博士論文（要約）

Study on Model Predictive Control for Flyby Space Mission

(フライバイミッションにおけるモデル予測制御に関する研究)

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Abstract

Our solar system has millions of asteroids and comets. Asteroids and comets are important entities that elucidate the origin and formation of our solar system. There are various methods to explore asteroids and comets. A flyby mission is one of the attractive space exploration missions. A flyby mission is an exploration mission to send a spacecraft to asteroids or comets and acquire scientific data by taking images while crossing close enough. A spacecraft must track a target while crossing close enough at high speed. Flyby space missions have conventionally used a PID scheme to control the direction of scientific instruments so far. Future flyby missions are planned to explore the target at a higher relative velocity than conventional missions. The conventional controller cannot track the target in future high-speed flyby missions. Therefore, a precise and robust control method is required to achieve future high-speed flyby missions. This thesis focuses on Model Predictive Control to develop a precise and robust control method for a high-speed flyby mission.

Model Predictive Control (MPC) is one of the control methods for a discrete-time system. The constraints are particularly severe for space missions. It is required to control while satisfying the constraints. Model predictive control is reported to be an optimal control method under the constraints. A satellite attitude and orbit control in space applications is one of the applications of model predictive control. The predictive control algorithm based on numerical models is reported as an effective solution for satellite systems dynamics. The optimal controller for model predictive control is necessary to consider control performance and robustness. This thesis addresses the approaches for the optimal controller design considering the control performance and robustness. This thesis also proposes a new model predictive control scheme for the precise and robust control of a flyby mission.

In Chapter 3, the weight selection algorithm for MPC satisfying the user's requirements is proposed. The control performance can be improved without increasing computational cost by optimally selecting weight matrices used in the evaluation function. The new evaluation function for the proposed algorithm with SPSA is also designed by using overshoot and settling time as the user's requirements. The proposed algorithm can provide a new scheme to select the control parameters according to the requirements. Simulation study is conducted to confirm the effectiveness of the proposed algorithm as an example of attitude control of the zero momentum spacecraft. The proposed algorithm can select the weight matrices that accurately satisfy numerical values based on simulation results.

In Chapter 4, the expanded form of MPC with the cross product term is proposed. Simulation study is conducted to evaluate the effectiveness of the cross product term as an example of attitude control of the zero momentum spacecraft. The improvement of control performance by the cross product term is confirmed by simulation results. Since the control performance can be improved by changing one coefficient to the cross product term, the weight in the Multiple Input and Multiple Output system can be easily selected.

In Chapter 5, the robust MPC based on Disturbance Accommodation Control (DAC) is proposed for rejecting the influences of disturbances. The internal disturbance in a spacecraft is generated by attitude control wheels, gyros, solar cell paddle drives, mechanical scanning antennas, and refrigerators. Since the internal disturbance directly affects the control system, it is necessary to reject the influence of the internal disturbance. Simulation study is conducted to confirm the rejection of the influence by the robust MPC based on DAC as an example of attitude control of the zero momentum spacecraft. The proposed robust MPC based on DAC can reject the influence of disturbance without increasing computational cost.

In Chapter 6, the proposed MPC is applied to a flyby mission called DESTINY$^+$ to evaluate control performance and robustness. Simulations using parameters of DESTINY$^+$ compare the conventional controller and the proposed MPC. The control performance is evaluated using slip angle during the exposure time. If the slip angle is small, it is possible to track with reduced blur. Simulation results show that the proposed MPC is more effective than conventional control. The robustness is evaluated for a periodic disturbance in the tracking system of the spacecraft. Even if there is an error in the estimated trajectory, the proposed MPC can track the asteroid while considering the angular velocity constraint.

In chapter 7, the conclusions of this thesis and the future directions are discussed.