論 文 内 容 の 要 旨

Unmanned Aerial Vehicle (UAV) has gained much attention among researchers and widely researched since the last two decades. It is expected that the application of UAVs will keep expanding and the market grows dramatically within the decade. Existing fixed-wing and helicopter UAVs can be applied to meet the demands of these missions, However, these have inherent operational disadvantages. Fixed-wing UAVs generally offers good cruise performance but require runways or special launch and recovery equipment such as catapult launchers, parachutes or nets. Helicopter UAVs can take off and land without runways but have poor cruise and payload carrying performance compared to Fixed-wing UAVs. Vertical Takeoff and Landing (VTOL) UAVs are one means to overcome these disadvantages. They can take off and land without runways like a helicopter, and cruise at high speed like a fixed-wing vehicle.

In particular, Quad-Tilt-Wing Unmanned Aerial Vehicle (QTW-UAV), which contains a combination between VTOL in helicopter mode as well as high-speed cruise capabilities in Fixed-wing airplane mode, has particularly been considered. This is considered as a possible tool for numerous fields of applications, e.g. surveillance, monitoring and scientific measurement. Japan Aerospace Exploration Agency (JAXA) has thus designed and developed a series of QTW-UAVs (McART2, AKITSU, and McART3). The aircrafts contain the ability to tilt its wing starting from vertical to horizontal position. By rotating its tilt wings, the McART3 offers an ability to smoothly shift from vertical take-off to landing while the aircraft retains its flight attitude and satisfies the trim speed requirements. The preset tilt angles are commanded through a radio control transmission operated by ground pilot. The aircraft configurations are consisted of three major modes including helicopter, conversion and airplane modes. Pitch and roll can be controlled in longitudinal and lateral-directional motion using CAS controller. In helicopter mode, pitching moment is generated by differential thrust between forward and aft propellers, rolling moment is generated by differential thrust between left and right propellers, and yawing moment is generated by aerodynamic forces on the flaperons due to propeller slipstream. In airplane mode, pitching moment is generated by deflections of forward and aft flaperons, rolling moment is generated by opposite deflections of left and right flaperons, and yawing moment is generated by the rudder and differential thrust between left and right propellers. During conversion between helicopter and airplane modes, interpolation between the helicopter and airplane control schemes. To verify the aircrafts feasibility, the flight test of AKITSU was conducted with practically sized QTW-UAV in outdoor environments. It successfully flied from helicopter mode to airplane mode, and vice versa; however, oscillatory motions were found in both longitudinal and lateral-directional motions. Likewise, for AKITSU; similar motions were found during the flight test of McART3. In particular, the oscillatory motion in the lateral-directional motions was sometimes large which increase pilot workloads to control the aircraft, and hence it should be suppressed for flight safety.

For this reason, on the one hand, this dissertation aims to tackle the previous drawbacks in McART3 flight controller design method. A design method with frequency domain constraints via reduced computational complexity for the optimization is proposed; that is, controller gains are designed by loop shaping technique within H_∞ framework, and Particle Swarm Optimization (PSO) method which is one of oriented search algorithms is used as an alternative to the brute-force method, i.e., gridding method, with small computational complexity. In particular, that PSO does not require the smoothness of the cost function with respect to design variables, nonlinear constraints, such as, admissible intervals for design variables, discontinuous cost functions, can be easily incorporated by defining modified cost functions. PSO has been applied to various design problems, e.g., non-convex optimization problems, equality/ inequality constraints optimization problems, structured controller design problem.

On the other hand, in this research, QTW-UAV prototype is developed in both hardware as well as its unique flight firmware. In attempt to design the QTW-UAV. The airplane is able to tilt both wings from 0 to 90-degree tilt angles to operate in three different configuration modes, that is; airplane, helicopter and transition modes. The aircraft parts are particularly design to meets the specific aircraft requirements. Size of the aircraft is decided by the limited length of the wind tunnel cross section area. Such that, the wing span is designed within those ranges. Therefore, the front wing span is design to be 800 mm. and the rare wing is design to be 840 mm as a canard configuration. The weight of the aircraft is approximately 6.5 kg. The propulsion system uses four high power electric motors. The flight control frameworks are designed based on the requirements of multitasking inflight process. The designed firmware is divided into four major parts; ground station, central flight controller, mechanism driver and actuators. In ground control part, two modes are available for pilot to control the airplane. i.e., direct input keyboard using Wi-Fi or long-range remote controller using radio frequency modes. The signal form ground station is sent to onboard central flight control unit. In particular, in QTW-UAV control, flaps and motors are required to separately operate in real-time as much as they can. Therefore, kernel based Operating System (OS) is required for multi-tasking process. The central flight control received commands from pilot and calculate the different flight operating condition for each actuator.

This dissertation consists of six chapters as follows;

Chapter 1 offers a short introduction to UAV, QTW-UAV and McART3 QTW-UAV which is used as a based model in this research. The next section, research problem and hypothesis, covers an existing CAS controller problems. Last the research objective is given as the strategy to solve those previous CAS controllers designed drawbacks.

Chapter 2 provides McART3 dynamical model configuration in both longitudinal as well as lateral-directional motions. In particular, CAS controller is given as a fixed-structure controller consists of only two control gains (proportional and integral gains). Hence, the derivation of McART3 model with fixed-structured controller framework is demonstrated. The next section covers fundamental theories regarding to H_∞ control combines with weighted sensitivity function with classical loop shaping technique. Last, Particle Swarm Optimization (PSO) is derived as an optimizer for proposed CAS controller design.

Chapter 3 proposes a method for CAS design in nominal model with the application of PSO. To address the drawbacks in existing design methods for Quad Tilt Wing Unmanned Aerial Vehicle (QTW- UAV), i.e., oscillatory motions and a large numerical complexity in controller gain design. Alternative design requirements are given in frequency domain which is different from existing controller design as the previously published reports from JAXA. Weighted sensitivity function from attitude command to attitude error is demanded to satisfy an H_∞ norm constraint. The applicability of proposed method is verified by CAS design for McART3 in which the target sensitivity function is given by using the gains in an existing paper. Then, as an extension, we address oscillatory suppressing CAS design. In exchange for slightly slow responses, oscillatory sup-pressing CAS gains are obtained in the latter problem.

Chapter 4 complements Chapter 3. The proposed design CAS gains are enhanced to satisfy the robust performance. To realize robust control performance of the design CAS gains against possible plant modeling errors, "multiple models approach" is applied as the same manner as the previously published reports from JAXA; however, in contrast to the previously used method, this chapter has two main contributions. The applicability of our method is first confirmed by designing common CAS gains which guarantee the robust performances of all candidate models, CAS gains that suppress oscillatory motions, which is one of the drawbacks of the previously designed CAS gains, are designed using the proposed method. The applicability of the designed CAS gains is examined by faithful nonlinear flight simulations under no gust and wind gust conditions. It is confirmed that the designed CAS gains worked well throughout the flight simulation. McART3 can fly safely in helicopter mode, airplane mode, and transition in nominal conditions as well as slightly off-nominal conditions. In particular, roll angle faithfully follows their commands in all tilt angles which represent good tracking performance in both with and without wind gust conditions. The oscillations motions are barely found in roll angles as expected and slightly slow responses are apparently found. This confirms the applicability of our designed gains which are consistent. In addition, the improvement of the performance of nominal models are further investigated when the probability density functions for the nominal models and the perturbed models are given a priori and the latter is less than the former.

Chapter 5 demonstrate the QTW-UAV prototype. In attempt to construct QTW-UAV, the overall aircraft design process is firstly implement through series of simulations e.g. airfoil, wings, fuselage, rudder, tilting mechanism. Next section covers overall manufacturing as well as aircraft assembling process. The flight control unit are developed through raspberry PI with C++ programing language. Furthermore, full system flight test is conducted in order to verify the aircraft feasibility.