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ABSTRACTS (PH D THESIS)

Satisficing Nonlinear Spacecraft Rendezvous Under Control Magnitude and Direction Constraints

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We treated the satellite formation and reconfiguration problem subject to constraints on control magnitude and direction. Firstly, the necessary condition of the optimal controller under these constraints was derived using a sequential smoothing method, in which a sequence of unconstrained optimal control problems was solved according to Pontryagin's Minimum Principle by introducing multiple barrier functions to the original performance index. By introducing the proposed additional barrier function concerning the constraints on control direction, the derived equations for the necessary condition with respect to optimal control magnitude and direction became decoupled, thereby facilitating their solution. The solutions converged toward solving the original problem and strictly satisfied the treated constraints as the perturbation coefficients of the barrier functions approached zero. Optimal controllers were successfully formulated in the $L1$- and $L2$-norm problems, and both solutions for the optimal control direction had the same form. These solutions are a natural extension of the solution with only the magnitude constraint. As the perturbation coefficients of the barrier functions approach zero, the smoothed optimal controller approaches the boundary of the inequality constraint near Lawden's primer vector, while the control, the primer, and the admissible direction vectors are coplanar. This extremal property is completely consistent with the result whereby the optimal thrust is directed along the projection of the primer vector onto the boundary of the restricting set. Numerical simulations demonstrated that the sequential optimal controller subject to such mixed constraint was obtained by solving the two-point boundary value problem with the shooting method in non-coplanar circular and coplanar eccentric orbits. In addition, the control angles of the derived solutions were confirmed as suppressed within the control direction constraint.

Secondly, we examined how to maintain a small-magnitude thrust angle based on continuous optimal feedback control for the problem of satellite rendezvous. Consider-ing the constraints on the parameters set in the general quadratic performance index, a control design process was proposed using modal analysis to make the thrust angle small at the initial and final phases. Using a candidate control Lyapunov function (CLF) by solving the Riccati equation for the performance index considered, a new control applying the satisficing method was devised to meet the constraints strictly from start to finish. If the limitation angle is small, the devised control may become null transiently because the candidate CLF is not strictly defined. However, this paper showed that thrust angle can be practically maintained and that the control law leads to convergence at the origin in some simulations. Extending the theory to an eccentric orbit and time-varying system was explained and numerical calculations showed effectiveness.

Although the application of two-dimensional plane motion was discussed, this technique can be extended to the design method, including out-of-plane motion. This method can also be applied to nonlinear control problems and extended to multiple control constraints, such as sensor field of view sun direction. In addition, we took steps to improve satisficing theory under input constraint. A constraint-satisficing scheme was newly proposed by introducing two barrier functions and it was shown that when the positive coefficients of both barrier functions approach zero, the constraint-satisficing set smoothly attained the intersection of the unconstrained satisficing and input constraint sets. A simple and effective nonlinear controller was proposed with the projected control as member of the constraintsatisficing set. By adopting the value function in the constraint-free case as a constraint control Lyapunov function, and choosing appropriate weight matrix parameters, the state trajectory converged to the origin; strictly satisfying the input constraint in the final phase. For the proposed controller, linearized stability analysis was investigated using a graphical description plot used to assist in designing certain practical rendezvous trajectories. It was found that when starting periodic orbit, the local subspace was widely covered by the region of attraction, provided highly

damped modes were stable.

Although the effectiveness of the proposed design was verified in the nonlinear affine system, the same satisficing approach can be easily extended to a time-varying system when the target orbit is elliptic.