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FRACTIONAL PID CONTROL OF SPACECRAFT ATTITUDE DYNAMICS USING ROTATION MATRICES

Abstract

A fractional PID feedback controller is proposed for rigid spacecraft rotational dynamics on the tangent bundle of SO(3), which is the Lie group of rigid body rotational motion, using states consisting of a rotation matrix and an angular velocity vector in the fractional order derivative and integral feedback terms. Using the rotation matrix avoids the use of attitude parameterizations and their accompanying issues of non-uniqueness, unwinding, singularities, and discontinuous controllers and has been shown to have significant advantages in spacecraft attitude control and estimation. Almost-global asymptotically stable Liapunov-based controllers utilize Liapunov-Morse functions, which have isolated critical points on the manifold TSO(3). In fractional PID control, the orders of the state's derivative and integral in the controller are not restricted to integer values, while the resulting closed-loop system is in the form of a fractional integro-differential equation. The fractional order terms in the controller are approximated using a backward fractional differencing technique. To integrate the kinematic differential equation for the rotation matrix, a fourth order Runge-Kutta scheme is used which is more accurate than, for instance, forward difference integration schemes used in the literature. Using the proposed controller, the system states are shown to go to the desired equilibrium state asymptotically. That is, the spacecraft attitude aligns with a desired attitude with a vanishing angular velocity. The performance of the controller is studied for different values of the derivative and integral fractional orders in terms of control effort, transient and steady-state response characteristics, and robustness to unmodeled disturbances and the results are compared with those of an integer order controller. It is shown that the inclusion of fractional orders in the controller allows for a desired shape and spectrum of the controlled response to be obtained by tuning the fractional derivative and integral orders. For instance, the overshoot, settling time, and control effort may be simultaneously reduced in contrast to the case of integer PID control in which a trade-off exists between these competing design specifications. The proposed fractional PID feedback attitude control strategy thus allows for a greater degree of flexibility over its integer order analogue.