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NONLINEAR OPTIMAL FEEDBACK CONTROL DESIGN FOR SAFE RENDEZVOUS AND PROXIMITY OPERATIONS

Abstract

The main focus of this paper is on developing nonlinear optimal feedback control laws for spacecraft rendezvous and proximity operations (RPO). RPOs are critical for in-space servicing, assembly and manufacturing (ISAM) missions, which may include inspection, repair, refuel, upgrade or assembly activities. Though there have been a lot of developments in generating open-loop trajectories for RPOs, a very little attention has been paid to the design of optimal nonlinear feedback control laws which guarantee safe RPO in presence of model as well as navigation errors. This work will utilize recent advances in uncertainty quantification (UQ) and sparse machine learning (ML) to develop nonlinear optimal guidance laws while solving the Hamilton-Jacobi-Bellman (HJB) equation in a prescribed domain of interest. A non-product quadrature scheme is used to optimally sample the domain of interest representing model and navigation errors around a nominal trajectory. The conjugated unscented transformation (CUT) approach judiciously selects special structures to extract symmetric quadrature points constrained to lie on specially defined axes in a multi-dimension space and hence avoids tensor product of 1-D points. Sparse ML tools are used to derive a parsimonious model that can parameterize a family of trajectories as a function of mission parameters. An important challenge in any parameterization stems from the choice of basis functions to accurately represent the inherent input-output mapping. A small number of units may not be enough to capture the underlying true mapping and alternately a large number of units bring the risk of overfitting the data. Prevalent ML methods such as multi-layered neural networks (NNs) (also known as deep NNs) focus on improving the approximation accuracy in a brute force manner by increasing the number of basis functions, local models and/or layers of the network. There is no doubt that the choice of basis function significantly influences the approximation accuracy and complexity of the model. In this respect, this work will focus on adapting the architecture of the network by selecting appropriate models from a pre-defined dictionary of models through the application of tools from compressed sensing and sparse regression. This results in a convex optimization problem with a guaranteed solution, known as the sparse collocation method. Various numerical simulations will be conducted to showcase the efficacy of the developed control laws for safe RPOs. State inequality constraints will also be incorporated in the control design formulation to define safe corridors around the target space structure.