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AUTONOMOUS IMAGE-BASED NAVIGATION IN CISLUNAR ORBITS VIA META-REINFORCEMENT LEARNING

Abstract

Spacecraft navigation is a vital component of any space mission. Conventionally, spacecraft are guided by onboard sensors and communication with ground-based tracking stations. These data are utilized within a navigation algorithm, typically the Kalman filter, to ensure the spacecraft stays on its desired trajectory. However, with the increasing trend toward autonomous spacecraft missions, new navigation methods are being developed to provide a more efficient, flexible, and robust solution. Image-based navigation is a promising solution for autonomous real-time navigation applications in deep space exploration missions. It involves computer vision techniques and mathematical models to determine the spacecraft's position, velocity, and orientation based on images taken by the onboard cameras. Traditional algorithms for image-based navigation include feature-based navigation and structure-from-motion. However, these methods typically require high onboard computational power and the availability of high-resolution images, which can be challenging to obtain in certain low-light or limited-visibility conditions. Recently, meta-reinforcement learning (meta-RL) has emerged as a promising approach to autonomous spacecraft guidance, navigation, and control in various challenging mission scenarios. Meta-RL is a type of reinforcement learning that enables an agent to learn how to adapt its policy based on past experiences to achieve better performance in new, unseen tasks. In this paper, meta-RL is applied to autonomous image-based spacecraft navigation by employing a convolutional-recurrent neural network as a trajectory estimation policy. A recurrent network is a type of neural network that has feedback connections, allowing it to incorporate and store information from previous time steps. In the context of image-based navigation, the convolutional-recurrent network can be used to process the last image data and combine it with the information about the past spacecraft's trajectory to adjust its estimate of the current spacecraft's state accordingly. With meta-RL, the agent can learn to adapt seamlessly to changes in the environment, such as different lighting conditions or the appearance of new features on the celestial body's surface, as well as deal with noise on the collected images and an inaccurate dynamical model. Furthermore, once trained on high-performance computing hardware, the network can be integrated onboard and used in real-time, thanks to its short in-flight computational times. This framework is applied to the autonomous navigation of a spacecraft along an L2 south Halo orbit in cislunar space. A simulated lunar environment model

is created using the 3D computer graphics software Blender to generate realistic images of the moon as taken by a camera onboard the vehicle.