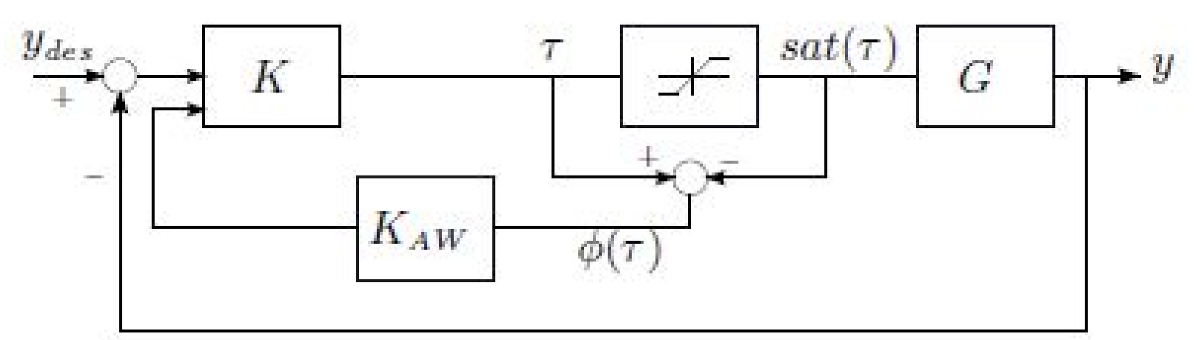

Figure: Closed-Loop AW Model

- The closed loop system in Fig 2 indicates the output y which is controlled using the reaction wheels of the satellite. Where
- y_{des} is the reference, $K(s)$ is the controller, τ is the torque input, ϕ_τ is the deadzone AW input, $sat(\tau)$ is the saturated torque input.
- the state space representation of the satellite system or plant, $G(s) \in \mathcal{RH}_\infty^{p\times m}$ is given in [1]

Conclusion and Future Work

- AW integrated Fault-tolerant control is proposed to deal with RW saturation.
- The saturation in the momentum of the wheel causes the limit in torque produced by the wheel.
- Fig a indicates the Angular velocity performance without the proposed AW integration where the angular velocity on the z-axis is unable to limit its rotation.
- Fig b indicates the Angular velocity performance with the proposed AW integration where the angular velocity on the z-axis is maintained within 10 deg/s. A precesion controller can then be applied to completely attenuate the rotation.
- Simulation results show improved performance during saturation.
- A comprehensive design based on the proposed method would be incorporated to account for several faults and disturbances in the satellite system.

Simulation Results

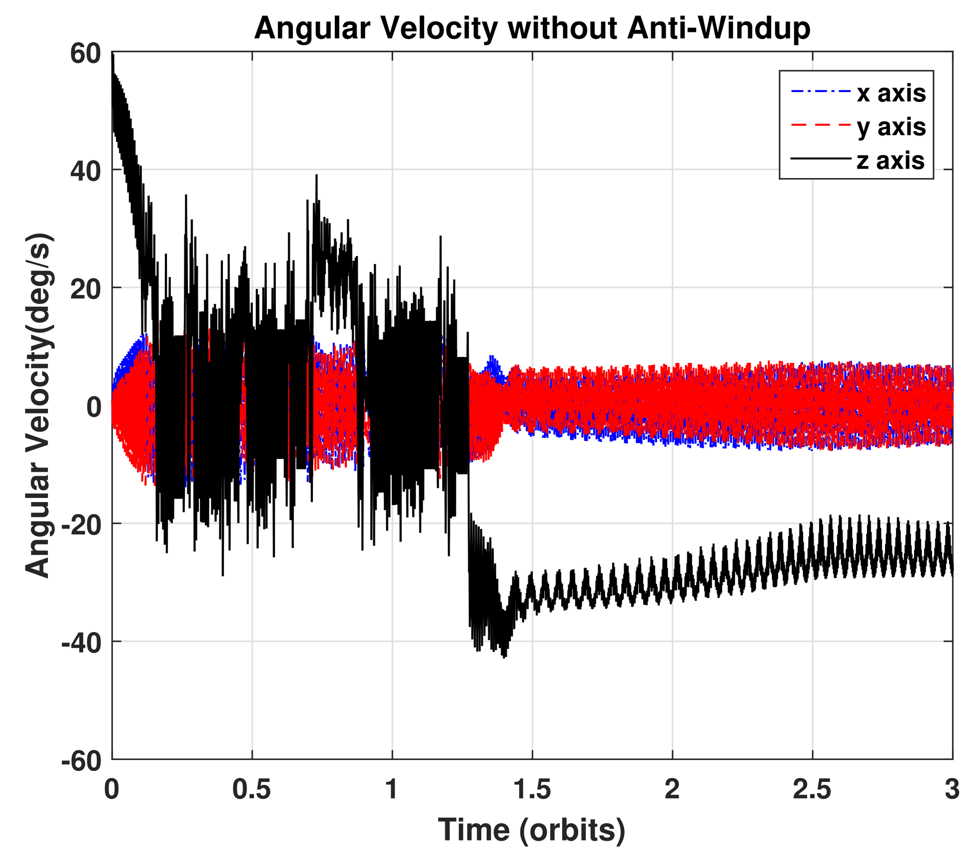

Figure: a

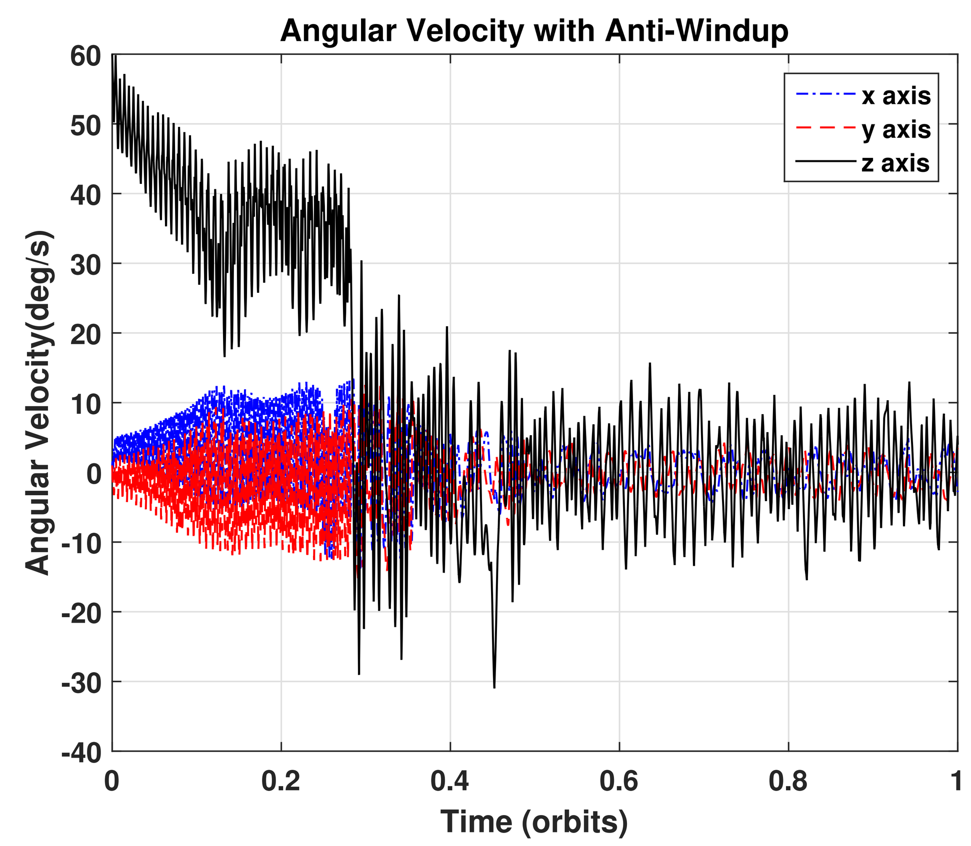

Figure: b

References

[1] Nkemdilim A Ofodile and Matthew C Turner. Decentralized approaches to antiwindup design with application to quadrotor unmanned aerial vehicles. *IEEE Transactions on Control Systems Technology*, 24(6):1980–1992, 2016.

[2] Iaroslav Iakubivskyi and Et al. Coulomb drag propulsion experiments of estcube-2 and foresail-1. *Acta Astronautica*, 2019.