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LSTM-BASED FAST PREDICTIVE GUIDANCE FOR AUTONOMOUS SAFE DOCKING WITH PATH AND CONTROL CONSTRAINTS

Abstract

The presented work addresses the complexities of the autonomous spacecraft rendezvous and docking, for operations such as On-orbit Servicing, and deorbiting decommissioned satellites, which involves meeting the stringent requirements during the docking operation. This work presents a novel approach of fast computational guidance by integrating LSTM (Long Short-Term Memory) based predictive neural network with Model Predictive Static Programming (MPSP) for optimal motion planning while incorporating the path and control constraints associated with the docking process. The path constraint is formulated as the critical approach cone and permissible relative state constraints. The MPSP provides the framework to solve the finite horizon non-linear optimal control problem with hard terminal requirements without the need to linearise the dynamics by transforming the dynamic programming optimisation into an equivalent static programming problem where a static adjoint variable is needed to update the entire control history. The constraints of the mission are applied by converting the whole problem into control variables and state constraints are reshaped into equivalent control constraints. These constraints are pivotal in ensuring the safety and success of docking maneuvers, requiring precise control and prediction of the spacecraft's position and velocity within a predefined safe zone.

The traditional system propagators have proved to be computationally heavy for complex systems with a large number of state variables. To mitigate this issue, we present a novel integration of the Long Term-Short Memory (LSTM) network, trained on spacecraft data to learn the underlying system dynamics, along with MPSP to increase the efficacy of the algorithm. The traditional RNNs (Recurrent Neural Networks) faced the issue of vanishing gradient during back-propagation, especially in long sequences. This complication was addressed by the LSTM network through additive gradient structure and its direct access to the forget gate activation, thus enabling it to learn long-term dependencies in the large sequence which is very much needed to infer how spacecraft dynamics evolve during time. This LSTM-based propagator offers an efficient alternative while maintaining high accuracy in predicting system based on the previous state and control input. The predictive capability, rooted in LSTM's proficiency in handling sequential data, allows for anticipatory adjustments to the control strategy, thus improving the robustness and reliability of the docking process.

The presented methodology is validated through a series of simulations that prove the benefits of the combined MPSP and LSTM approach in navigating complex space rendezvous missions.