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INVERSE REINFORCEMENT LEARNING FOR COLLISION AVOIDANCE AND TRAJECTORY PREDICTION IN DISTRIBUTED RECONFIGURATIONS

Abstract

Distributed space systems composed of several micro-satellites flying in formation are becoming increasingly attractive for the space community. This concept can significantly impact the capabilities of micro-sats mission (e.g. distributed EO, distributed antenna, etc.), enhancing flexibility and reducing mission failure points. The possibility to reconfigure allows the adaptation of the system configuration to meet several different scientific objectives in a single mission. Nevertheless, the actual breakthrough in performance is achieved only with high-grade autonomy of the agents. The satellites must be able to coordinate, reconfigure or maintain their relative position in order to fulfill the scientific objectives imposed by the mission. Accurate planning and maneuver execution must be worked out, coping with low computational power. One critical task for distributed operation is to safely maneuver avoiding collision between agents. In a distributed architecture no information is globally available on the planning of each agent with respect to the formation, therefore each spacecraft need to predict future maneuvers of potentially colliding agents. A novel approach is here presented where Inverse Reinforcement Learning (IRL), often referred as Inverse Optimal Control (IOC), is employed for trajectory prediction of neighbouring satellites. The algorithm solves an inverse optimal control problem using the Feature Matching Approach (FMA) based on sampled observations to reconstruct the cost function of the maneuvering spacecraft. The direct optimal control problem is solved based on the estimated cost function to predict the trajectory of the spacecraft. The predicted trajectory is used by the spacecraft to adapt its guidance for a safe reconfiguration. The algorithm performs well in trajectory prediction: by using less than 5 measurements of relative distance between objects, the prediction reaches an accuracy of ~ 10 m in the worst case. Such accuracy is assumed to be below the safety ellipsoid that represent the collision avoidance constraint for reconfiguration and formation keeping. The paper discusses the achieved performance of the trajectory prediction algorithm through numerical simulations in relevant orbital environment. Moreover, the trajectory prediction is integrated and validated for collision avoidance in a numerical simulation for distributed reconfiguration maneuver with a high-fidelity orbit propagator. Additionally, results from Hardware-In-the-Loop (HIL) tests are presented, using representative computational power to demonstrate the feasibility of on-board implementation. The presented methodology enhances the autonomy of each individual spacecraft providing the capability of reconstructing the formation dynamics with only relative distances measurements.