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KINEMATIC STEERING ENABLING SPEED-CONSTRAINED THREE-AXES ATTITUDE CONTROL

Abstract

Three-axes spacecraft attitude control continues to be an active area of research. Extensive work has been performed on both nonlinear and linear attitude closed loop solutions. Such control solutions seek a stabilizing control torque which drives both the attitude and rate errors to zero. In essence, the linearized closed loop dynamics resemble mathematically a spring-mass-damper system. A particular challenge of the attitude feedback control development is handling complex rigid body kinematics simultaneously with the rigid body kinetics equations. For example, popular non-singular control solutions are developed for quaternions or Euler parameters or Modified Rodrigues Parameters (MRPs). If Lyapunov's direct method is employed to argue closed loop stability, care must be given in how the Lyapunov candidate function is formulated to provide insight into both the convergence of attitude and rate errors.

In contrast, the robotic control community often employs a very different approach. Their multi-link manipulator equations of motion are much more complex than those of a single rigid body. Instead of developing a torque level control to achieve the desired tracking, a kinematic steering control is implemented where the rates are treated as a control variable in an outer control loop. To implement such a kinematic control, an inner speed control loop is required that has a much faster response time than the outer loop. Using the separation principle stability is examined by arguing that each loop individually is stable. In the field of spacecraft attitude control the use of steering laws is common when employing single-axis Control Moment Gyroscopes (CMGs). Here the control solution is written in terms of the gimble rates, not in terms of gimbal axis torques. An inner control loop is assumed to track the desired gimble rate trajectory.

This paper investigates creating kinematic steering laws to achieve novel three-axis attitude control laws. Lyapunov's direct method is employed on the kinematic differential equation to establish necessary outer loop stability conditions. Specific implementations using the MRPs and the Principle Rotation Vector (PRV) components are developed that enforce pre-specified spacecraft rotational speed limits on the nominal closed loop control. Next, a spacecraft angular velocity vector based closed loop servo control is investigated for the inner speed servo loop. Robustness modifications using integral terms are considered to reject unmodeled external torques. Numerical simulations illustrate the resulting performance, and the ease with which the steering law feedback gains can be selected.