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MACHINE LEARNING-BASED MODEL PREDICTIVE CONTROL MOTION PLANNING FOR AUTONOMOUS ON-ORBIT ASSEMBLY

Abstract

Building complex space structures, such as the Lunar Gateway, in deep space is vital for the future of space exploration and the long-term colonization of other planets. The communication challenges due to long distances, harsh environments, launch vehicles' size and mass limitations, and the need for on-site assembly of structures manufactured in space with in-situ obtained materials make autonomous on-orbit assembly operation a crucial technology for this purpose. To move toward autonomy, the development of online motion planners becomes a priority, where the Model Predictive Control framework is superior in this domain. At the same time, machine learning techniques open up new horizons for designing autonomous systems. This paper proposes a novel method integrating machine learning techniques with the model predictive control to perform on-orbit assembly autonomously using a robotic spacecraft.

The presence of many active spacecraft and structure modules in the assembly environment requires multiple large-scale optimal control problems with collision avoidance constraints to be solved onboard multiple times in the model predictive control framework. Our research previously addressed the need for a fast, nonconservative collision avoidance technique for space structures in close proximity, commensurate to on-orbit assembly environments, which resulted in a large-scale optimal control problem in a self-assembly operation. In this work, a machine learning architecture, which is trained using the datasets obtained from the high-fidelity model developed in our previous research, is proposed to predict a set of optimization parameters in the large-scale optimal control problem to accelerate computations for online planning. More specifically, the proposed machine learning architecture is trained on a dataset generated from the shape, size, position, and orientation of space structures present in the assembly environment to predict the closest point of each space structure with respect to the other one; hence the minimum distance between each space structure pair. This approach reduces the number of optimization parameters in the respective optimal control problems and speeds up computations drastically. The resulting neural network is later utilized within a model predictive control's prediction horizon to propose a fast online motion planner for autonomous on-orbit assembly. Numerical simulations demonstrate that the proposed architecture maintains a generalization error of less than 5% of the corresponding structure's size in closest points predictions. Finally, the online motion planner is applied to an autonomous on-orbit assembly of a complex space structure using a robotic spacecraft to show the efficiency and capability of the proposed approach.