Paper ID: 41406
oral
student

ASTRODYNAMICS SYMPOSIUM (C1)
Attitude Dynamics (2) (2)

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ADAPTIVE SPACECRAFT ATTITUDE CONTROL WITH INCREMENTAL APPROXIMATE DYNAMIC PROGRAMMING

Abstract

This paper presents an adaptive control technique to deal with attitude control problems for spacecraft disturbed by internal liquid sloshing. Unknown liquid sloshing causes unobservable internal dynamics. A typical case is that the liquid in the fuel tank sloshes around and changes the internal dynamics. The forces and torques acting onto the spacecraft will slosh the fuel around. The fuel will, in turn, interact with the fuel tank and thus produce additional forces and torques to the spacecraft, which degrades the performance of attitude control systems. In order to improve the performance, a model-free nonlinear self-learning attitude control method is necessary.

Reinforcement Learning (RL) controllers have been proposed to solve adaptive, optimal control problems without using accurate system models. In the control field, RL is also referred to as Approximate Dynamic Programming (ADP), which applies function approximators to solve problems with continuous state and action spaces and to tackle the 'curse of dimensionality'. A widely used model-free ADP method for linear systems is the Linear Approximate Dynamic Programming (LADP) method. This method utilizes a quadratic cost-to-go function and adaptively learns it online. Because of the simple quadratic function, it is efficient and gives a complete and explicit solution to optimal control problems. Although the merits of model-free processes and efficiency of resource usage make LADP controllers suitable in the field of adaptive control, LADP methods are difficult to apply to nonlinear systems or time-varying systems. Incremental control methods, on the other hand, can deal with system nonlinearity without identifying the global system. The incremental form of a nonlinear dynamic system is a linear time-varying approximation of the original system assuming a sufficiently high sample rate for discretization.

This paper develops an innovative model-free nonlinear self-learning attitude control method based on incremental Approximate Dynamic Programming (iADP) to enhance the performance of the spacecraft attitude control systems. This method combines the advantages of LADP methods and the incremental nonlinear control techniques and generates a model-free, effective controller for unknown, time-varying dynamical systems. This algorithm is applied to the attitude control of a spacecraft disturbed by internal liquid sloshing. The result shows that the proposed method deals with the unknown, time-varying internal dynamics adaptively while retains the attitude control accuracy and efficiency of the LADP algorithm.