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Title

Optimising ConOps of Water Electrolysis Propulsion systems using Deep Q-Learning

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Abstract

Water electrolysis propulsion (WEP) systems produce gaseous propellants in-orbit by decomposing stored liquid water into hydrogen and oxygen by using an electrolysis unit supplied with electrical power. This enables the usage of water as a safe and green propellant while delivering higher performance capabilities compared to current hydrazine-based propellants. The propellants produced can be used in a multi-mode setup, including chemical (combustion and cold gas) and electrical means of propulsion.
However, the additional propellant production introduces elements of complexity to the system. Considering the temporal domain, the propellants need to be produced and stored before performing propulsive manoeuvres. Furthermore, the electrolyser and the thruster both have operational envelopes with affiliated efficiencies that interact with each other, but also with the spacecraft and its mission status. To use the on-board resources efficiently and effectively, a well-coordinated Concept of Operations (ConOps) is required that considers the envelopes and efficiencies mentioned.
To address this challenge, the paper at hand presents a novel approach for deriving and optimising the Spacecraft's Propulsion ConOps using reinforcement learning. This approach uses a videogame-like simulation environment that contains a digital twin of a spacecraft incl. its WEP system and is coupled with an orbit propagator. The environment is wrapped to fit the OpenAI 'gym' API, easing comparability and providing reference cases for validation of the implemented algorithms. Building on and interacting with this environment, an agent is trained using Deep Q-learning (DQN). Within DQN, such an agent approximates a Q-function, that maps the state of the environment to actions that maximise a reward function.
The paper shows, that such an agent can achieve the objectives set by this reward function. The function can be adapted to favour varying qualities such as minimising propellant resp. power consumption or time-to-target orbit. Initially, the resulting ConOps is analysed on a mission scenario incorporating a de-orbit of a CubeSat using WEP, already described in a previous publication [1]. The optima derived and the corresponding component interplay and behaviour of the WEP system is described and discussed.

References

[1] Dengler, S.; Ebert, F.; Leichtfuß, S.; Manfletti, C.: Water Electrolysis Propulsion in CubeSats : A case study, 8th International Conference on Space Propulsion (SPC), Estoril, Portugal, May 2022