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UNSATURATED MAINTENANCE AND RECONSTRUCTION OF HIGH SPECIFIC IMPULSE SPACECRAFT FORMATION

Abstract

High specific impulse (Isp) spacecraft appear to be promising and effective for interplanetary missions; however, practical limitations result in the small magnitude of their thrust. Usually, the control thrust domain of a high Isp spacecraft is a small axisymmetric bounded region, which may even be non-convex and time-varying in some cases. The non-convexity makes absolute control of spacecraft formation tend to keep the error in the error box with intermittent control, because of mismatch between control capabilities and control requirements. Much of the available research in the micro-thrust domain problem focuses on the adaptive adjustment of control parameters or controller stability proof with input saturation under the condition of a simple time-invariant convex control domain. Nevertheless, the issue of relative control problem of the complex time-varying micro-thrust domain has not yet been addressed in the astrodynamics community.

The relative control approach is developed for superior properties in its control domain by differentiating the control domain between formation members. For example, the irregular spherical shell control domain of the sail-type spacecraft can be converted into a convex solid relative control region. Considering that high magnification control saturation is detrimental to control, this work aims to develop a novel approach for maintaining and reconstructing control problems in formations without harmful control saturation via the theory of positive invariant (PI) set and the physics-informed neural network (PINN). The relative control domain is initially described as a time-varying polyhedral set with the desired precision. Considering the presence of imaginary eigenvalues in the system matrix of the relative motion dynamics equation, the positive invariance condition with overshoot in a specified region of the controlled system is derived using linear programming theory. Hence, the control matrix within the specified polyhedral control domain can be distinguished to ensure system convergence without control saturation. For faster reconstruction path planning, a PINN is adopted to design the reconstruction path. By reducing the residual term of the relative motion dynamics and the saturation of control, the PINN enables rapid planning of reconfiguration paths that meet control constraints. For better precision, the control value generated by PINN and the aforementioned control feedback are homotopy based on the distance.

As an illustrative example, our proposed approach can achieve rapid and accurate transverse formation maintenance and reconstruction without control saturation, parameter optimization, and long-term planning. This approach is compatible with the results obtained by the traditional projection method (Ivanov et al., Acta, 2018).