Research on Key Technologies of Flight Control of Unmanned Aerial Vehicles

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Abstract: Unmanned aerial vehicle (UAV) is a kind of modern mechanical equipment with high technology level. It is widely used in many fields of society and has high value. In the current practical application process of UAV equipment, relevant technical personnel must master the key flight control technologies. In this paper, the range of available angle of attack in various typical flight states with parameter perturbation is given, which provides a key basis for ensuring flight safety.

1. Introduction

Unmanned aerial vehicle (UAV) is a kind of aircraft which uses radio remote control device or its own software automatic control device to control flight [1]. It is divided into rotor UAV and fixed-wing UAV. Multi-rotor UAV can take off and land vertically, hover freely, and has good stability and maneuverability, so it has attracted wide attention of all countries. With the increasing diversification of UAV missions, single-aircraft combat and pure manual flight mode cannot meet the daily needs of its mission. Therefore, formation flight and route planning of multiple UAVs have become an inevitable requirement. The key technology of autonomous flight of multi-UAV formation is divided into two parts: tracking control and trajectory planning of multi-UAV. The UAV tracking control part requires a complete UAV control system, and then the UAV can fly according to the given trajectory. Trajectory planning requires the connection between the given starting and ending states, as well as the time, velocity parameters and collision-free positions in three-dimensional space. In practical systems, both tracking control and trajectory planning are facing many difficulties, which has become one of the bottlenecks of autonomous flight technology. Compared with man-machine, UAV has the advantages of low price, small airframe, flexible maneuverability, no casualties, relatively simple take-off conditions and aircrew support. However, in the face of the new form of combat demand, the current UAV is not intelligent enough. In complex and uncertain environment, the existing UAV system, once lack of human control decision-making intervention, often cannot successfully complete the task. Autonomous control technology has become one of the key points in the development of UAV, and has been paid more and more attention. The concepts of semi-autonomous control and autonomous control have been put on the agenda. How to give the UAV the greatest degree of intelligence and replace the manned aircraft in some areas is the main direction of future research [2].

2. Structure Analysis and Task Analysis of UAV

2.1 Structure Analysis.

The operation of UAV mainly depends on the effective control of flight control system, in order to make it run and work in accordance with the requirements of the mission. From the structure of its control system, it mainly includes three parts: sensors, actuators and flight controllers. Among them, different structures are composed of detailed structures, such as sensor devices, inertial measurement unit MIMU altitude sensor and GPS satellite receiver for receiving satellite signals. The steering gear can be divided into lifting steering gear, aileron steering gear and throttle steering gear according to its different uses. Flight controllers are controlled by computer systems. In these three parts, the flight control system is the core structure unit, which coordinates different units and structures in UAV operation. Its main working mode and principle is to control the take-off and landing of UAV by issuing instructions based on the program obtained through calculation and analysis. Throughout the whole control and management system, the most important one is the control and management computer, which mainly carries out information collection and processing, control and navigation solution, various management and monitoring and control output in the whole operation process. In the process of UAV flight control and management, the core content is the troubleshooting and prevention of equipment. Usually in the work of fault detection of airborne related facilities, the main work is the key equipment of mid-flight control system, remote control link, engine and electrical system.

2.2 Task Analysis.

Before the actual operation of UAV, the flight trajectory and route range should be designed in advance by using computer system [3]. In this process, the main function of computer control system is to monitor and observe the flight route of UAV at any time to determine whether it conforms to the trajectory set by the program, so as to avoid the occurrence of directional errors which deviate from the flight path and effectively prevent the impact on the completion of the flight mission. In the actual flight process, if there is a deviation from the flight path, the core control system is used to correct the flight path, so that UAV flight can be better controlled. In the process of nobody's actual operation, there are usually a series of data information generated. In the overall operation system, the wireless transmission mode is used to transmit to the core control system, so that the data reading and acquisition can be completed, which can be better applied in the process of data analysis in the later stage. In the actual operation of UAV, there will inevitably be some faults. For this situation, the flight control system can be used to deal with the faults, so as to eliminate the UAV faults quickly and ensure that the UAV can successfully complete the task. Before the UAV is put into operation, its flight trajectory and route range need to be pre-designed and completed in advance in a computer-based computer system. In this process, the main function of the computer control system is to monitor and observe whether the flight path of the UAV is consistent with the trajectory set by the program at any time, so as to avoid the directional errors which deviate from the flight path, and ultimately affect the successful completion of the flight mission. If the deviation occurs, the core control system completes the alignment of the flight path and realizes the control of the UAV [4].

3. Key Technologies of Flight Control of Unmanned Aerial Vehicles

3.1 Control Law Design.

The development of UAV is an inseparable part of people's colorful life, and the control law is very important to them. It is not only the basic theoretical basis of modern control, but also the product of the development of intermediate and artificial intelligence in pole preparation. The introduction of networked functions makes people realize that UAV has both advantages and disadvantages, but the control law is the highest factor to connect UAV technology. With the passage of time, people have constantly upgraded their consciousness, expanded their concepts and broadened their horizons, thus confusing them. But the control law takes up a large proportion. Transition and judgment in flight process need the management of decision-makers. Of course, control methods, control forms and control modes, power of generators and treatment of backup equipment need the design and management of decision-makers. Normally, the design of multi-mode control law is at the level of implementation, control and management decision-making is to coordinate the organizational level. They will form an organic whole to complete the complex control and management work together. Under the guidance of modern science and technology, UAV's mission equipment and devices are more and more developed, and its organizational structure is more rigorous, including cameras, infrared thermal imagery, photoelectric reconnaissance platform which integrates visible light, infrared, laser ranging, laser target indication, and synthetic aperture radar with ground moving target indication function. Mission equipment management mainly monitors and manages the status of mission equipment. Because UAV may perform tasks when the network is disconnected and the remote-control link loses control, it is necessary to seek program control and realize autonomous mission equipment management. If the link is unblocked, task equipment management can be monitored and managed by contacting ground operators. In the process of UAV operation, a series of data information will be generated and carried. In the whole operation system, it transmits the data to the core control system by wireless transmission, completes the data reading and acquisition work, in order to prepare for the application in the later stage of data analysis.

3.2 Flight Envelope Assessment.

In the nominal state, all parameters of UAV are nominal values, and altitude and speed are taken as uncertain parameters. The range of variation is [0m, 8000m] and [25m/s, 70m/s]. According to the wind tunnel test data, the range of angle of attack is [-4 degrees, 20 degrees], and the natural aircraft without flight control system and the system using the designed control law are evaluated at different angles of attack at intervals of 2 degrees. Since there are only two uncertain parameters, the two-dimensional mesh of the evaluation results can be obtained directly. When a natural aircraft flies at an angle of attack of 5 degrees, there is an unappeasable area in the whole flight envelope, but after the function of flight control system, the whole flight envelope becomes an assessable area. Under the function of flight control system, the robust stability and flight quality of the longitudinal motion of the UAV are greatly improved. The range of assessable angle of attack for the longitudinal motion of the whole flight envelope is [-2 degrees, 18 degrees], that is, the angle of attack is in the range of [-2 degrees, 18 degrees]. When the above range changes, the UAV in nominal state meets the unstable eigenvalue criterion at all points in the whole flight envelope, and the angle of attack exceeds this range. Assessable areas begin to appear in flight envelopes, first at high altitude and low speed, and then spread to the whole flight envelope. By evaluating flight envelopes at different angles of attack, the range of assessable angles of attack can be obtained when uncertain parameters are nominal values under different flight states. The UAV has a wide range of usable angles of attack when flying at high speed and poor performance at high altitude and low speed. This is due to the low air density at high altitude and the low speed, which directly leads to the insufficient lift available for UAV. Therefore, in order to ensure the safety of UAV flying in the whole flight envelope, the flight angle of attack should be limited to [-2 degrees, 18 degrees]. The range of assessable angles of attack in typical flight states is shown in Table 1.

Table 1. Attack angle range in typical flight status

Flight status	FS 1	FS 2	FS 3	FS 4	FS 5	FS 6
Attack angle range (degree)	[-2, 18]	[-4, 20]	[-2, 18]	[-4, 20]	[-4, 20]	[-4, 20]

3.3 Single Parameter Perturbation.

As can be seen from Table 1, the range of assessable angles of attack for each nominal flight state is different, so different flight states should be considered separately when considering uncertain parameter perturbations. The research methods of other flight states are similar. The angle of attack and some uncertain parameter are used as input of adaptive block partition. Without losing generality, this section evaluates the effect of uncertain parameters on the available angle of attack. The initial evaluation range of angle of attack can be appropriately selected according to the evaluation results given in Table 1, thus reducing the computational complexity. For example, when flying at altitude of 4000m and speed of 25m/s, the evaluation range of angle of attack is [-2 degrees, 18 degrees]. When studying the influence of parameter perturbation on the stability of the system, the situation when the angle of attack is greater than 18 degrees can be ignored. When the X-axis center of gravity changes in the range of [-0.05m, 0.05m] before and after the nominal position, the angle of attack range of the safe flight of the aircraft is [0,15 degrees] under the condition of unstable eigenvalue criterion. When the deviation derivative of pitch moment coefficient to the angle of attack of the UAV changes in the range of [-20%, 20%] based on the nominal value, the angle of attack range of the safe flight of the aircraft is [-2 degrees, 15 degrees]. When the partial derivative of pitch moment coefficient to elevator of UAV varies within the range of [-20%, 20%] on the basis of nominal value, the angle of attack range for safe flight of UAV is [-2 degrees, 17 degrees]. The range of inertia [-20%, 20%] based on nominal value and the mass of UAV change between the air plane and the full oil have no effect on the available angle of attack. The variation of the rotational inertia and mass around the axis of the airframe has little effect on the longitudinal motion stability of the UAV. Therefore, before UAV flight test, the accuracy of center of gravity position measurement should be higher, while the accuracy of mass and moment of inertia measurement can be properly relaxed.

3.4 Multiple Parameter Perturbations.

When the number of uncertain parameters increases, the dimension of adaptive block partition increases accordingly. From the previous discussion, it can be seen that the range of assessable angle of attack will further decrease with the increase of the number of uncertain parameters. Because the uncertain parameters are multi-dimensional, it is impossible to draw the evaluation effect map directly. The method of processing is to store the results of the adaptive block partition at each angle of attack into files, to judge the stability of the partition results at each angle of attack according to the criteria, and then to draw the two-dimensional evaluation map between each uncertain parameter and angle of attack separately, to obtain the perturbation range of each parameter. Finally, the final evaluation results are obtained by intersecting the angles of attack. When three uncertain parameters are considered and unstable eigenvalue criterion is adopted, the change of the center of gravity has the greatest influence on the stability. When UAV flies at high angle of attack, it is most vulnerable to unstable state. For the flight state with altitude of 4000m and speed of 25m/s, the range of UAV's assessable angle of attack is [0 degree, 11 degrees]. That is to say, in the actual flight process of UAV. If the uncertain parameters such as cgdX, mdC and emdC have perturbation range, the angle of attack should be controlled in the range of [0 degree, 11 degrees]. Otherwise, the UAV may appear uncontrollable state and cause divergence. The longitudinal and lateral evaluation results of selected typical states in flight envelope are shown in Figure 1 and Figure 2. Taking the longitudinal motion of UAV as an example, the control law is evaluated, and the available angle of attack range of UAV in nominal state is obtained. The effect of single parameter perturbation and simultaneous parameter perturbation on the available angle of attack of UAV is studied. The degree of influence of each perturbation parameter on the system stability is defined. The available angle of attack range of each typical flight state with parameter perturbation is given. The key basis is to ensure flight safety and obtain permission for release.

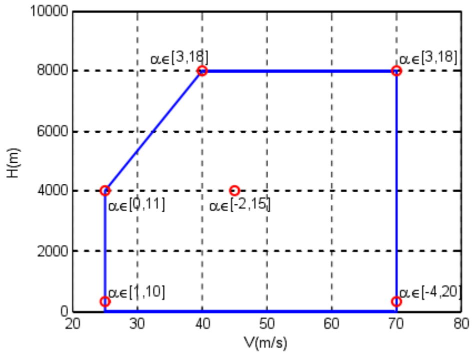

Figure 1. Assessment results of longitudinal movement

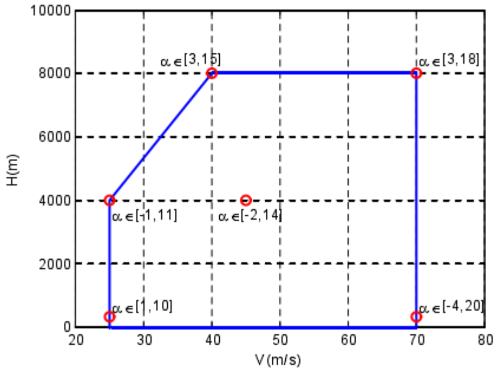

Figure 2. Assessment results of lateral movement

4. Conclusion

As a modern mechanical equipment, UAV is more and more widely used in all aspects, so it is necessary to ensure UAV to run better. In the practical application of UAV, in order to achieve its normal operation, relevant technical personnel should reasonably apply flight control technology and analyze the control system and technology. We should take effective measures to improve the operation efficiency of the control system to better control the UAV operation and ensure that it can better complete its tasks.

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