

Research on Modeling and Verification of Flight Control Laws for Aerial Photography Unmanned Aerial Vehicles in Simulink Environment

Ziwei Bian

Hefei No.1 High School, Hefei, China, 231199
541842998@qq.com

Abstract

This paper focuses on the key issue of modeling and verifying the flight control law of aerial photography unmanned aerial vehicles in the Simulink environment. Firstly, the current development status of aerial photography unmanned aerial vehicles (UAVs) and their significance in the modeling and verification of flight control laws were expounded. Then, the characteristics and advantages of the Simulink environment, as well as its application basis in UAV modeling, were introduced in detail. The process of modeling the flight control law of aerial photography unmanned aerial vehicles was deeply discussed, including key links such as system architecture construction, module selection and parameter setting. Meanwhile, a comprehensive analysis was conducted on the verification methods of the flight control law model, covering static verification, dynamic verification, and key points of verification in different scenarios. It aims to provide theoretical support and practical guidance for the design and optimization of the flight control system of aerial photography drones and promote the further development of aerial photography drone technology.

Key words: Simulink; Aerial photography drone; Flight control law; Modeling verification.

1. Introduction

1.1 The Current Development Status of Aerial Photography Drones

With the rapid development of technology, aerial photography drones have made remarkable progress in recent years and are widely used in many fields such as film and television shooting, geographic mapping, agricultural monitoring, and disaster rescue [1]. Aerial photography drones, with their advantages such as strong flexibility, unique perspectives, and the ability to reach areas that are difficult for humans to reach, have become an important tool for modern information acquisition and image creation.

At present, the types of aerial photography drones are increasingly diverse, ranging from light and small consumer-grade drones to large professional-grade drones, and their performance is constantly improving. In terms of flight altitude, some professional-grade drones can reach several thousand meters in the air, meeting the demands of large-scale geographic mapping [2]. The battery life has also been greatly improved. Some drones can fly tens of kilometers on a single charge and work continuously for several hours, providing a guarantee for long-term mission execution. In terms of load capacity, in addition to being equipped with high-definition cameras for aerial photography, it can also be equipped with various professional devices, such as lidar and multispectral cameras, to achieve more complex functions [3].

Meanwhile, the intelligence level of drones is also gradually increasing. The automatic obstacle avoidance function has become a standard feature of many drones. Through technologies such as lidar and ultrasonic sensors, drones can perceive their surrounding environment in real time and avoid colliding with obstacles [4]. The autonomous flight function enables drones to fly automatically along preset routes without the need for real-time manual control, significantly enhancing flight efficiency and safety. The intelligent tracking function can automatically lock onto the target and follow it for shooting, providing convenience for film and television shooting and sports event coverage [5].

However, the flight safety and stability of aerial photography drones in complex environments remain the key factors restricting their further development. For instance, in complex environments such as strong winds, air flow disturbances, and electromagnetic interference, drones may experience issues like attitude loss of control and flight trajectory deviations, leading to the failure of aerial photography missions or even crashes [6]. Therefore, improving the flight performance and stability of aerial photography drones in complex environments is an important research direction at present.

1.2 The Importance of Modeling and Verification of Flight Control Laws

Flight control law is the "brain" of aerial photography drones, which determines the response and control effect of drones in different flight states [7]. Accurate flight control laws can ensure that unmanned aerial vehicles maintain a stable flight attitude under various weather conditions and flight tasks, precisely fly along the preset route, and thus achieve high-quality aerial photography tasks.

Modeling and verification of flight control laws is an important link to ensure the reliable performance of flight control systems. By establishing an accurate mathematical model and verifying it in a simulation environment, problems existing in the control law design can be detected in advance, avoiding dangerous situations during actual flight. Meanwhile, modeling verification can also provide a basis for the optimization of control laws, improving the flight performance and adaptability of unmanned aerial vehicles.

1.3 The Application Significance of Simulink in Unmanned Aerial Vehicle Modeling

Simulink is a dynamic system simulation software based on model design launched by MathWorks. It features an intuitive graphical interface, a rich module library and powerful simulation analysis capabilities. In unmanned aerial vehicle (UAV) modeling, Simulink can conveniently build dynamic models, sensor models, and flight control law models of UAVs, achieving integrated simulation of the entire flight control system.

The modular design of Simulink makes the construction and modification of models more flexible and efficient. Users can quickly adjust the model structure and parameters according to their actual needs. In addition, Simulink also supports integration with hardware-in-the-loop (HIL) simulation systems, enabling the connection of simulation models with actual hardware devices for tests and verifications that are closer to actual flight conditions. This significantly shortens the development cycle of unmanned aerial vehicle (UAV) control systems and reduces development costs.

2. Overview of the Simulink Environment

2.1 Features and Advantages of Simulink

Simulink has been widely applied in the field of dynamic system modeling and simulation due to its unique advantages. Firstly, it adopts a graphical modeling approach. Users do not need to write complex code. They can build a system model simply by dragging and dropping modules and connecting lines, which greatly reduces the difficulty of modeling and improves the modeling efficiency.

Secondly, Simulink has a rich library of modules, covering multiple fields such as signal processing, control systems, communications, and power electronics, which can meet the modeling requirements of different types of systems. Users can also customize modules as needed to expand the functionality of the module library. Furthermore, Simulink possesses powerful simulation analysis capabilities, supporting the simulation of continuous systems, discrete systems, and hybrid systems, and is capable of conducting various analyses such as time-domain analysis, frequency-domain analysis, and stability analysis. Meanwhile, Simulink also offers a wealth of visualization tools that can visually display simulation results, facilitating users' data analysis and model evaluation.

2.2 Application Foundation of Simulink in Unmanned Aerial Vehicle Modeling

In unmanned aerial vehicle (UAV) modeling, Simulink provides strong support for the construction of UAV dynamic models, sensor models, and flight control law models. The dynamic model of unmanned aerial vehicles (UAVs) describes the motion laws of UAVs during flight, including attitude motion and position motion. The mechanical system module library and aerospace module library in Simulink provide the modules needed to build dynamic models of unmanned aerial vehicles, such as rigid body modules, moment modules, aerodynamics modules, etc.

Sensor models are used to simulate the outputs of various sensors on unmanned aerial vehicles, such as accelerometers, gyroscopes, magnetometers, GPS, etc. The sensor module library of Simulink contains models of various common sensors. Users can configure the sensors based on their performance parameters to accurately simulate the measurement errors and noise of the sensors.

The flight control law model is the core of the unmanned aerial vehicle (UAV) flight control system. It calculates control instructions based on the measurement data from sensors and drives the actuator of the UAV. Simulink's control system module library offers a variety of control algorithm modules, such as PID controllers, fuzzy controllers, state feedback

controllers, etc. Users can select appropriate modules to build control law models based on the design requirements of the control law.

3. Modeling Process of Flight Control Laws for Aerial Photography Drones

3.1 System Architecture Construction

The flight control system of an aerial photography unmanned aerial vehicle (UAV) typically consists of a sensor module, a flight control law module, and an actuator module. When building a system architecture in Simulink, it is first necessary to clarify the input and output relationships among each module. The sensor module is responsible for collecting information such as the attitude, position and speed of the unmanned aerial vehicle, and converting it into electrical signals to output to the flight control law module. The flight control law module calculates control instructions based on the information input from the sensors according to the preset control algorithm, such as the deflection Angle of the rudder surface and the motor speed. The actuator module receives control instructions, drives the rudder surface and motor of the unmanned aerial vehicle, and realizes the flight control of the unmanned aerial vehicle.

3.2 Module Selection and Parameter Settings

3.2.1 Sensor Module

According to the actual configuration of the aerial photography drone, select the corresponding sensor module. For example, for attitude measurement, gyroscope and accelerometer modules can be selected; For position measurement, a GPS module can be selected. When choosing a module, parameters such as the sensor's accuracy, range, and sampling frequency need to be considered, and Settings should be made based on the actual situation. Meanwhile, to simulate the measurement error and noise of the sensor, a noise module, such as a Gaussian white noise module, can be added to the output end of the sensor module.

3.2.2 Flight Control Law Module

According to the design requirements of the flight control law, select the appropriate control algorithm module. If the PID control algorithm is adopted, the PID controller module in Simulink can be selected, and the proportional coefficient, integral coefficient and differential coefficient can be set. When setting parameters, empirical values can be referred to and optimization can be carried out through simulation debugging to achieve good control effects.

3.2.3 Actuator Module

The actuator module includes the servo module and the motor module. The rudder module is used to control the deflection of the rudder surface of the unmanned aerial vehicle (UAV), and the motor module is used to drive the propeller of the UAV. When choosing an actuator module, parameters such as its response speed and maximum torque need to be considered, and Settings should be made based on the characteristics of the unmanned aerial vehicle's power system.

3.3 Model Integration and Debugging

After completing the selection and parameter setting of each module, connect them according to the system architecture to form a complete flight control law model for aerial photography drones. During the model integration process, it is necessary to pay attention to the matching of data types and units between modules to ensure that the signals can be transmitted correctly.

After the model integration is completed, debugging work is required. First, check whether the connection of the model is correct and whether there are any unconnected signal lines or incorrect connections. Then, conduct a preliminary simulation of the model to observe whether the simulation results are reasonable. If the simulation results do not meet expectations, it is necessary to analyze the reasons, adjust and optimize the model parameters until the model can operate normally and achieve the expected control effect.

4. Verification Method for Flight Control Law Model of Aerial Photography Unmanned Aerial Vehicles

4.1 Static Verification

Static verification mainly involves checking and analyzing the structure and parameters of a model when it is not in operation. First, check whether the topological structure of the model is reasonable and whether the connection

relationships between each module are correct. For example, confirm whether the output of the sensor module is correctly connected to the input of the flight control law module, and whether the output of the flight control law module is correctly connected to the input of the actuator module.

Secondly, conduct a rational analysis of the model's parameters. Check whether the parameter Settings of each module are within a reasonable range and whether they meet the actual performance indicators of the aerial photography drone. For instance, check whether the proportional coefficient, integral coefficient and differential coefficient of the PID controller are set too high or too low to avoid problems such as system instability or slow response.

4.2 Dynamic Verification

4.2.1 Open-loop Simulation Verification

Open-loop simulation verification involves inputting the output of the sensor module as a known signal into the flight control law module to observe whether the output of the flight control law module meets expectations. In open-loop simulation, different flight states and sensor input signals can be simulated, such as uniform flight, accelerated flight, and turning flight, to check the control effect of the flight control law module under different working conditions.

Through open-loop simulation verification, the correctness and rationality of the flight control law model can be preliminarily evaluated, and possible problems in the model can be discovered, such as errors in the control algorithm and unreasonable parameter Settings.

4.2.2 Closed-loop Simulation Verification

Closed-loop simulation verification involves simulating the entire flight control law model of the aerial photography unmanned aerial vehicle as a closed-loop system, including the sensor module, flight control law module, and actuator module. In closed-loop simulation, various conditions of the unmanned aerial vehicle (UAV) during actual flight, such as wind disturbance and sensor noise, are simulated, and the changes in parameters such as the flight attitude, position and speed of the UAV are observed.

Closed-loop simulation verification can more truly reflect the performance of the flight control law model in actual flight, and test the stability, robustness and control accuracy of the model. By analyzing the closed-loop simulation results, the flight control law model can be further optimized and improved.

4.3 Key Points for Verification in Different Scenarios

4.3.1 Normal Flight Scenarios

Under normal flight scenarios, the main verification is whether the flight control law model can enable the unmanned aerial vehicle to maintain a stable flight attitude and fly accurately along the preset route. Observe whether the roll Angle, pitch Angle and yaw Angle of the unmanned aerial vehicle fluctuate within a reasonable range, and whether the position error and speed error meet the design requirements.

4.3.2 Fault Scenarios

Fault scenario verification is to test the fault-tolerance and recovery capabilities of the flight control law model when encountering faults. For instance, simulate situations such as sensor failure and actuator failure, and observe whether the unmanned aerial vehicle can detect the faults and take corresponding measures, such as switching backup sensors and adjusting control strategies, to maintain flight safety.

4.3.3 Complex Environmental Scenarios

Complex environmental scenarios include strong winds, air flow disturbances, electromagnetic interference and other situations. In these scenarios, the robustness of the flight control law model is verified to observe whether the unmanned aerial vehicle can maintain stable flight performance in complex environments and avoid dangerous situations such as loss of control or crashes.

5. Conclusion

This paper conducts an in-depth study on the modeling and verification of flight control laws for aerial photography unmanned aerial vehicles in the Simulink environment. The characteristics and advantages of the Simulink environment are introduced, and the process of modeling the flight control law of aerial photography unmanned aerial vehicles is

elaborated in detail, including the construction of system architecture, module selection and parameter setting, as well as model integration and debugging. Meanwhile, a comprehensive analysis was conducted on the verification methods of the flight control law model, including static verification, dynamic verification, and key points of verification in different scenarios. Although this paper has achieved certain results in the modeling and verification of flight control laws for aerial photography unmanned aerial vehicles, there are still some deficiencies. For instance, during the model verification process, the simulation verification method was mainly adopted, lacking the verification through actual flight tests. Future research can further integrate hardware-in-the-loop simulation and actual flight tests to enhance the accuracy and reliability of model verification.

With the continuous development of artificial intelligence technology, it is possible to consider applying intelligent control algorithms to the design of flight control laws for aerial photography drones to enhance their autonomous flight capabilities and adaptability. At the same time, efforts should be made to enhance research on the flight safety of unmanned aerial vehicles (UAVs), establish a more complete safety assessment system, and ensure the flight safety of aerial photography UAVs in various complex environments.

REFERENCES

- [1] Nawaz, H. (2019). Applications of unmanned aerial vehicles: a review. *3C Tecnología_Glosas de innovación aplicadas a la pyme*.
- [2] Goraj, Z., Frydrychewicz, A., Świtkiewicz, R., Hernik, B., Gadomski, J., Goetzendorf-Grabowski, T., ... & Chajec, W. (2004). High altitude long endurance unmanned aerial vehicle of a new generation—a design challenge for a low cost, reliable and high-performance aircraft. *Bulletin of the Polish Academy of Sciences Technical Sciences*, 173-194.
- [3] Mohsan, S. A. H., Khan, M. A., Noor, F., Ullah, I., & Alsharif, M. H. (2022). Towards the unmanned aerial vehicles (UAVs): A comprehensive review. *Drones*, 6(6), 147.
- [4] Zuo, Z., Liu, C., Han, Q. L., & Song, J. (2022). Unmanned aerial vehicles: Control methods and future challenges. *IEEE/CAA Journal of Automatica Sinica*, 9(4), 601-614.
- [5] Cruz, G. C. S., & Encarnação, P. M. M. (2012). Obstacle avoidance for unmanned aerial vehicles. *Journal of Intelligent & Robotic Systems*, 65(1), 203-217.
- [6] Lee, J., Ryu, S., & Kim, H. J. (2020). Stable flight of a flapping-wing micro air vehicle under wind disturbance. *IEEE Robotics and Automation Letters*, 5(4), 5685-5692.
- [7] Çalışır, A. (2015). Development of a model unmanned aerial vehicle with Simulink: modelling and control.