Development and Practice of Intelligent Unmanned Cluster Systems: A Full-Stack Development Case Study Based on the RflySim Platform

Lecture 5: Pose Control and Filter Estimation

飞思实验室

Outline

1.1 Reference Materials

- 全权, 戴训华, 王帅著. 多旋翼飞行器设计与控制实践[M]. 北京:电子工业出版社. 2020

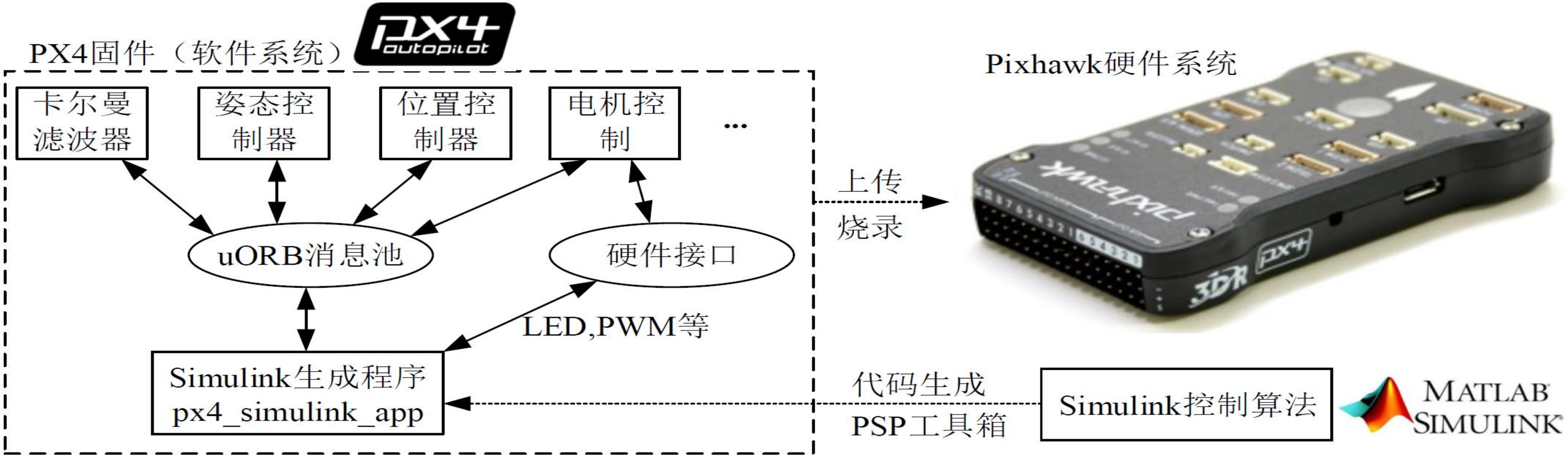
  Quan Quan, Dai Xunhua, Wang Shuai, "Design and Control of Multirotor Aircraft: Practice" [M], Published by Electronic Industry Press, 2020.

Note:

- The book 《多旋翼飞行器设计与控制实践》 on the left was released in 2020 and is a practical course focused on the development of flight control algorithms. It includes some theoretical knowledge and a series of experiments, enabling readers to quickly program their algorithms in Simulink and download them to Pixhawk for flight experiments.
- The book 《多旋翼飞行器设计与控制》 on the right was released in 2017 and primarily focuses on multicopter control theory.

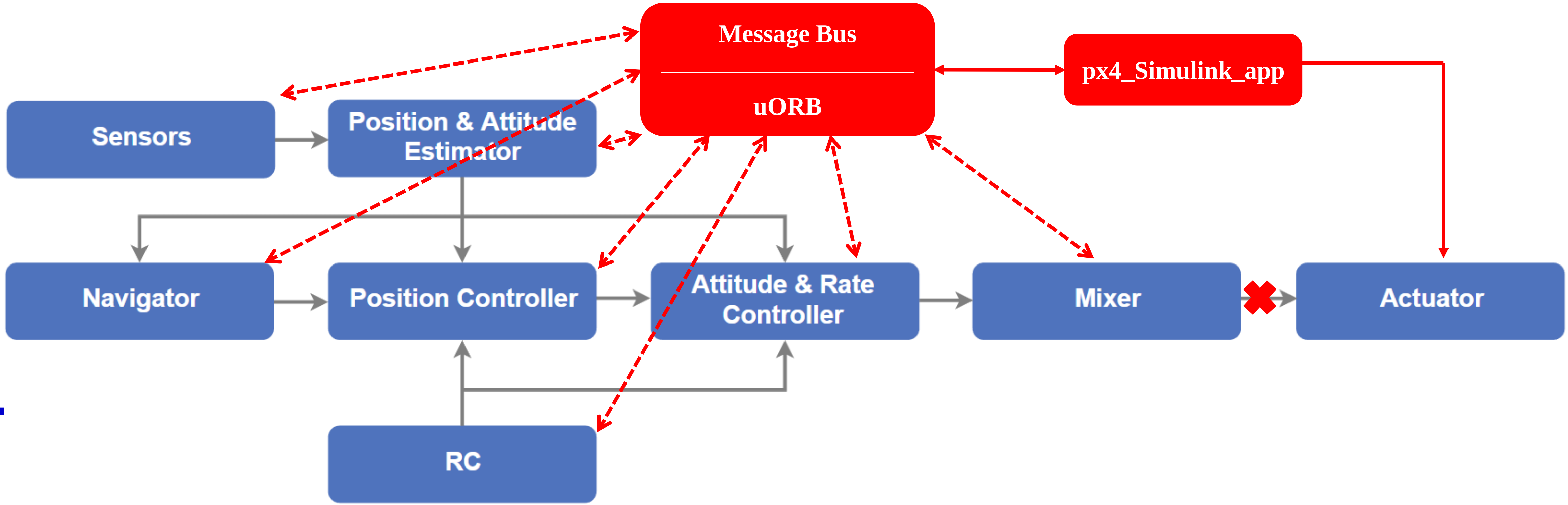
1.2 Pixhawk/PX4/Simulink Code Generation Platform Architecture

Pixhawk is the hardware (equivalent to a computer mainframe), PX4 is the flight control software (equivalent to the Windows operating system), Simulink generates controller code which is then compiled into firmware (equivalent to a system ISO image), uploaded to the Pixhawk hardware (similar to reinstalling the system), and the Simulink controller runs as a new thread (similar to a third-party app on a computer), operating independently of the official PX4 controller (similar to pre-installed software on the system), and running in parallel.

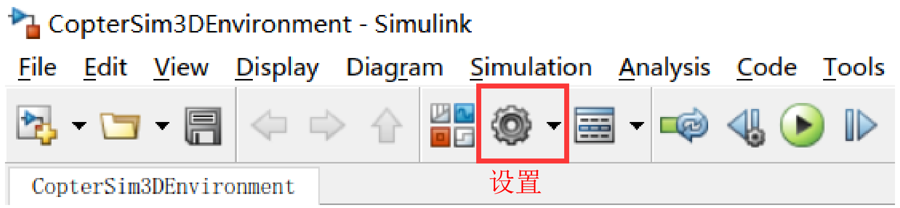


1.3 Why Disable PX4 Output

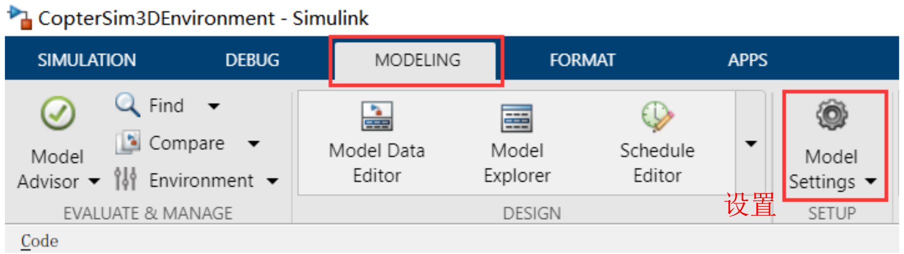
- PX4 adopts the uORB publish-subscribe message mechanism, allowing any app to retrieve and publish data from the uORB message pool.
- After Simulink code is generated and uploaded to Pixhawk, it creates an app named px4_Simulink_app. This app communicates with other apps through the uORB message pool mechanism.
- Simulink_App cannot access the motors simultaneously with the PX4 controller to avoid conflicts. Therefore, it is necessary to disable the official PX4 output.



1.4 Simulink Automatic Code Generation Configuration



(a) Simulink “设置”按钮（MATLAB 2017b~2019a）



(b) Simulink “设置”按钮（MATLAB 2019b及更高版本）

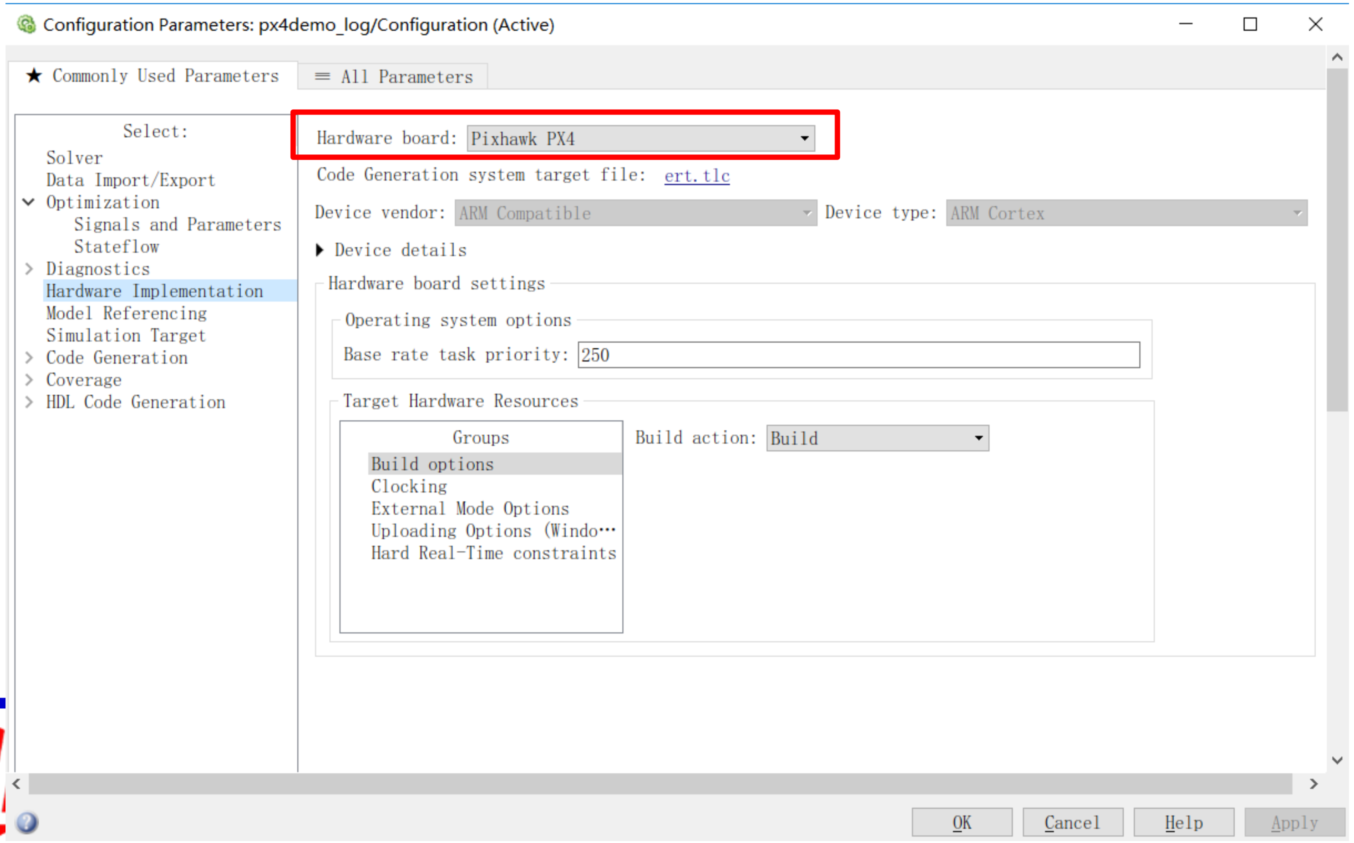
Creating a new blank slx routine file

1. Go to the Simulink settings page (For MATLAB 2019b and above, cli ck the "Settings" button on the MO DELING tab).

2. Select the Hardware board setting as Pixhawk PX4, which will automat ically complete all the code generati on settings required for this platfor m.

3. Custom task priorities can be set.

4. Configure compilation options.

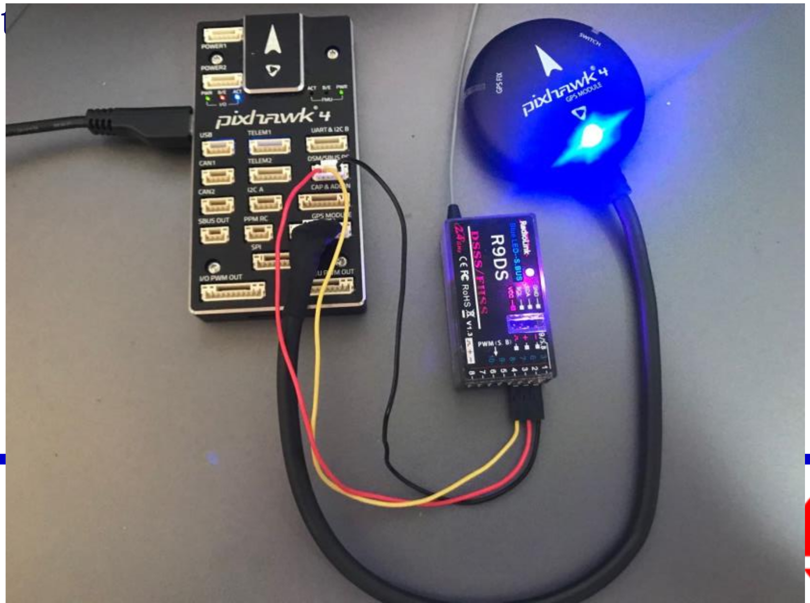


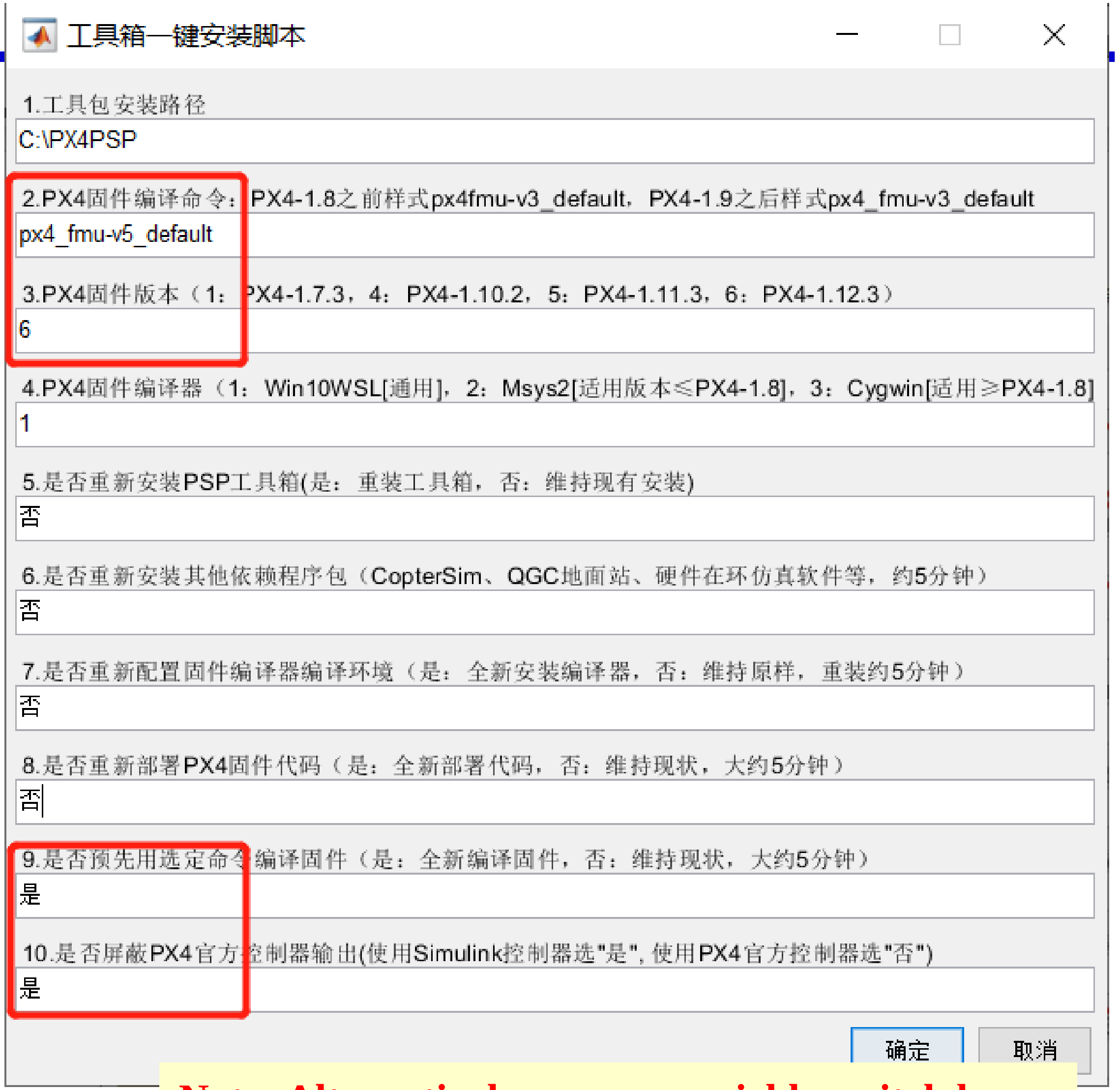
1.5 PX4PSP Toolbox Location

- Open any Simulink file, click the "Library Browser" button, and you will find the "Pixhawk Target Blocks" module library in it.
- The modules in this library can be considered as higher-level interfaces encapsulating the subscription or publication of data from the PX4 uORB pool. They include functions related to sensors, remote controllers, motors, serial ports, and more.
- Note: These modules do not contain internal models; data can only be obtained when the code is generated and compiled into PX4 firmware. If run directly in Simulink, the received data will be all zeros.
- For detailed usage of each module, refer to the Basic Edition course or the third tutorial.

1.6 Experimental Configuration - Recommended Installation Options

- **Recommended Installation Options:**
- **It is recommended to use the latest Pixhawk 4 autopilot (refer to the image below), with the compilation command named px4_fmu-v5_default.**
- **Re-run the "OnekeyScript.p" script included in the installation package.**
- **Utilize the latest PX4 firmware version "6" - PX4-1.12.3.**
- **Other configurations are as shown in the image on the right**



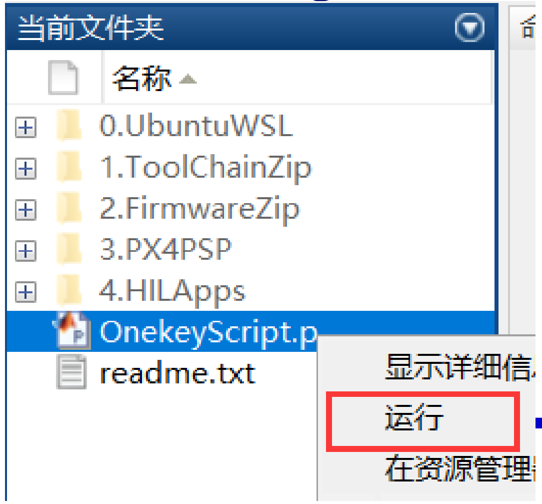


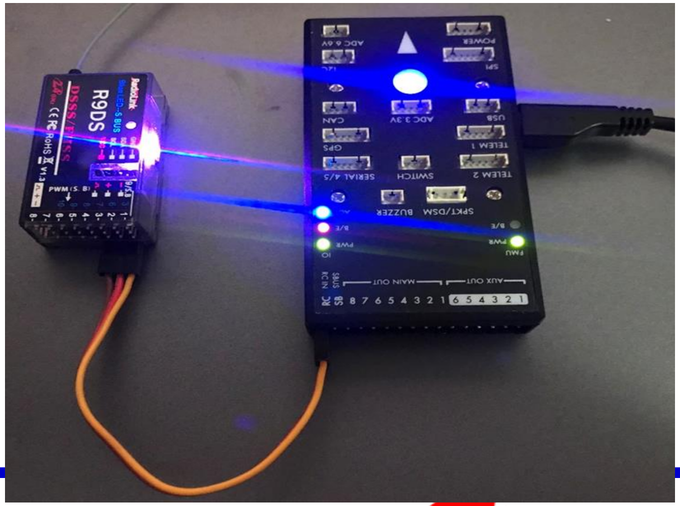
Note: Alternatively, you can quickly switch by entering the command "PX4CMD px4_fmu-v5_default" in MATLAB.

1.7 Experimental Configuration - Installation Options for Old Version of the Textbook

- If using the recommended Pixhawk 1 autopilot from the textbook (refer to the image below), the compilation command is px4_fmu-v3_default.
- Re-run the "OnekeyScript.p" script included in the installation package.
- Utilize the latest PX4 firmware version "6" - PX4-1.12.3, and compiler "1" - Win10WSL.
- Other configurations are as shown in the image on the right.

Note: If using the Pixhawk 1 autopilot recommended in the tutorial, it is advised to configure according to this page. Alternatively, you can follow the configuration method in the book, choosing PX4 1.7.3 version + Msys2 compiler (not recommended).





Note: Alternatively, you can quickly switch by entering the command "PX4CMD px4_fmu-v3_default" in MATLAB.

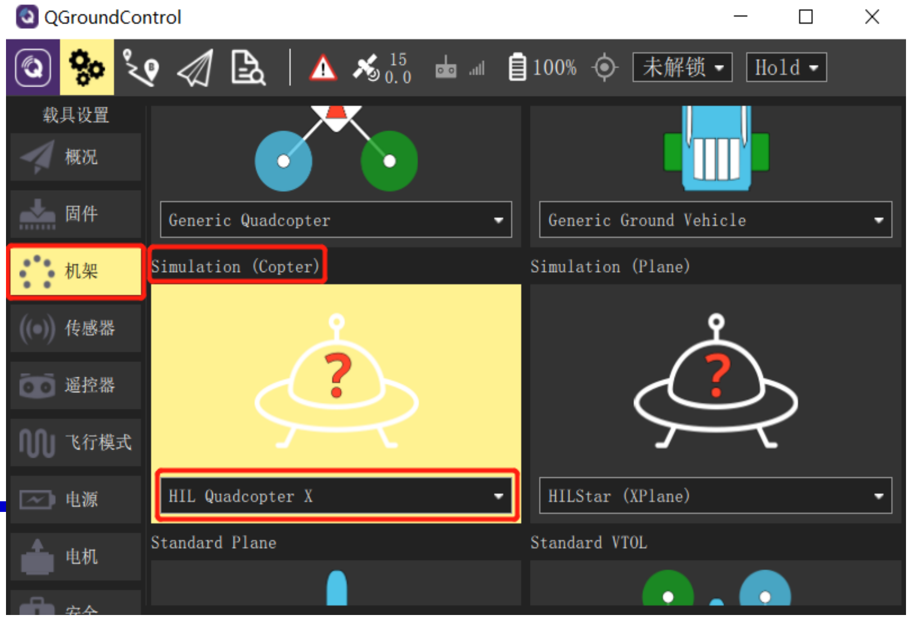
1.8 Experimental Configuration - Hardware Setup and Verification

1、Please refer to the tutorial link for hardware setup:
https://doc.rflysim.com/hardware/3RC/AT9s_Pro.html

2、Confirm the following configurations:

- **Ensure Pixhawk has been flashed with the latest official firmware version 1.12 in QGroundControl (QGC), and the LED is blinking normally.**
- **Correctly connect Pixhawk to the receiver, connect the remote controller to the receiver, open QGC ground station, and ensure that the movement signals of the remote controller joysticks can be observed.**
- **Properly configure the remote controller and calibrate it in QGC, ensuring that the lowest and highest positions meet the definitions in the tutorial link.**
- **Confirm that Pixhawk flight controller has been set to select HIL Quadcopter X frame in QGC.**
- **Ensure flight modes in QGC are configured according to the tutorial.**

注：箭头表示PWM值增大的拨动方向



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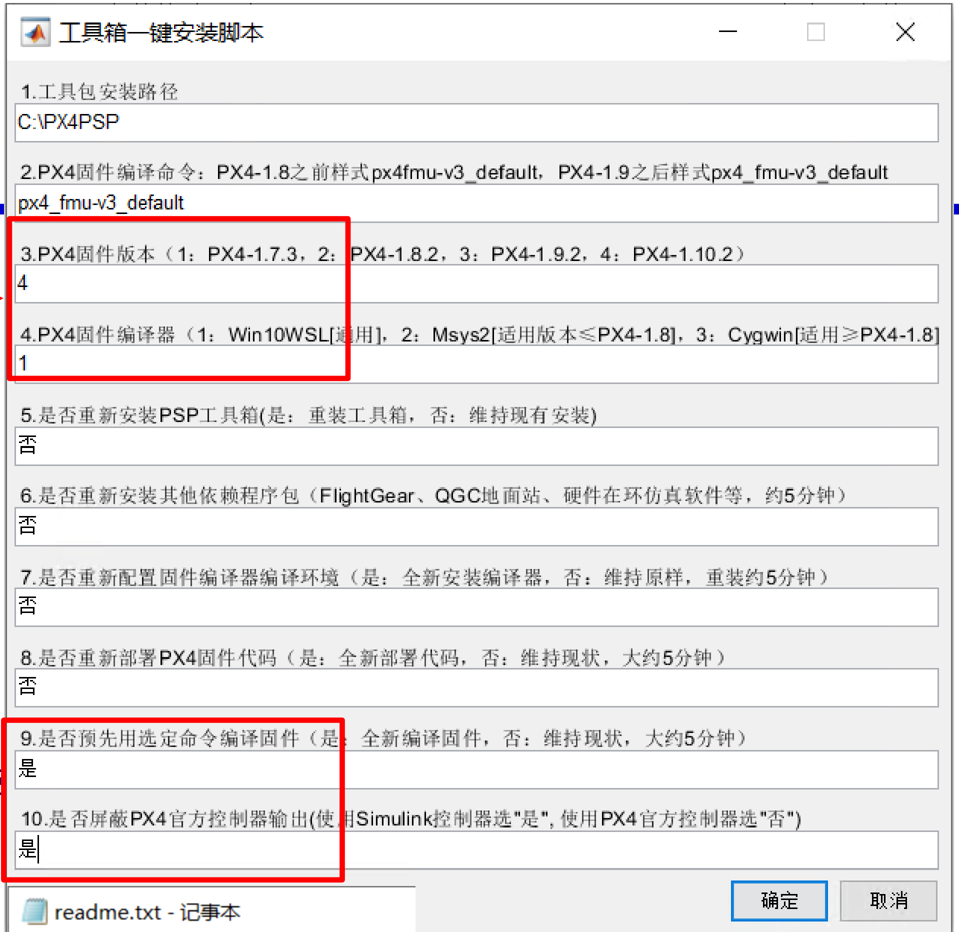
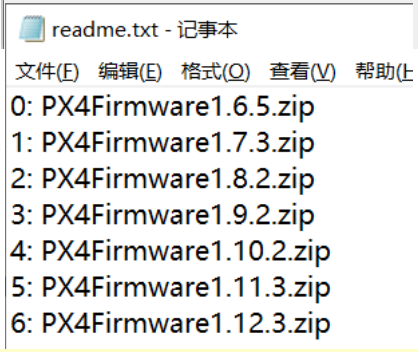
1.9 Choose a different firmware version.

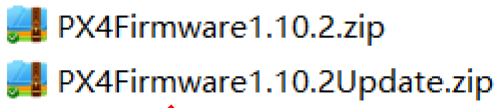
- If you need to use your own PX4 firmware code, rename your code folder to "Firmware", compress it into a Firmware.zip file, and then rename it according to the rules in 2.FirmwareZip\readme.txt. Choose the desired firmware version.
- For example, if you have developed your code based on PX4 1.10, name it "PX4Firmware1.10.2.zip" and replace the corresponding file under the "2.FirmwareZip" folder. In the firmware version selection in the installation options on the right, choose "4".
- Whether to shield PX4 output project selection "Yes", the script will automatically complete all the necessary firmware modifications to adapt to this platform.

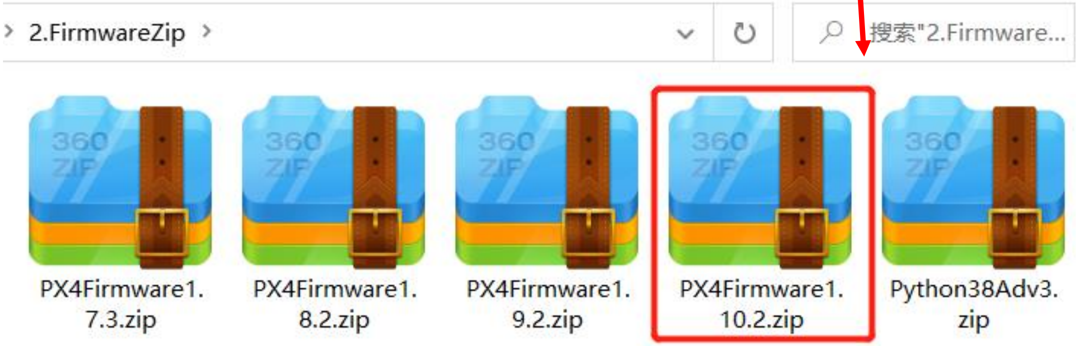



readme.txt - 记事本

文件(F) 编辑(E) 格式(O) 查看(V) 帮助(H)

0: PX4Firmware1.6.5.zip
1: PX4Firmware1.7.3.zip
2: PX4Firmware1.8.2.zip
3: PX4Firmware1.9.2.zip
4: PX4Firmware1.10.2.zip
5: PX4Firmware1.11.3.zip
6: PX4Firmware1.12.3.zip



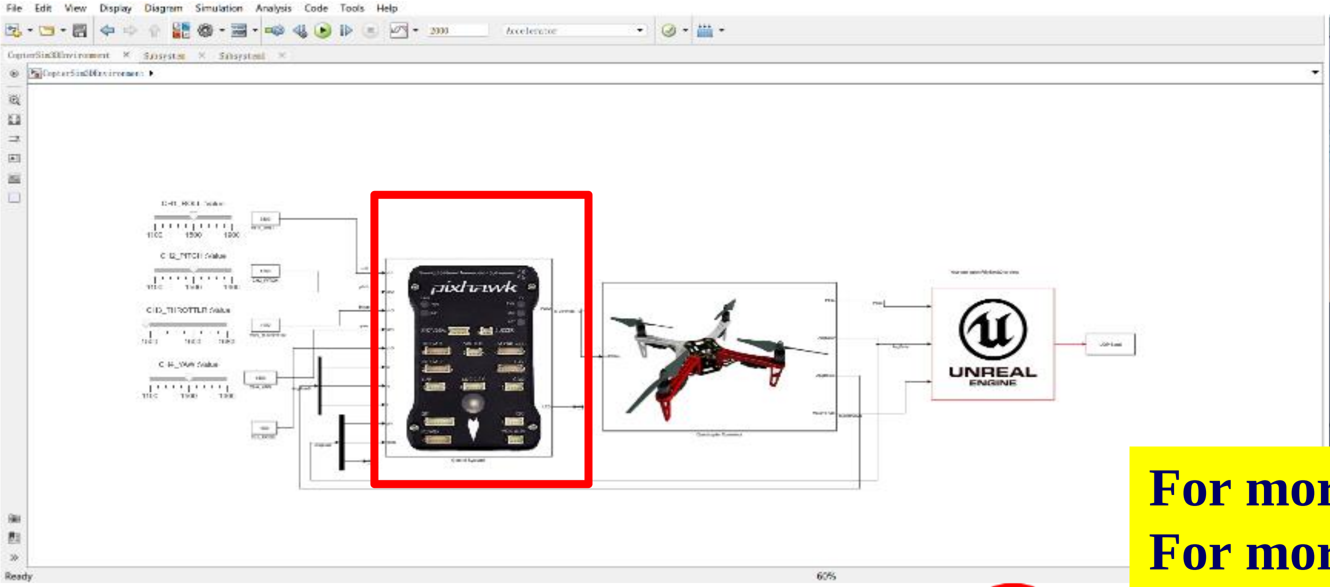


注：也可以将PX4Firmware1.10.2.zip官方固件的增量文件打包并命名为“PX4Firmware1.10.2Update.zip”的格式放在2.FirmwareZip目录，安装时会自动拷贝到固件文件夹。

Outline

2.1 Software in-the-loop simulation experiment

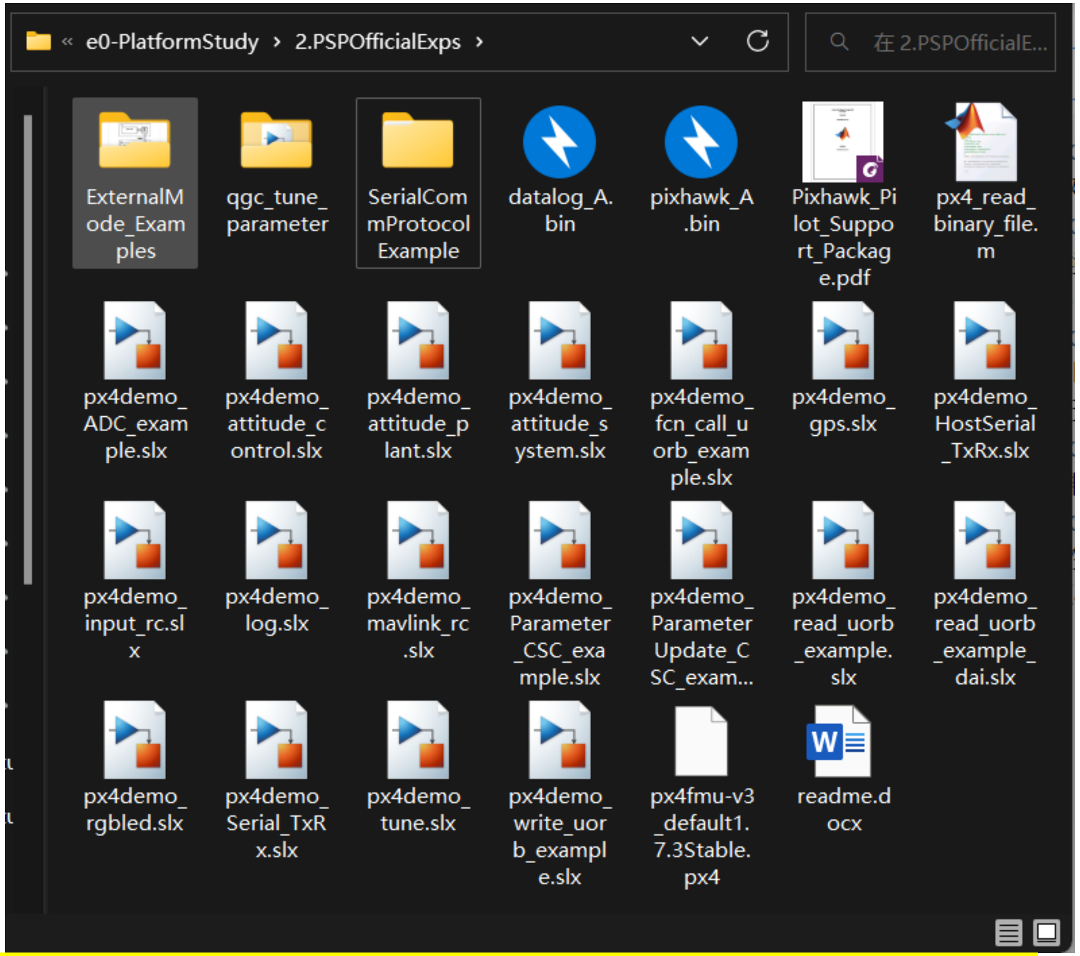
As shown in the right figure, control the multirotor to the specified pitch and roll angles, maintaining and controlling the attitude. The controller responds to the control inputs from the remote control, and you can simulate the remote control input by dragging the Slider module on the left. For specific experimental operations, refer to the file [0.ApiExps\1.SoftwareSimExps\Readme.pdf] . The experimental results are shown in the right figure.



For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2.2 Official Examples Experiment for Automatic Code Generation Toolbox

MATLAB provides relevant examples and documentation for the Pixhawk Pilot Support Package (PSP) in the document titled "Pixhawk_Pilot_Support_Package.pdf". Users can learn to model, simulate, and validate flight control models in Simulink, and deploy them to PX4 hardware integrated into the control system using the automatic code generation feature. For specific experimental operations, please refer to the file: [0.ApiExps\2.PSPOfficialExps\Readme.pdf](0.ApiExps\2.PSPOfficialExps\Readme.pdf) .



For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2.3 Attitude Control Design Experiment

This experiment designs a controller with inputs from remote control channels Ch1~Ch5 signals, angular velocity feedback AngRateB, and multirotor Euler angles (in radians). The entire process, from software in-the-loop simulation to automatic code generation, hardware in-the-loop simulation, and actual flight, is implemented by building a model in Simulink.

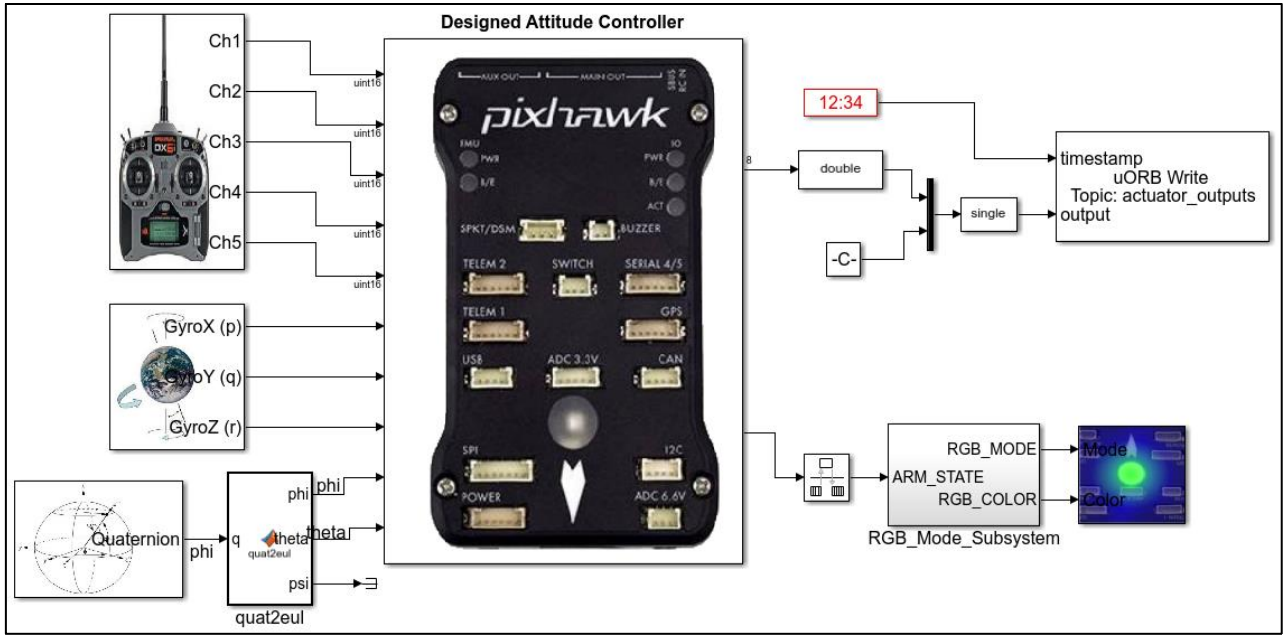
The specific operations of the experiment are detailed in the file:0.ApiExps\3.DesignExps\Readme.pdf 。

软件在环RflySim3D显示

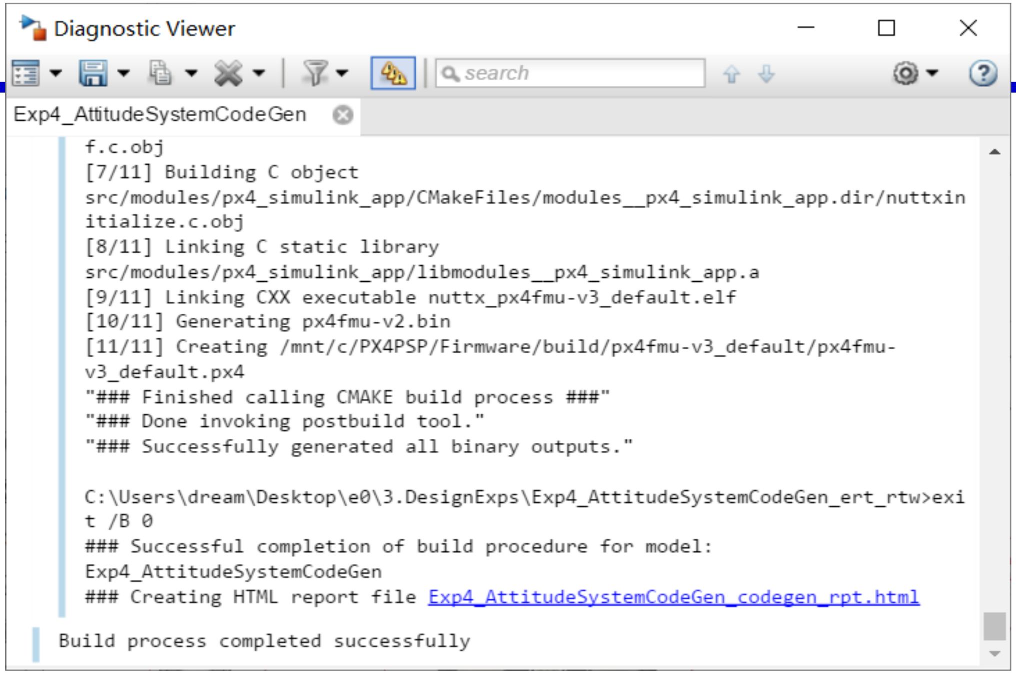
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2.Introduction to Key Interfaces

2.3 Attitude Control Design Experiment



硬件在环Simulink模型



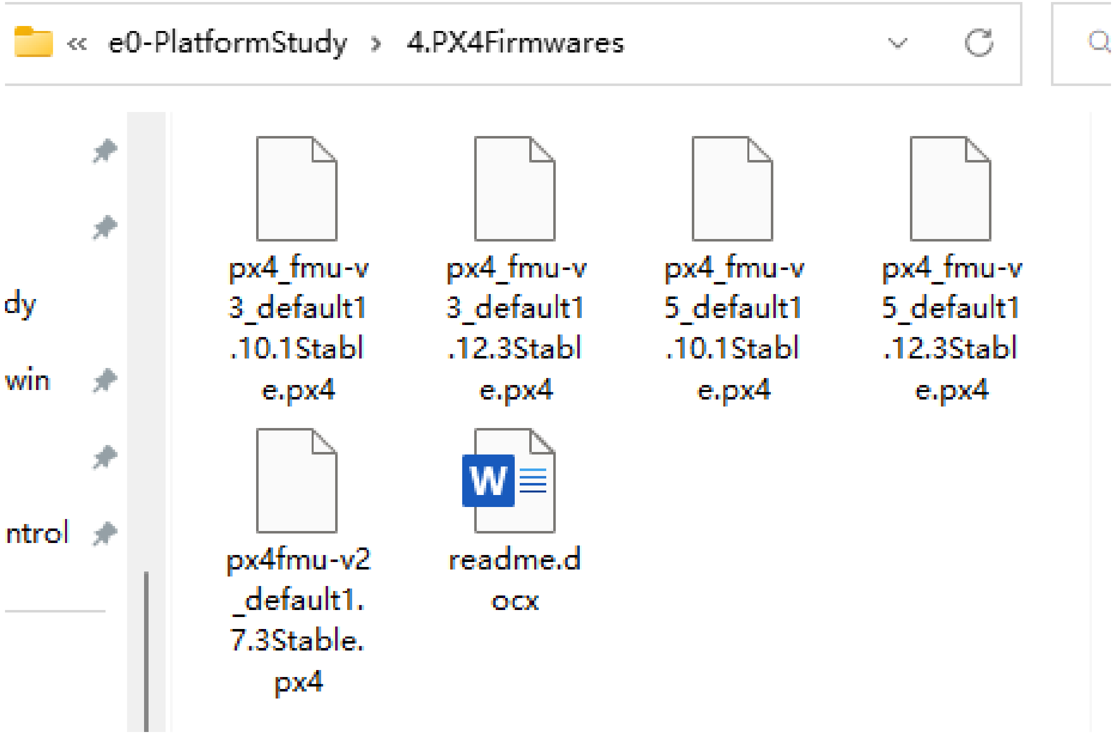
Simulink自动代码生成

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.4 Flight Controller Firmware Flashing Experiment

This experiment provides some flight controller firmware for conducting flight controller firmware flashing experiments using QGroundControl. For specific operating steps, please refer to the file:[0.ApiExps\4.PX4Firmwares\Readme.pdf] 。

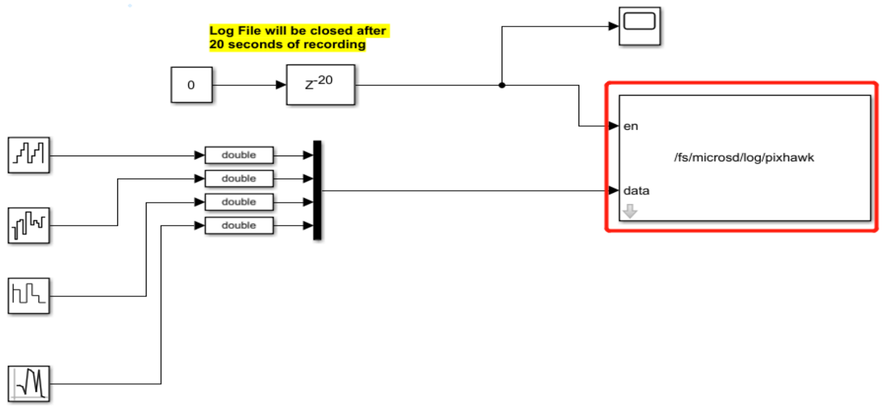


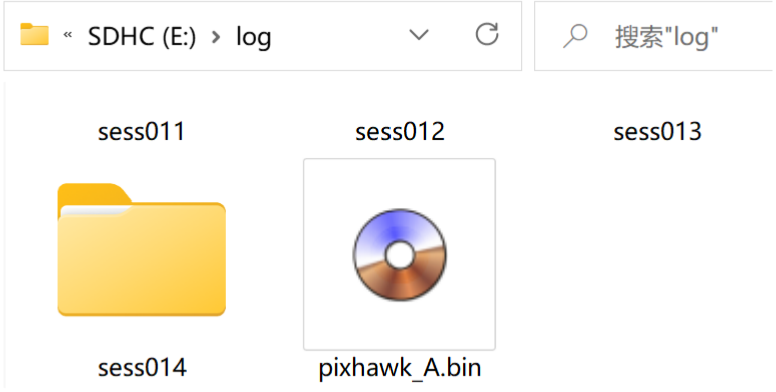
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

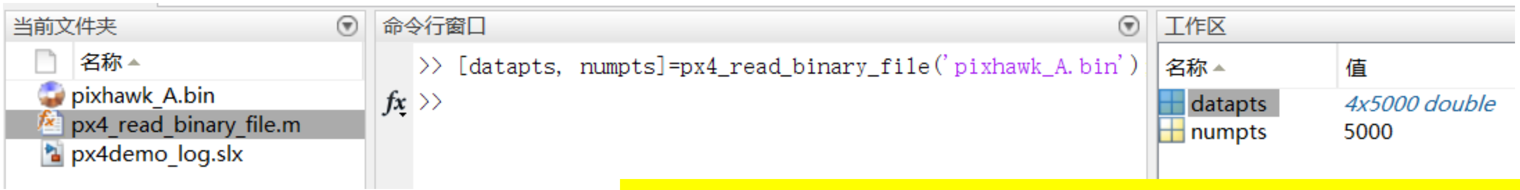
2. Introduction to Key Interfaces

2.5 Log Data Recording

Using the binary logging module "binary_logger" to accomplish flight data writing and reading. For specific operating steps, please refer to the file [0.ApiExps\5.Log-Write-Read\Readme.pdf] . The experimental results are as follows:





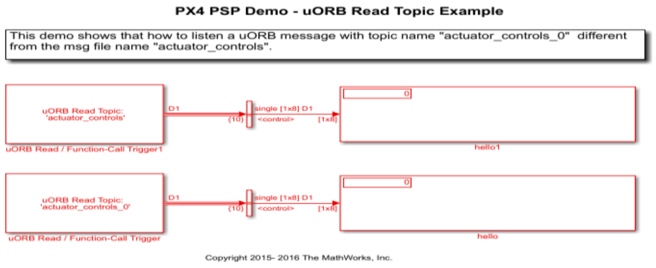


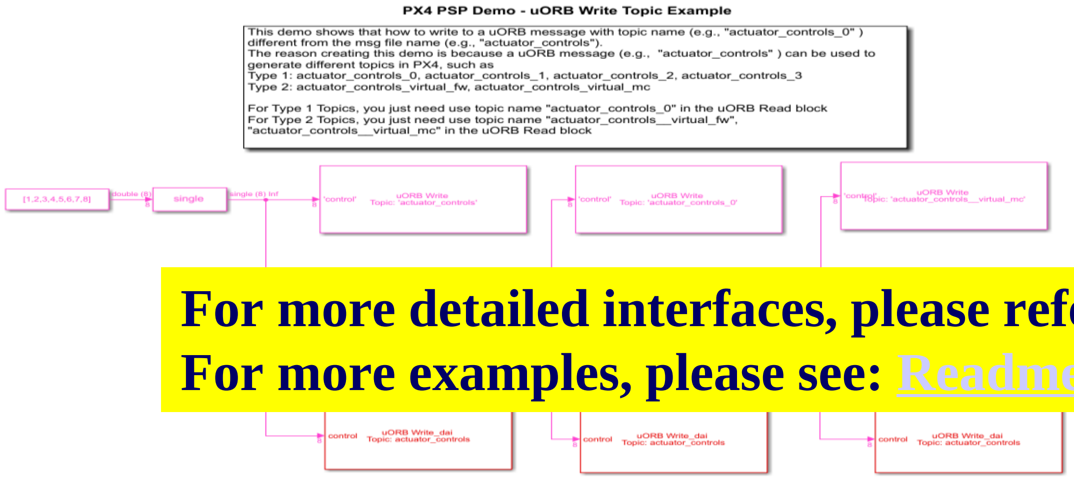
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.6 uORB Read-Write Communication

The uORB messaging system in PX4 provides a powerful and convenient way for internal modules to interact with each other by allowing all modules to place data in a message pool, from which other modules can subscribe to the desired data. For specific operating steps, please refer to the file 0.ApiExps\6.uORB-Read-Write\Readme.pdf . The experimental results are as follows:



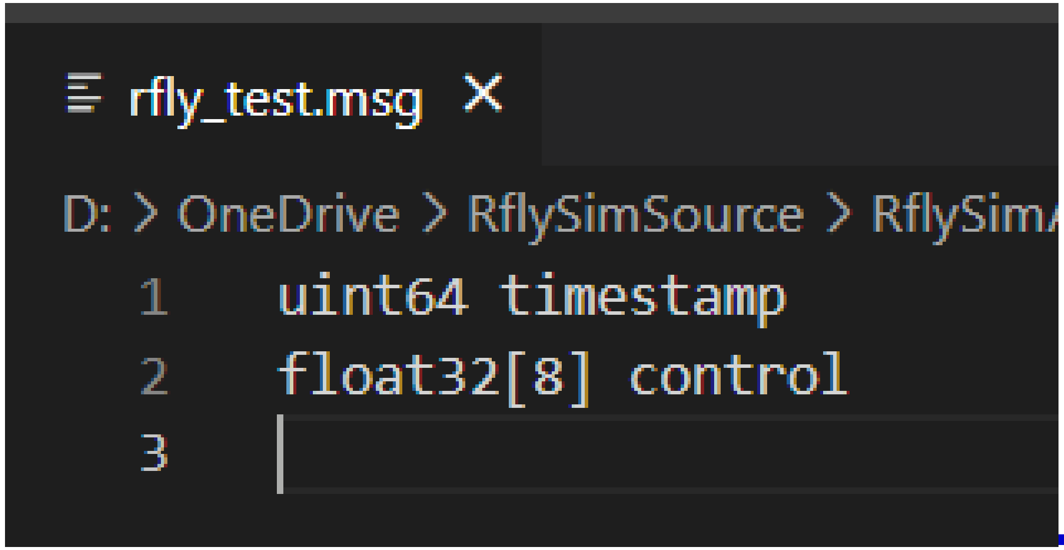


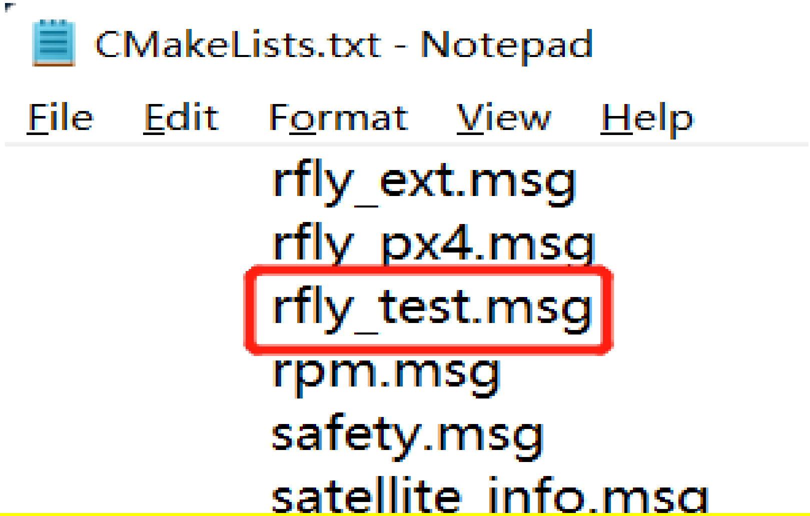
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.7 Custom uORB Messages

By creating a custom uORB message, you can implement read and write functionality to familiarize yourself with and master PX4's uORB messaging system. For specific operating steps, please refer to the file 0.ApiExps\7.uORB-Create\Readme.pdf . The experimental results are as follows:



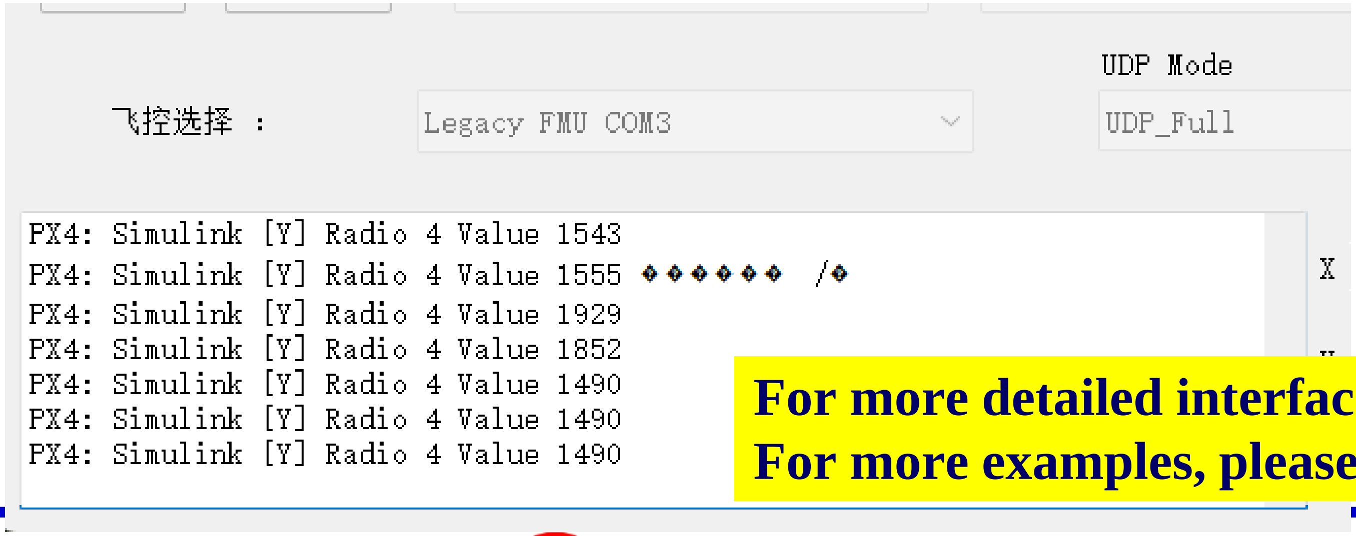


For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.8 Feedback Prompt Messages

In flight control systems, it is often necessary to publish textual messages to reflect the current operational status of the system. This functionality can be achieved by sending uORB messages with "mavlink_log". For specific operating steps, please refer to the document 0.ApiExps\8.Mavlink-Msg-Echo\Readme.pdf . The experimental results are as follows:



For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.9 External Communication of PX4 Controller

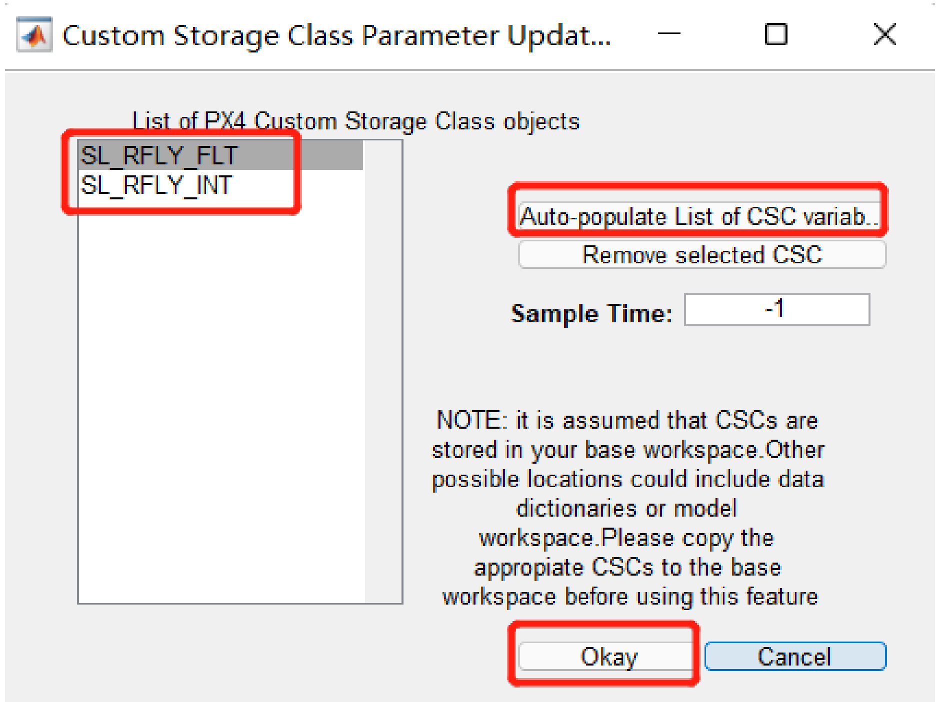
This example uses externally transmitted "rfly_ctrl" data as remote control inputs, while also sending received data to "rfly_px4" for external program feedback. For specific operating steps, please refer to the document 0.ApiExps\9.PX4CtrlExternalTune\Readme.pdf . The experimental results are as follows:

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.10 Real-Time Adjustment of Controller Parameters in QGC

During hardware-in-the-loop simulation and real-flight experiments, it is often necessary to observe the flight status in the QGroundControl (QGC) ground station and adjust controller parameters in real-time to achieve the best control performance for the aircraft. For specific operating steps, please refer to the document 0.ApiExps\10.QGC-Param-Tune\Readme.pdf . Partial experimental results are as follows:

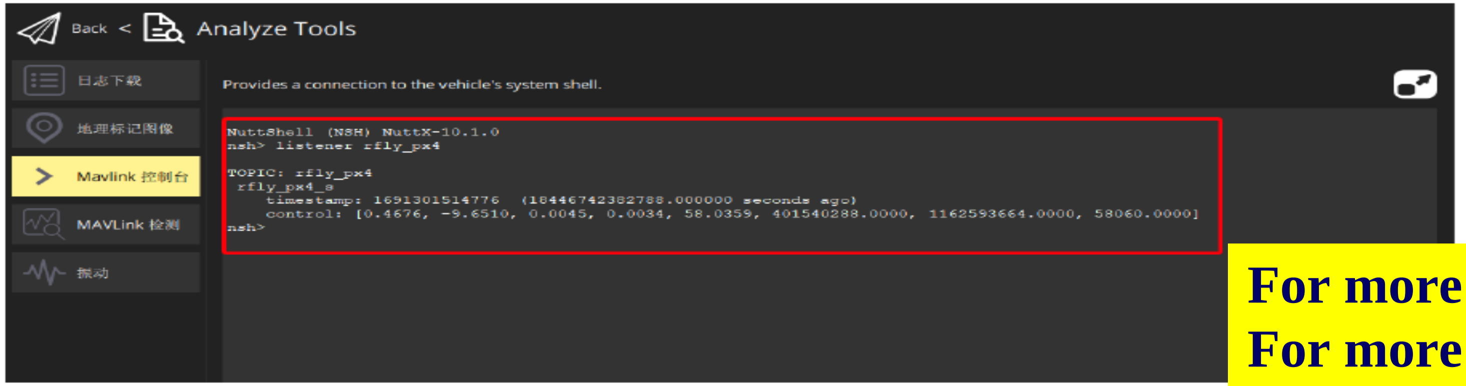


For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.11 Sensor Data Reading Experiment

Through the low-level development interface of RflySim, accessible sensor data includes magnetometer, accelerometer, gyroscope, barometer, timestamp, and GPS data, among other information. This experiment will focus on acquiring partial data from the aforementioned sensors. By following this approach, a variety of sensor data can be subscribed to. For specific operating steps, please refer to the document 0.ApiExps\11.SenorDataGet\Readme.pdf . Partial experimental results are as follows:

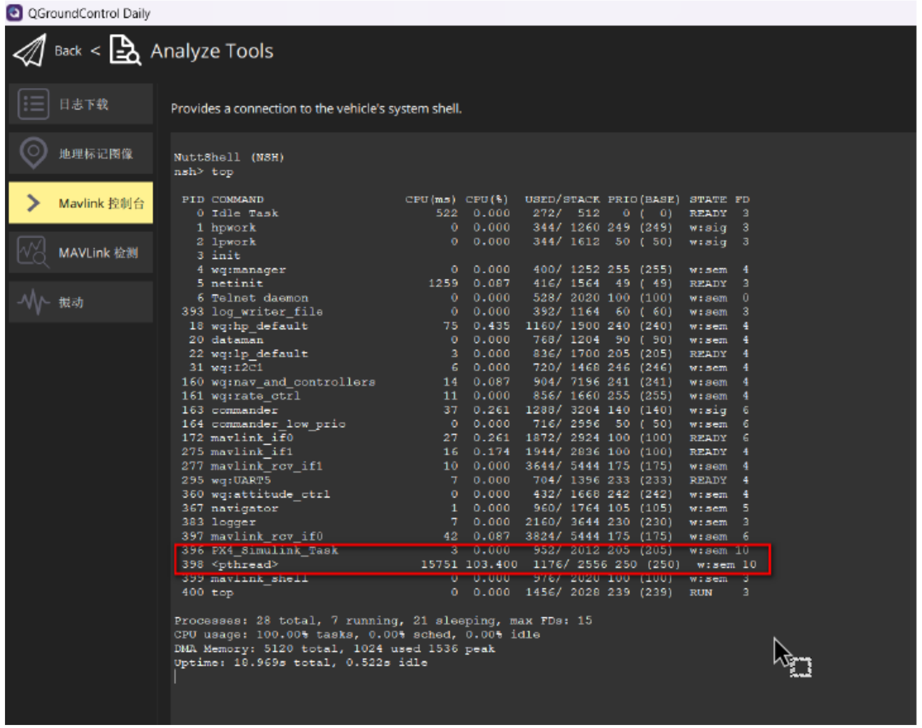


For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.12 Autopilot CPU Usage Monitoring Experiment

When conducting low-level development on the RflySim platform, it is common to validate our developed algorithms on the autopilot hardware. However, when the algorithm model built in Simulink is automatically generated into autopilot firmware, the complexity of the algorithm and the rationality of model construction may lead to an overload of the autopilot system's CPU usage, causing experiment failure, as shown in the figure below. This experiment will demonstrate how to monitor the CPU usage of the autopilot system. For specific operating steps, please refer to the document 0.ApiExps\12.AutopilotCPUUsageGet\Readme.pdf . Partial experimental results are as follows:

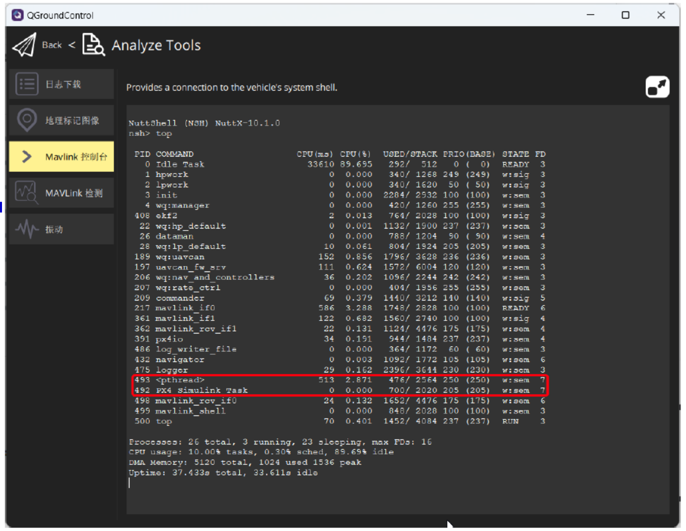


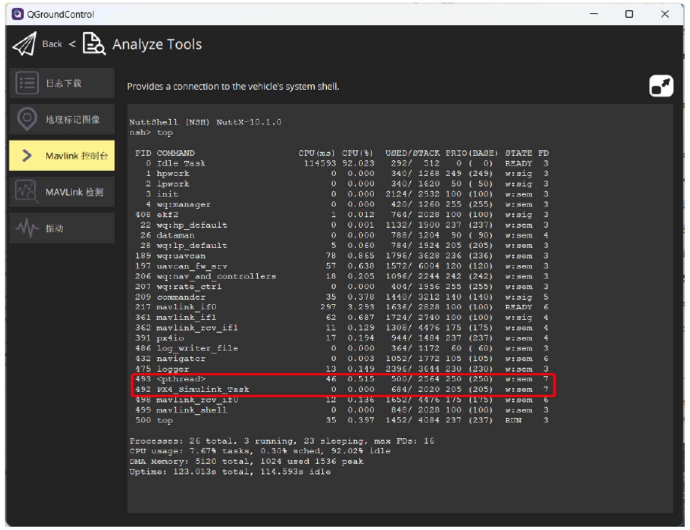
For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

2. Introduction to Key Interfaces

2.13 Experiment on Comparing Autopilot System Resource Usage Between M Function and S Function in Simulink

The flight control system of the PX4 firmware is based on the Nuttx operating system. Nuttx is a real-time embedded operating system (RTOS), known for its compact size and suitability for microcontroller environments. This experiment will flash Simulink models constructed separately by M Function and S Function. Through an analysis of the resource utilization of the autopilot system, it is observed that the Simulink model built with S Function consumes fewer autopilot resources. For detailed operating steps, please refer to the document 0.ApiExps\13.Simulink_MS_FuncVS\Readme.pdf . Partial experimental results are as follows:





For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

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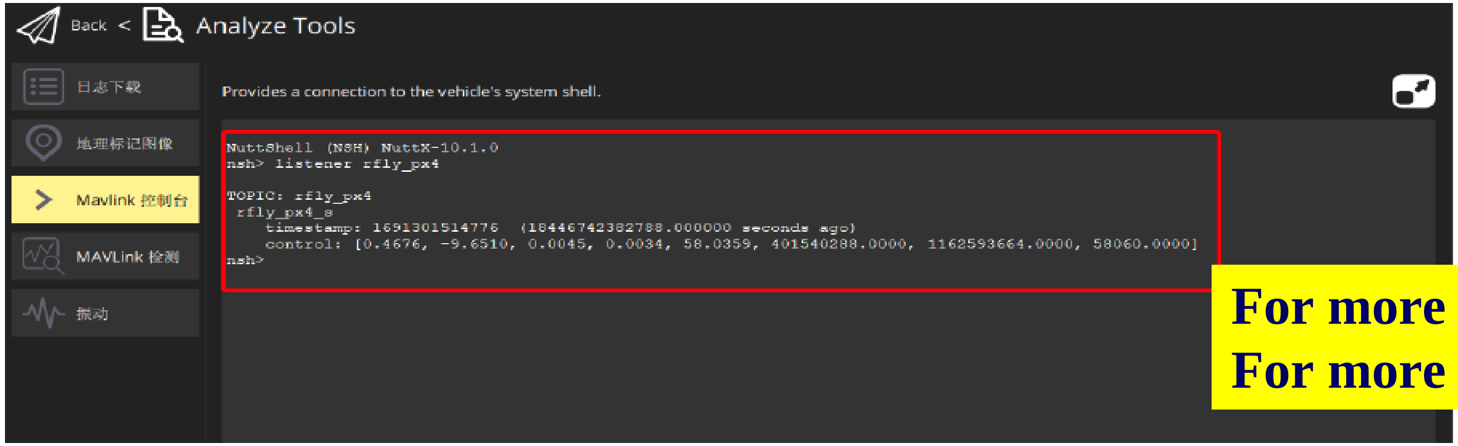
2. Introduction to Key Interfaces

2.14 Sensor Data Reading Experiment

Through the low-level development interface of RflySim, accessible sensor data includes magnetometer, accelerometer, gyroscope, barometer, timestamp, and GPS data, among other information. This experiment will focus on acquiring partial data from the aforementioned sensors. By following this approach, a variety of sensor data can be subscribed to. For specific operating steps, please refer to the document 0.ApiExps\14.SITLVeriGenCodeFirm\Readme.pdf . Partial experimental results are as follows:

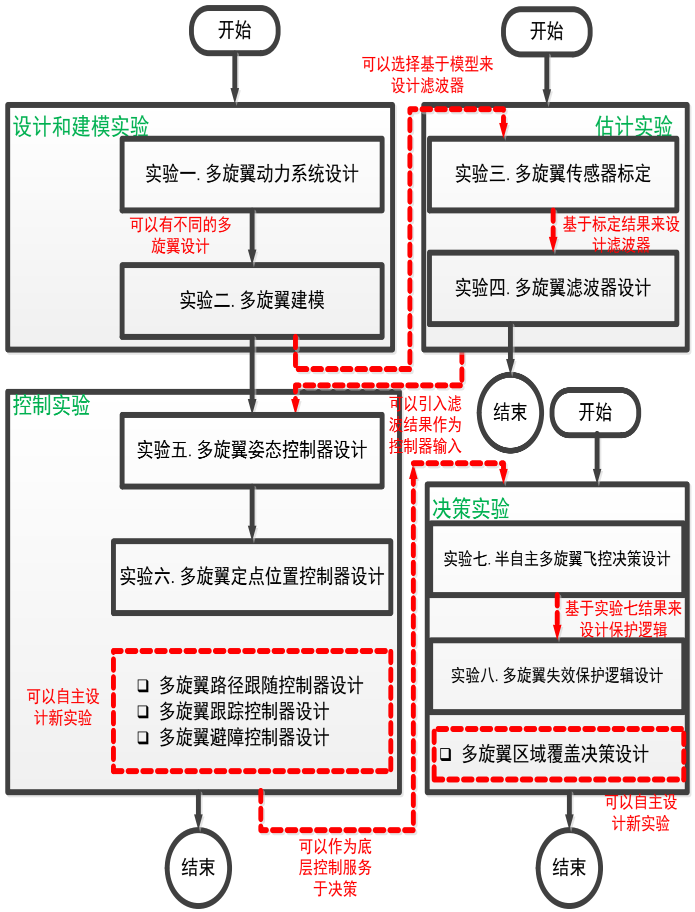


For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

Outline

3.Basic Experimental Cases (Free Version)

3.0 Advanced Experiment Overview



- The routines provided on this platform ensure that each experiment or section thereof can be completed independently.
- To introduce diversity in the task objectives, our curriculum can be structured progressively. The progressive path can be divided into:

  (1) Design and Modeling Experiment -> Control Experiment

  (2) Design and Modeling Experiment -> Control Experiment -> Decision-making Experiment

  (3) Design and Modeling Experiment -> Estimation Experiment -> Control Experiment -> Decision-making Experiment
- Different types of aircraft need to be designed, resulting in varying models and different modeling approaches. Similarly, the design of control experiments varies.
- Teachers may also choose to add additional experiments at their discretion.

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3.Basic Experimental Cases (Free Version)

3.0 Advanced Experiment Overview

Open the routine, read and execute the program code, then observe, record, and analyze the data.

Guide the reader to modify the routine, run the modified program, and collect and analyze the data.

Based on the two aforementioned experiments, independently design for the given task.

3.Basic Experimental Cases (Free Version)

3.0 Advanced Experiment Overview

Table. Types, objectives, and content of the experiment

Aim	Basic experiment	Analysis experiment	Design the experiment
Familiar with development platform	✓	✓	✓
Be familiar with the analysis process	×	✓	✓
Familiar with design methods	×	×	✓
Carry out software-in-the-loop simulation	✓	✓	✓
Perform hardware-in-the-loop simulation	✓	✓	✓
Actual experimental test	×	×	✓

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3.Basic Experimental Cases (Free Version)

3.1 Power system design experiment

The objectives of this lab are as follows:

1、design a power system of that multi-rotor aircraft by use a multi-rotor flight evaluation website;

2、According to the known information, the power system of the multi-rotor aircraft is designed and compared with the parameters generated by the multi-rotor flight evaluation website, and the effects of different cities, temperatures, propeller sizes and numbers on the hovering events of the multi-rotor aircraft are analyzed.

Please learn the advanced version of the course for the specific experimental principles, and see the file 1. BasicExps\e1-FlightEval\Readme.pdf . PDF for the experimental operation steps.

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

飞思实验室

3.Basic Experimental Cases (Free Version)

3.1 Power system design experiment

The experimental results are as follows (in part):

详细信息

悬停性能：		最大油门性能：		整体性能：	
悬停时间	: 22.5 min.	飞行时间	: 7 min.	正常使用	: 17.8 min.
油门百分比	: 63.6 %	总升力	: 94.3 N	整机重量	: 4.56 kg
电调电流	: 6.69 A	电机电流	: 21.8 A	剩余载重	: 2.8 kg
电机转速	: 4623.5 rpm	电机转速	: 6716.3 rpm	最大起飞海拔	: 3.85 km
电机输出功率	: 132.2 W	电机输出功率	: 417.8 W	最大倾斜角度	: 51.7 °
电池输出电压	: 23.7 V	电池输出电压	: 22.9 V	最大平飞速度	: 12.4 m/s
电池输出电流	: 27.2 A	电池输出电流	: 87.3 A	单程飞行距离	: 8.5 km
能量效率	: 80.9 %	能量效率	: 79.8 %	抗风等级	: 4 级

Location	Elevation/m	Hover time/min
Shanghai	4	16.5
Beijing	43.5	16.5
Changsha	500	16.1
Lhasa	3658	13.5

Propeller size/inch	Hover time/min
10	17
9.4	16.5
9	15.9
8	14.5

Temperature	Hover time/min
0	17.1
10	16.8
20	16.6
30	16.3

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

飞思

3.Basic Experimental Cases (Free Version)

3.2 Dynamic modeling experiment

The objectives of this lab are as follows:

1. The effects of multi-rotor mass, moment of inertia matrix, propeller thrust coefficient and propeller thrust coefficient on the multi-rotor flight performance are analyzed.

2. Build a complete multi-rotor aircraft model, and add a three-dimensional model of the quadrotor in RflySim3D.

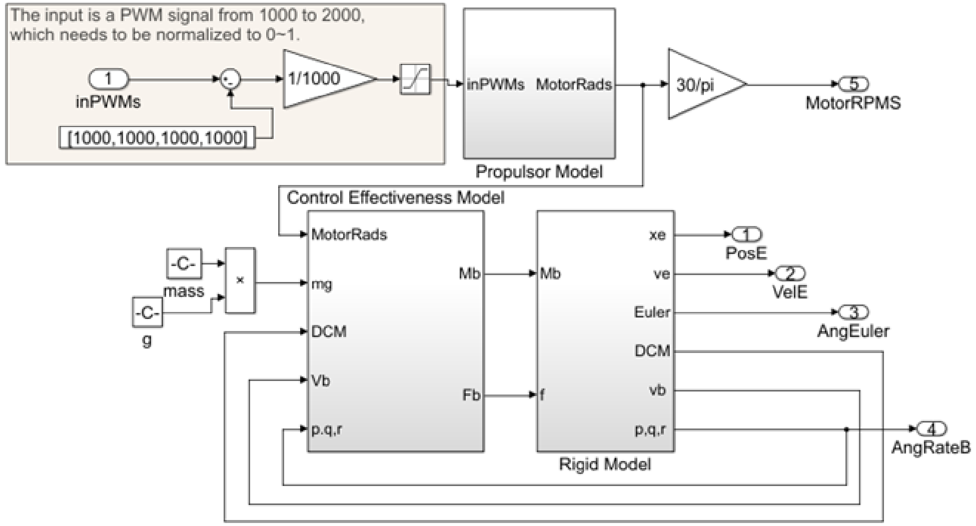
Please learn the advanced version of the course for the specific experimental principle. See the file 1.BasicExps\e2-UavModeling\Readme.pdf for the experimental operation steps.

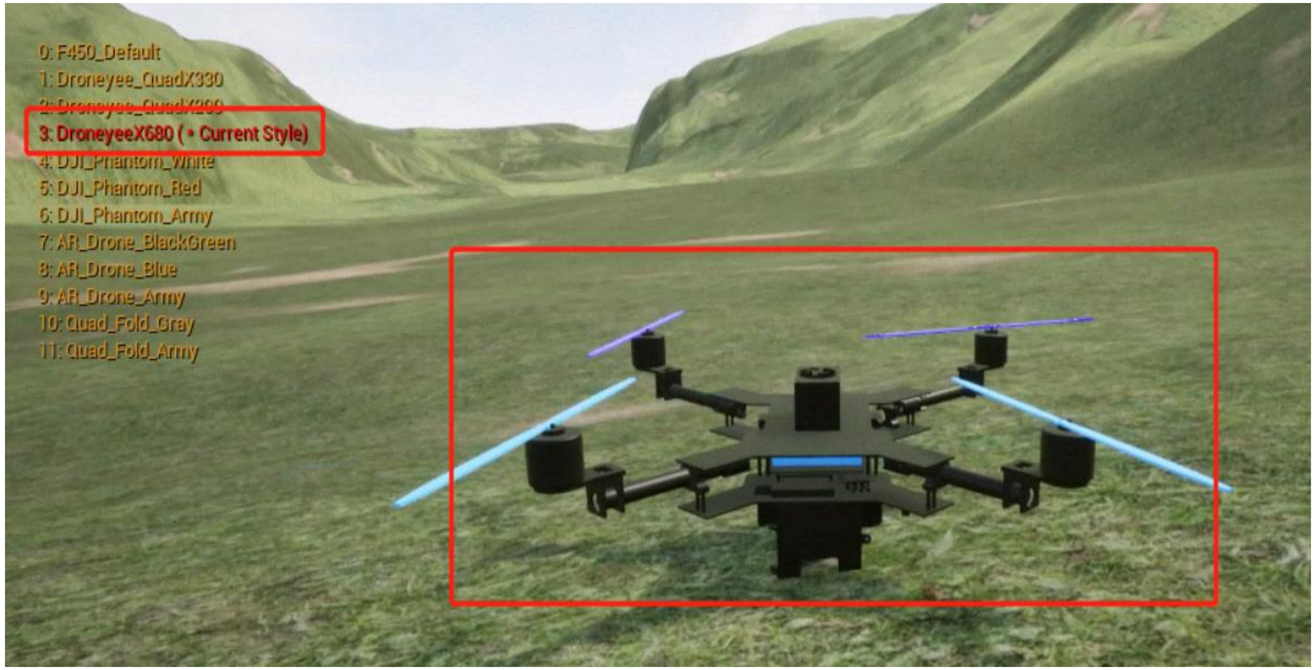
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.2 Dynamic modeling experiment

The experimental results are as follows (in part):





For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

飞思实验室

3.3 Sensor calibration experiment

The objectives of this lab are as follows:

1. Complete the calibration of acceleration according to the experimental steps.

2. According to the given error model of magnetometer, the data acquisition model of magnetometer is designed, and the optimal solution of model parameters is obtained by using the measured data and LM algorithm function to complete the calibration of magnetometer.

Please learn the advanced version of the course for the specific experimental principles, and see the file 1.BasicExps\e3-SensorCalib\readme.pdf for the experimental operation steps.

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.3 Sensor calibration experiment

The experimental results are as follows (in part):

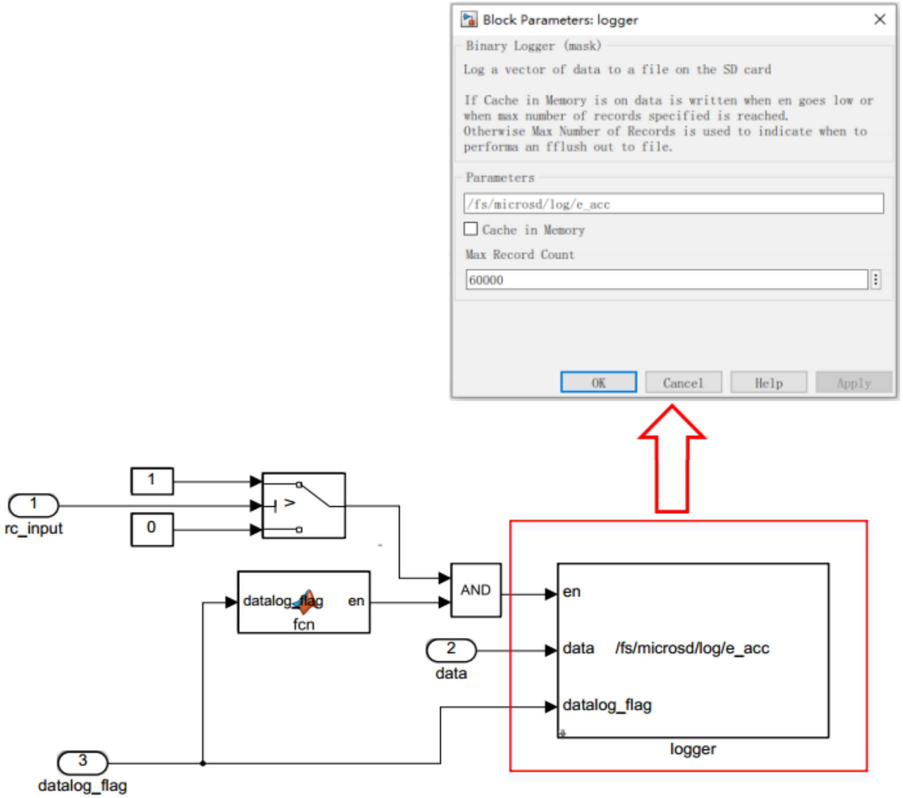


图. 加速度数据采集“binary_logger”模块

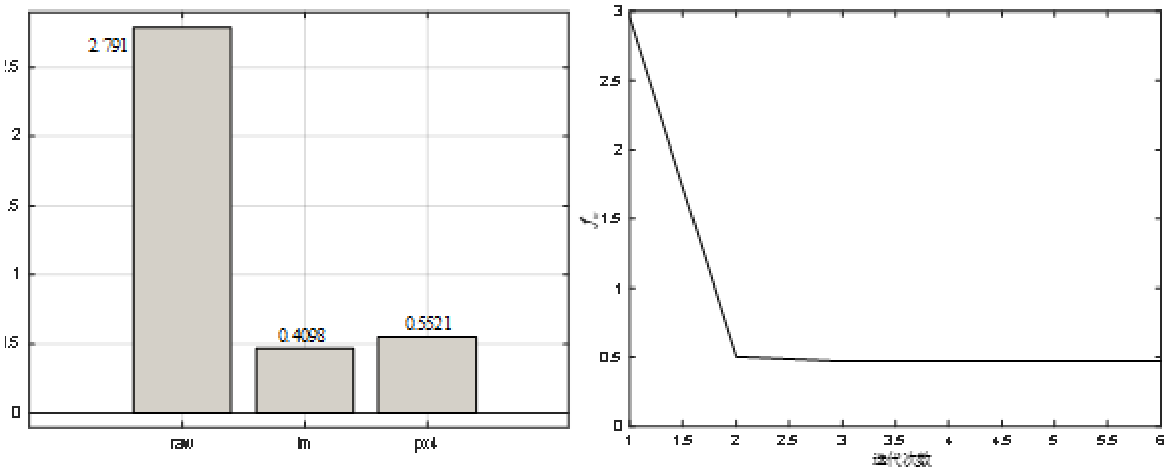


图. 磁力计校正对比值

For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

飞思实验室

3.Basic Experimental Cases (Free Version)

3.4 Sensor calibration experiment

The objectives of this lab are as follows:

1. According to the data provided in the experiment, complete the complementary filtering, and compare it with the original data and the data calculated by Pixhawk's own filter to understand the advantages of the c omplementary filter.

2. Improve the parameters of the complementary filter and analyze the influence of the parameters of the complementary filter on the filtering effect.

3. Understand the principle of Kalman filter, design the Kalman filter to realize the filter, process the acc eleration and angular velocity data, and draw the data map of the relevant attitude angle.

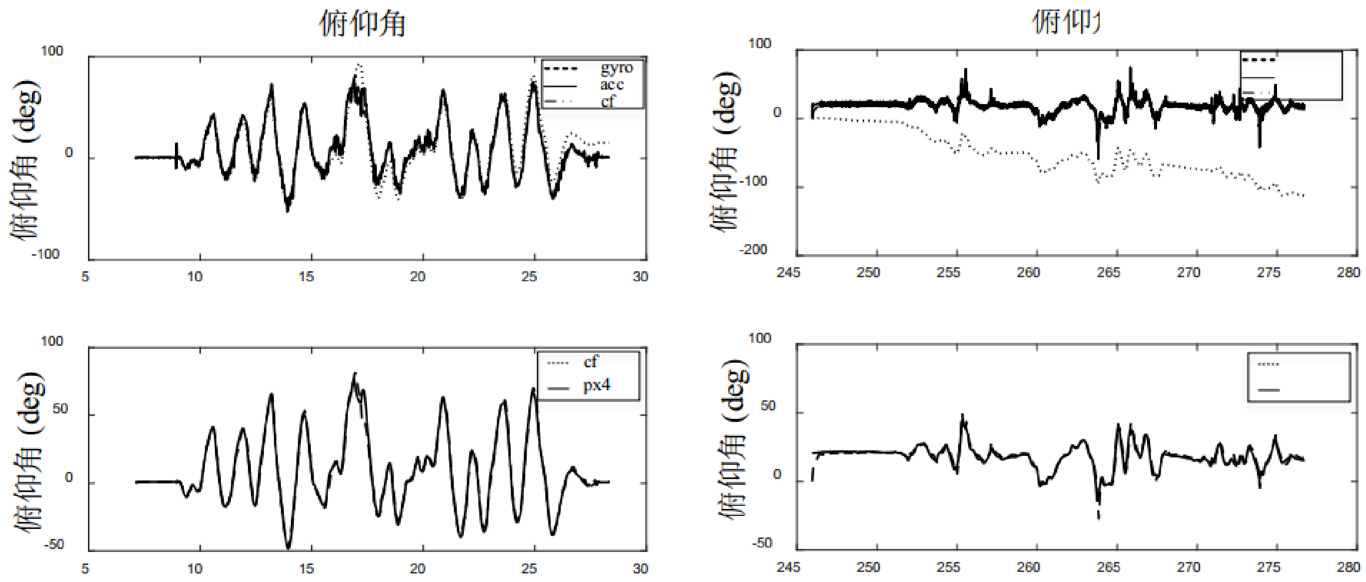
Please learn the advanced version of the course for the specific experimental principles, and see the file 1. BasicExps\e4-FilterDesign\Readme.pdf for the experimental operation steps.

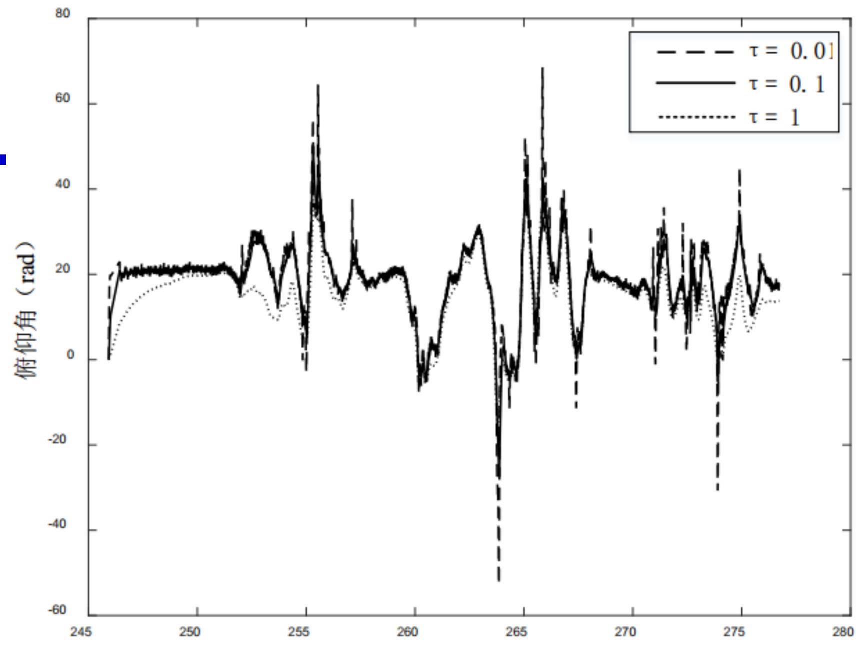
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

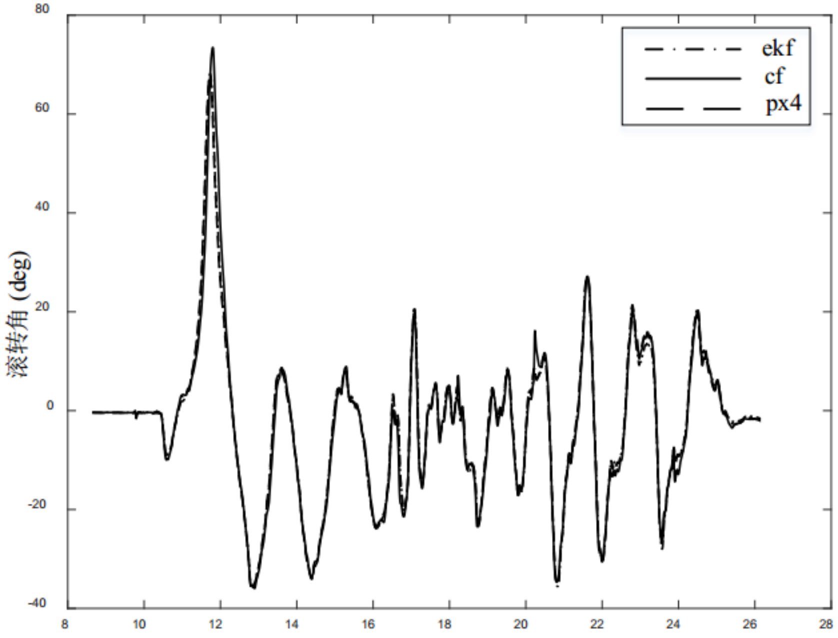
3.Basic Experimental Cases (Free Version)

3.4 Sensor calibration experiment

The experimental results are as follows (in part):







For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

飞思实验室

3.Basic Experimental Cases (Free Version)

3.5 Attitude controller design experiment

The objectives of this lab are as follows:

1. Reproduce the Simulink simulation of the quadrotor aircraft, analyze the role of the control distributor; record the step response of the attitude, sweep the open-loop attitude control system to draw the Bode diagram, and analyze the stability margin of the closed-loop attitude control system; complete the hardware-in-the-loop simulation of the quadrotor aircraft.

2. Adjust the relevant parameters of PID controller to improve the control performance and record the overshoot and adjustment time to get a set of appropriate parameters; use the parameters after debugging to sweep the frequency of the system to draw the Bode diagram, observe the amplitude-frequency response and phase-frequency response curve of the system, and analyze its stability margin.

3. The transfer function model of the attitude control channel is established, and the correction controller is designed. The software and hardware simulation experiments and flight experiments are carried out with the controller designed by ourselves.

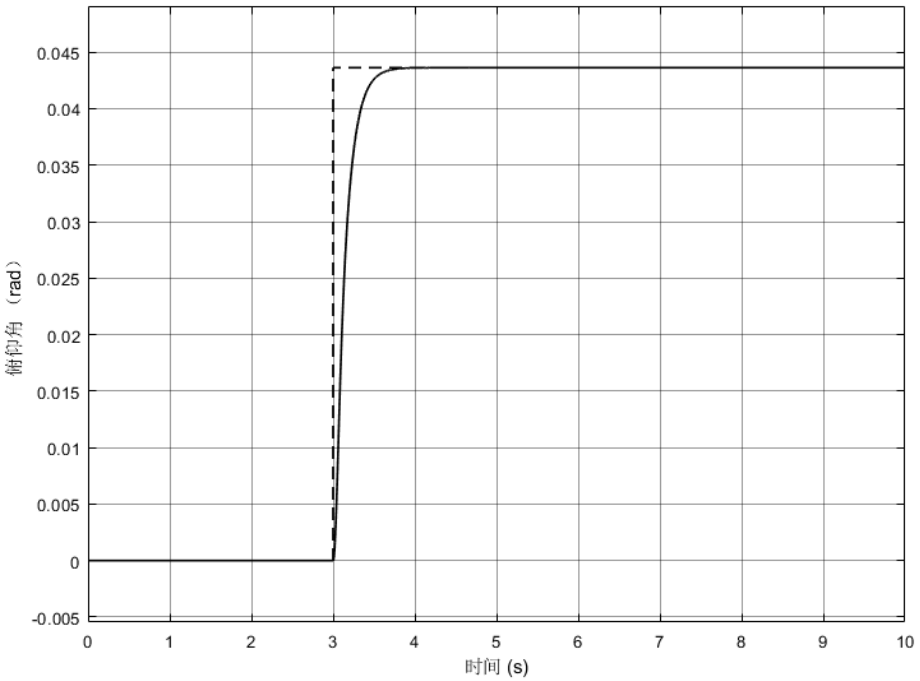
Please learn the advanced version of the course for the specific experimental principles, and see the file 1.BasicExps\e5-AttitudeCtrl\Readme.pdf for the experimental operation steps.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.5 Attitude controller design experiment

The experimental results are as follows (in part):



For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.6 Fixed-point position controller design experiment

The objectives of this lab are as follows:

1. Reproduce the quadrotor Simulink simulation to analyze the decoupling of the control action on the axis $o_b x_b$ and the axis $o_b y_b$; sweep the frequency of the system to draw the bode diagram to analyze the stability margin of the closed-loop position control system.

2. Adjust the relevant parameters of the PID controller to improve the control performance of the system. After obtaining satisfactory parameters, sweep the frequency of the system to draw the Bode diagram.

3. Establish the transfer function model of the position control channel, use the MATLAB "Control SystemDesigner" to design the correction controller, and adjust the system error, relative margin and other parameters.

Please learn the advanced version of the course for the specific experimental principle. See the file 1.BasicExps\e6-PositionCtrl\Readme.pdf for the experimental operation steps.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.6 Fixed-point position controller design experiment

The experimental results are as follows (in part):

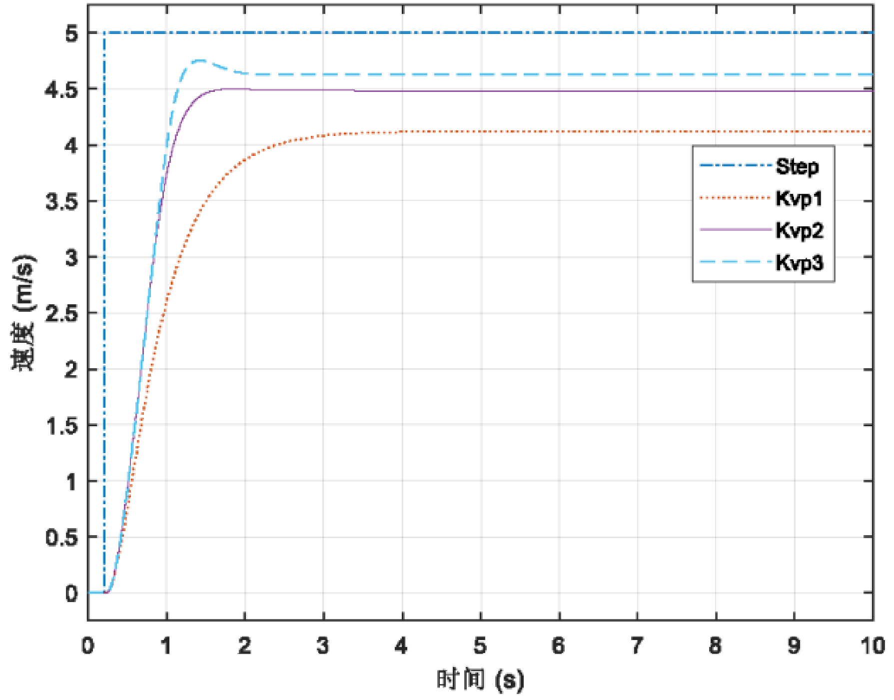
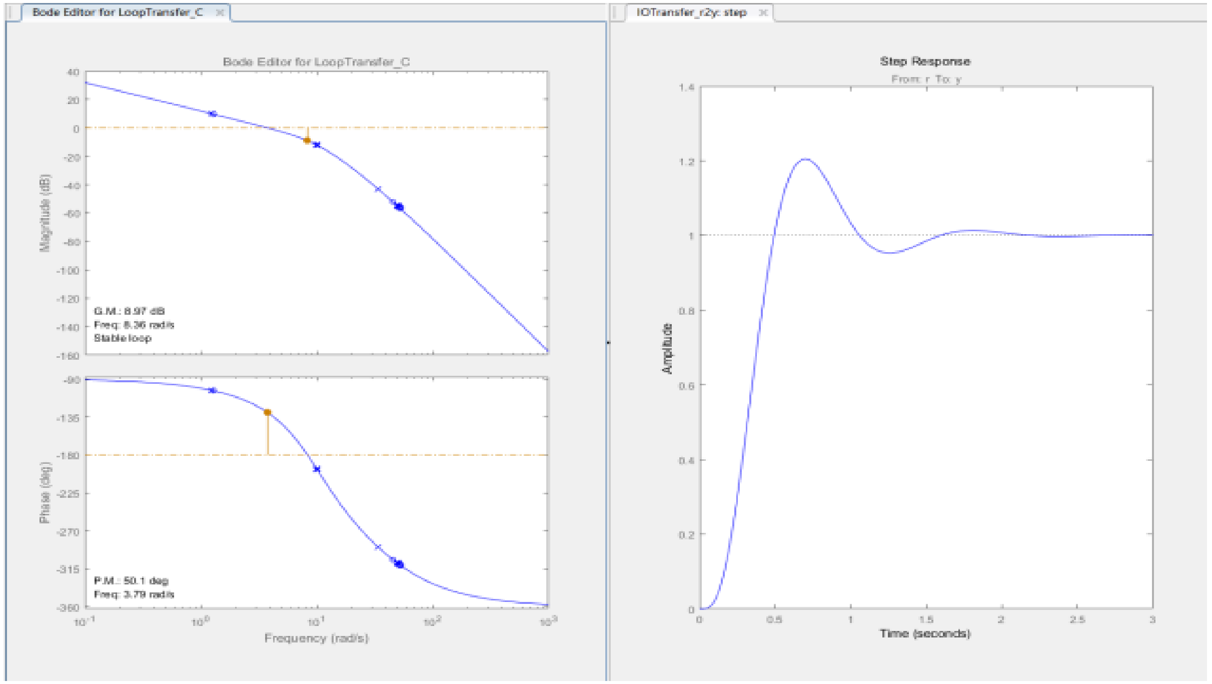


图. 不同比例项系数下的阶跃响应



For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.7 Semi-autonomous control mode design experiment

The objectives of this lab are as follows:

1. On the controller design and simulation platform based on Simulink, the characteristics of the attitude and position response of the quadrotor are reproduced from the simulation experiment;

2. Change to fixed height mode on the basis of self-stabilization mode. According to the experimental analysis, the change of attitude and position output values of the multi-rotor in the fixed altitude mode is compared with that in the self-stabilized mode.

3. Change to fixed-point mode on the basis of self-stabilization mode. According to the experimental analysis, compared with the self-stabilization mode, the output values of the attitude and position of the multi-rotor in the fixed-point mode are changed, and the free switching of the three modes is realized by using a three-segment dial switch.

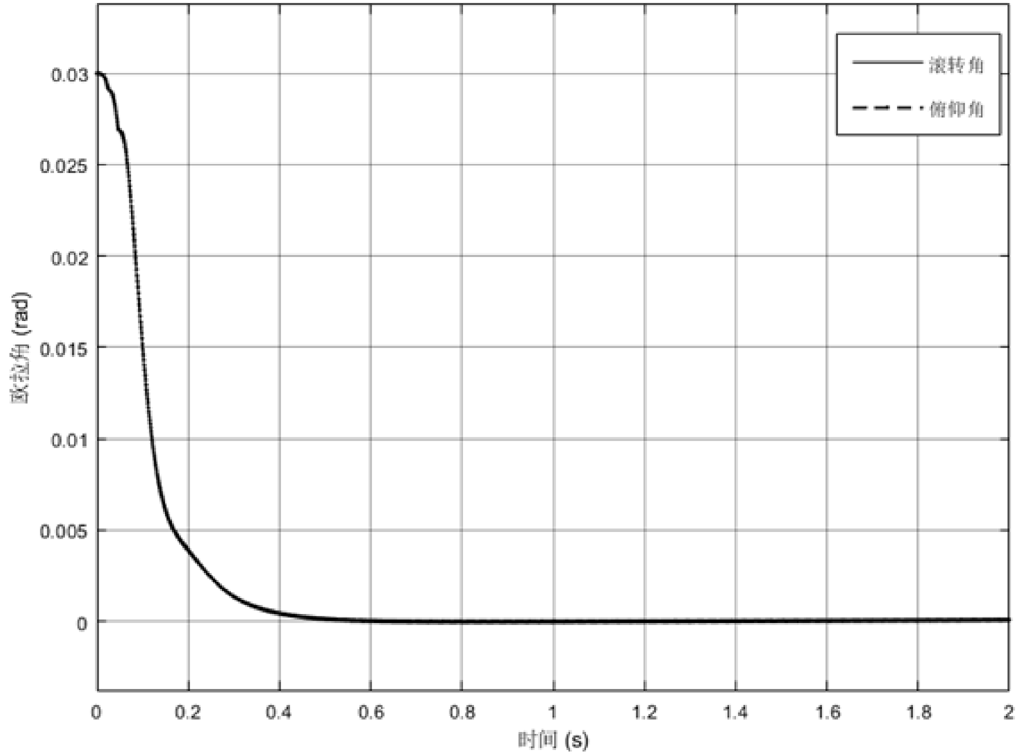
Please learn the advanced version of the course for the specific experimental principle. See the file 1.BasicExps\e7-SemiAutoCtrl\Readme.pdf for the experimental operation steps.

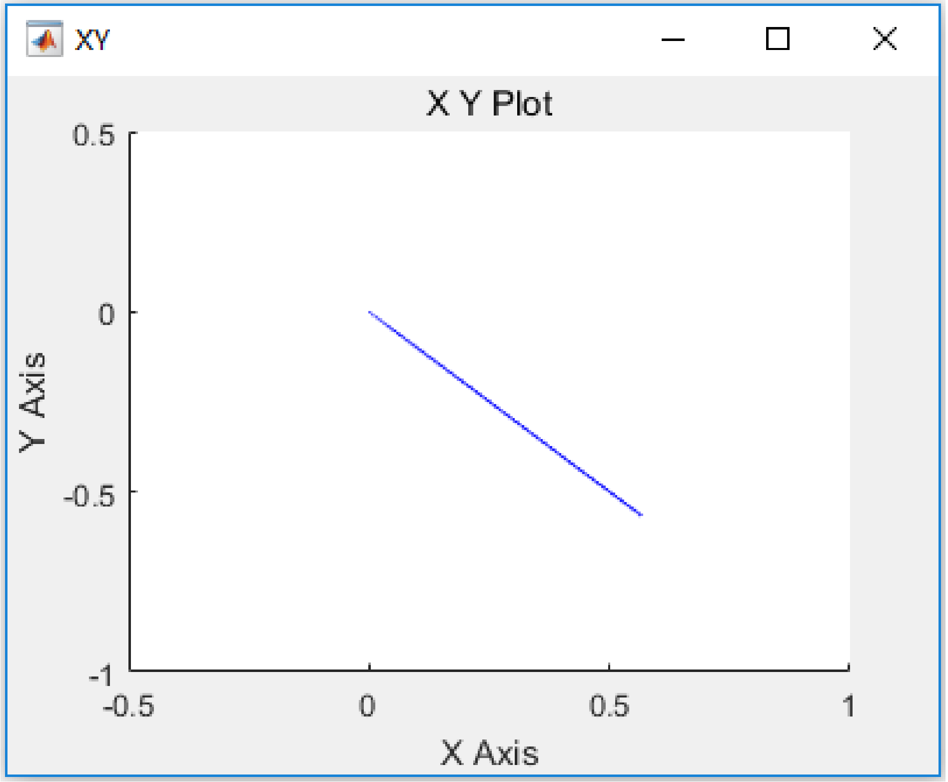
For more detailed interfaces, please refer to: API.
For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.7 Semi-autonomous control mode design experiment

The experimental results are as follows (in part):





For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.8 Fail-safe logic design experiment

The objectives of this lab are as follows:

1. In the Simulink simulation environment, in the manual mode, realize the return and landing of the air craft, and record and analyze the simulation results.

2. On the basis of the basic experiment, the corresponding state transition is added to realize the return a nd landing of the aircraft in the manual mode, and the return and landing can be switched to each other.

3. On the basis of the previous experiment, add the remote control power failure and loss of contact event, complete the new mode and switching design, that is, add two States of failure return and failure landing, and complete the design of the state machine.

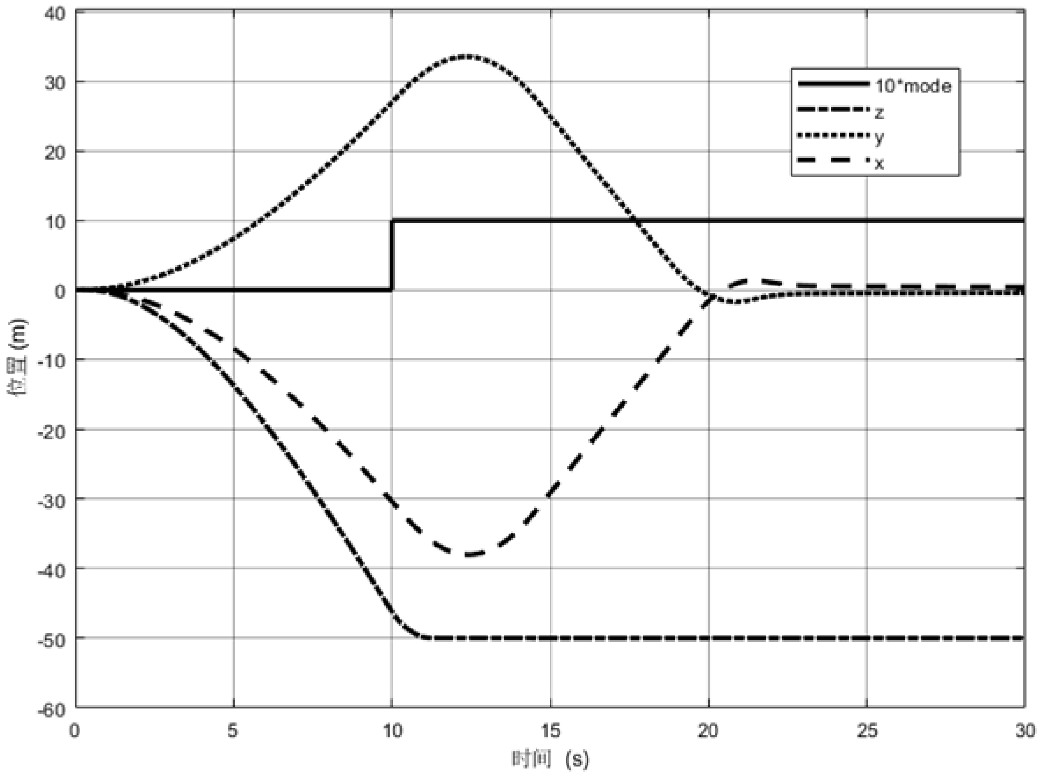
Please learn the advanced version of the course for the specific experimental principle. See the file 1.BasicExps\e8-FailsafeLogic\Readme.pdf for the experimental operation steps.

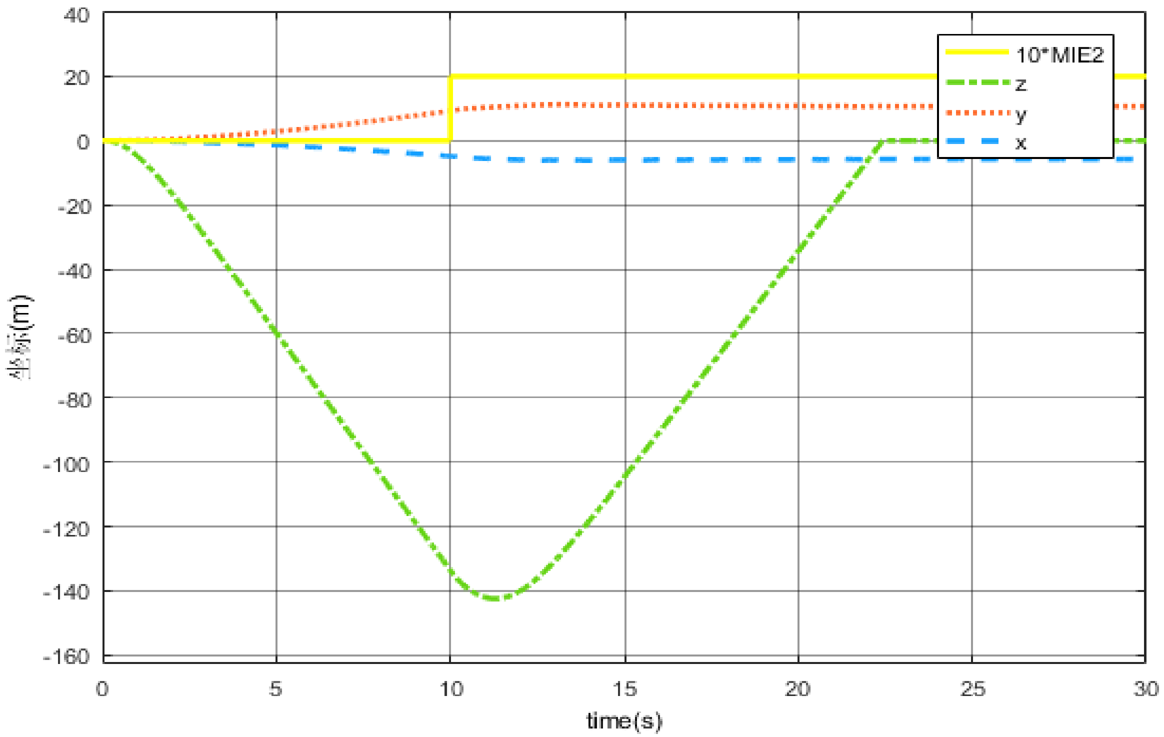
For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.8 Fail-safe logic design experiment

The experimental results are as follows (in part):





For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

飞思实验室

3.Basic Experimental Cases (Free Version)

3.9 PX4 Module Replacement Lab

The objectives of this lab are as follows:

In order to quickly replace some native modules (sensors, filters, attitude controllers, etc.) of the PX4 control software with the generated Simulink code, the experiment provides two methods to achieve this:

1. Open the " Firmware\src\modules\ekf2\ekf2_main.cpp "file, and manually comment out the module code to be shielded;

2. Modify the startup script file " Firmware\ROMFS\px4fmu_common\init.d\rcS " of the PX4 module, and comment out the module to be shielded.

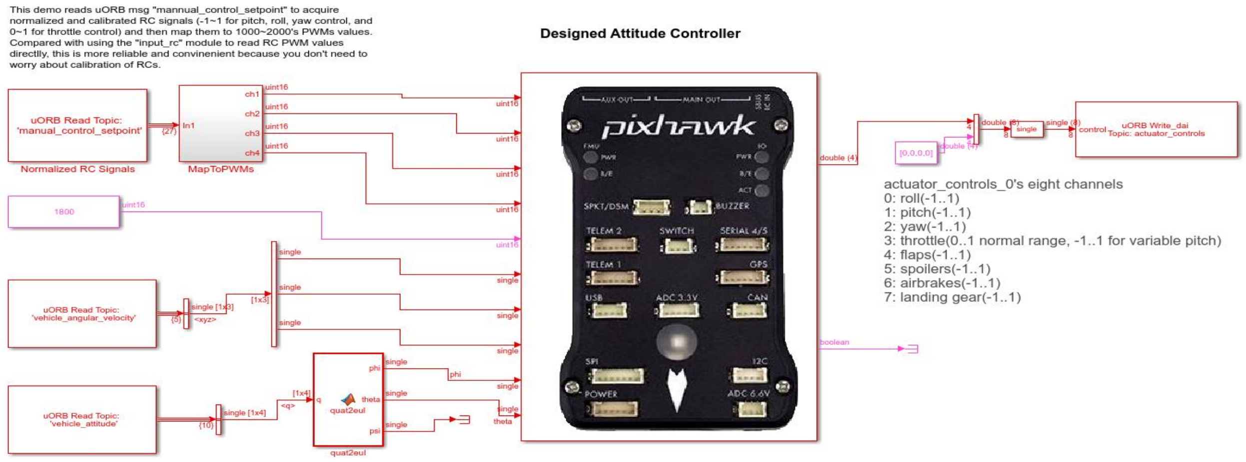
Please learn the advanced version of the course for the specific experimental principles. The lab steps are shown in File 1.BasicExps\e9-ReplacePX4Module\Readme.pdf .

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

3.Basic Experimental Cases (Free Version)

3.9 PX4 Module Replacement Lab

In this experiment, the "Position & Attitude Estimator" filter module "is shielded, and the section 2.3 (attitude controller design experiment) is modified to build the" Exp6 _ ReplacePX4AttitudeCtrler.slx "model, as follows:



Note: After the development of this experiment is completed, please be sure to return the modified code to the original place, so as not to affect the development of other functions.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

Outline

1. Experimental Platform Configuration

2. Introduction to Key Interfaces

3. Basic Experimental Cases (Free Version)

4. Advanced Interface Experiments (Free Version)

5. Advanced Case Experiments (Free Version)

6. Extended Cases (Full Version)

7. Summary

4. Advanced Interface Experiments(Free Version)

4.1 User-defined shielding of any module output in PX 4

In this experiment, the relevant functions of PX 4 are shielded by replacing the uORB message " actuator_controls_0 " of the attitude angular r ate ring in PX4 and replacing the modified CPP file. The experimental steps are described in detail. See the file [2.AdvExps\e0_AdvApiExps\1.CusMaskPX4Code\Readme.pdf] . PDF for the specific oper ation steps. The (partial) experimental results are a s follows:

For more detailed interfaces, please refer to: [API]. For more examples, please see: [Readme].

4. Advanced Interface Experiments(Free Version)

4.2 Rename PX 4 Application Name Experiment:

Based on the multi-process running status of PX 4 software system, the name of PX 4 application generated by MATLAB is PX 4 _ simulink _ a pp. This experiment can rename it and create a new application in PX 4 software system and compile it. See the file 2.AdvExps\e0_AdvApiExps\2.RenamePX4App\Readme.pdf for the specific operation steps. The (partial) experimental results are as follows:

```
>> PX4AppName 'rfly_simulink_app'
Firmware目录中已存在rfly_simulink_app目录。
当前的编译命令为: px4_fmu-v5_default
成功找到px4_fmu-v5_default的cmake文件
重命名完成.
开始重新添加px4_simulink_app模版...
```

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

4. Advanced Interface Experiments(Free Version)

4.3 Loading PX 4 application experiment:

The RflySim platform supports the loading of custom developed PX 4 applications. The PX 4 applications provided in this experiment can be directly loaded into the PX 4 software system for firmware compilation. See the file 2.AdvExps\e0_AdvApiExps\3.LoadPX4App\Readme.pdf for the specific operation steps. The (partial) experimental results are as follows:

```
>> PX4AppLoad('C:\PX4PSP\rfly_simulink_app')
当前的编译命令为: px4_fmu-v5_default
Firmware目录中已存在rfly_simulink_app目录。
当前的编译命令为: px4_fmu-v5_default
成功找到px4_fmu-v5_default的cmake文件
重命名完成.
开始重新添加px4_simulink_app模版...
```

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

4. Advanced Interface Experiments(Free Version)

4.4 Creating Multiple PX 4 Application Labs:

Based on the multi-process running status of PX4 software system, the PX4 application name generated by MATLAB code automatically is px4 _ simulink _ app, which can be renamed in this experiment, and then a new PX4 application can be generated by MATLAB code automatically. This allows multiple PX 4 applications to be created at the same time. See the file 2.AdvExps\e0_AdvApiExps\4.MultPX4App\Readme.pdf for the specific operation steps. The (partial) experimental results are as follows:

```
>> PX4AppName 'rfly_simulink_app'
Firmware目录中已存在rfly_simulink_app目录。
当前的编译命令为: px4_fmu-v5_default
成功找到px4_fmu-v5_default的cmake文件
重命名完成.
开始重新添加px4_simulink_app模版...
```

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

Outline

1. Experimental Platform Configuration

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7. Summary

5. Advanced Case Experiments (Free Version)

Under development...

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

Outline

1. Experimental Platform Configuration
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5. Advanced Case Experiments (Free Version)
6. Extended Cases (Full Version)
7. Summary

6. Extended Case (Full Version)

6.1 Experiment of ESO design:

The scheme is applicable to the aircraft control problem under disturbance and uncertainty. By decouple that aircraft into multiple cascaded SISO system comprising a nominal model and an uncertainty comprising model/identification uncertainties, control mismatch, and external disturbances. In order to estimate the system state and the total uncertainty, an extended state observer (ESO) is designed. Using the output of ESO, the controller compensates the total uncertainty online. See File 3.CustExps\e1_ESO-CtrlExp\Readme.pdf for specific operation steps.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

飞思实验室

6. Extended Case (Full Version)

6.2 Optimal control experiment based on reinforcement learning:

The optimal control problem is decomposed into two phases: approximate policy evaluation and policy promotion by using the model-based reinforcement learning method and the approximate policy iteration algorithm. In the approxi mate policy evaluation phase, a linear approximator is used to approximate the value function, and the system model and Bellman equation are used to update the parameters of the approximator. In the policy lifting phase, a linear-structured approximator is used to approximate the optimal control policy, and the value function and the system model are used to update the parameters of the approximator. The two phases alternate until convergence to a near optimal solution. Based on this, the experiment first observes the uncertainty of the aircraft model based on the extended state observer and com pensates it, then approximates the optimal value function of the compensated system by using the model-based reinforce ment learning optimal control method, and then determines the optimal control law, and then designs the safety feedback item for the optimal control law based on the control barrier function. The forward invariance of the safety set of the clos ed-loop system is guaranteed. See File 3.CustExps\e2_RL-CtrlExp\Readme.pdf for specific operation steps.

6. Extended Case (Full Version)

6.3 Model Compensated Controller (MCC) Design Experiment:

All the experiments in this folder are model compensation controller (MCC) design experi ment routines, and the traditional Extended State Observer (ESO) is abandoned in MCC. A Com pensation Function Observer (CFO) with higher accuracy is used to estimate the complex disturb ance or fast time-varying disturbance with high accuracy, and the estimation of the total disturba nce is fed back to the controller to realize the high-precision tracking control of the UAV system. This folder contains the quadrotor controller design routines for attitude, altitude, position, and s emi-bootstrap modes. See File 3.CustExps\e3_MCC-CtrlExp\Readme.pdf for specific operati on steps.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

6. Extended Case (Full Version)

6.4 Design experiment of ADRC controller:

All the experiments in this folder are quadrotor-based ADRC design experiment routines, a model-free control method suitable for designing controllers for plants with unknown dynamics and internal and external disturbances. This algorithm only needs to approximate the dynamic characteristics of the controlled object, and can design a controller with robust anti-disturbance function and no overshoot. This folder contains the quadrotor controller design routines for attitude, altitude, position, and semi-bootstrap modes. See File 3.CustExps\e4_ADRC-CtrlExp\Readme.pdf for specific operation steps.

For more detailed interfaces, please refer to: API. For more examples, please see: Readme.

Outline

1. Experimental Platform Configuration
2. Introduction to Key Interfaces
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5. Advanced Case Experiments (Free Version)
6. Extended Cases (Full Version)
7. Summary

7. Summary

This session primarily focuses on the development course of flight control algorithms, divided into two parts: basic experiments and advanced experiments. This is to help students quickly become familiar with the theoretical design of multirotors, simulation using the RflySim platform, and the development process of physical control.

The basic experiments mainly involve learning the simulation process based on the RflySim platform, focusing on software-in-the-loop and hardware-in-the-loop simulations. The advanced experiments follow a learning path from theoretical design and modeling experiments for multirotors, estimation experiments, control experiments, to decision-making experiments.

For any inquiries, please visit https://doc.rflysim.com/ for more information.

More tutorials for RflySim

Scan the code for inquiries and communication.

FeiSi RflySim Technical Exchange Group

Thank you!