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主論文の要旨

論文題目　**Nonlinear optimal flight control design under various constraints**
(様々な制約の下での非線形最適飛行制御の設計)

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論文内容の要旨

The developments of unmanned aerial vehicles (UAVs) have attracted many researchers recently. Although a large proportion of significant development stays in military sector, the growth of UAVs in civil uses can be observed, such as aerial surveillance, terrain mapping, rescue mission, goods deliver and so on. Depending on requirements of each task, a specific type of UAVs is preferred: fixed-wing configuration is used in mission that requires high cruise speed, while rotary-wing one is proven to be superior in mission that requires hovering flight. Along with traditional fixed-wing and rotary-wing UAVs, tilt-wing one is also being developed. It can preserve strengths of fixed-wing and rotary-wing configurations in one while eliminating their weaknesses. However, controller design for tilt-wing UAV is not an easy task due to its complex structure and the natural nonlinearity of aerial vehicles. During the transition flight of the tilt-wing UAV, the aerodynamic characteristics change dramatically in accordance with the tilt-wing angle. Therefore, gain-scheduling technique is a promising candidate to deal with the nonlinearities of the aircraft during transition flight.

Additionally, when implementing designed flight controller to the UAV, one has to encounter many practical difficulties, one of them is the limitation of the system due to various reasons such as actuator saturation, actuator rate-limit or some performance constraints that he/she wants to achieve. When the system reaches to its limitation, for example actuator saturation or actuator rate-limit happens, the system becomes nonlinear and the controller might not be able to handle such nonlinearities. Eventually, it can lead to oscillation or system instability.

First, this thesis is concerned with the flight controller design of a quad-tilt-wing vertical take-off and landing unmanned aerial vehicle (QTW VTOL UAV). Due to the change in aerodynamic characteristics, the mathematical model at each tilt-wing angle is obtained; then, a controller candidate corresponding to each tilt-wing angle is designed. Finally, the flight controller for all tilt-wing angles is obtained by interpolating among candidates. The flight controller structure includes two control loops, i.e. the stabilization augmentation system (SAS) and the control augmentation system (CAS). Researchers in JAXA designed the CAS using PID controller. This thesis proposed a CAS design method via robust output regulation approach. Moreover, in order to further improve the tracking performance, the original robust output regulation controller is modified to include an additional feed-forward term. The gain bound of the controller is considered in order to avoid actuator saturation. The improvement in tracking performance of the robust output regulation controller compared with the PID controller is confirmed in experiment.

Second, this thesis considers the nonlinearities caused by actuator rate-limit of F-16 aircraft. The rate-limit is a well-known factor that can cause pilot-induced-oscillation (PIO) phenomenon. A nonlinear optimal flight controller is proposed to deal with the nonlinearities of the aircraft when the actuator rate-limit happens by using nonlinear optimal output regulation theory and center-stable manifold method. We focus on the PIO phenomenon in longitudinal motion caused by rate-limit of elevator. The flight controller is verified in a six degree-of-freedom simulator. It confirms that the designed controller is able to control the aircraft even when the rate-limit happens with robustness against modeling error, measurement noises and time delay.

Last, this thesis investigates a nonlinear optimal control design method to deal with a class of nonlinear hard constraints. It is an extension of the stable manifold method with the use of Lagrange multipliers to consider inequality constraints. Due to the Lagrange multipliers, the canonical Hamiltonian system becomes discontinuous. This thesis discusses the existence and continuousness of the stable manifold of the Hamiltonian system via the notion of Filippov solution. The method is verified in both simulations and experiments on different mechanical systems such as control moment gyroscopes and magnetic levitation systems.