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HARDWARE-IN-THE-LOOP SIMULATION FRAMEWORK FOR CUBESATS PROXIMITY OPERATIONS: APPLICATION TO THE MILANI MISSION

Abstract

Milani is a 6U CubeSat that will be released by Hera in proximity of the Didymos binary asteroid. Milani will demonstrate autonomous GNC capability for CubeSats in deep space enhancing the scientific outcome of the mission. The Deep-space Astrodynamics Research and Technology (DART) Group at Politecnico di Milano is responsible for the Milani Mission Analysis, GNC and Image Processing (IP) design. Operations in proximity of minor bodies demand high levels of autonomy to achieve cost effective, safe, and reliable solutions. The On-Board Software has a central role in these applications, thus it must be extensively tested and validated to satisfy mission requirements and to guarantee robustness to uncertainties. A robust and standardized methodology to design, validate, and test vision-based AOCS algorithms is fundamental to achieve fast prototyping while facing at the same time limited availability of resources and time. This paper presents a modular and flexible approach, developed by DART Group, used to validate Milani's GNC algorithms with camera-and processor-in-the-loop simulations. This framework is characterized by three elements: 1) a functional engineering simulator for six-degrees-of-freedom closed-loop simulations, 2) a vision-based navigation test-bench for camera-in-the-loop simulations, and 3) a single-board computer to test the algorithm in a representative environment of the on-board computer. The first element is the modular CuBesat ORbit and Gnc (CUBORG) tool, developed in MATLAB/Simulink at DART Lab. This contains a high-fidelity model of the environment suitable for simulating different operative scenarios, and a digital twin of the spacecraft AOCS. The modularity adopted during the implementation allows to easily switch from one configuration set, in terms of sensors, actuators and AOCS software modules, to another, with minimum effort. Camera-in-the loop simulations are performed with the in-house developed Tiny Versatile 3D Reality Simulation Environment (TinyV3RSE). It is composed of a high-resolution screen which displays synthetic images as seen from the probe during the mission, and stimulates, through a collimator, the camera mounted in the facility. The third element is a Raspberry Pi which is selected as external board to run processor-in-the-loop simulations. The proposed approach shows testing and validation for the Milani GNC and IP, assessing consistency and robustness against real hardware limitations. These results also represent a step forward in proving the feasibility of on-board implementation, thus enabling autonomous GNC capability for CubeSat platforms in deep-space missions.