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Title

An Indirect Estimation Approach of Underactuated Evader Strategy for Orbital Pursuit-evasion Game

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Abstract

Spacecraft orbital pursuit-evasion game (PG) has received increasing attention in recent years because of its promising applications in removing space debris or approaching out-of-control spacecraft. This paper investigates the short-distance orbital PG problem for underactuated spacecraft with incomplete-information. Different from the existing fully-actuated game strategy [1], we analyze the feasibility of the spacecraft game without radial or along-track thrust and design the underactuated game strategy.

The main contributions are threefold: Firstly, for the case without radial control, PG is feasible without additional conditions; for the case without along-track control, PG is conditionally feasible and only applicable to some scenarios such as spacecraft rendezvous, on-orbit servicing, and approach of out-of-control spacecraft. The dynamics constraints of game capture positions are derived based on nonlinear and linear orbital dynamics for both underactuated cases. Notably, there exists no position where the evader can reach but the pursuer cannot. Secondly, an underactuated zero-sum equilibrium game is proposed with minimal interception cost as the objective. By using differential game theory, the underactuated saddle-point strategy pairs of plays (i.e., pursuer and evader) for either case with complete information are derived. Finally, compared to previous direct estimation methods for evader control parameters [2], we propose an indirect estimation approach, which is more suitable for engineering applications. To be specific, it is assumed that the pursuer can observe the state information and the tail flame of the evader through the Kalman filter method and some on-board sensors, from which the pursuer can obtain an estimate of the acceleration for evader. Then, a new differential Riccati equation is constructed to solve the saddle point strategy of the pursuer and the escapee. The indirect estimation approach can estimate the time-varying parameter of the evader with only one filter, while the multiple model adaptive control method running a bank of filters in parallel can only estimate the static parameter [2]. More importantly, the idea of the indirect approach can also be applied to the linear quadratic regulator approach to estimate the control parameters indirectly.

References

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