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Author: Mr. Matteo Stoisa
AIKO S.r.l., Italy, matteo@aikospace.com

Mr. Luca Romanelli
AIKO S.r.l., Italy, luca.romanelli@aikospace.com
Mrs. Federica Paganelli Azza
AIKO S.r.l., Italy, federica@aikospace.com
Mr. Pietro De Marchi
AIKO S.r.l., Italy, pietro@aikospace.com
Mr. Mattia Varile
AIKO S.r.l., Italy, mattia@aikospace.com

AUTONOMOUS AND ROBUST LOW-THRUST ORBIT TRANSFERS VIA DEEP REINFORCEMENT LEARNING

Abstract

The progress of space operations together with the expanding space economy introduces many complex challenges. Solid reliability and optimal performance are crucial requirements. Scalability represents a new key objective, pushed by tech advancements such as the hardware miniaturization. As a result, there is the need to reduce human interaction, not only to address the well-known space communication difficulties, but also to simplify operation management. Thus, the improvement of traditional approaches into methods with a higher degree of autonomy is an already ongoing process that meets these requirements. Autonomous operations will be beneficial in a wide range of mission scenarios regarding planetary and interplanetary operations, constellation management, up to the deep space exploration frontiers. In particular, autonomous Guidance and Control (G&C) systems will be a crucial technology in applications such as low-thrust orbit transfers, station keeping, rendezvous and deep space maneuvers.

Our aim is to develop a generalizable framework for autonomous G&C. In this work, a low-thrust orbit transfer in LEO is addressed as the initial application scenario. This problem is chosen due to its several challenges, such as the need for robust uncertainty management and real-time computation. We propose an AI-based solution capable of autonomous and robust on-board G&C. The core of our approach leverages a Deep Neural Network (DNN) trained using Reinforcement Learning (RL) techniques, which have already proven their effectiveness in numerous control tasks. In particular, our method aims at enhancing a traditional guidance approach by managing environmental perturbations such as physical model uncertainties, disturbances in the control actuation and navigation subsystem.

In our discussion, we summarize the state-of-the-art in low-thrust G&C technologies, with particular attention to the guidance algorithm used as the baseline for our solution. Then we describe the selected use case in terms of physical model and simulation environment. Afterwards, we introduce the RL framework formalizing the problem as a Markov Decision Process, describing its implementation and the choices made. Then, we present the achieved results, analyzing and comparing statistics. In particular, the algorithm's behavior is investigated through different maneuver profiles by assessing the effects of different external perturbations. Finally, conclusions are presented together with the roadmap for further development.