Multicopter Design and Control Practice
—— A Series Experiments Based on MATLAB and Pixhawk

Lesson 12 Failsafe Logic Design Experiment

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Outline

1. Preliminary
2. Basic Experiment
3. Analysis Experiment
4. Design Experiment
5. Summary

Preliminary

Initially, the major types of failures that may cause accidents will be introduced. Here, the following three types of failures are mainly considered:

1. Communication Breakdown
2. Sensor Failure
3. Power System Anomaly

□ Safety issues

（1）Communication Breakdown

Communication breakdown mainly refers to a contact anomaly between the RC transmitter and the multicopter, or between the ground control station (GCS) and the multicopter. Such failures can be categorized as follows.

1）RC transmitter not calibrated

An RC transmitter without calibration implies that the remote pilot does not calibrate the RC transmitter before the first flight of the multicopter. As a result, the flight control system cannot recognize the user instructions given by the sticks of the RC transmitter. This will lead to flight accidents due to the misinterpretation of the user instructions.

Preliminary

☐ Safety issues

（1） Communication Breakdown

2）Loss of RC

Loss of RC implies that the RC transmitter is unable to communicate with the corresponding RC receiver onboard before the multicopter takes off or during flight. The loss of RC will result in the multicopter going out of control, which will lead to an accident.

3）Loss of GCS

Loss of GCS implies that the GCS is unable to communicate with the corresponding multicopter before the multicopter takes off or during flight. The loss of GCS will cause the multicopter to fail to reach the mission position, and then the task will fail.

Preliminary

☐ Safety issues

（2）Sensor Faillure

Sensor failure mainly implies that a sensor on the multicopter cannot measure accurately or cannot work properly. Such failures can be categorized as follows:

1） Barometer failure

2） Compass failure

3） GPS failure

4） Inertial Navigation System (INS) failure

Preliminary

□ Safety issues

(3) Propulsion System Anomaly

A propulsion system anomaly mainly refers to either battery failure, or hardware failure of propulsors of the flight control system caused by Electronic Speed Controllers (ESCs), motors, or propellers.

1） Battery failure. This usually refers to a lack of power caused by low battery capacity or a degradation in the battery life and is mainly reflected in the following three aspects.

2） ESC failure. This is mainly reflected in the following two aspects. 1) An ESC cannot correctly recognize the Pulse Width Modulation (PWM) instructions given by the autopilot or RC transmitter. 2) An ESC cannot drive the motor as expected.

3） Motor failure. This mainly means that the motor cannot work correctly under the given ESC control signal.

4） Propeller failure. This is mainly caused by worn and broken blades, or a loose blade from the propeller shaft, etc.

□ Decision-making design process

（1）Flight Mode Definition

1）MANUAL FLIGHT MODE

This mode allows a remote pilot to control a multicopter manually

2）RTL MODE

Under this mode, the multicopter will return to the home location from the current position and hover there. In the process, if the current relative altitude comparison with that of the home location is higher than a set value (the default relative height is 15m in the autopilot), the multicopter will maintain the current altitude and return home. Otherwise, it will first ascend to the preset height before returning home.

3）AUTO-LANDING MODE

In this mode, the multicopter realizes the automatic landing by adjusting the throttle command according to the estimated height.

Preliminary

□ Decision-making design process

（2）Event Definition

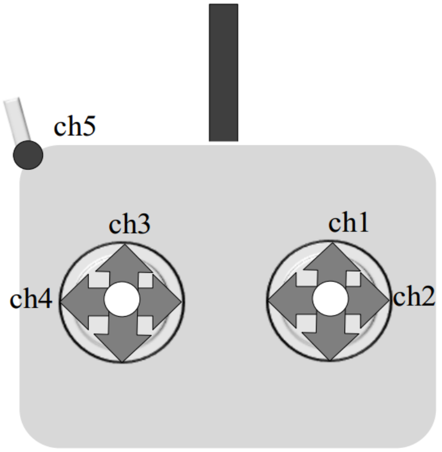

Figure: RC transmitter

Here, two kinds of events are defined: Manual Input Events (MIEs) and Automatic Trigger Events (ATEs). These events will cause the state or mode transition.

1) MIEs are instructions from remote pilots sent through the RC transmitter

MIE1: Arm and Disarm instructions. MIE1 = 1 denote the arm instruction, and MIE1 = 1 denote the disarm instruction.

MIE2: Manual operation instruction (1: Switch to MANUAL FLIGHT MODE; 2: Switch to RTLMODE; 3: Switch to AUTO-LANDING MODE).

MIE3: Turn on or turn off the multicopter. (1: turn on; 0: turn off).

MIE4: Power cutoff for maintenance. (1: repaired; 0: repairing).

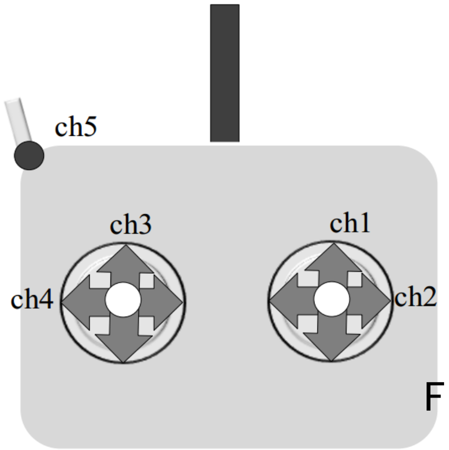

Figure: RC transmitter

Decision-making design process

（2） Event Definition

Here, two kinds of events are defined: Manual Input Events (MIEs) and Automatic Trigger Events (ATEs). These events will cause the state or mode transition.

2）ATEs are independent of the remote pilot's operations, but mainly generated by the status of components on board and status of the multicopter.

In the basic experiment, it is assumed that the RC transmitters is connected normally, that is, the ATES of the aircraft is not taken as the judging condition, but only the MIES is taken as the condition.

Preliminary

☐ Decision-making design process

（3） Autopilot Logic Design

Take the basic experiment for experiment

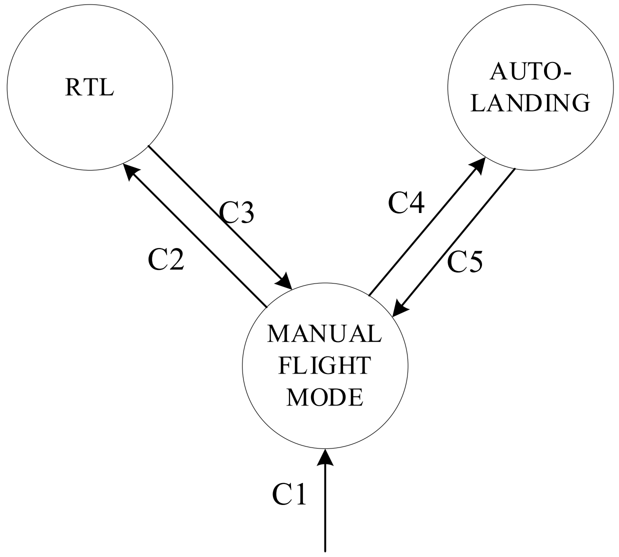

Figure: EFSM of quadcopter in basic experiment

C1:MIE1=1；

This condition implies a successful arm operation. This condition is true when the remote pilot arms the multicopter (MIE1 = 1).

C2: MIE2=2；

This condition implies a switch from MANUAL FLIGHT MODE to RTL MODE. Such a switch can take place in the following case: the flight mode switch to RTL MODE happens (MIE2 = 2).

C3、 C5:MIE2=1；

These conditions imply a switch from RTL MODE to MANUAL FLIGHT MODE and a switch from AUTO-LANDING MODE to MANUAL FLIGHT MODE. Such a switch can take place in the following case: the flight mode switch to MANUAL FLIGHT MODE happens (MIE2 = 1);

C4:MIE2=3；

This condition implies a switch from MANUAL FLIGHT MODE to AUTO-LANDING MODE. Such a switch can take place in the following case: the flight mode switch to AUTO-LANDING MODE happens（MIE2 = 3）.

Decision-making design process

（4）Controller command

After the model generate state transition after judging according to different input events, the controller needs to be given corresponding instructions according to different states to make the multicopter meet the requirements of different states

1） MANUAL FLIGHT MODE: only the input module of the RC transmitter and the module that receives the input of RC transmitter for normalization processing are connected to the attitude controller.

2） RTL MODE: RTL MODE requires multicopters to return to the take-off point, which belongs to set-point position control, so the input of the attitude controller needs to be connected to the output of the position controller. Therefore, the position control command at this time is $p_{x_\mathrm{d}}=0, p_{y_\mathrm{d}}=0$, i.e., add the command of returning to the HOME point to the controller. At the same time, in the altitude channel, if the current altitude is higher than the set safe altitude, then $p_{z_\mathrm{d}}=\hat{p}_z$ the altitude of the multicopter will be controlled unchanged; if the current altitude is lower than the set safe altitude, then the multicopter will first rise to the set altitude and then return to the HOME point.

Preliminary

□ Decision-making design process

（4）Controller command

After the model generate state transition after judging according to different input events, the controller needs to be given corresponding instructions according to different states to make the multicopter meet the requirements of different states

3） AUTO-LANDING MODE： AUTO-LANDING MODE requires the multicopter to maintain the original horizontal position, and adjust the throttle command to achieve landing. At this time, the input of the attitude controller needs to be connected to the output of the position controller. At the same time, the control command given to the position controller is the horizontal desired velocity $v_{x_d}=0, v_{x_d}=0$, so that the multicopter maintains the original horizontal position; on the altitude channel, $p_{z_d}=0$ to make the multicopter achieve landing.

Preliminary

□ Software and hardware implementation

（1） Stateflow

State machine can be implemented in stateflow toolbox. Stateflow is a tool developed by MathWorks to use state machine and flow chart to model response system. It is a graphic design tool, which can realize the finite state machine and the transformation between different states. When it is used with Simulink at the same time, it can receive the input of Simulink and output to Simulink to realize the connection with the model in Simulink. The designed state machine is implemented in stateflow.

Preliminary

☐ Software and hardware implementation

（2）RC transmitter

MANUAL FLIGHT MODE in the mode switching requires the RC transmitter to send the control command, so when adding the command, we should simulate the signal value actually sent by the remote control, as shown in the right figure. In the port of the RC transmitter, channel 1 controls the front and back movement of the remote control, channel 2 controls the left and right movement, channel 3 controls the throttle, channel 4 controls the yaw angle, and channel 5 sends the control command to the mode , channel 5 is a three-position switch, which just meets the three modes.

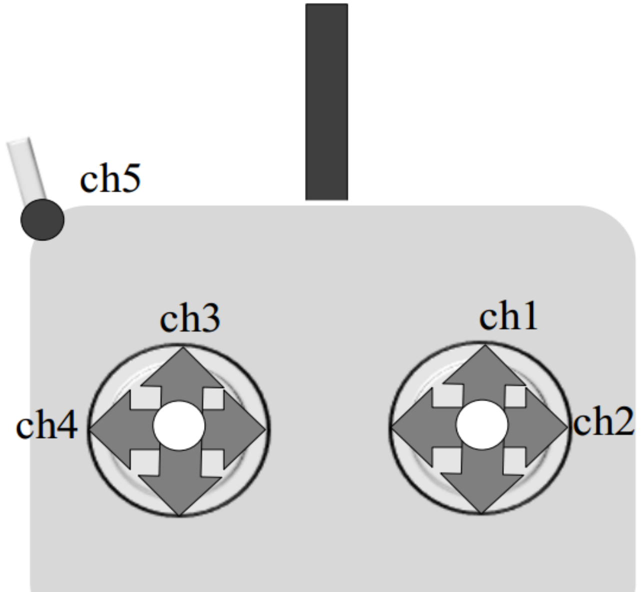

Figure: RC transmitter

In the actual operation, the values of these five channels are all in the range of 1000-2000. In order to be closer to the real situation, the values of 1000-2000 are also input in the simulation. At the same time, these signals need to be normalized before entering the controller, so that they become the values between 0-1. For channel 5, when its value is 1000-1400, the manual input event MIE2 in mode switching is 1, which corresponds to the MANUAL FLIGHT MODE; when its value is 1400-1600, the manual input event MIE2 in mode switching is 2, which corresponds to the RTL MODE; when its value is 1600-2000, MIE2 is 3, which corresponds to the AUTO-LANDING MODE.

Preliminary

In order to make this chapter self-contained, the experiment preliminary is borrowed from Chapter. 11 of “**Quan Quan. *Introduction to Multicopter Design and Control*. Springer, Singapore, 2017**”。

Basic Experiment

□ Experimental Objectives

■ Things to prepare

（1）Hardware: Multicopter System, Pixhawk Autopilot System;

（2）Software: MATLAB 2017b and above, Simulink-based Controller Design and Simulation Platform, HIL(Hardware in the loop) Simulation Platform, Experiment Instruction Package “e8.1”（https://flyeval.com/course）.

■ Objectives

(1) In SIL simulation, repeat the given code to realize RTL MODE, AUTO-LANDING MODE and MANUAL FLIGHT MODE;

（2）Perform the HIL simulation.

Basic Experiment

◻ Simulation procedure

（1） Step1:SIL simulation

1）Parameter Initialization

Run the file “e8/e8.1/Init_control.m” to initialize the parameters, then the Simulink file “Attitude-Control_Sim” will open automatically。

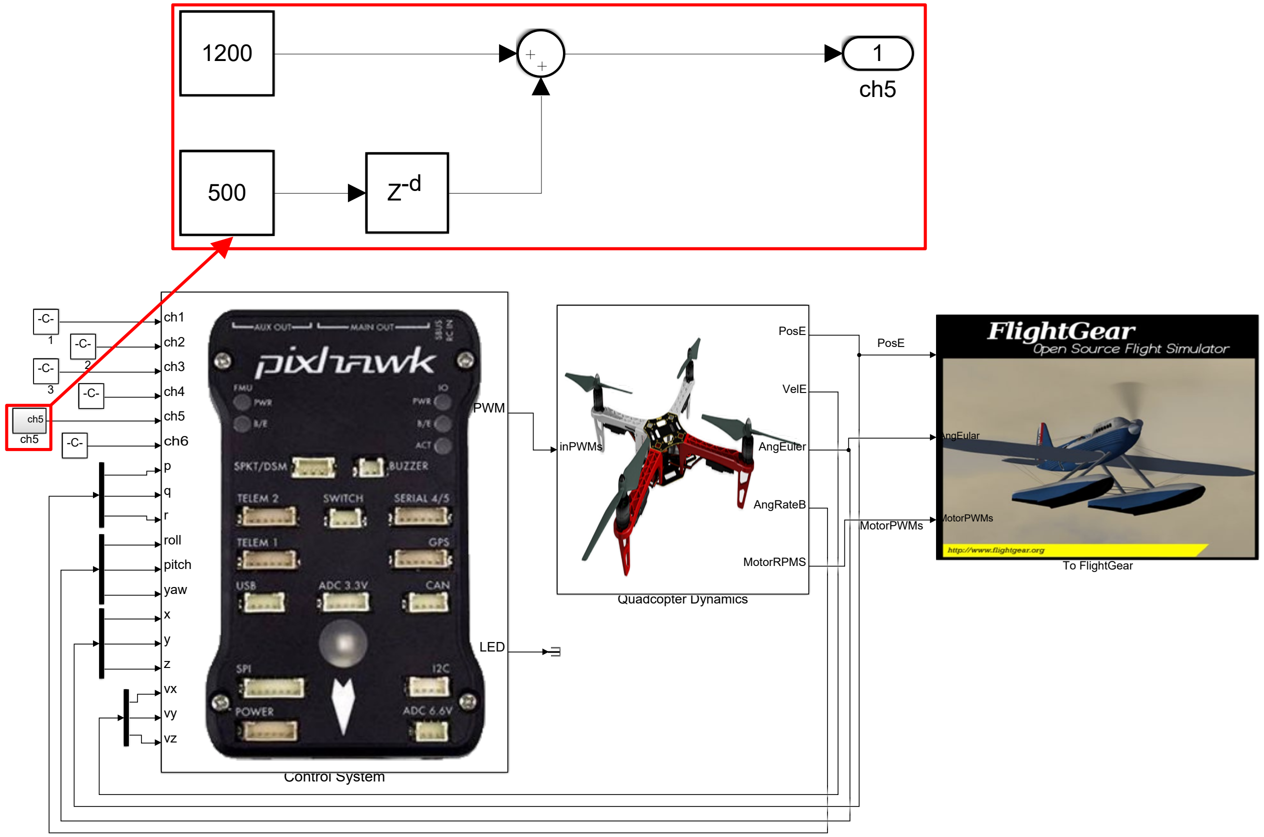

Figure: Simulink model “e8_1sim.slx”

Basic Experiment

◻ Simulation procedure

2） RTL simulation

The simulation performance can be observed on the right, the quadcopter is in MANUAL FLIGHT MODE, and the state of the quadcopter is determined by the values of “ch1~ch4”. After 10s, the condition C2 is satisfied, the quadcopter enters RTL MODE. Then, the altitude remains unchanged while the horizontal position gradually returns to 0.

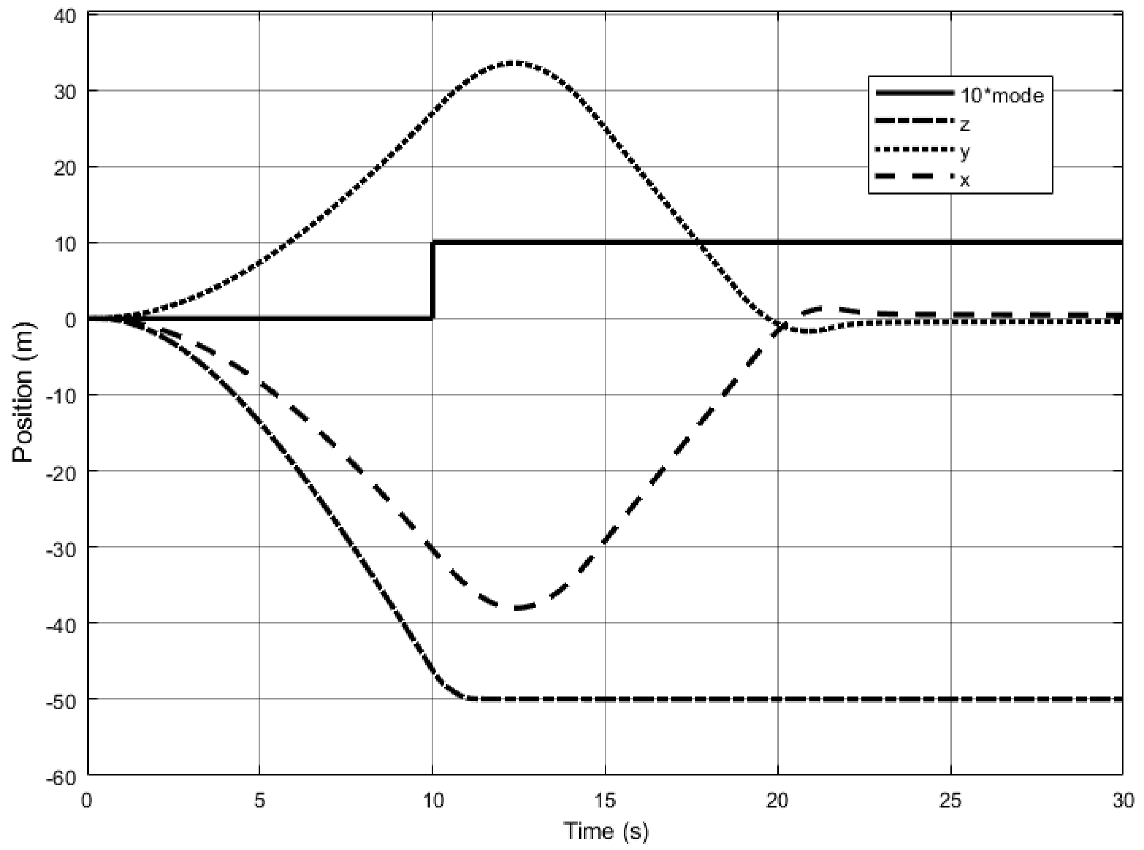

Figure: Position response with RTL MODE

Basic Experiment

☐ Simulation procedure

3） Auto-Landing simulation

In 0~10s, the quadcopter takes off and climbs up under the given command in MANUAL FLIGHT MODE. After 10s, the condition C4 is satisfied and the quadcopter enters AUTO-LANDING MODE.Then, the horizontal position remains unchanged, while the altitude gradually reduces to 0.

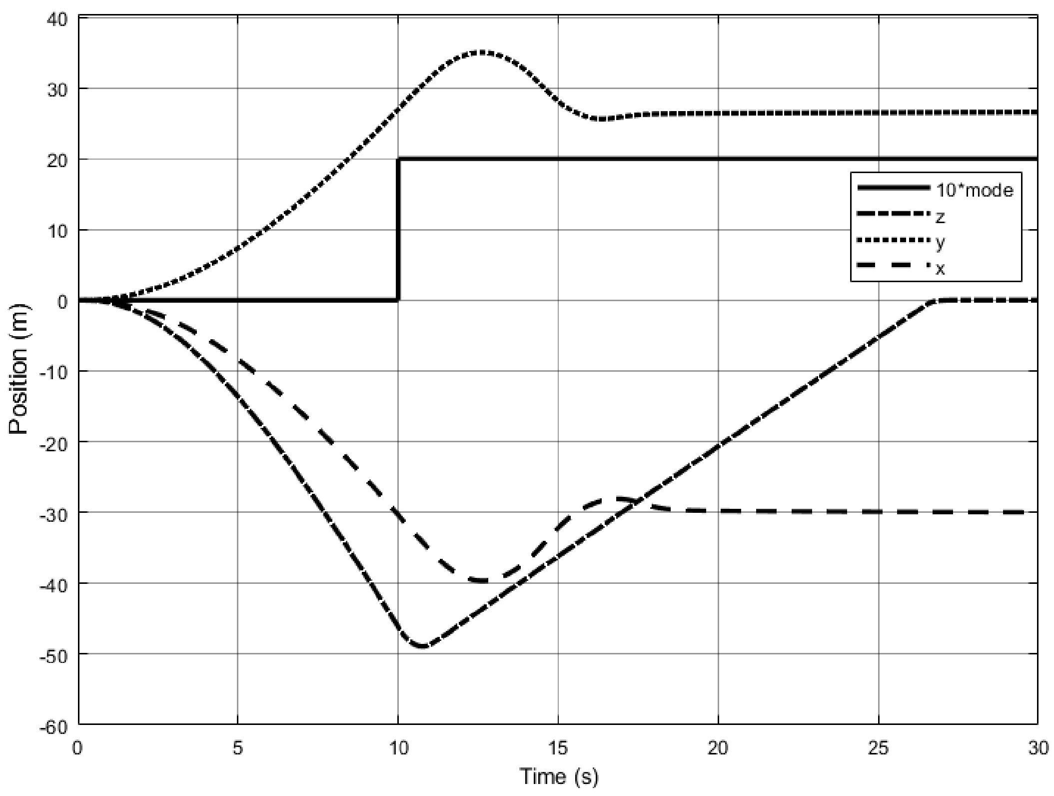

Figure: Position response with AUTO-LANDING MODE

Basic Experiment

□ Simulation procedure

（2） Step2: HIL simulation

1） Parameter Initialization

Open the simulink file "e8/e8.1/HIL/e8_1_HIL.slx" and run the file "Init_control.m" to initialize the parameters in the same folder.

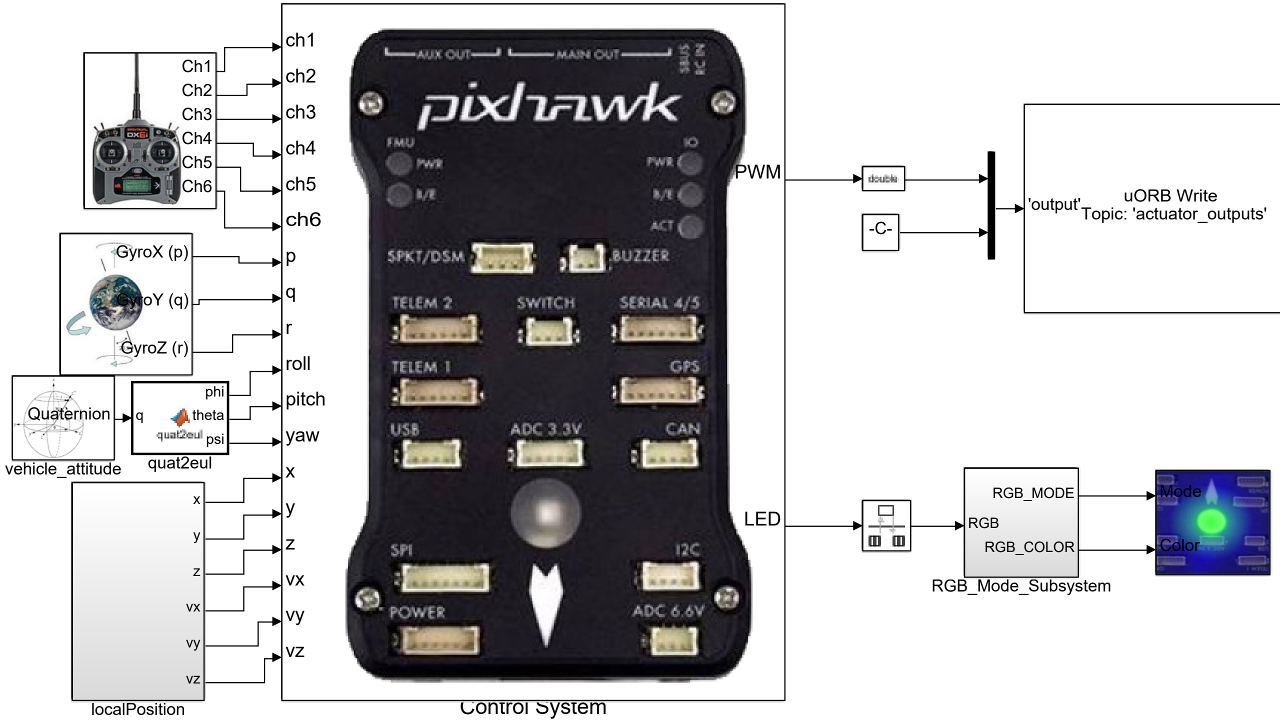

Figure: Simulink "e8_1_HIL.slx"

Basic Experiment

□ Simulation procedure

2）Connect hardware

It should be noted that the airframe type "HIL Quadcopter X" should be selected in HIL simulation.

Figure: Connection between Pixhawk hardware and RC receiver

Basic Experiment

□Simulation procedure

3）Compile and upload code

Compile the HIL simulation model and upload the file to the given Pixhawk autopilot. Later, the designed attitude control program can be run on Pixhawk autopilot.

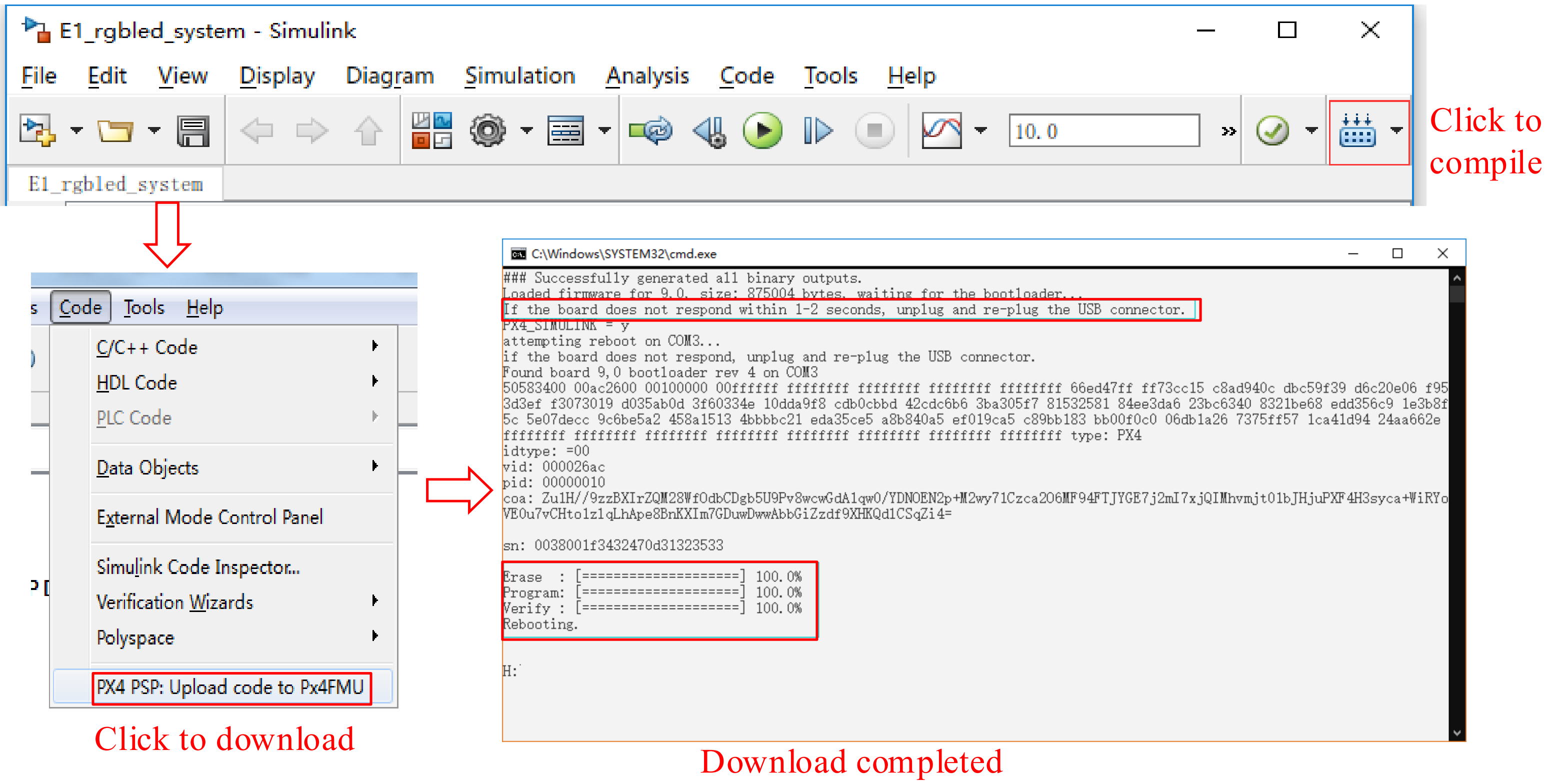

Figure: Code compilation and upload process

Basic Experiment

◻ Simulation procedure

4） Configure CopterSim

Double-click on the desktop shortcut CopterSim to open it. Readers can choose different propulsion systems using the following procedure. Click on “Model Parameters” to customize the model parameters and, then click on “Store and use the parameters” to make them available. The software will automatically match the serial port number. Readers would click the“Run”button to enter the HIL simulation mode. After that, readers could see the message returned by the Pixhawk autopilot in the lower-left corner of the interface.

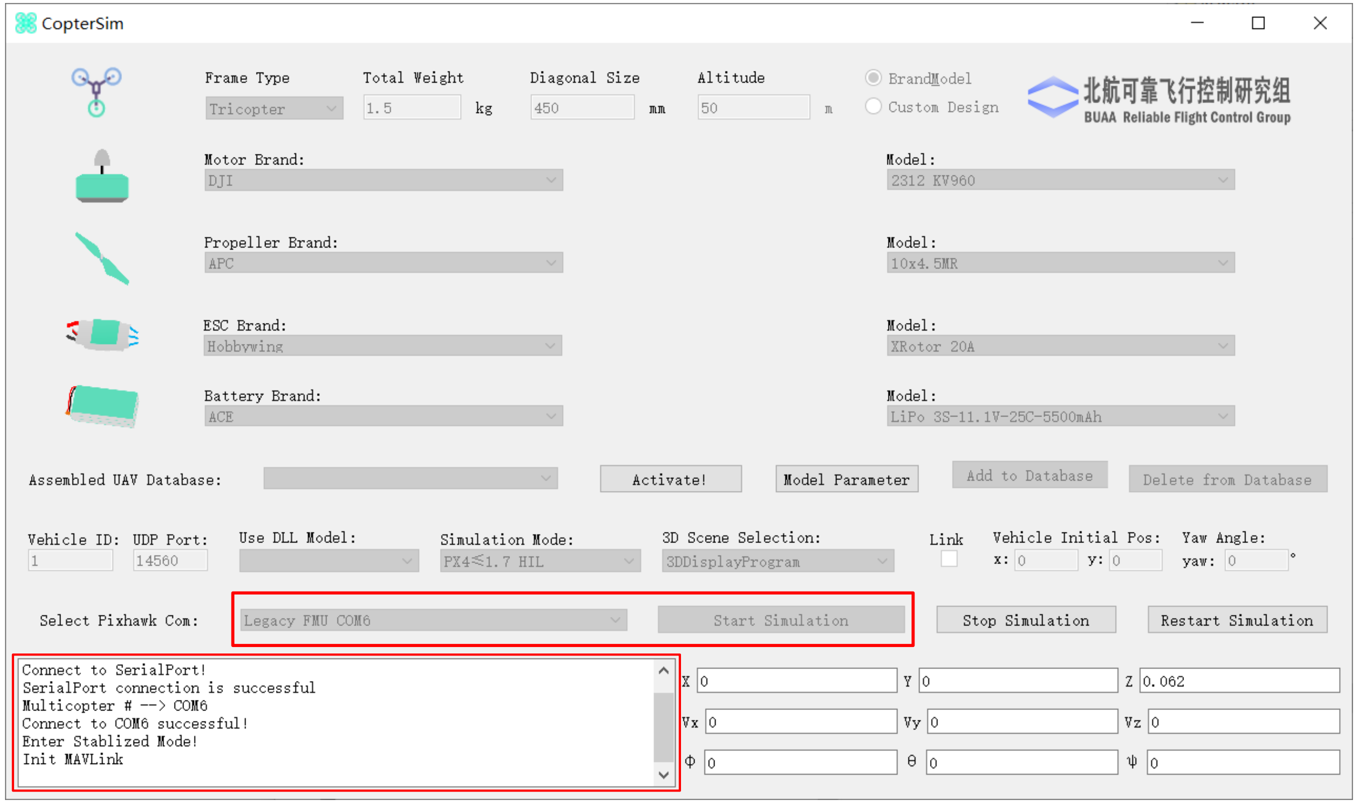

Figure: User interface of CopterSim

Basic Experiment

□Simulation procedure

5）Open 3DDisplay

Double-click on the desktop shortcut 3DDisply to open it.

6）Simulation performance

Arm the quadcopter for manual control. Readers could pilot the quadcopter to a certain altitude. Then, push three-position switch CH5 back (closest position from user) to realize the return or push the switch CH5 forward (farthest position from user) to make the quadcopter land.

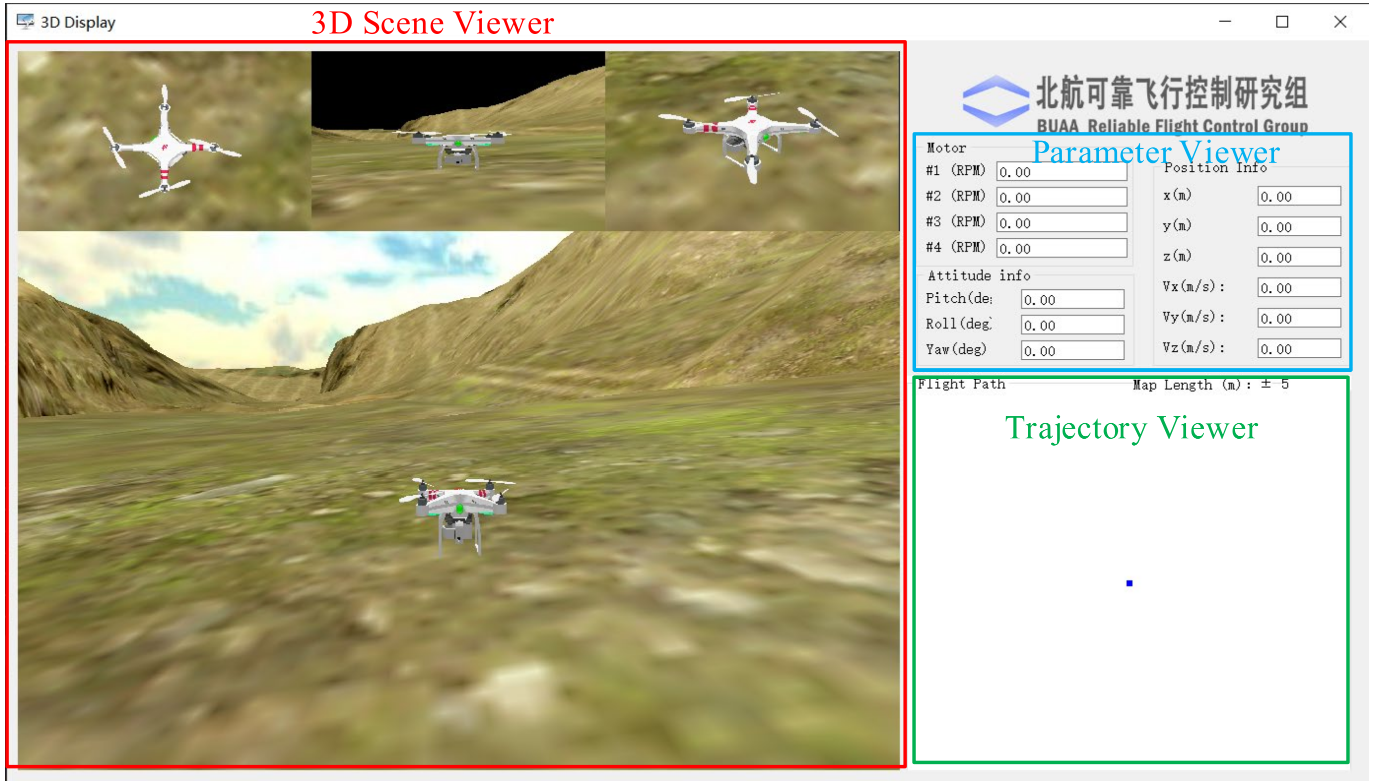

Figure: User interface of 3DDisplay

Analysis Experiment

□ Experimental Objectives

■ **Things to prepare**

（**1**）Hardware: Multicopter System, Pixhawk Autopilot System;

（2）Software: MATLAB 2017b and above, Simulink-based Controller Design and Simulation Platform, HIL Simulation Platform, Experiment Instruction Package “e8.2”（https://flyeval.com/course）.

■ **Objectives**

(1) Based on the basic experiment, design a new logic to realize that the quadcopter can switch between RTL MODE and AUTO-LANDING MODE manually.

（2）Perform the HIL simulation.

Analysis Experiment

Experimental Analysis

This experiment adds a dual switching between RTL MODE and AUTO-LANDING MODE based on the basic experiment. The corresponding EFSM is shown below.

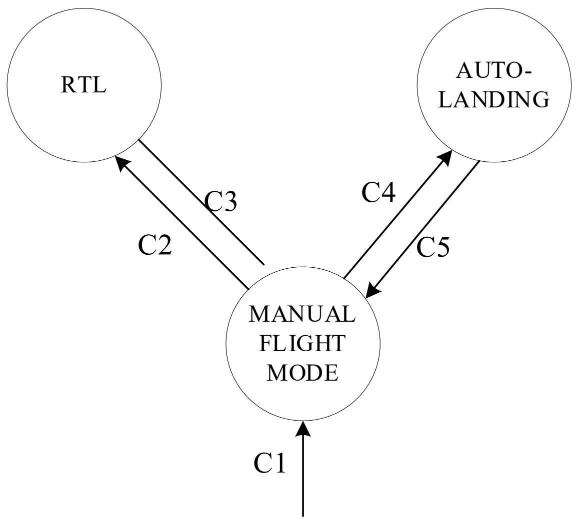

Figure: EFSM of quadcopter in analysis experiment

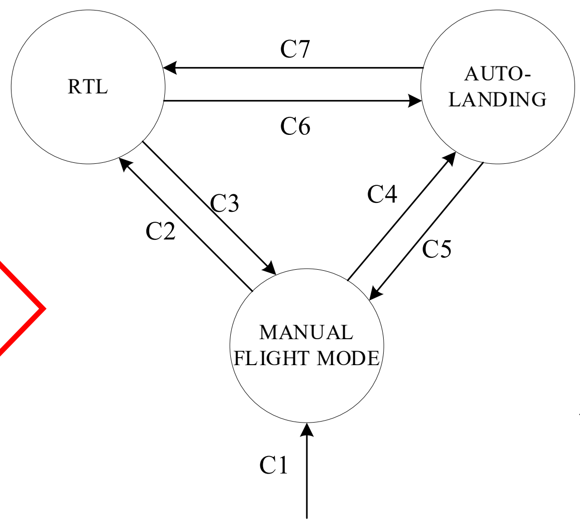

Figure: EFSM of quadcopter in analysis experiment

The new transition conditions are presented below.

C6：MIE2=3

This condition implies a switch from RTL MODE to AUTO-LANDING MODE. This switch will occur in the following case: the flight mode switching to AUTO-LANDING MODE happens (MIE2 = 3).

C7：MIE2=2

This condition implies a switch from AUTO-LANDING MODE to RTL MODE. This switch will occur in the following case: any flight mode switching to AUTO-LANDING MODE happens (MIE2 = 2).

Analysis Experiment

□ Simulation procedure

（1） Step1: SIL simulation

1)Copy the model from the basic experiment and find the state machine named “mode switch” in the “Control System model” as shown on the right.

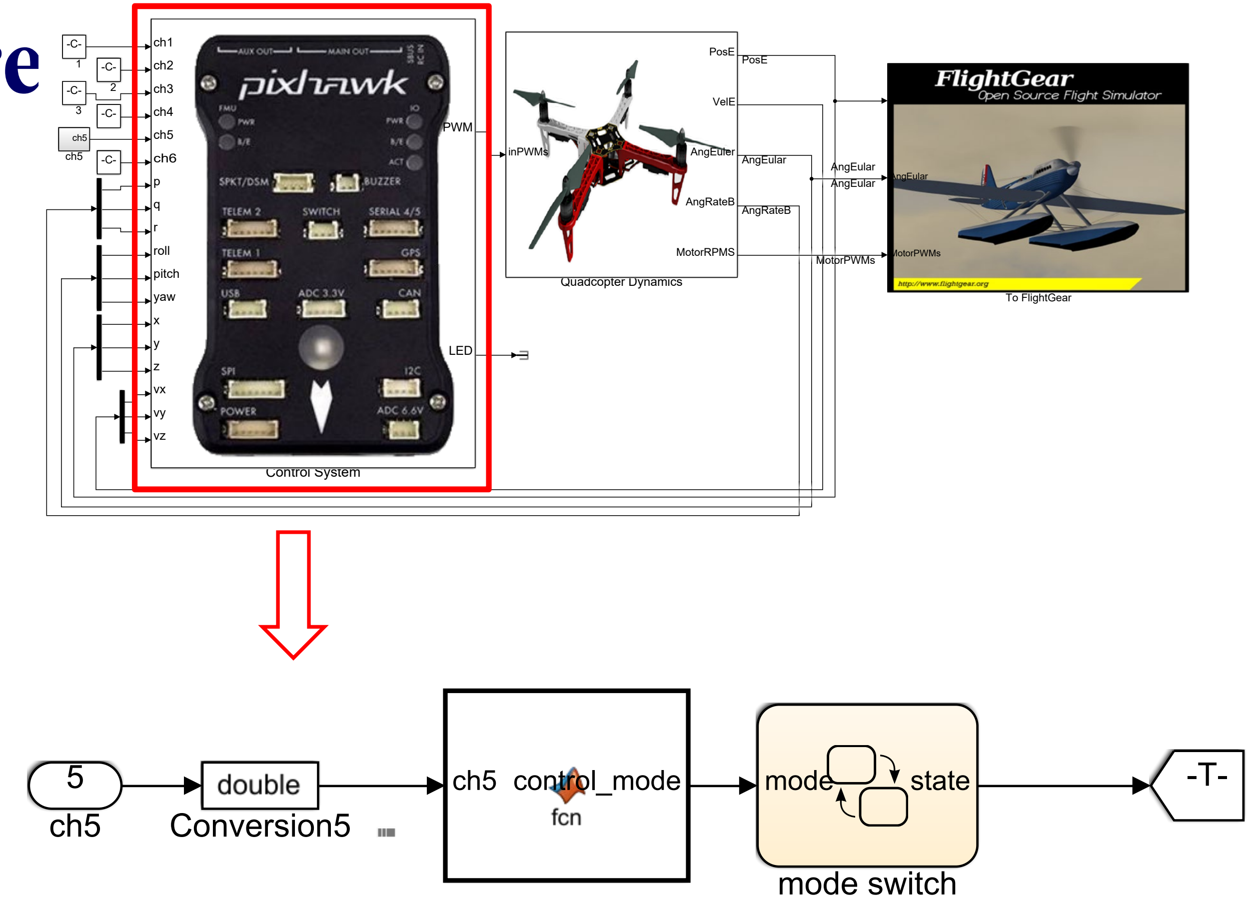

Figure: Mode switch model in “Control System” submodule

Analysis Experiment

□ Simulation procedure

2) Modify the state machine

The transition condition of the state machine is determined by events, such as MIE2, which is the input condition. The transition conditions between RTL MODE and AUTO-LANDING MODE are added.

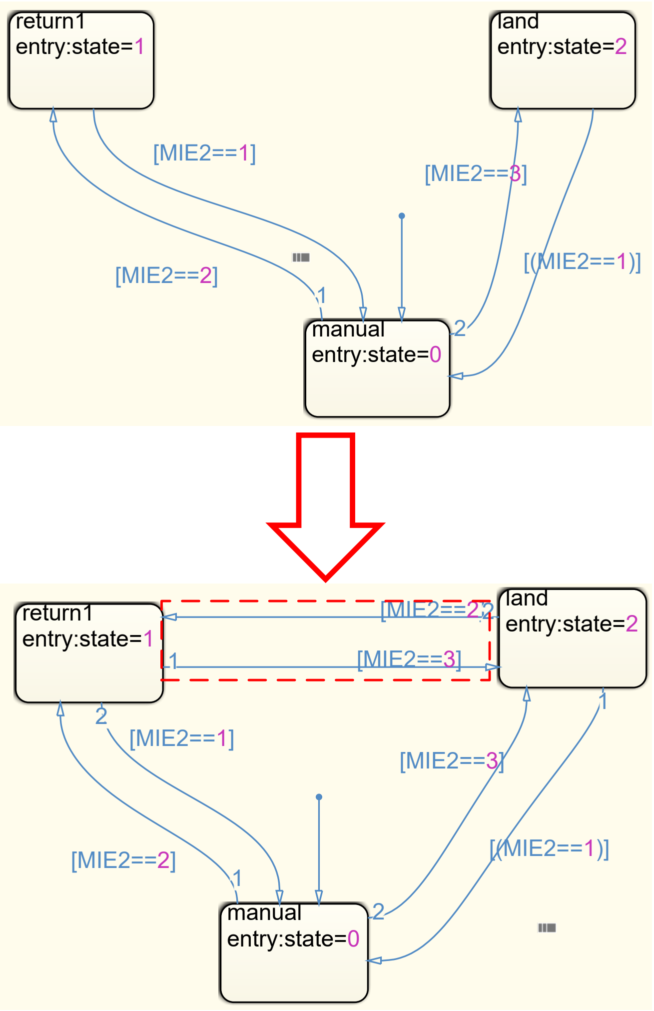

Figure: Modify state machine for analysis experiment

Analysis Experiment

□ Simulation procedure

3)Modify the model input

Change the input value of the "ch5" in the model to simulate the PWM value from three position switch of an RC transmitter. During 0~10s, the value is 1200, corresponding to MANUAL FLIGHT MODE and MIE2 = 1; during 10~30s, the value is 1500, corresponding to RTL MODE and MIE2 = 2; during 30~50s, the value is 1800, corresponding to AUTO-LANDING MODE and MIE2 = 3. The entire process simulates the RC transmitter switching from MANUAL FLIGHT MODE to RTL MODE and then to AUTO-LANDING MODE.

4)Save the model and initialize the parameters

Save the model to the file"e8/e8.2/SIM/e8_2_sim.slx" and run the file "e8/e8.2/Init_control.m" to initialize parameters.

Analysis Experiment

◻ Simulation procedure

5) Simulation performance

It can be observed that during 0~10s,

the quadcopter flies freely in the air; then, during 10~30s, it enters RTL MODE, the altitude remains unchanged while the horizontal position goes to (0,0); after 30s, it enters AUTO-LANDING MODE, where the horizontal position remains (0,0) and the altitude drops down to zero.

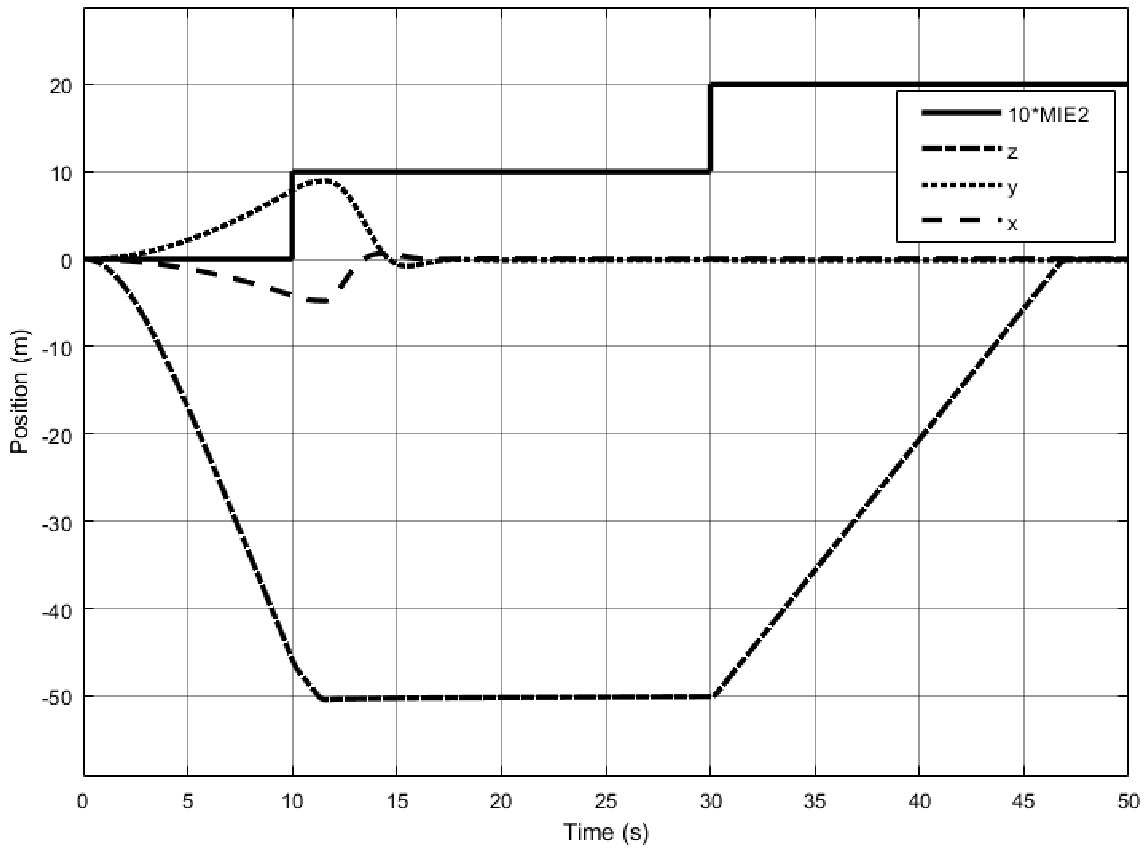

Figure: Position response with difference modes in analysis experiment

Analysis Experiment

□ Simulation procedure

□ （2） Step2: HIL simulation

1） Open the Simulink file for HIL

Open the simulink file "e8/e8.2/HIL/ Init_control.m" and run the file "Init_control.m" to initialize the parameters in the same folder. It should be noted that "Control System" here is the same as that in the SIL simulation.

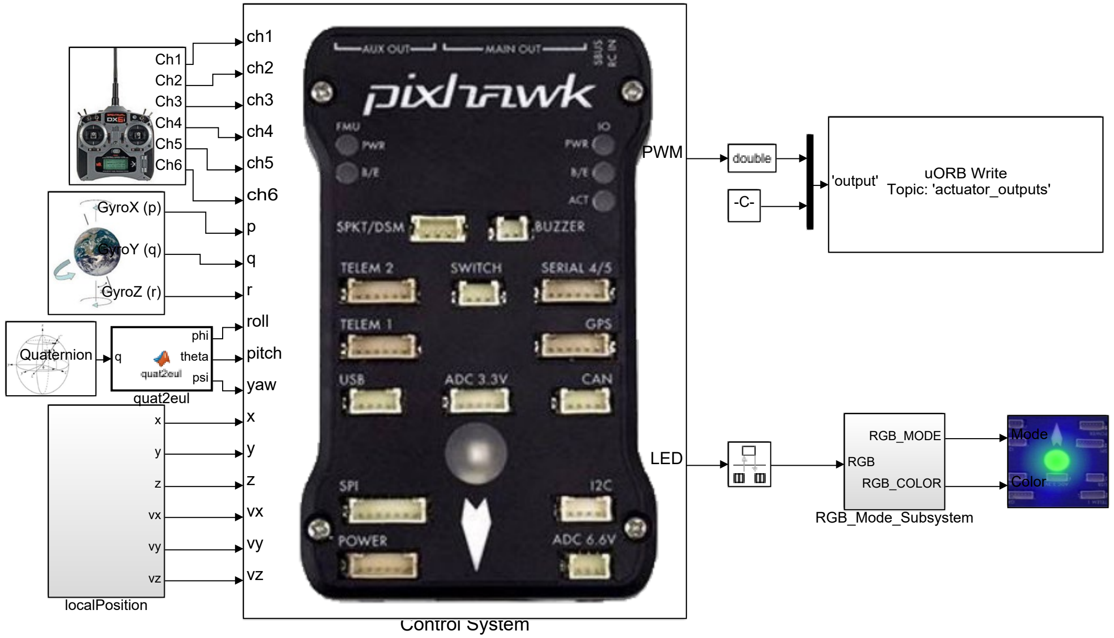

Figure: Simulink file "e8_2_HIL.slx"

Analysis Experiment

☐ Simulation procedure

2）Connect hardware

It should be noted that the airframe type "HIL Quadcopter X" should be selected in HIL simulation.

Figure: Connection between Pixhawk hardware and RC receiver

Analysis Experiment

□Simulation procedure

3）Compile and upload code

Compile the HIL simulation model and upload the file to the given Pixhawk autopilot. Later, the designed attitude control program can be run on Pixhawk autopilot.

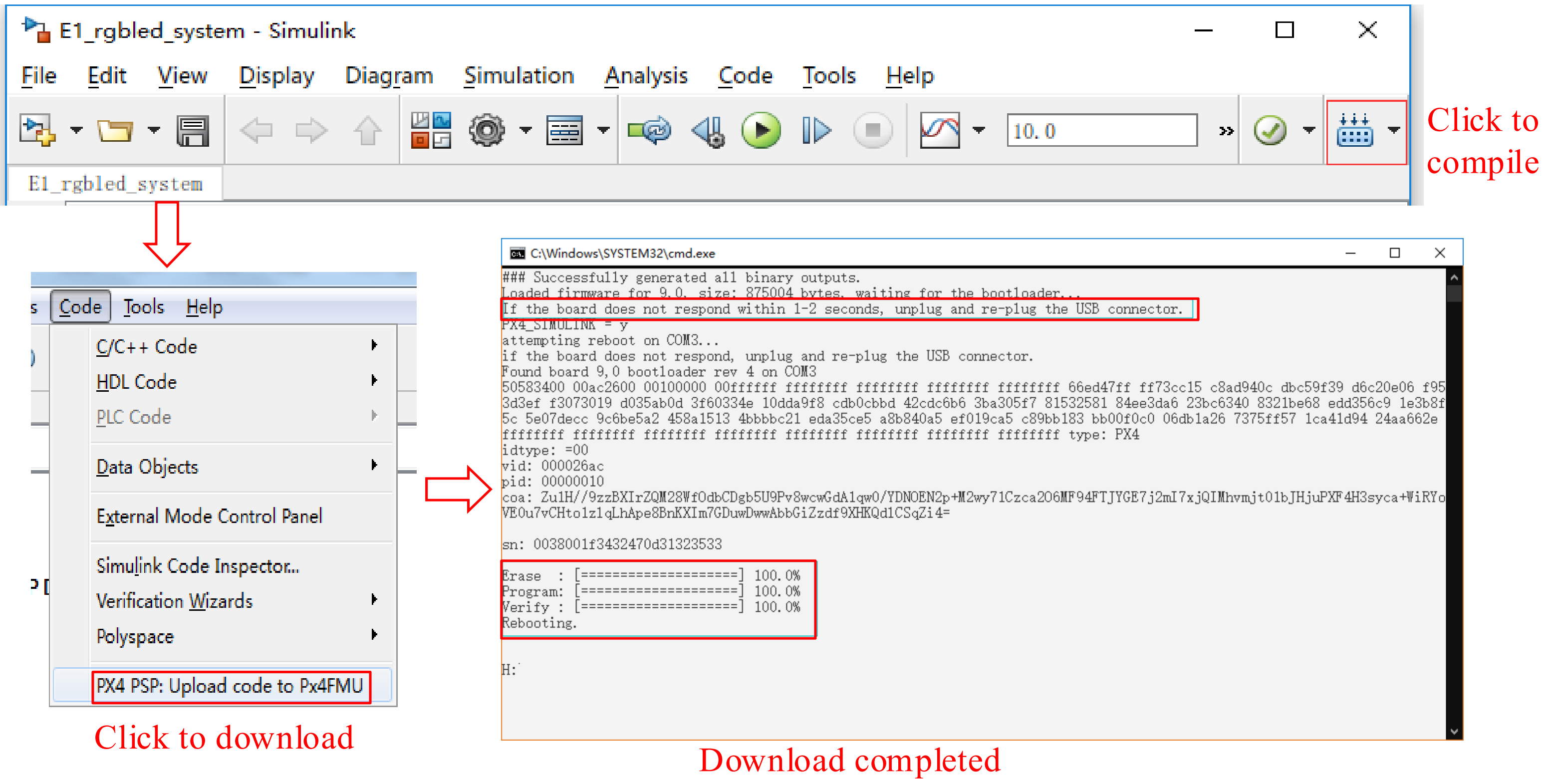

Figure: Code compilation and upload process

Analysis Experiment

□ Simulation procedure

4） Configure CopterSim

Double-click on the desktop shortcut CopterSim to open it. Readers can choose different propulsion systems using the following procedure. Click on “Model Parameters” to customize the model parameters and, then click on “Store and use the parameters” to make them available. The software will automatically match the serial port number. Readers would click the“Run”button to enter the HIL simulation mode. After that, readers could see the message returned by the Pixhawk autopilot in the lower-left corner of the interface.

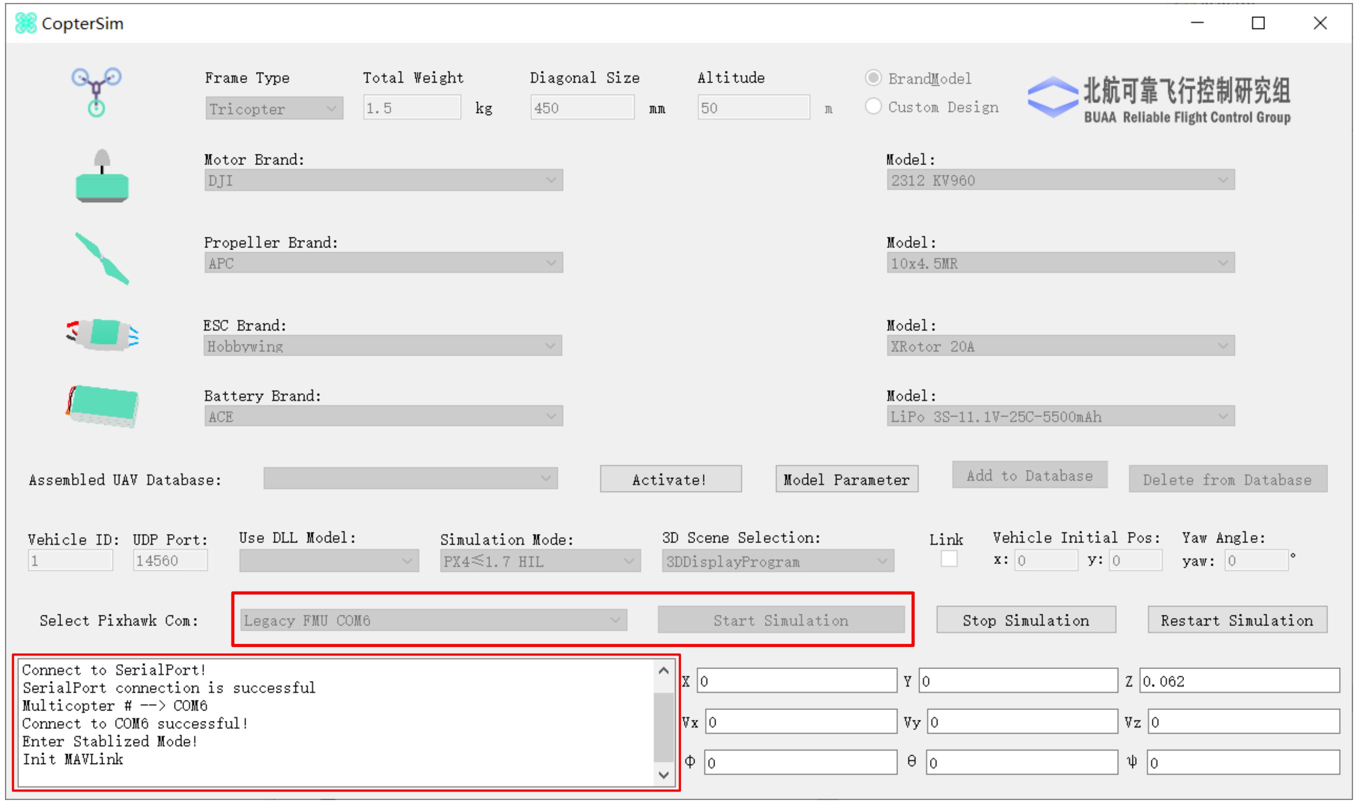

Figure: User interface of CopterSim

Analysis Experiment

□Simulation procedure

5）Open 3DDisplay

Double-click on the desktop shortcut 3DDisply to open it.

6）Simulation performance

Arm the quadcopter and fly it to a certain altitude. Then push the three-position switch CH5 back to realize RTL MODE. After RTL is completed, then push CH5 back for auto-landing. This is different from the basic experiment, as there is no switch between returning and landing in the basic experiment.

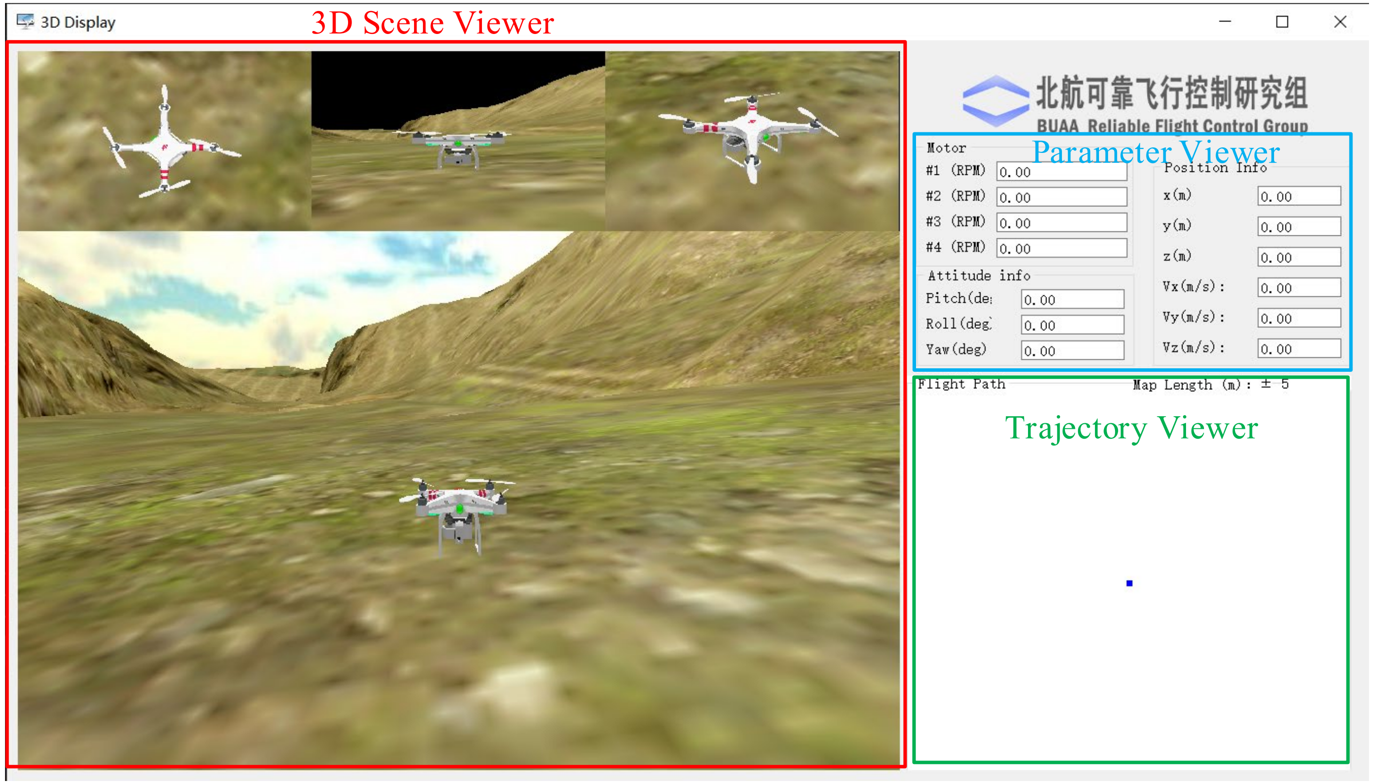

Figure: User interface of 3DDisplay

Analysis Experiment

□ Remark

The quadcopter needs some time in the process of returning and landing. During the simulation process, sufficient time should be left for the whole simulation.

Analysis Experiment

□ Experimental Objectives

■ **Things to prepare**

（**1**）Hardware: Multicopter System, Pixhawk Autopilot System;

（2）Software: MATLAB 2017b and above, Simulink-based Controller Design and Simulation Platform, HIL Simulation Platform, Experiment Instruction Package “e8.3”（https://flyeval.com/course）.

■ **Objectives**

(1) Based on the analysis experiment, a new state machine should be designed to deal with the case in which the RC transmitter is power-off. In addition, a requirement should be added that: if the quadcopter is close to HOME point, it will land directly; and if the quadcopter is at a certain distance from HOME point, it will first return and then land.

(2)Perform the HIL simulation and flight test.

Design Experiment

□ Design Procedure

（1） Step1: Flight modes

To simplify the logic design, the whole process from takeoff to landing of the multicopter is divided into five flight modes, where two additional modes for the case of failure are added.

1） MANUAL FLIGHT MODE

2） RTL MODE

3） AUTO-LANDING MODE

4） FAIL LANDING MODE : the quadcopter automatically lands when the RC transmitter is power-off.

5） FAIL RTL MODE : the quadcopter automatically returns to the initial horizontal position when the RC transmitter is power-off.

Design Experiment

◻ Design Procedure

（2）Step2: Event Definition

1)MIEs are instructions from remote pilots sent through the RC transmitter, including the following:

① MIE1: Arm and disarm instructions. ② MIE2: Manual operation instruction.

2)ATEs are independent of the remote pilot's operations, but mainly generated by the status of components on board and status of the multicopter.

① ATE1: Status of connections of RC. ATE1 = 1: normal, ATE1 = 0: abnormal.

② ATE3: Multicopter's distance from HOME point. ATE3 = 1: quadcopter's distance from HOME point is not greater than a specified threshold, ATE3 = 0: quadcopter's distance from HOME point is greater than the specified threshold.

Design Experiment

◻ Design Procedure

（3） Step3. Design the State Machine

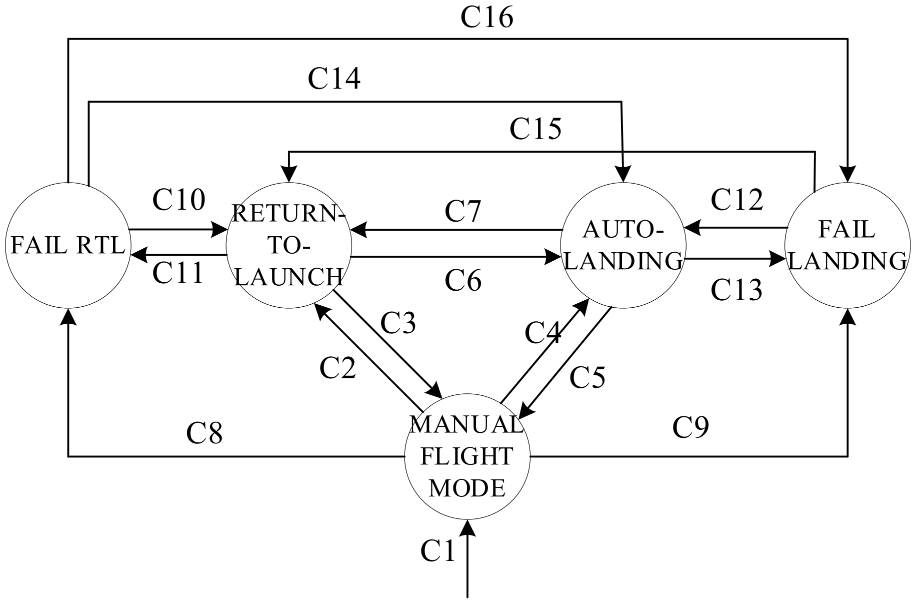

Figure: EFSM of design experiment

■ **C1:MIE1=1**

This condition implies a successful arm operation. This condition is true, when the remote pilot arms the quadcopter ($MIE1 = 1$);

■ **C2、 C7， C10、 C15: ATE1=1&MIE2=2**

These conditions describe the transition conditions of the quadcopter from MANUAL FLIGHT MODE(C2), AUTO-LANDINGMODE(C7), FAIL LANDINGMODE(C15), FAIL RTL MODE(C10) to RTL MODE, respectively. The quadcopter must meet the following requirements: the RC must be connected normally ($ATE1 = 1$) and a manual operation instruction to RTL MODE is performed ($MIE2 = 2$);

■ **C3、 C5: ATE1=1&MIE2=1**

There are conditions for switching of a quadcopter from RTL MODE(C3) and AUTO-LANDING MODE(C5) to MANUAL FLIGHT MODE, respectively. The quadcopter must meet the following requirements: the RC is connected normally ($ATE1 = 1$) and manual operation instruction to MANUAL FLIGHT MODE is performed ($MIE2 = 1$);

■ **C4、 C6、 C12、 C14: ATE1=1&MIE2=3**

These conditions describe the conditions for a quadcopter from MANUAL FLIGHT MODE(C4), FAIL LANDING MODE(C6), FAIL LANDING MODE(C12) and FAIL RTL MODE(C14) to AUTOLANDING MODE, respectively. The quadcopter must meet the following requirements: the RC must be connected properly ($ATE1 = 1$) and manual operation instruction to AUTO-LANDING MODE ($MIE2 = 3$);

Design Experiment

Design Procedure

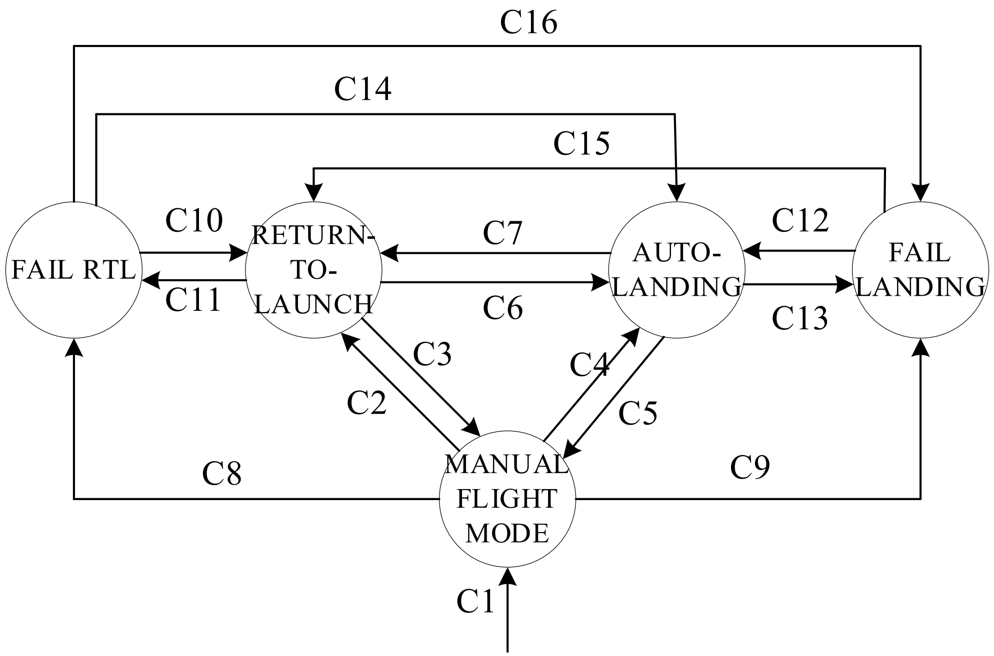

Figure: EFSM of design experiment

- **C8: ATE1=0&ATE3=0**

  This condition implies a switch from MANUAL FLIGHT MODE to FAIL RTL MODE. Such a switch will take place in the following case: the connection to the RC transmitter is abnormal ($ATE1 = 0$) and the quadcopter's distance from HOME point is greater than the specified threshold ($ATE3 = 0$);

- **C9: ATE1=0&ATE3=1**

  This condition implies a switch from MANUAL FLIGHT MODE to FAIL LANDING MODE. Such a switch will take place in the following case: the connection to the RC transmitter is abnormal ($ATE1 = 0$º and the quadcopter's distance from the HOME point is less than the specified threshold ($ATE3 = 1$);

- **C11、 C13: ATE1=0**

  These conditions imply switches from RTL MODE(C11) and LANDING MODE(C13) to FAILLANDING MODE, respectively. The conditions are triggered by the connection to the RC transmitter being abnormal ($ATE1 = 0$).

- **C16: ATE1=0&ATE3=1**

  This condition implies a switch from FAIL RTL MODE to FAIL LANDING MODE. Such a switch will take place in the following case: the connection to the RC transmitter is abnormal （$ATE1 = 0$) and the quadcopter's distance from HOME point is not greater than the specified threshold（$ATE3 = 1$).In this case, the quadcopter can make landing.

Design Experiment

◻ Design Procedure

（4） Step4: Modify the Simulink model

1) Modify the state machine model

According to Steps 1~3, the state machine model is modified and refined based on that in the analysis experiment.

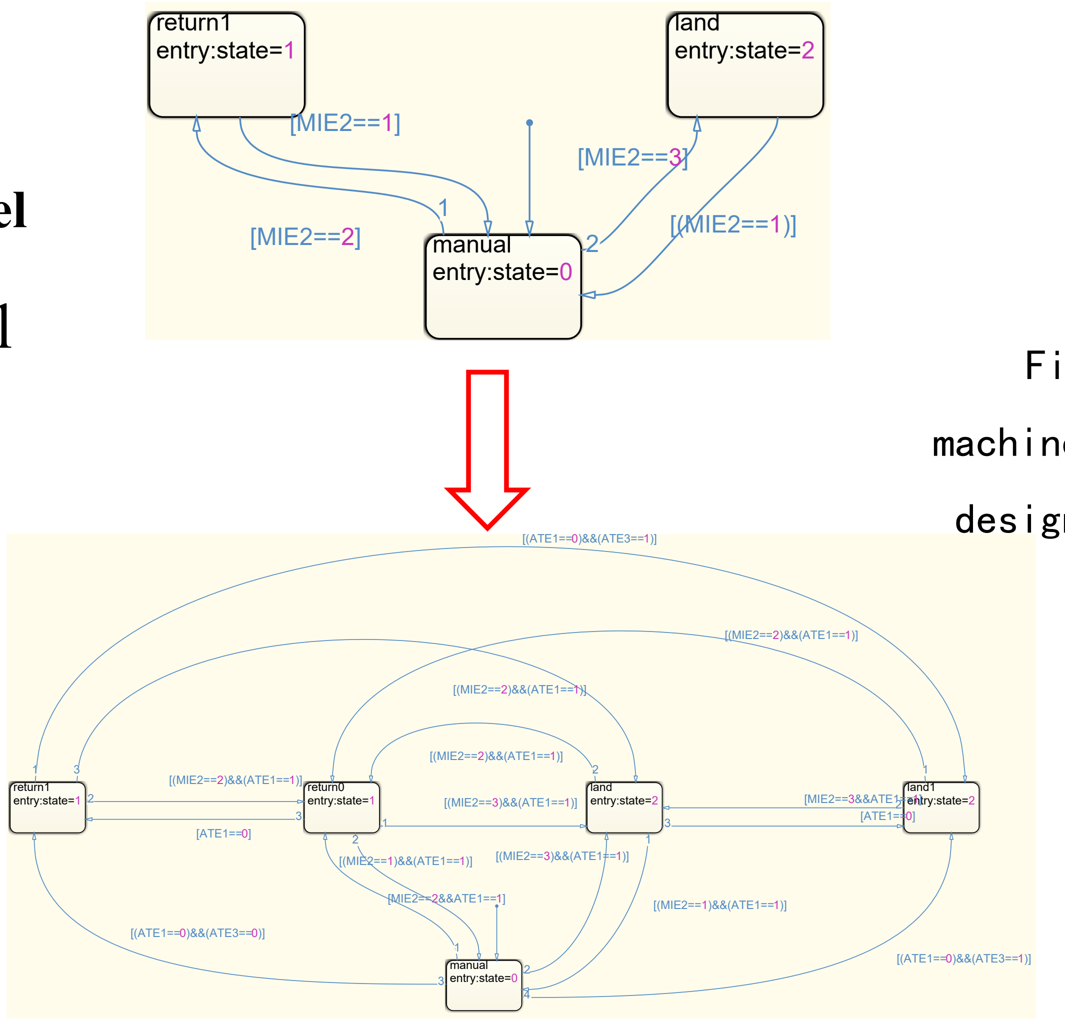

Figure: State machine designed in design experiment

Design Experiment

□ Design Procedure

2)Modify the RC input

Add an RC channel to simulate the RC transmitter power failure event, the input of which is 0 in the first 10s, corresponding to the normal connection of RC transmitter. It becomes 1 after 10s, corresponding to the connection lost.

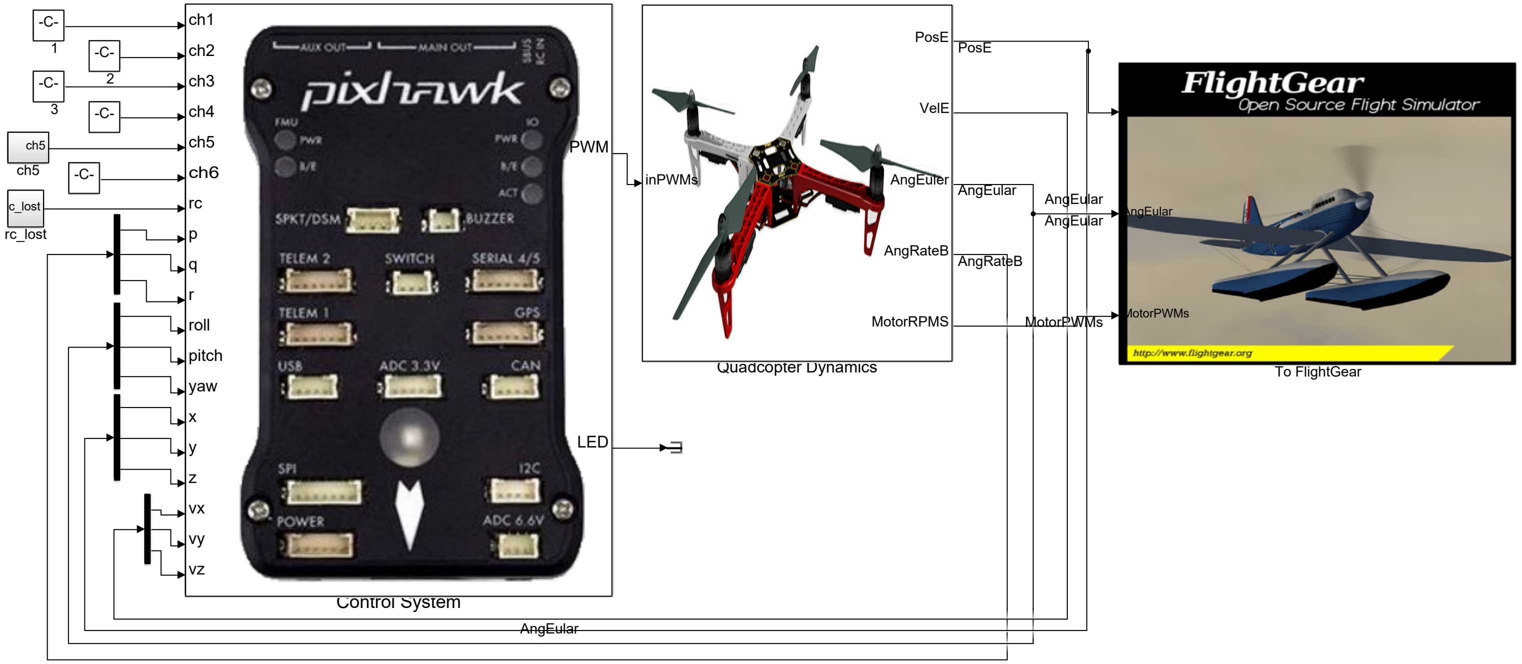

Figure: Simulink file ” e8/e8.3/SIM/e8_3.slx”

3） Save model

Save the model to “e8/e8.3/SIM/e8_3.slx”.

Design Experiment

Simulation Procedure

（1） Step1: SIL simulation

Run the file “Init_control.m” to initialize the parameters. Click on the “Run” button to run the simulation, It can be observed that, during 0~10s, the quadcopter is in MANUAL FLIGHT MODE and it can be piloted freely. After 10s, the RC is out of contact because of RC transmitter being power-off. At this time, the horizontal position of the quadcopter is far from HOME point and the altitude is less than the threshold. The quadcopter first climbs up to the safe altitude we set, then enters RTL MODE. The return process is completed at 18s with the horizontal position being 0. Then, the quadcopter enters AUTO-LANDING MODE and finally completes landing at 35s.

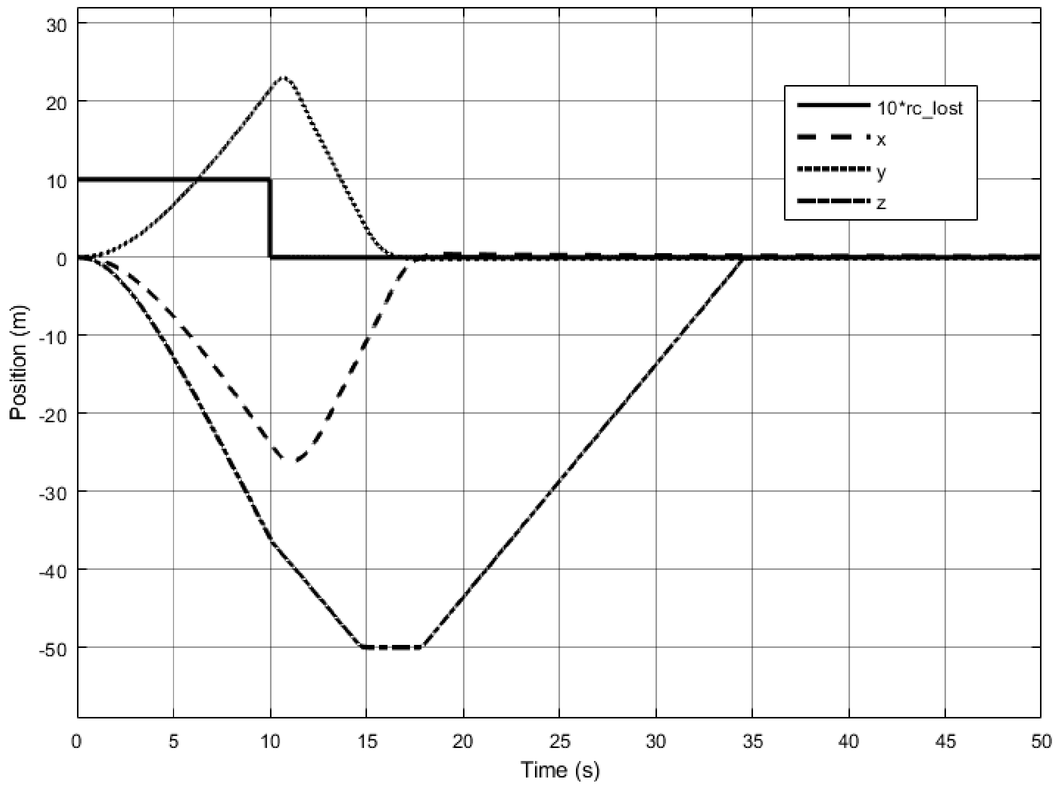

Figure: Position response when RC transmitter is power-off

Design Experiment

Simulation Procedure

（2） Step2. HIL simulation

1） Open the Simulink file for HIL

Open the Simulink file "e8/e8.3/HIL/e8_3_HIL.slx" and run the file "Init_control.m" to initialize the parameters. It should be noted that "Control System" here is the same as that in the SIL simulation.

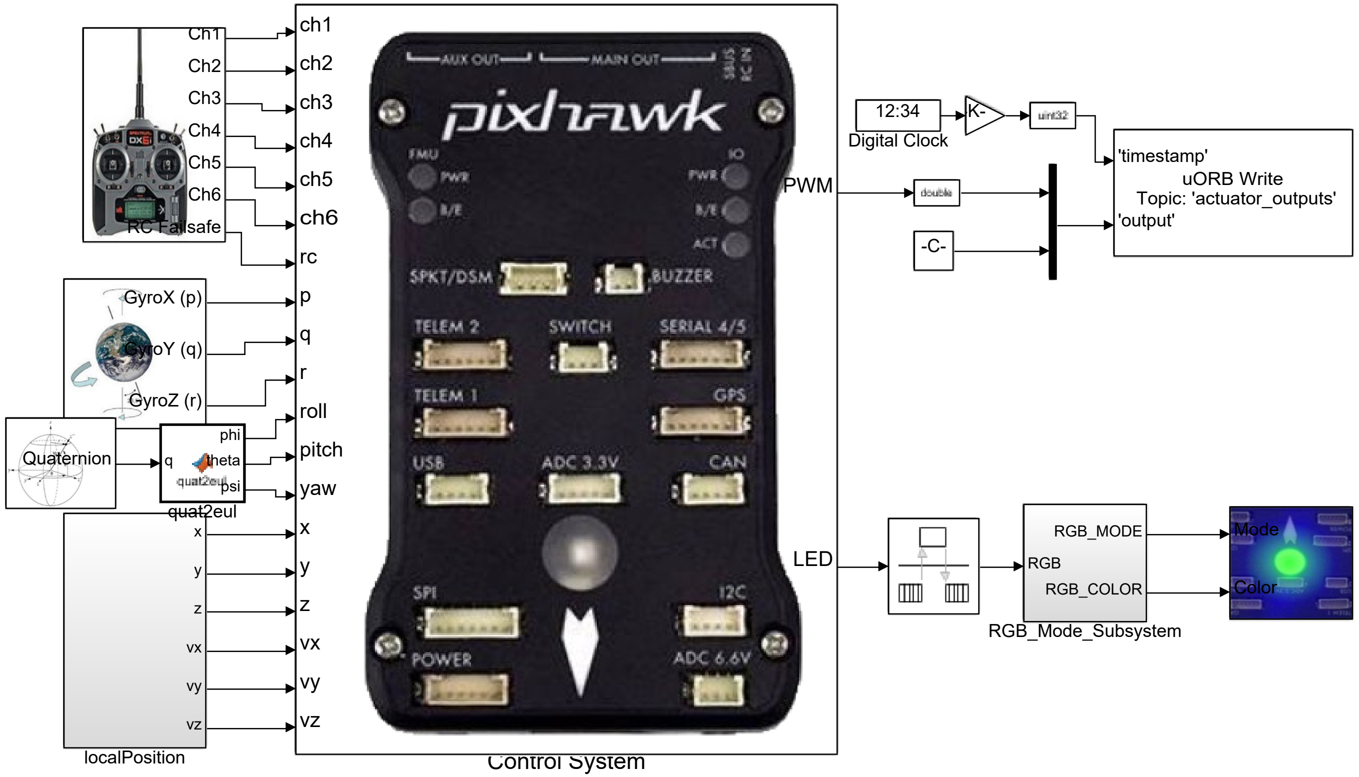

Figure: Simulink file "e8_1_HIL.slx"

☐ Simulation procedure

2）Connect hardware

It should be noted that the airframe type "HIL Quadcopter X" should be selected in HIL simulation.

Figure: Connection between Pixhawk hardware and RC receiver

Design Experiment

□Simulation procedure

3）Compile and upload code

Compile the HIL simulation model and upload the file to the given Pixhawk autopilot. Later, the designed attitude control program can be run on Pixhawk autopilot.

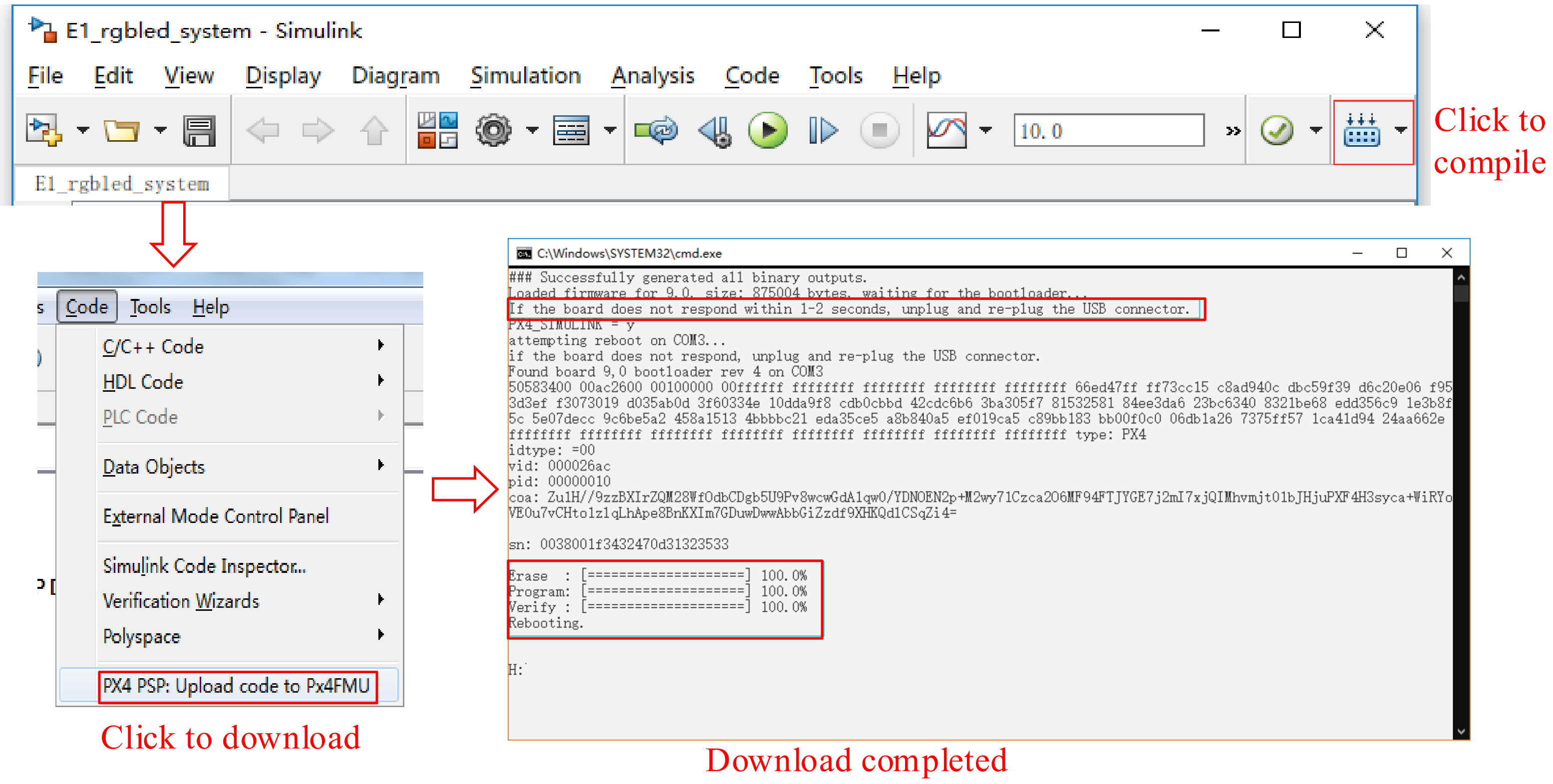

Figure: Code compilation and upload process

Design Experiment

□ Simulation procedure

4） Configure CopterSim

Double-click on the desktop shortcut CopterSim to open it. Readers can choose different propulsion systems using the following procedure. Click on “Model Parameters” to customize the model parameters and, then click on “Store and use the parameters” to make them available. The software will automatically match the serial port number. Readers would click the“Run”button to enter the HIL simulation mode. After that, readers could see the message returned by the Pixhawk autopilot in the lower-left corner of the interface.

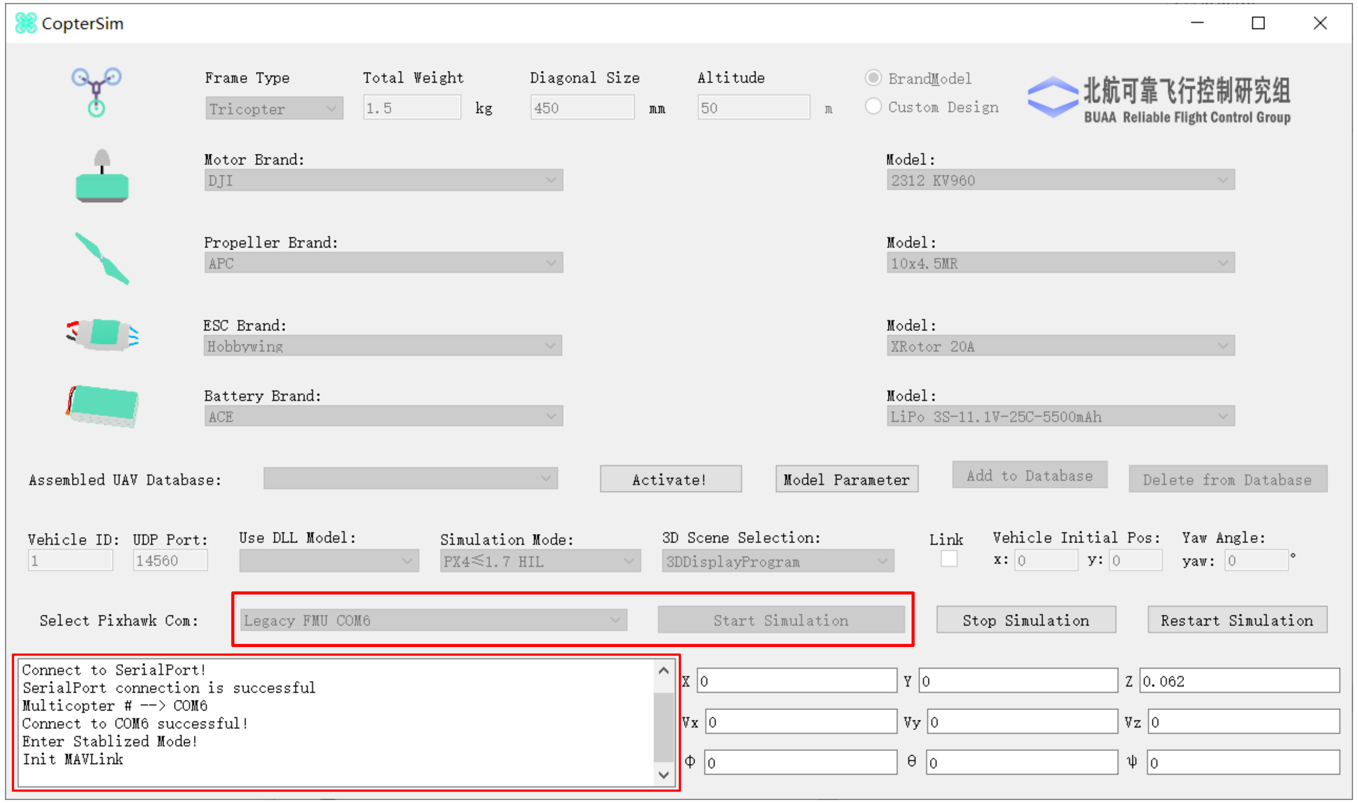

Figure: User interface of CopterSim

Design Experiment

◻Simulation procedure

5）Open 3DDisplay

Double-click on the desktop shortcut 3DDisply to open it.

6）Simulation performance

Arm the quadcopter which is first in MANUAL FLIGHT MODE for a while. Then, turn off the power of the RC transmitter. In this case, the RC is out of contact. By the logic designed, the quadcopter returns to HOME point and land automatically..

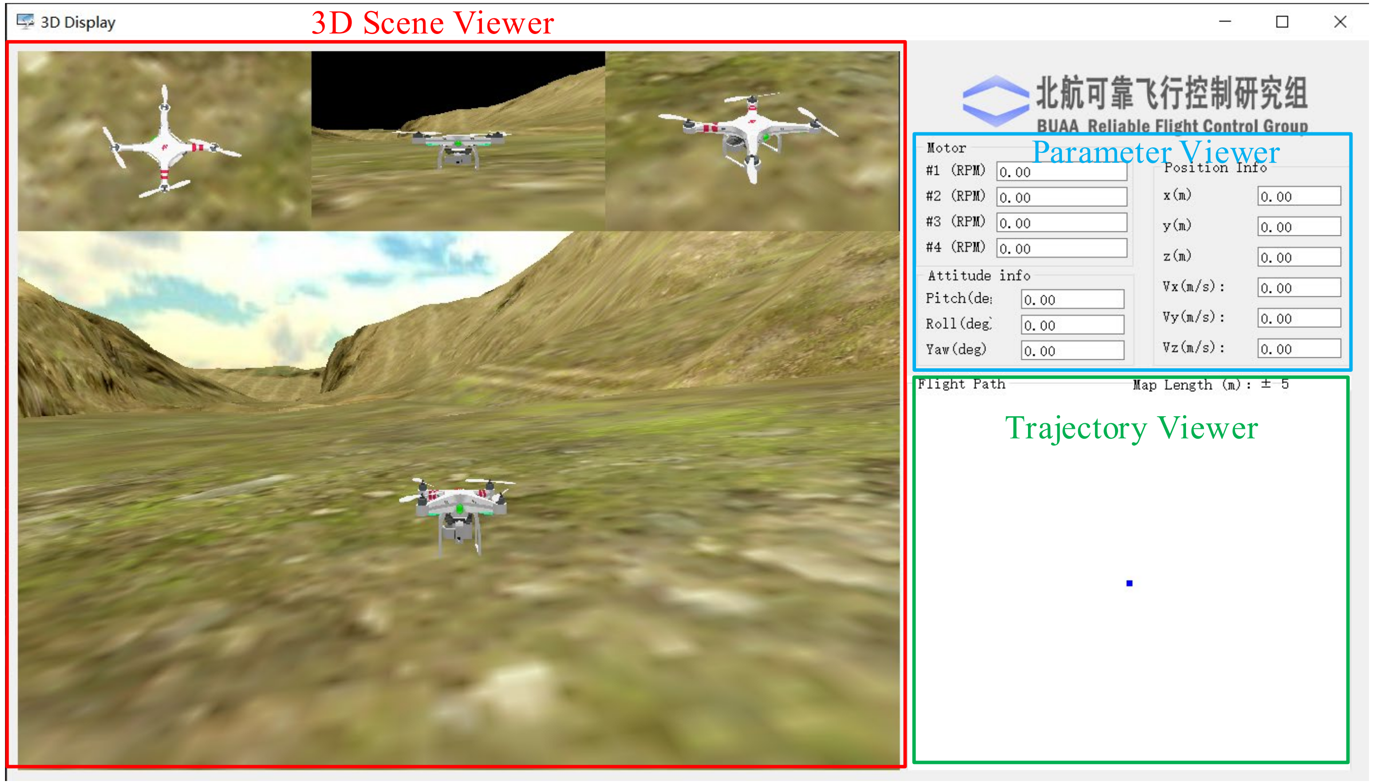

Figure: User interface of 3DDisplay

Design Experiment

☐ Flight Test Procedure

（1） Step1: Quadcopter configuration

The multicopter used in the outdoor flight tests is an F450 quadcopter For outdoor flight tests, the airframe of Pixhawk should be changed from “HIL Quadcopter X” to “DJI Flame Wheel F450” in QGC and all sensors should also be calibrated in QGC.

Figure: F450 airframe schematic

Design Experiment

□Flight Test Procedure

（2） Step2: Simulink model for flight test

Compared with the model in the HIL experiment, the flight test model is changed the PWM output. A new data recording module is added to the model, A “invalid.msg.specified” warning block appears automatically when the Simulink model is opened. The detailed procedures of adding logger data can be found in Experiment 5.

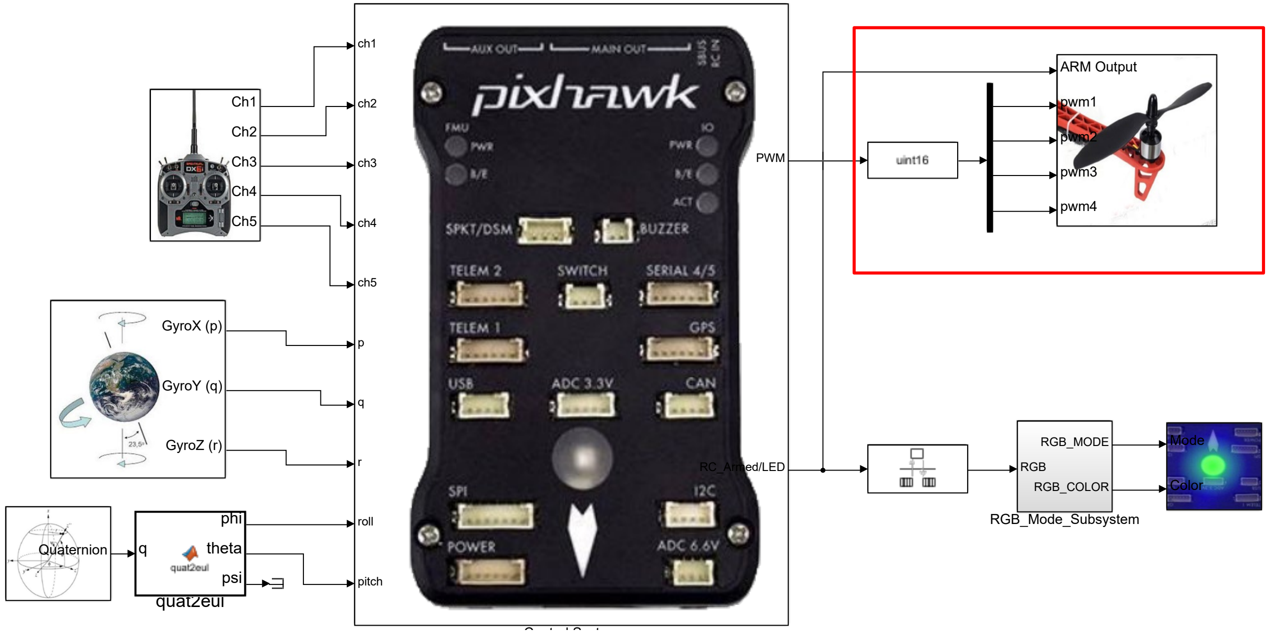

Figure: Model for flight test, Simulink model ” PosControl_FLY.slx”

Design Experiment

Flight Test Procedure

（3）Step3: Upload code

This process is similar to that used for compiling and uploading the code in HIL simulation.

（4）Step4: Outdoor flight test

To ensure safety, a rope is tethered to the quadcopter, and the other end is tethered to a heavy object. The remote pilot maintains a safe distance from the quadcopter during flight.

Figure: Outdoor flight test

(5) Step5. Analyze the data

During the first 335s, the quadcopter is in the stabilizing mode, corresponding the phase “a”, during which it flies freely under the control of the flight controller. At about 335s, the RC transmitter loses contact, corresponding to the phase “b”, the altitude of the quadcopter rises to 5m, and then returns to the HOME point at the horizontal position to complete the return flight.

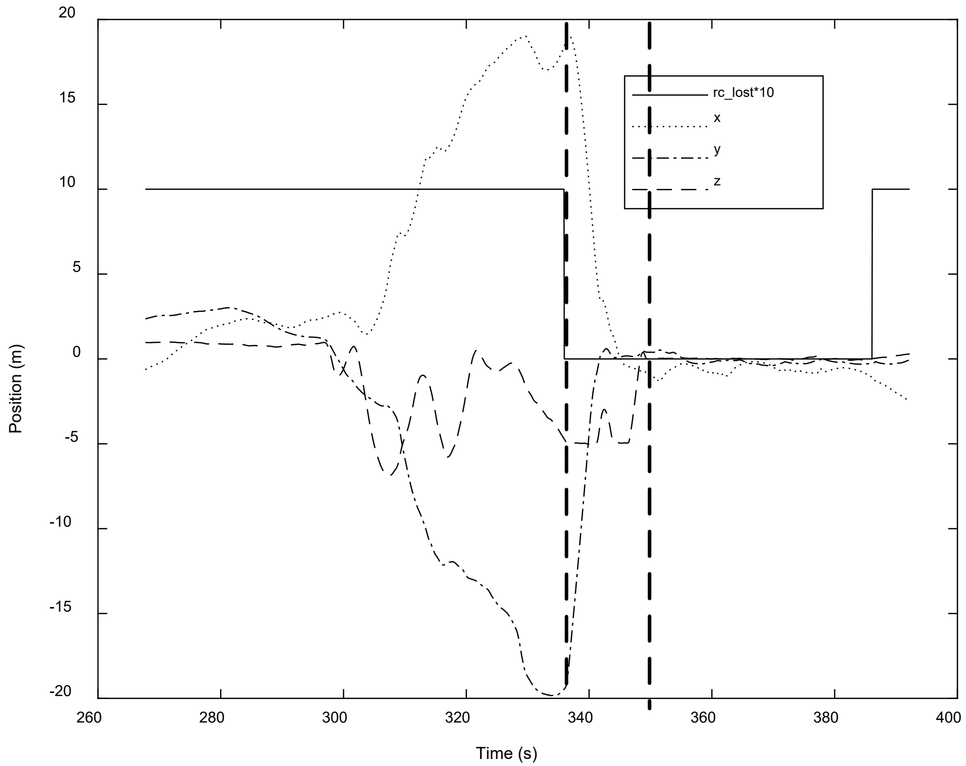

Figure: Position response with RC transmitter being power-off in flight test

Design Experiment

（5）Step5. Analyze the data

In order to ensure the safety, the safe altitude set in the flight test is 5m, i.e., when the quadcopter flight altitude is lower than 5m, it will rise to altitude 5m. Finally, the quadcopter land, corresponding the phase “c” the quadcopter’s horizontal position stays in the HOME point, while the altitude decreased to 0. The actual flight results and experimental data show that the quadcopter can achieve failsafe.

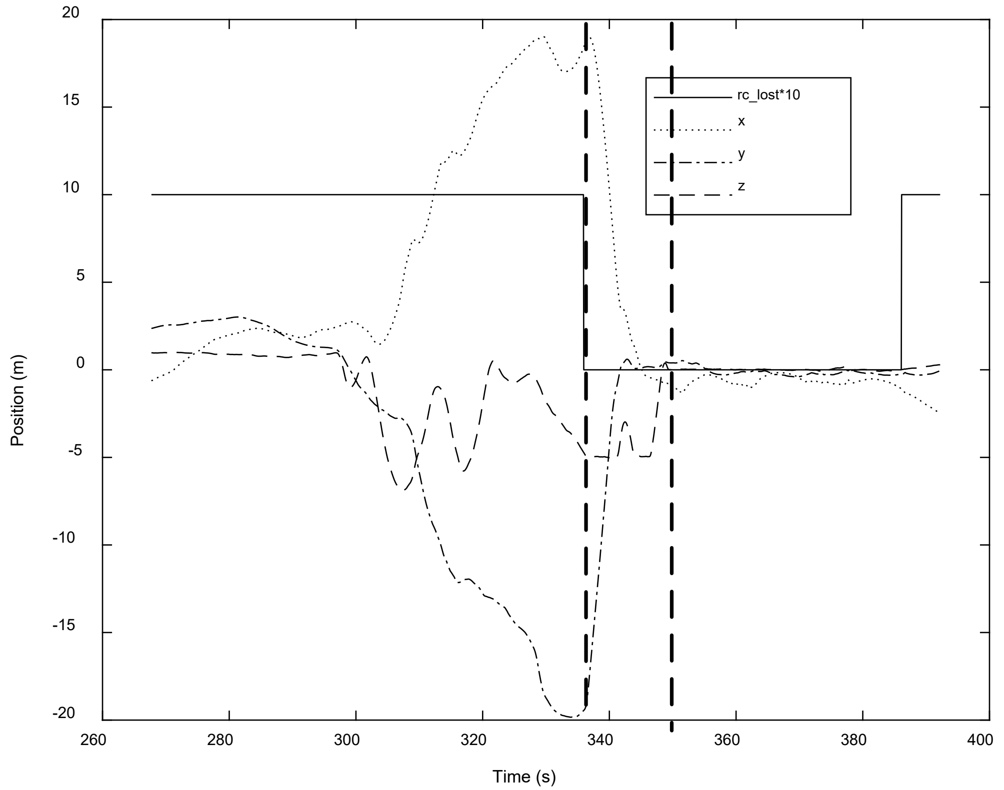

Figure: Position response with RC transmitter being power-off in flight test

Summary

(1)According to the given requirement, a state machine with several modes and events can be designed to simplify flight control.

(2)It is important to understand the three flight modes. RTL MODE is about returning to base and then hovering at a certain altitude. AUTO-LANDING MODE is about landing but the horizontal position keeps the same. In the two modes, autopilot is performed. In MANUAL FLIGHT MODE, the RC and automatic control both work.

(3) In this chapter, the main considerations are the connection of the RC as well as the altitude and horizontal position constraints. In an actual situation, it is necessary to consider other failures with the health evaluation (including pre-flight and in flight), making the design more practical.

Thanks