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

Appendix A: RflySim Platform Advanced Features

Dr. Xunhua Dai, dai@buaa.edu.cn

School of Automation Science and Electrical Engineering,

Beihang University, Beijing 100191, China.

Outline

1. Ideas and Goals of RflySim Platform

2. Single Vehicle Control and Test Framework

3. Multiple Vehicles Control and Test Framework

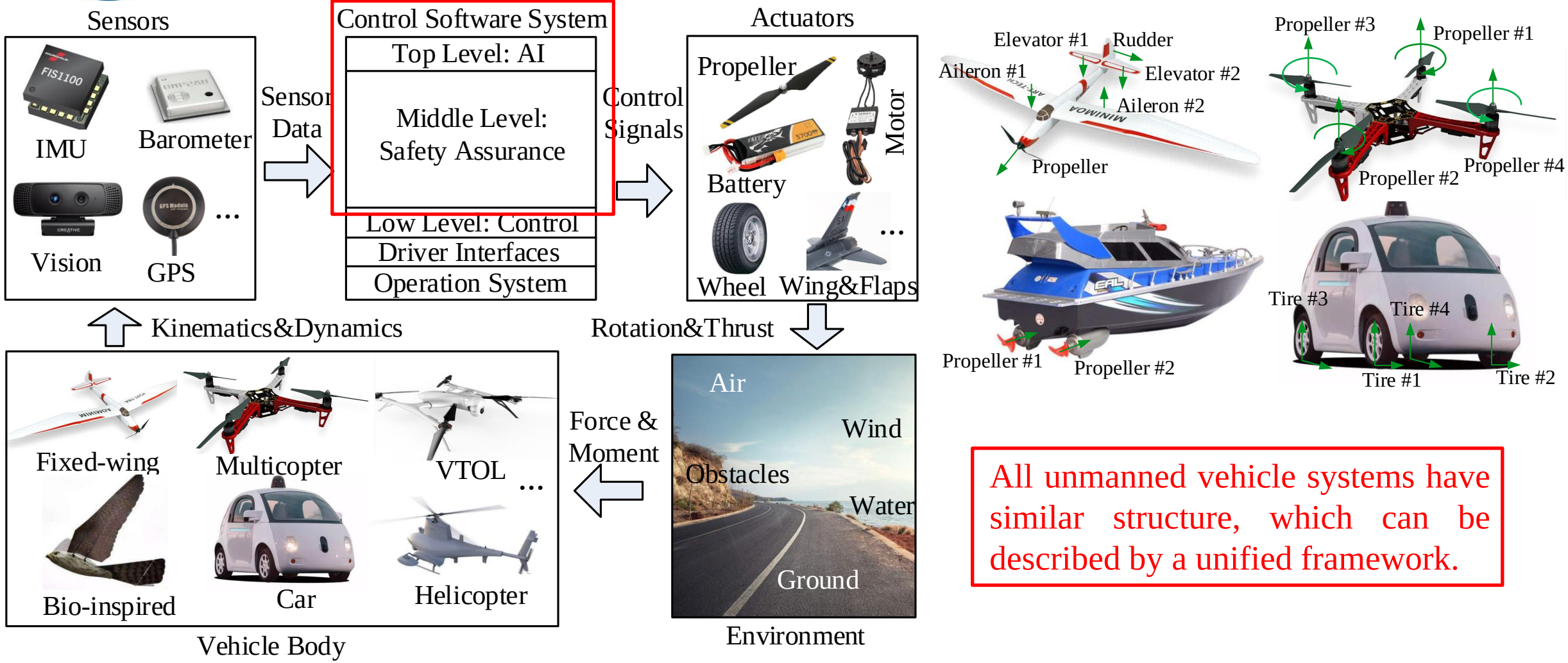
4. Vision/AI-based Control and Test Framework

5. Summary

1.1 Goals

RflySim (Reliable Flight Simulator): A Unified Development, Test and Assessment Platform for Unmanned Control Systems with High Credibility

1.2 Unified Framework



All unmanned vehicle systems have similar structure, which can be described by a unified framework.

1.3 Mode-based Design

Experiment Tests

- Outdoor
- Flight place, test engineers, time, money…
- Most faults are hard to reappear in experiments
- Test after the completion of system development
- The test results are more accurate and trustworthy

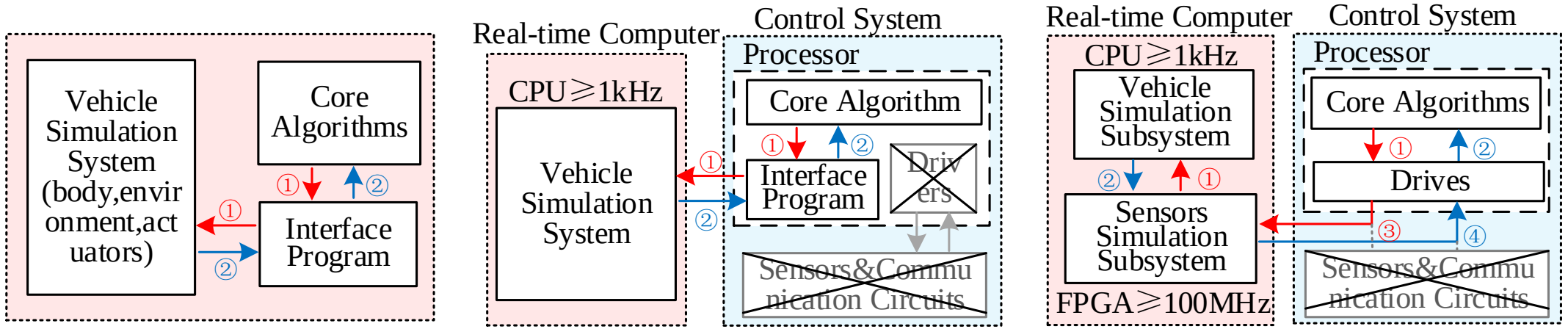
Simulations

- Indoor
- Only Computers
- Simulate any faults with proper modeling technologies
- Test during the development stage
- Require the modeling techniques

Key problem: How to make people (users, developers, authorities) believe the simulation results can be as reliable as experimental results

1.4 High-fidelity Real-Time Simulation

① Actuator Control Outputs ② Vehicle Motion States ③ Control Electronic Signals ④ Sensor Electronic Signals



(a) Software-in-the-loop Simulation (b) Hardware-in-the-loop (HIL) Simulation (c) FPGA-based HIL Simulation

Gazebo + ROS

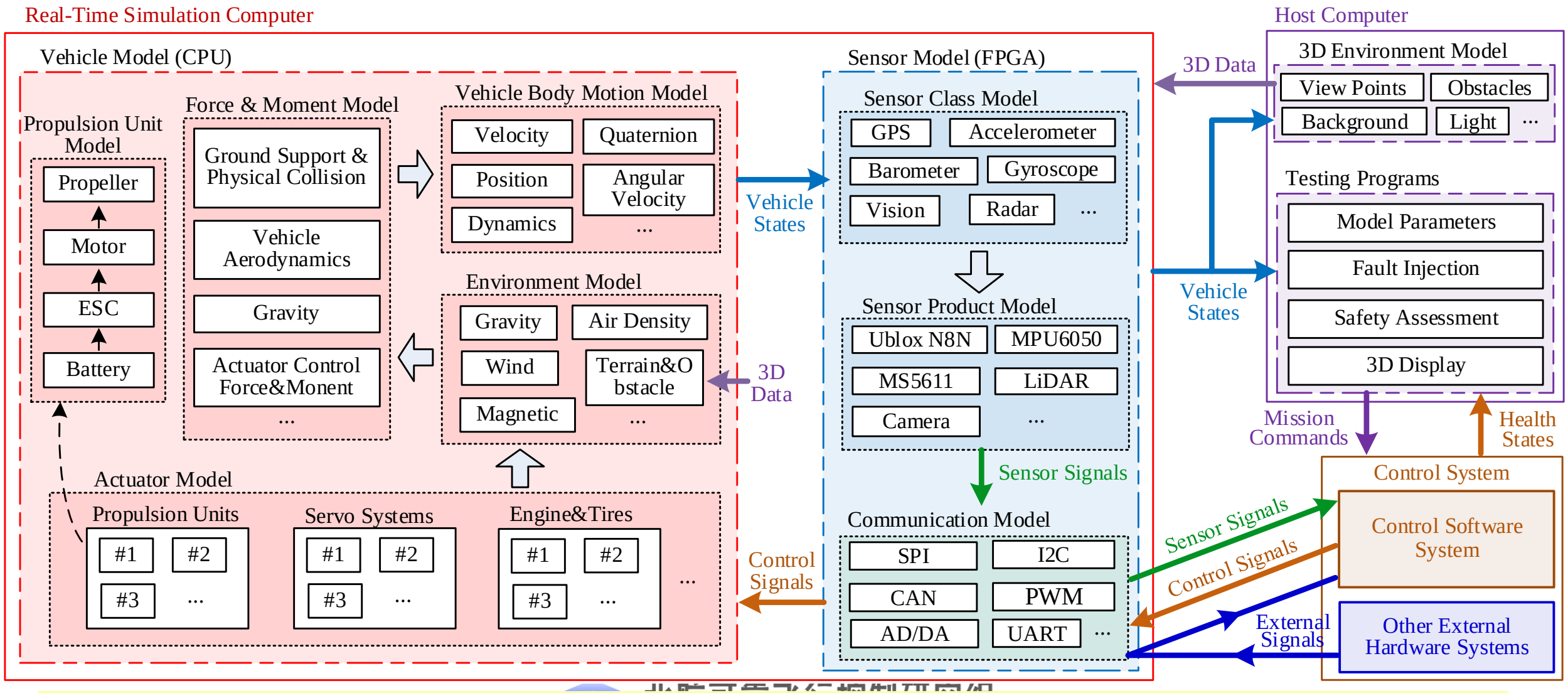
- Not fidelity enough
- No hardware tests for effect in real systems

- Airsim (Unreal Engine 4) by Microsoft in 2018
- FlightGogles (Unreal Engine 4) by Google in 2019
- RflySim Education Platform

- RflySim Commercial Platform
- Test real autopilot hardware without accessing or modifying source code (black box test).
- A standard safety assessment platform for any UAV systems

From motion state simulation to sensor data to sensor chip signals
From algorithm tests to the whole system test (hardware, RTOS, drivers, control, vision, AI)

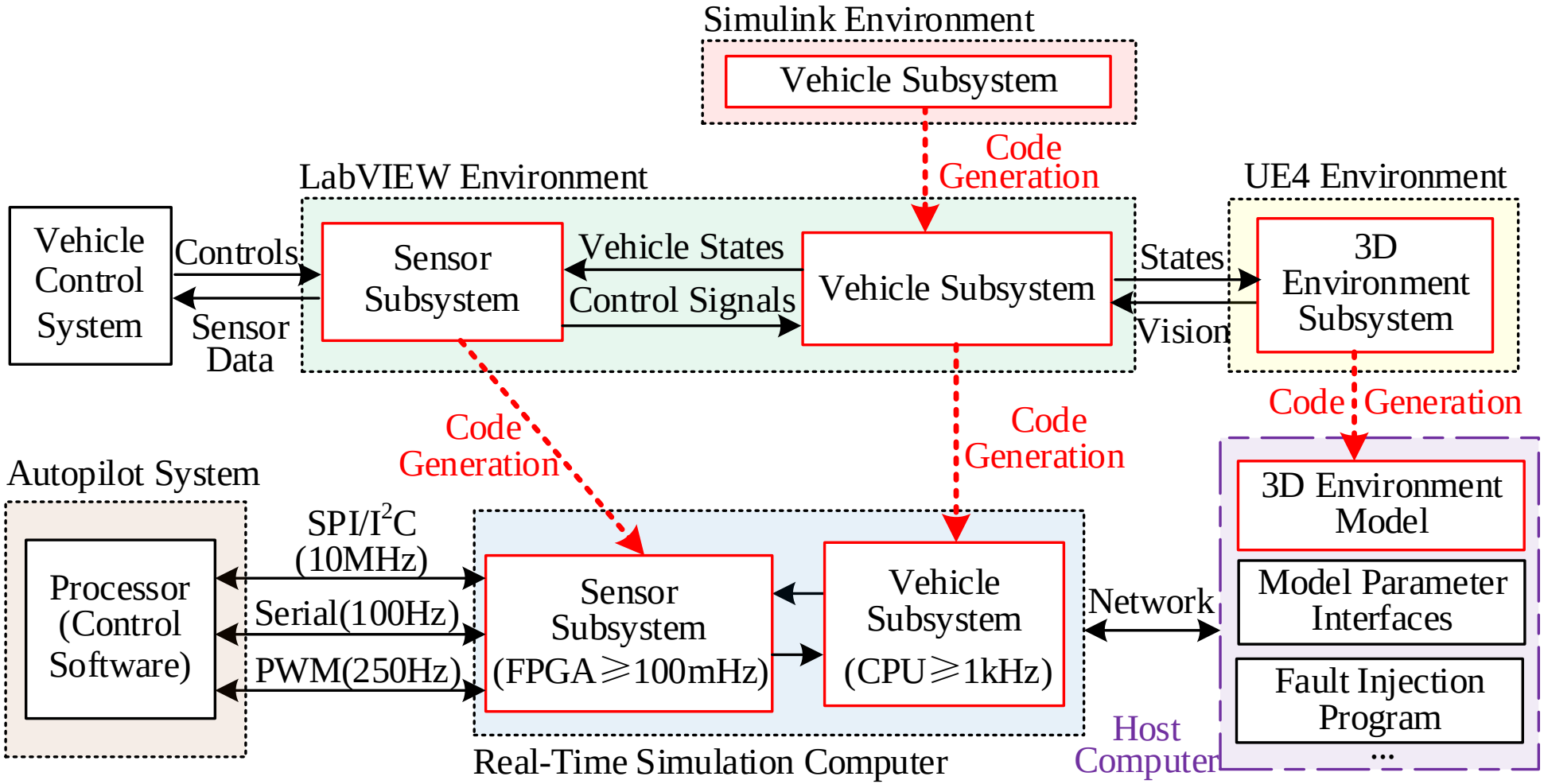
1.5 Standardization



Use standard component models to build the whole system to ensure consistency and standards compliant

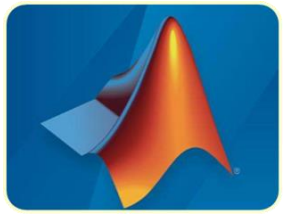
1.6 Automation

Modular programming & auto code generation

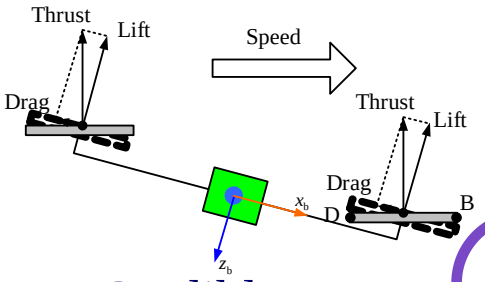


1.7 Credibility

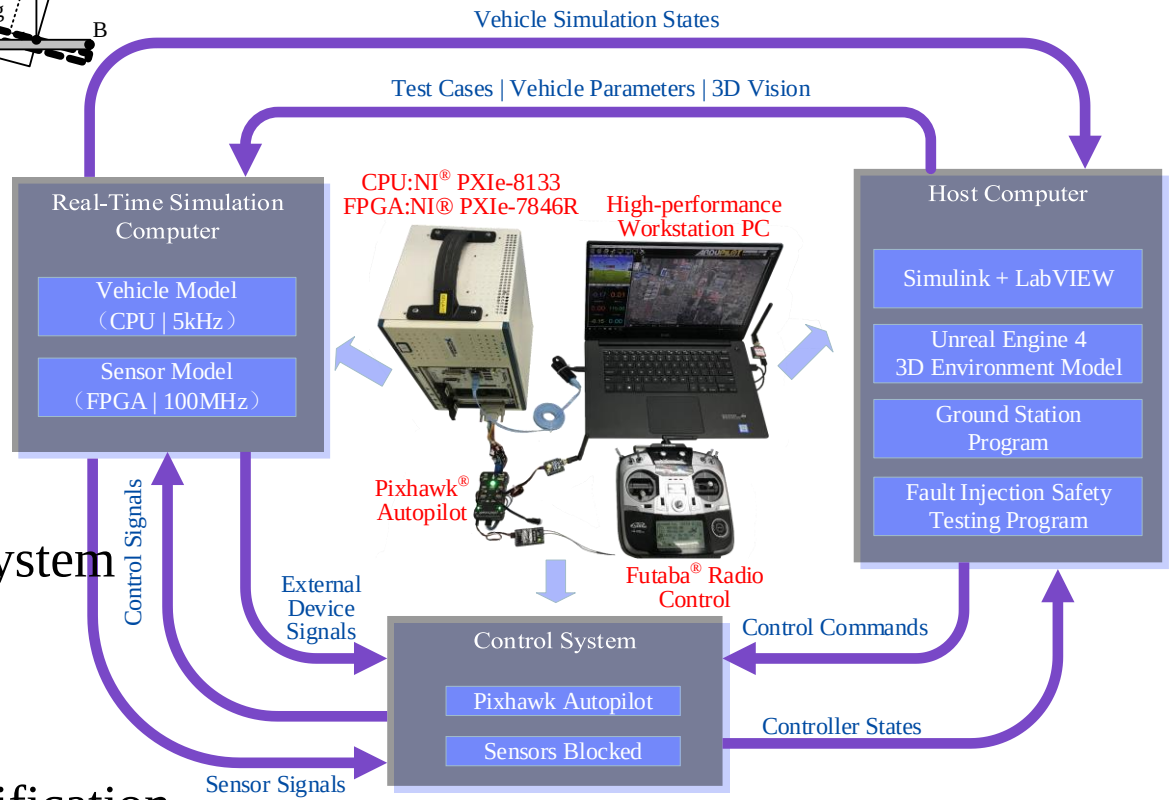
Credible Real-time Hardware Platform



Credible Simulation Software



Credible Mathematical Model



How to ensure simulation credibility:

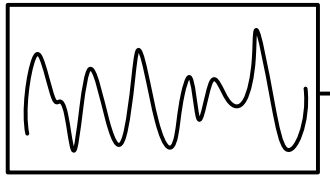
1. The simulation platform should be credible

   - Hardware aspect: performance & structure close to real system
   - Software aspect: standard development & verification

2. The Mathematical Model should be credible. System identification

1.8 Assessment

Testing Signals



Real Control System

Real Plant System & Sensors

Experimental Results

HIL Simulation Platform

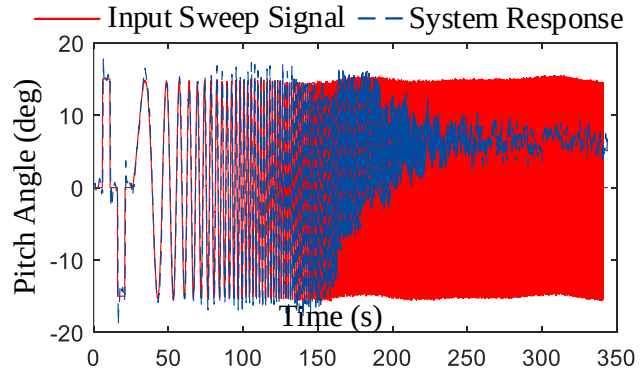
Simulation Results

Comparison & Assessment

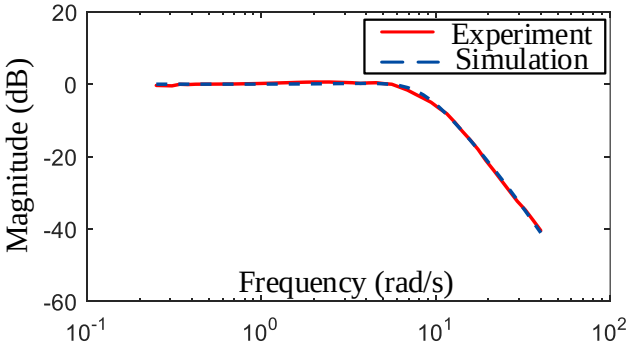
Reports

After the platform credibility is satisfied, by using hardware-in-the-loop simulation methods, we can input the same signals to simulation and real systems to compare and assess their results

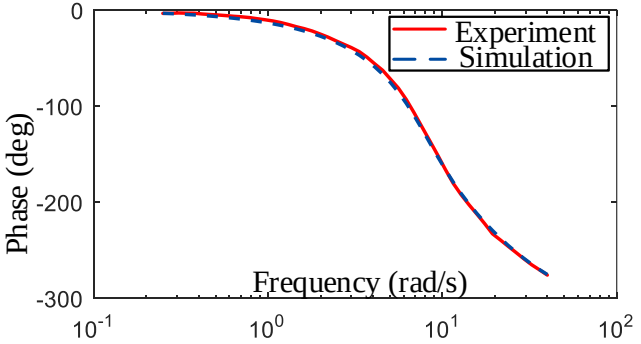
Sweeping Frequency for Model Accuracy



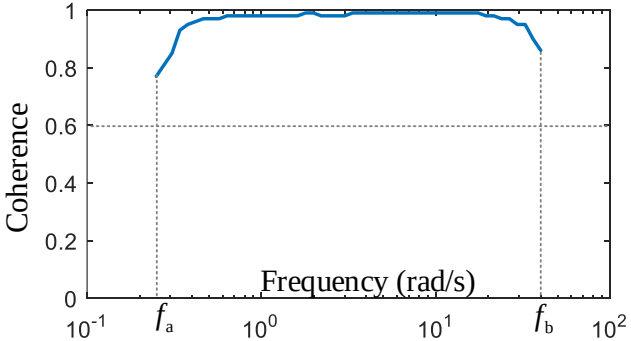
(a) Pitch channel frequency response testing



(b) Bode magnitude plot



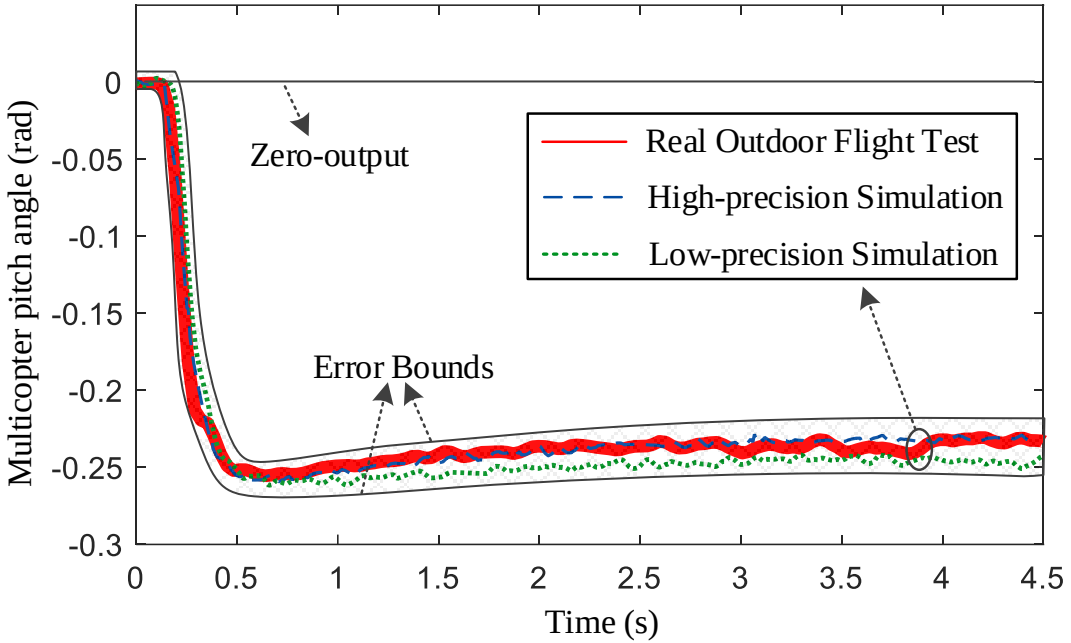
(c) Bode phase plot



(d) Coherence plot for frequency response

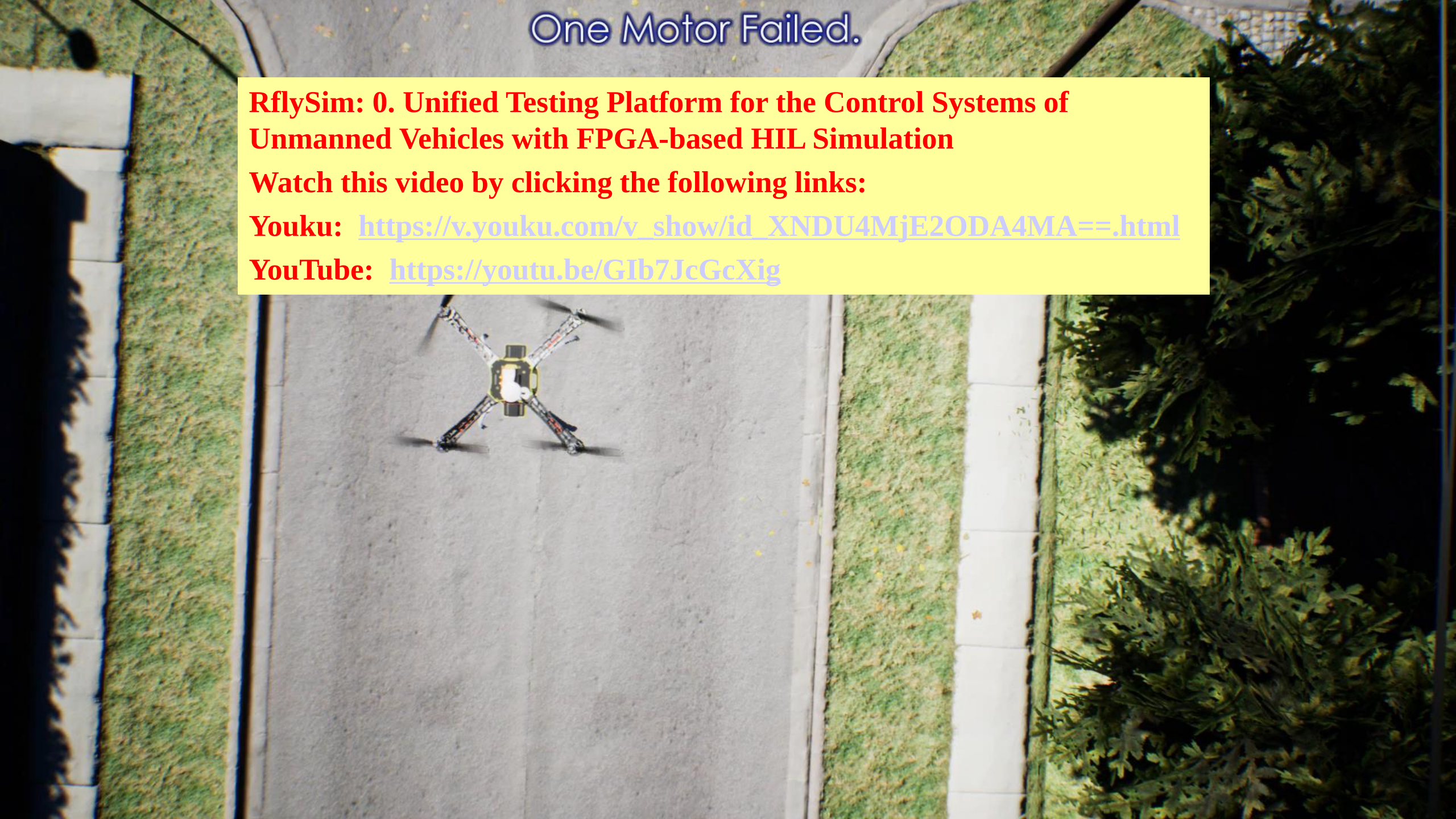
Sweep frequency tests with CIFER to compare the frequency-domain credibility

Comparison with Experiments



Propose quantitative assessment method by comparing simulation and experimental flight results.

[1] **Xunhua Dai**, Chenxu Ke, Quan Quan, and Kai-Yuan Cai. Simulation credibility assessment methodology with FPGA-based hardware-in-the-loop platform. *IEEE Transactions on Industrial Electronics*. Published Online, 2020.03. DOI: 10.1109/TIE.2020.2982122.



RflySim: 0. Unified Testing Platform for the Control Systems of Unmanned Vehicles with FPGA-based HIL Simulation

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDU4MjE2ODA4MA==.html

YouTube: https://youtu.be/GIb7JcGcXig

Outline

1. Ideas and Goals of RflySim Platform

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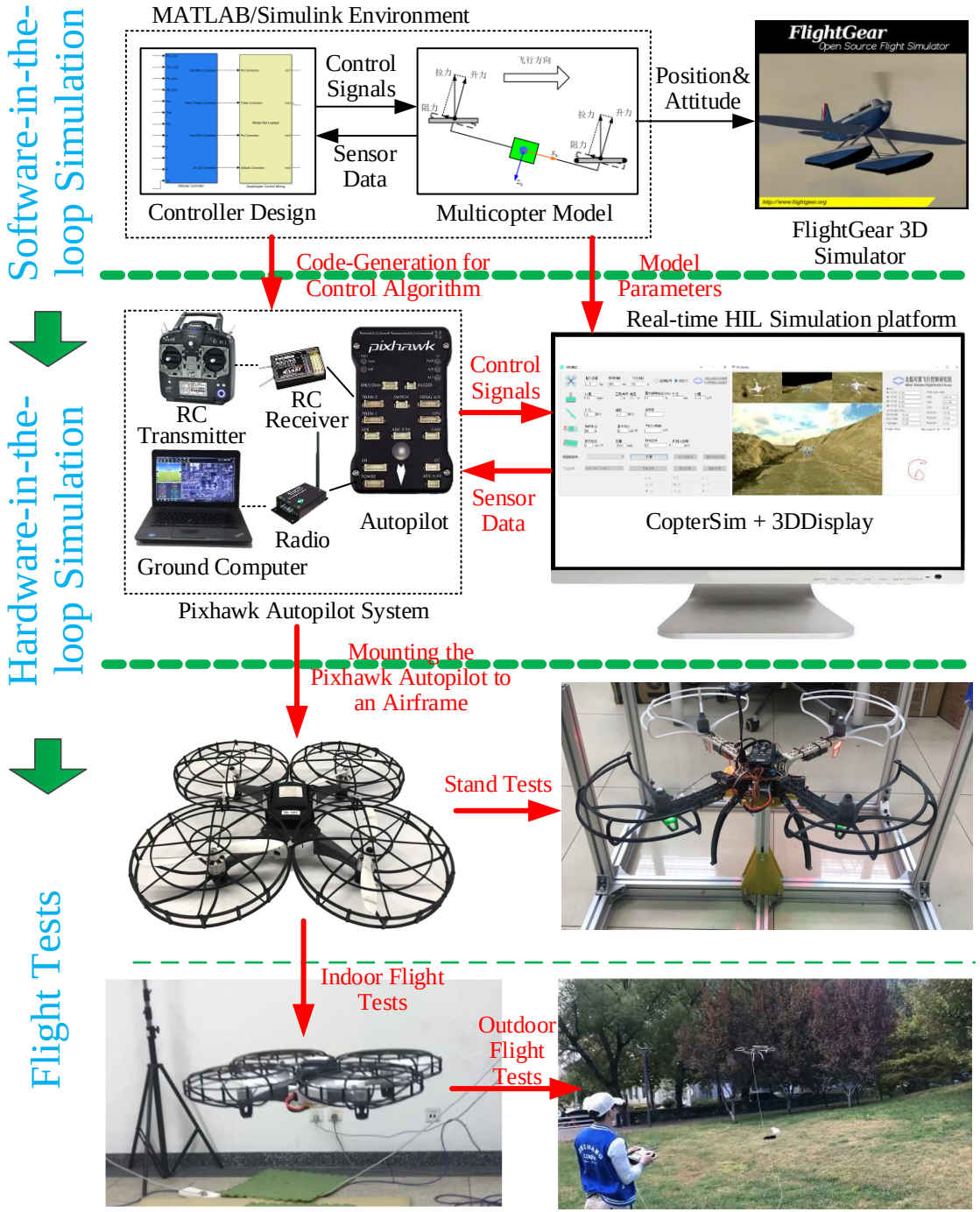
2.1 Experimental Process

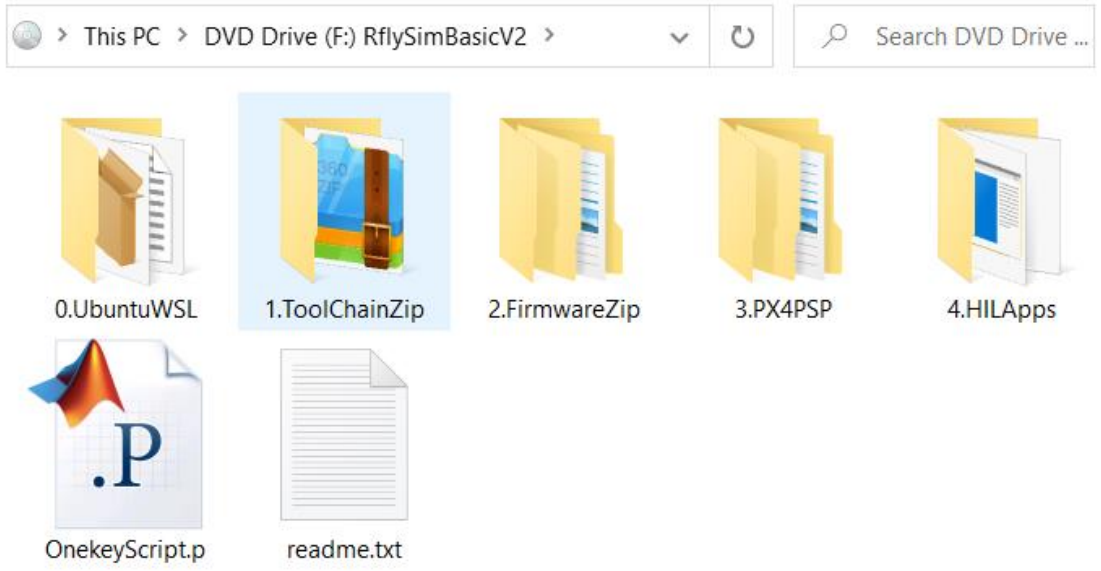
RflySim Education Platform:
How to quickly design control algorithm with requirements and apply it to a real vehicle system?

1. Design controller in Simulink
2. Quickly realize controller to real UAV through SIL, code generation, HIL, indoor, outdoor.
3. Greatly lower the threshold for learning and developing UAV control algorithms

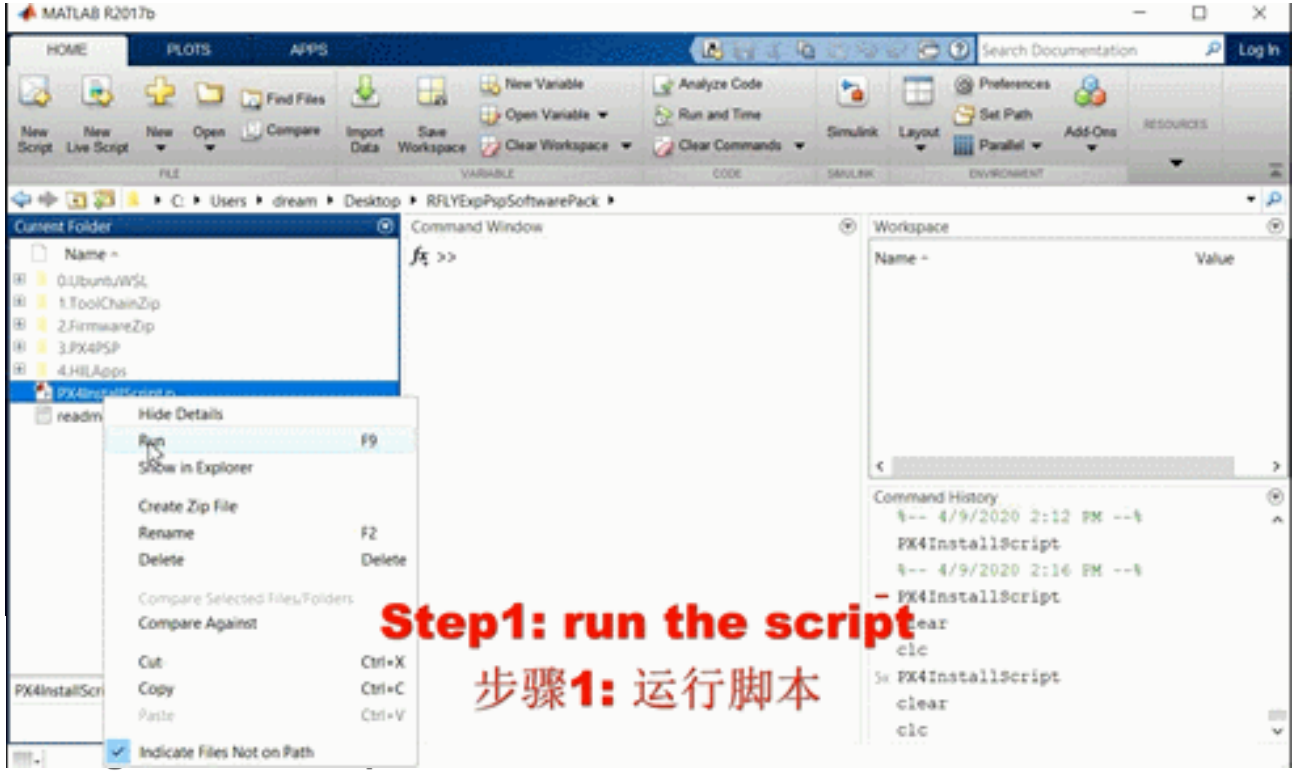


2.2 How to download RflySim and how to install

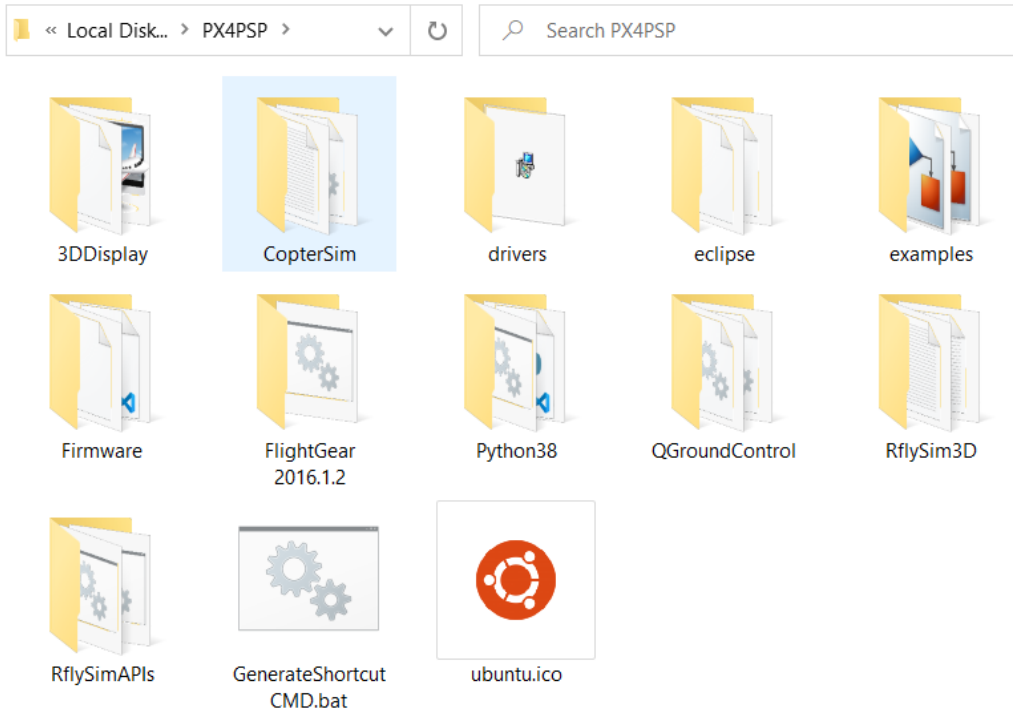
- Visit our website https://rflysim.com to download Basic free version to test the basic functions.
- If you want advanced functions, you can contact rflysim@163.com to buy advanced versions. All RflySim versions support one-key installation.



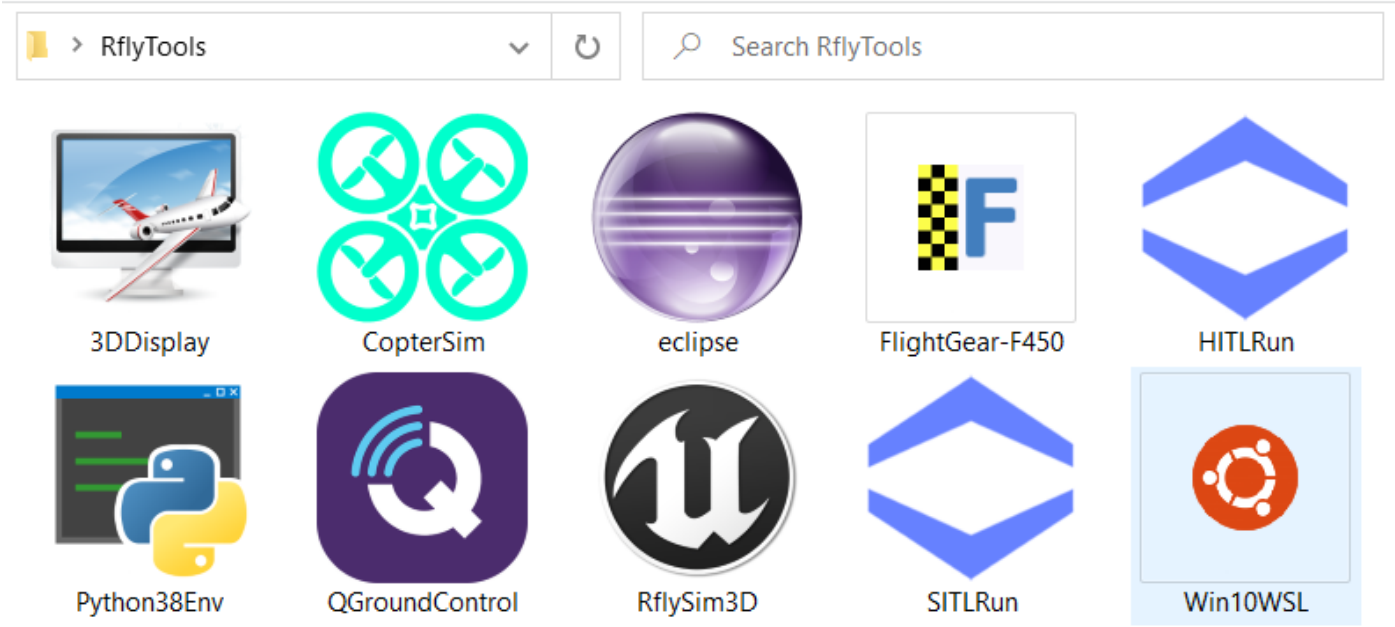
Here is the installation package, you can run the script in MATLAB to install it



2.3 Basic functions



Installation folder



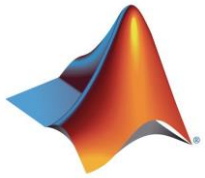
Shortcuts on Desktop

2.3 Basic functions

Software/Hardware Structure and Experimental Process:

1. Controller Design and Simulation
2. Simulink Code Generation and Python Programming
3. Software/Hardware-in-the-loop Simulations
4. Indoor/Outdoor Flight Tests and Assessment

Controller design and simulation



MATLAB/ Simulink

Python/ OpenCV

Flight Gear

Automatic code generation and firmware compiling

Simulink PSP toolbox

PX4 firmware source code

WSL/Msys2/ Cygwin compiling tool

Code view and modification

Eclipse

VS Code

HIL simulation

CopterSim

3DDisplay

RflySim3D

QGC

Pixhawk autopilot system

Ground computer

RC system

Indoor and outdoor flight tests

QGC

Ground computer

Airframe system

Propulsion system

Pixhawk autopilot system

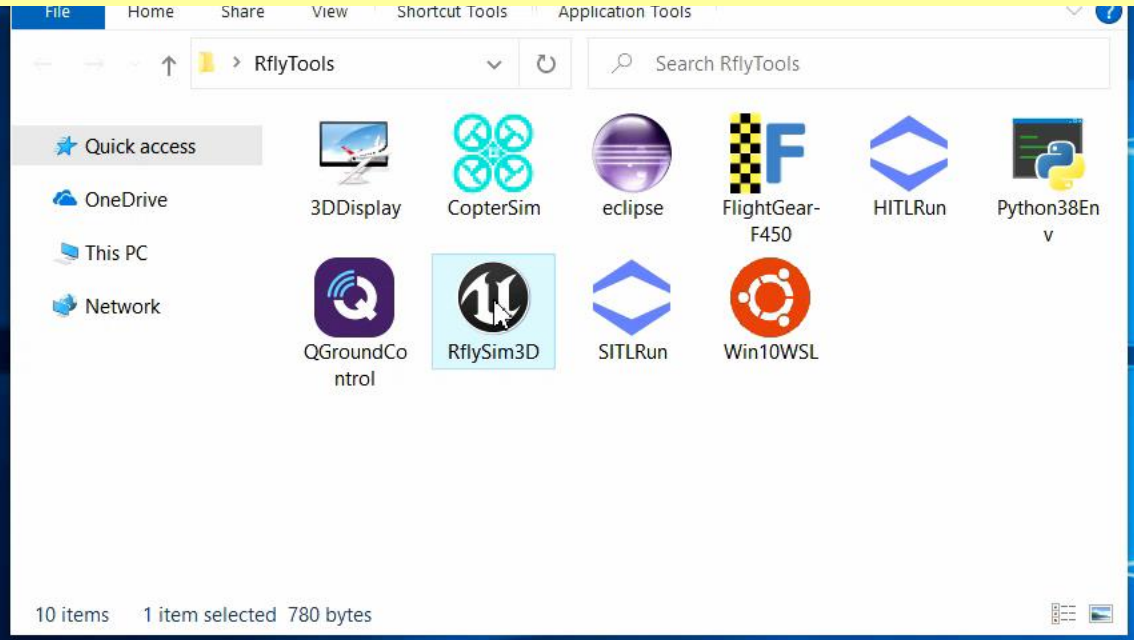
RC system

RflySim: 1. Platform introduction & How to use hardware-in-the-loop simulation for one vehicle

Watch this video by clicking the following links:

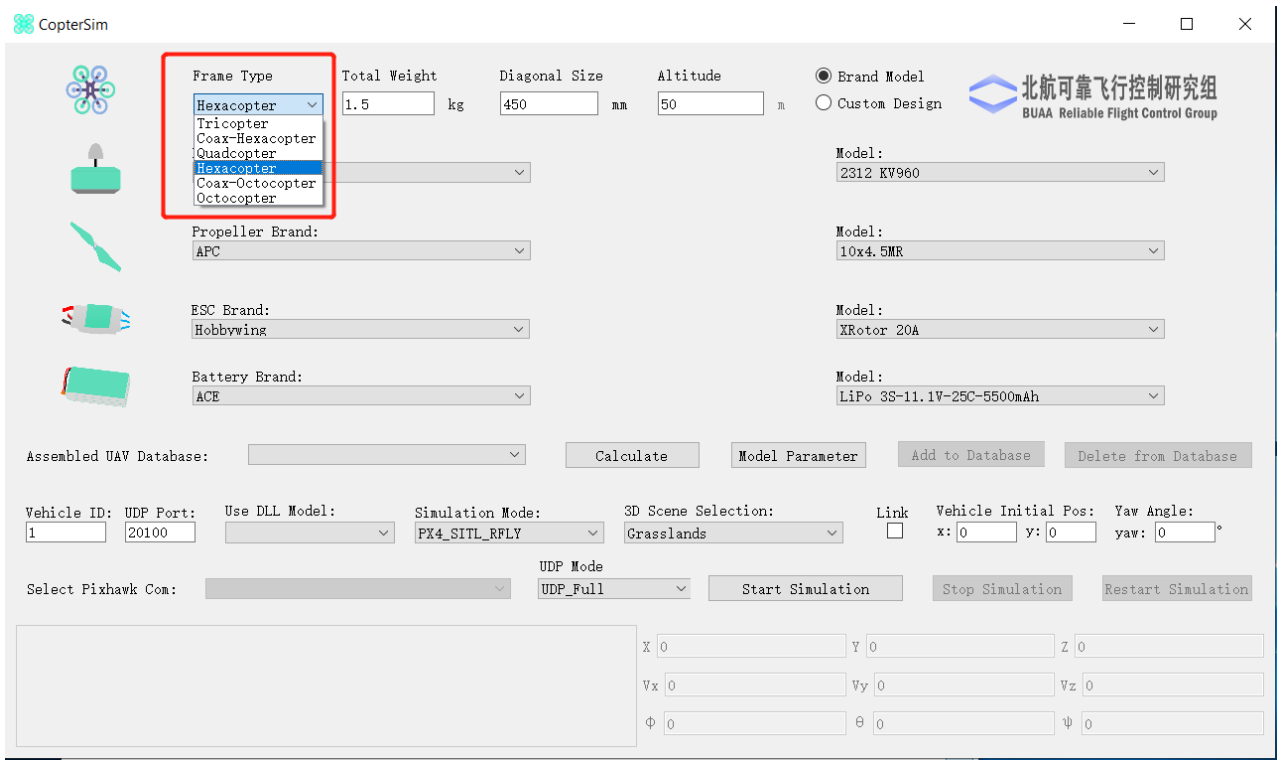
Youku: https://v.youku.com/v_show/id_XNDcwNjA4MjEwNA==.html

YouTube: https://youtu.be/3ytbk63Og5k

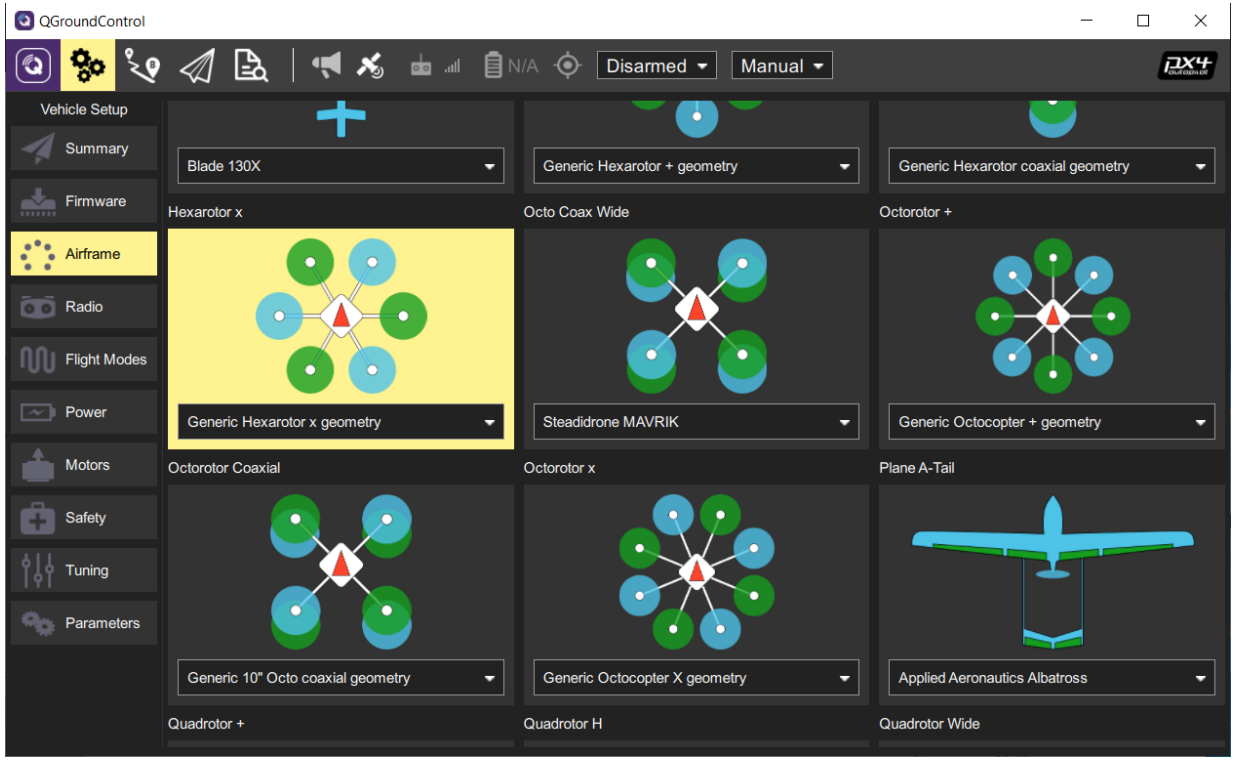


Click Desktop shortcut to Open RflySim3D

2.4 How to simulate other types of multicopters



Change and apply model to hexacopter in CopterSim



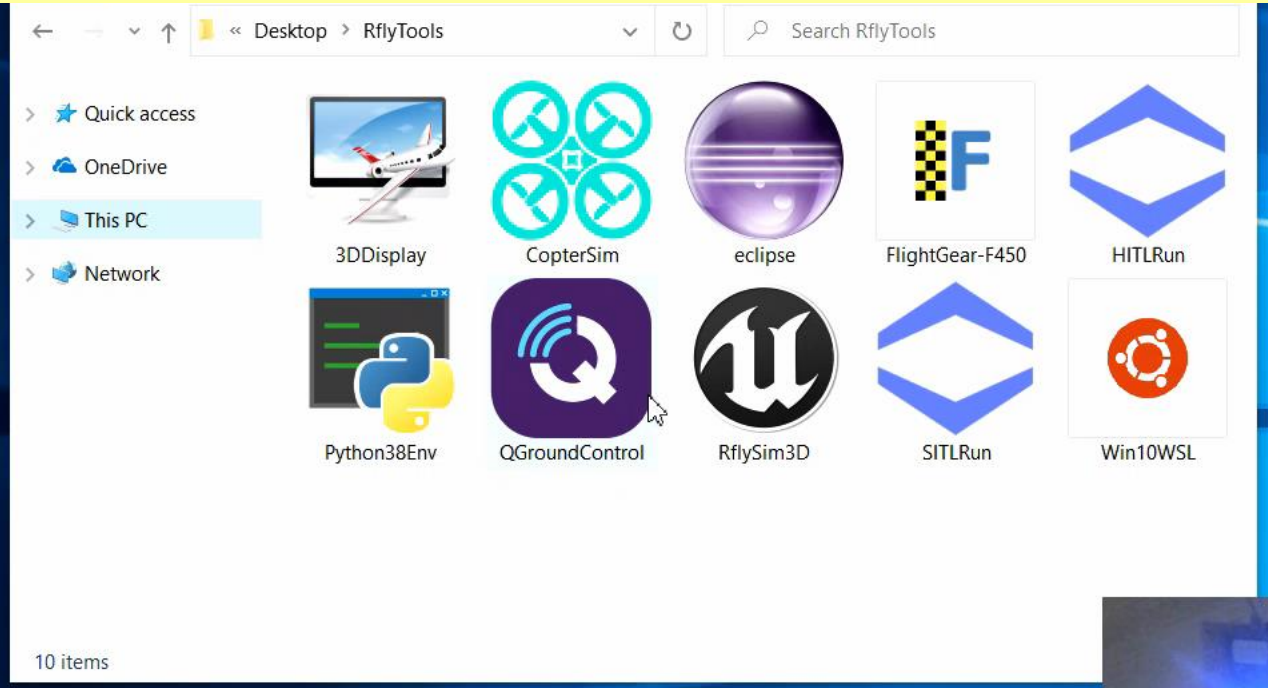
Select a hexacopter airframe and enable HITL mode in QGroundControl

RflySim: 2. How to simulate other types of multicopters

Watch this video by clicking the following links:

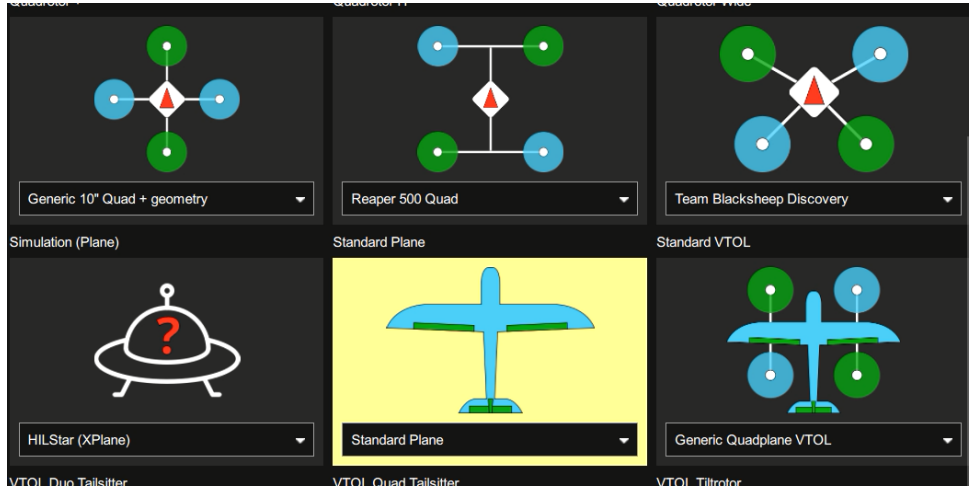
Youku: https://v.youku.com/v_show/id_XNDcwNjA4MDY2MA==.html

YouTube: https://youtu.be/bryZXxaJE5M

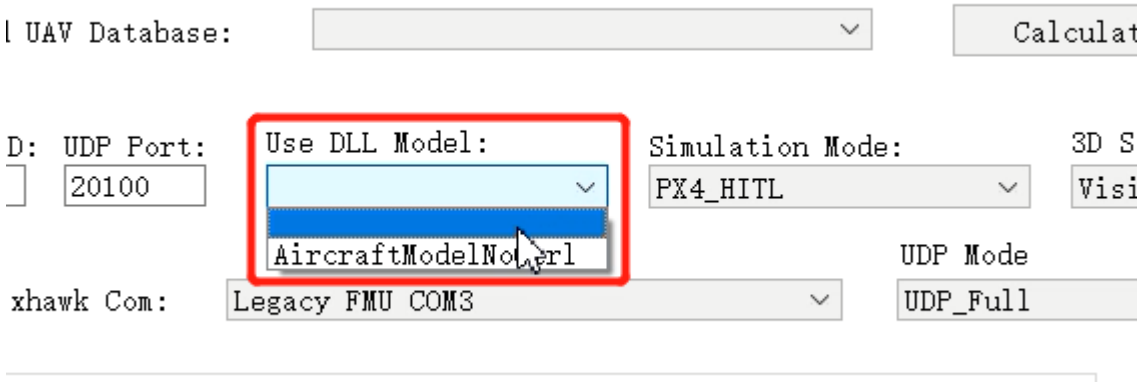


Connect Pixhawk and open QGC

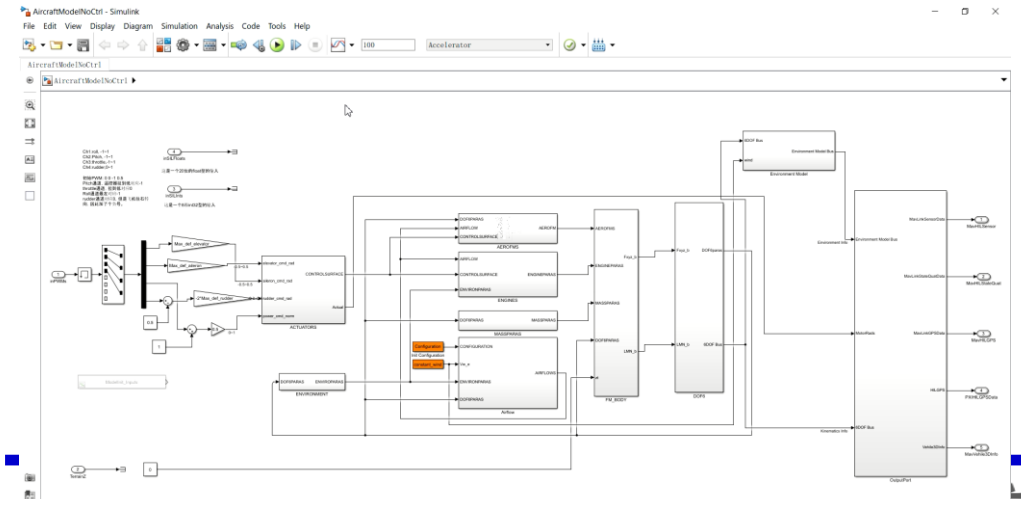
2.5 How to simulate other types of vehicles



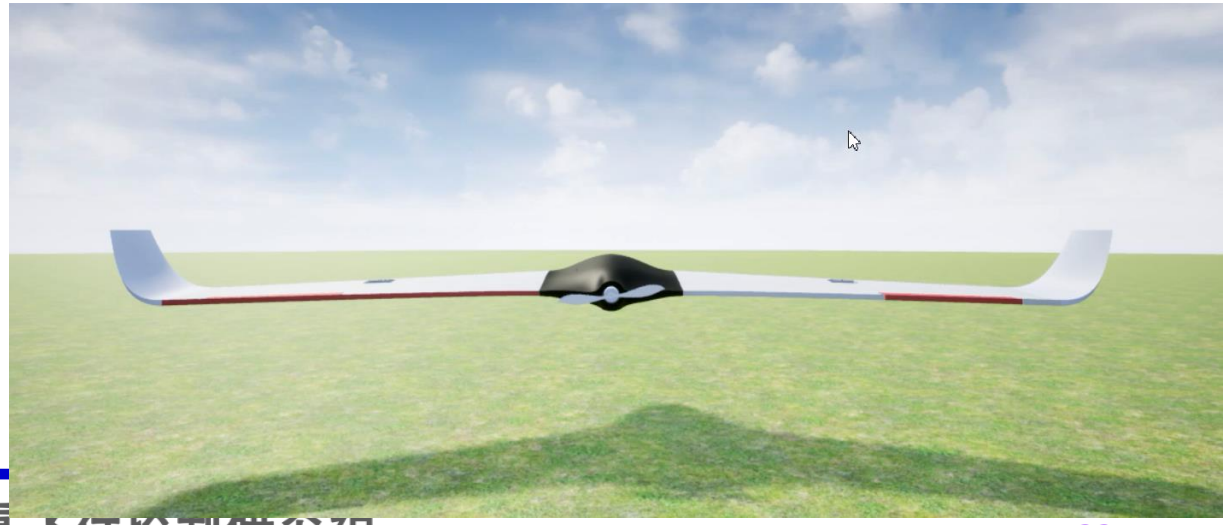
1. QGC change to fixed-wing aircraft mode



3. CopterSim select the aircraft DLL model



2. Simulink build aircraft model to DLL file



4. RflySim3D auto select aircraft's 3D model

QGroundControl

RflySim: 3. How to simulate other types of vehicles, for example fixed-wing aircraft

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4MTQxMg==.html

YouTube: https://youtu.be/gt7lIUx7JRc

Vehicle Setup

- Summary
- Firmware
- Airframe
- Radio
- Flight Modes
- Power
- Motors
- Safety
- Tuning
- Camera
- Parameters

Hexarotor Coaxial
Generic Hexarotor coaxial geometry

Generic Hexarotor x geometry

Steadidrone MAVRIK

Generic Octocopter + geometry

Octorotor Coaxial
Generic 10" Octo coaxial geometry

Octorotor x
Generic Octocopter X geometry

Plane A-Tail
Applied Aeronautics Albatross

Quadrotor +
Generic 10" Quad + geometry

Quadrotor H
Reaper 500 Quad

Quadrotor Wide
Team Blacksheep Discovery

Quadrotor x

Simulation (Copter)
opter X

Simulation (Plane)
HILStar (XPlane)

Standard Plane
Standard Plane

Standard VTOL
Generic Quadplane VTOL

VTOL Duo Tailsitter

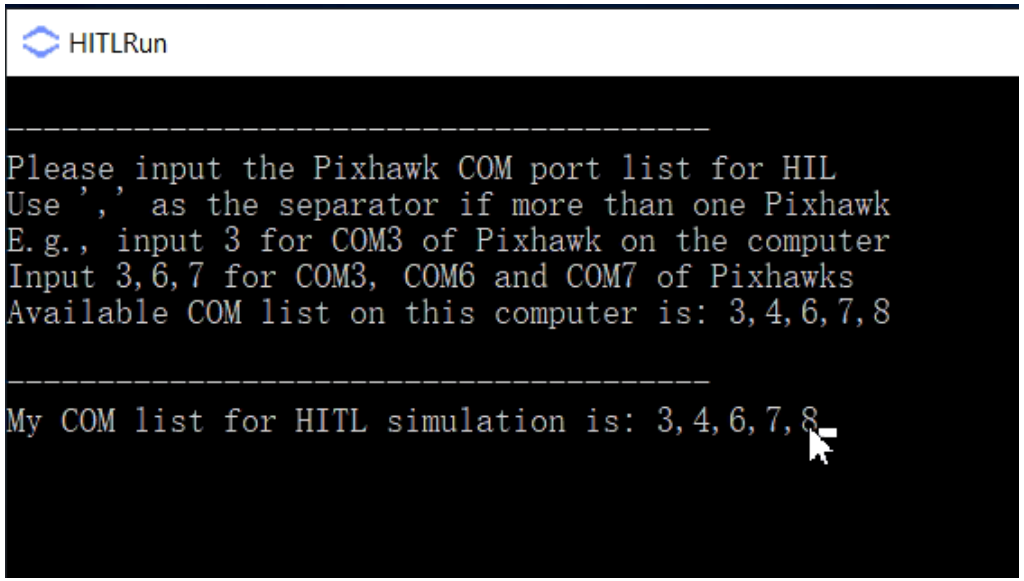
VTOL Quad Tailsitter

VTOL Tiltrotor

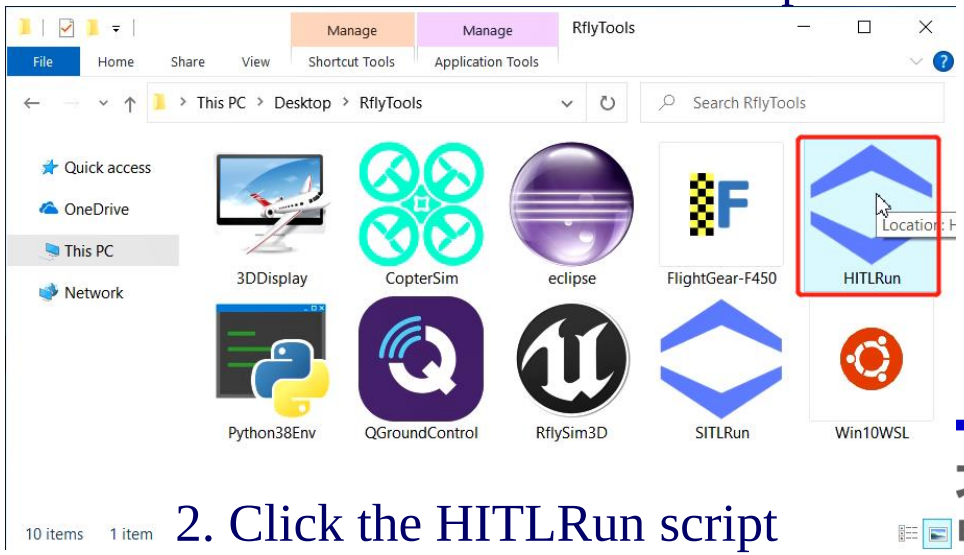
ENG 12:11 AM 5/30/2020

2.6 How to connect multiple Pixhawks for swarm simulation

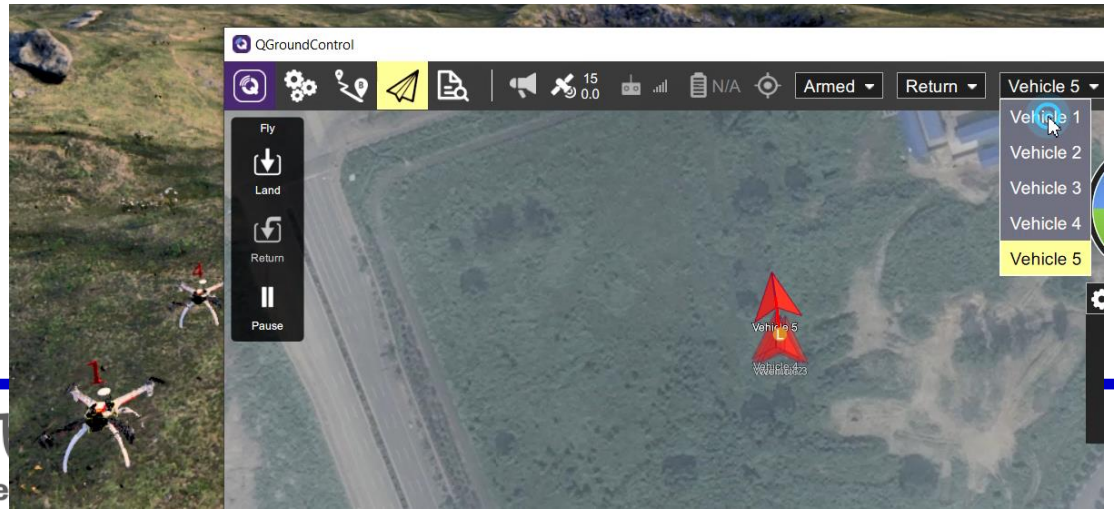
1. Connect several Pixhawks on computer



3. Input the list of all Pixhawk coms



2. Click the HITLRun script



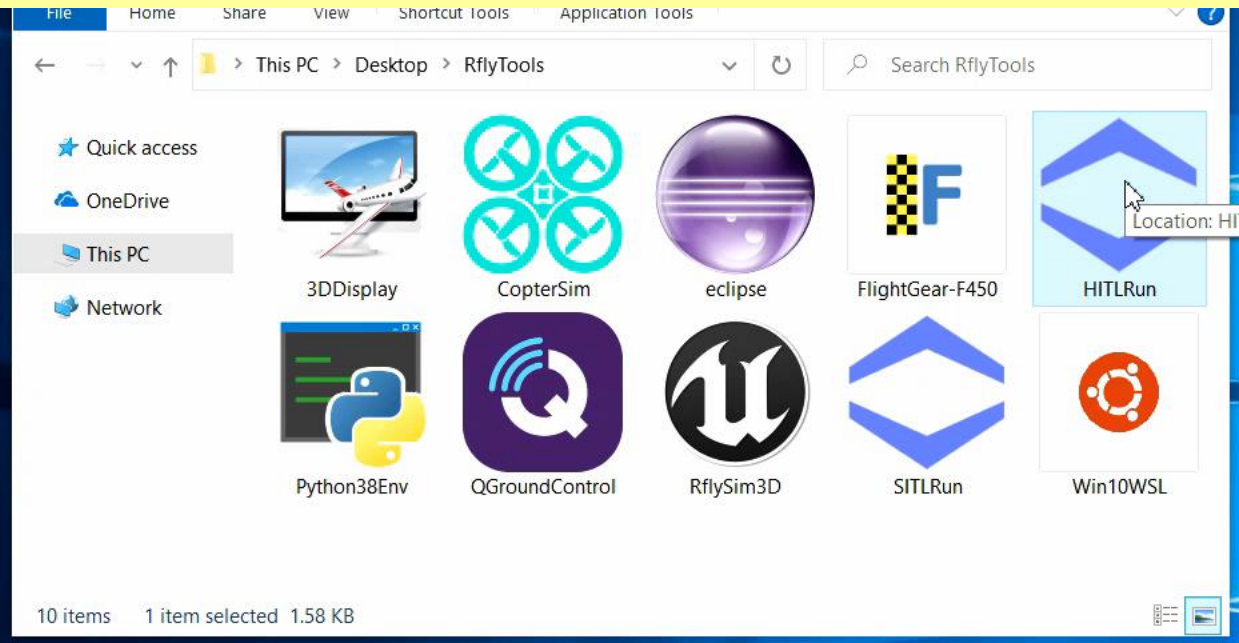
北航可靠飞
BUAA Reliable

RflySim: 4. How to use hardware-in-the-loop simulation for UAV swarm

Watch this video by clicking the following links:

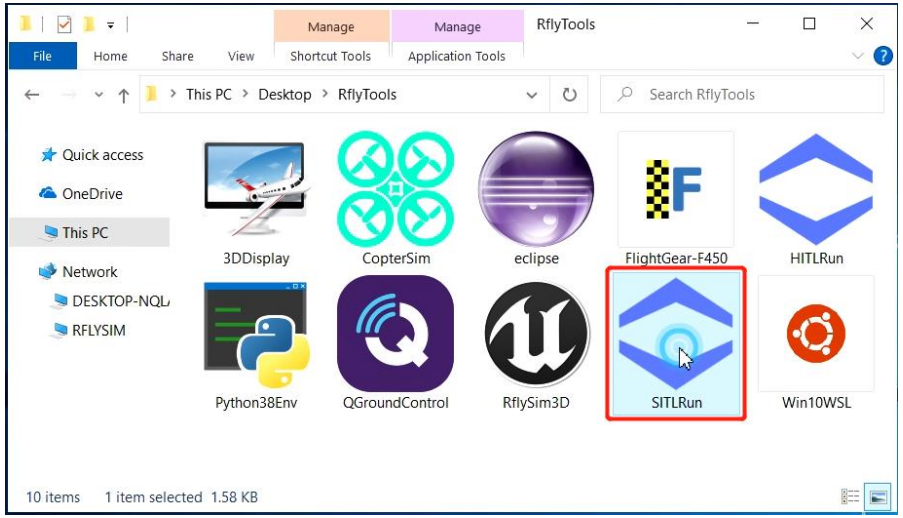
Youku: https://v.youku.com/v_show/id_XNDcwNjA3OTQ0MA==.html

YouTube: https://youtu.be/oZ_-yhEgebA

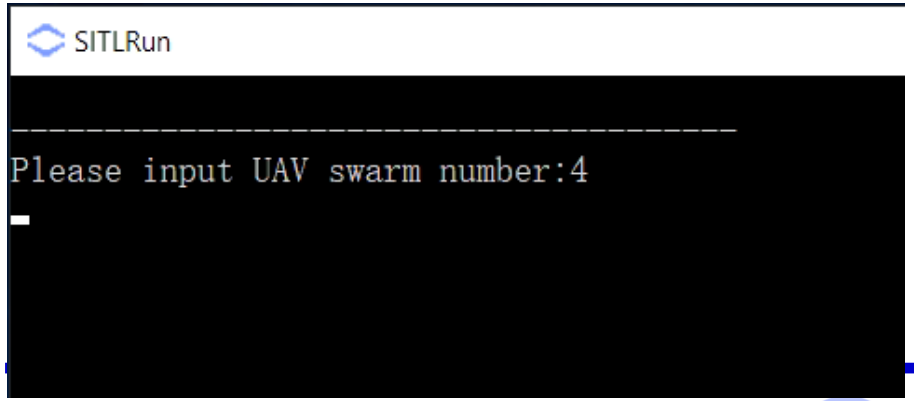


Connect all Pixhawks to computer with USB

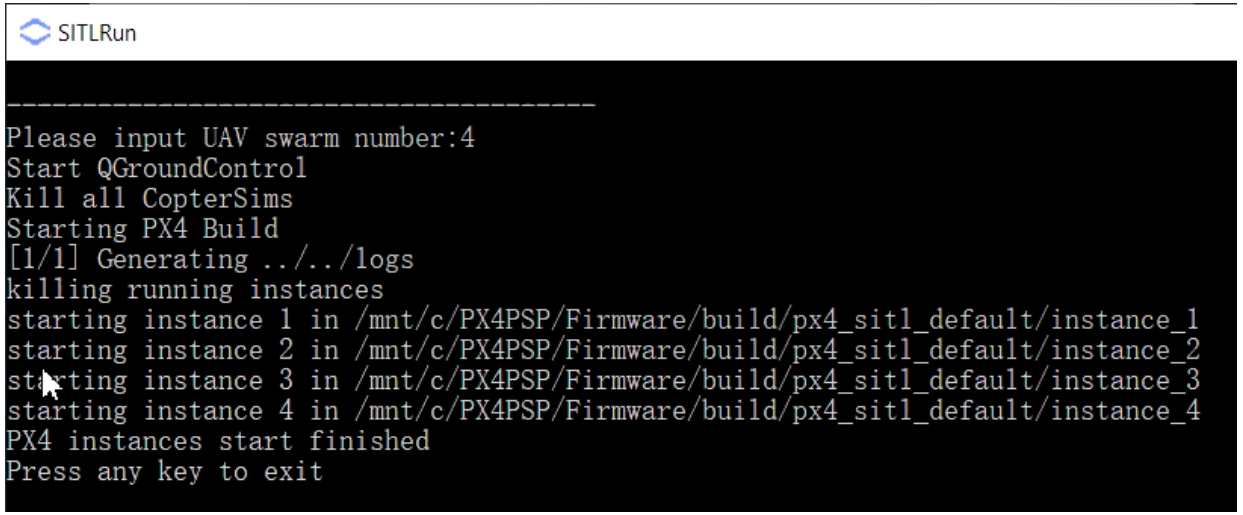
2.7 How to perform simulation without Pixhawk hardware



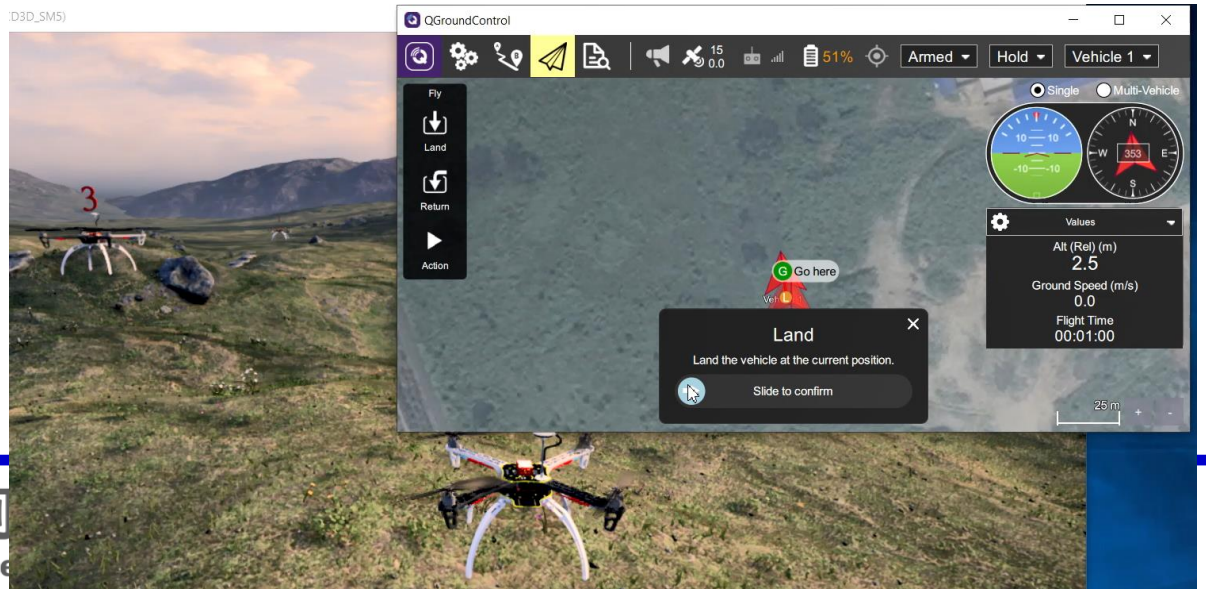
1. Click the SITLRun script



2. Input the vehicle number



3. Auto start N PX4 SITL controllers on computer

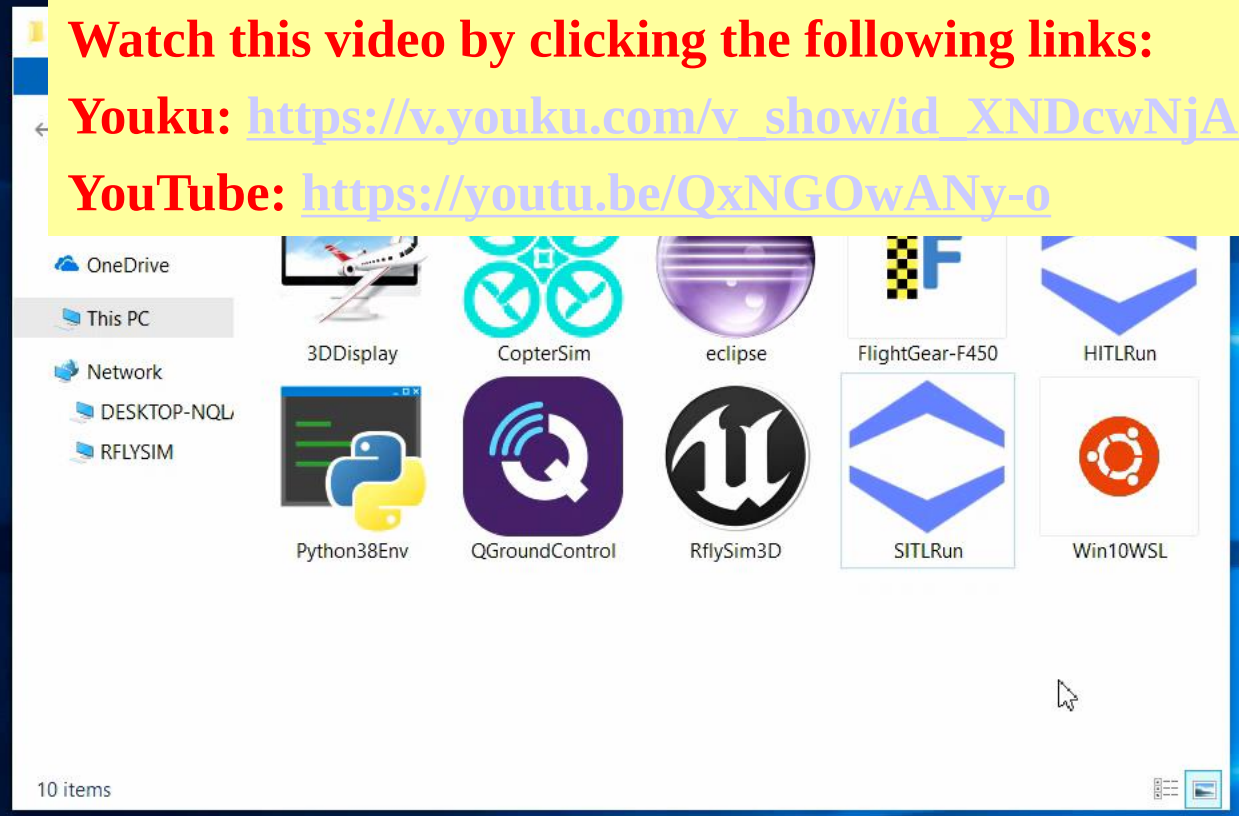


RflySim: 5. How to quickly perform software-in-the-loop simulation for one multicopter UAV

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4MzUxNg==.html

YouTube: https://youtu.be/QxNGOwANy-o



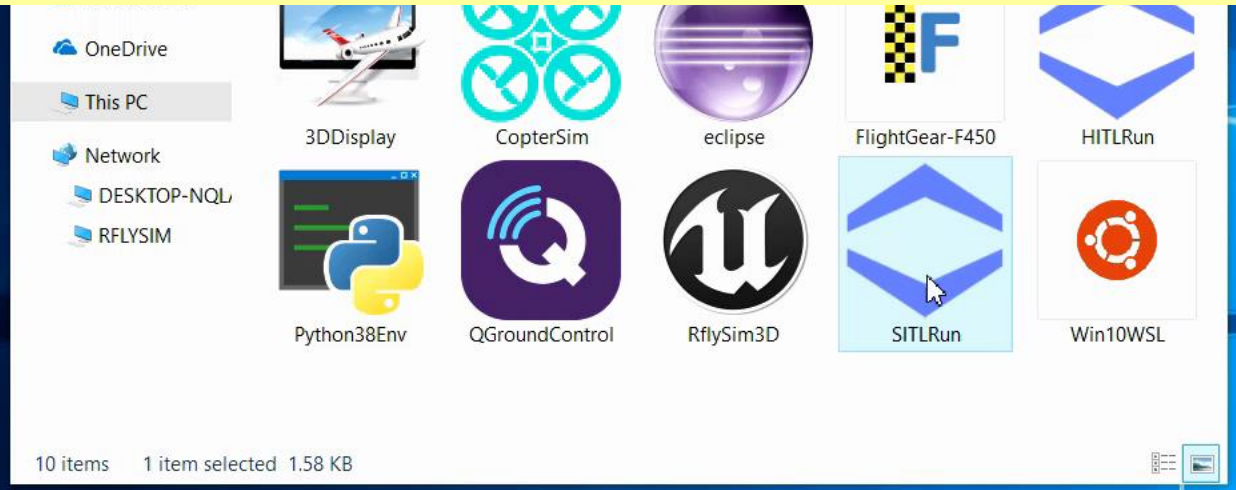
Click one-key script and input vehicle number 1

RflySim: 6. How to quickly perform software-in-the-loop (SIL) simulation for UAV swarm

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4MzA0NA==.html

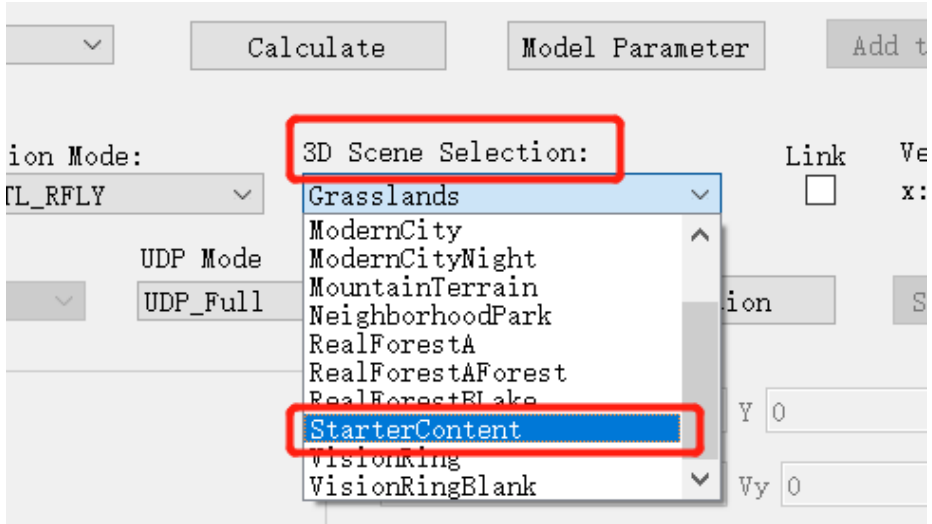
YouTube: https://youtu.be/88dGpErxPJ8

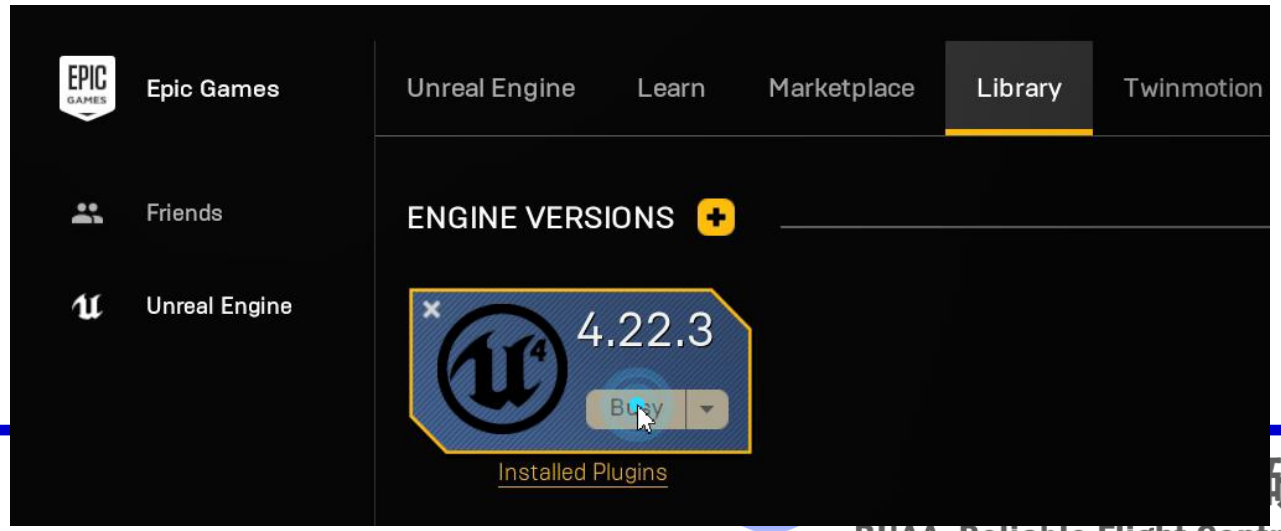


Start one-key script and input vehicle number 4

2.8 How to import your 3D scenes in RflySim3D

- Support to import all scenes in UE4 → RflySim3D will detect and import UE4 scene map files
- Create a 3D Scene in 3Ds Max (or imported from AutoCAD, SketchUp by fbx file) → imported to UE4 → imported to RlfySim3D
- Procedure: UE4 build and package project to files → copy the scene folder to RflySim3D content folder → Copy terrain files to CopterSim





RflySim: 7. How to import your own 3D scene to the UE4-based RflySim3D program

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4NjY2NA==.html

YouTube: https://youtu.be/W9kKZpLZ04U

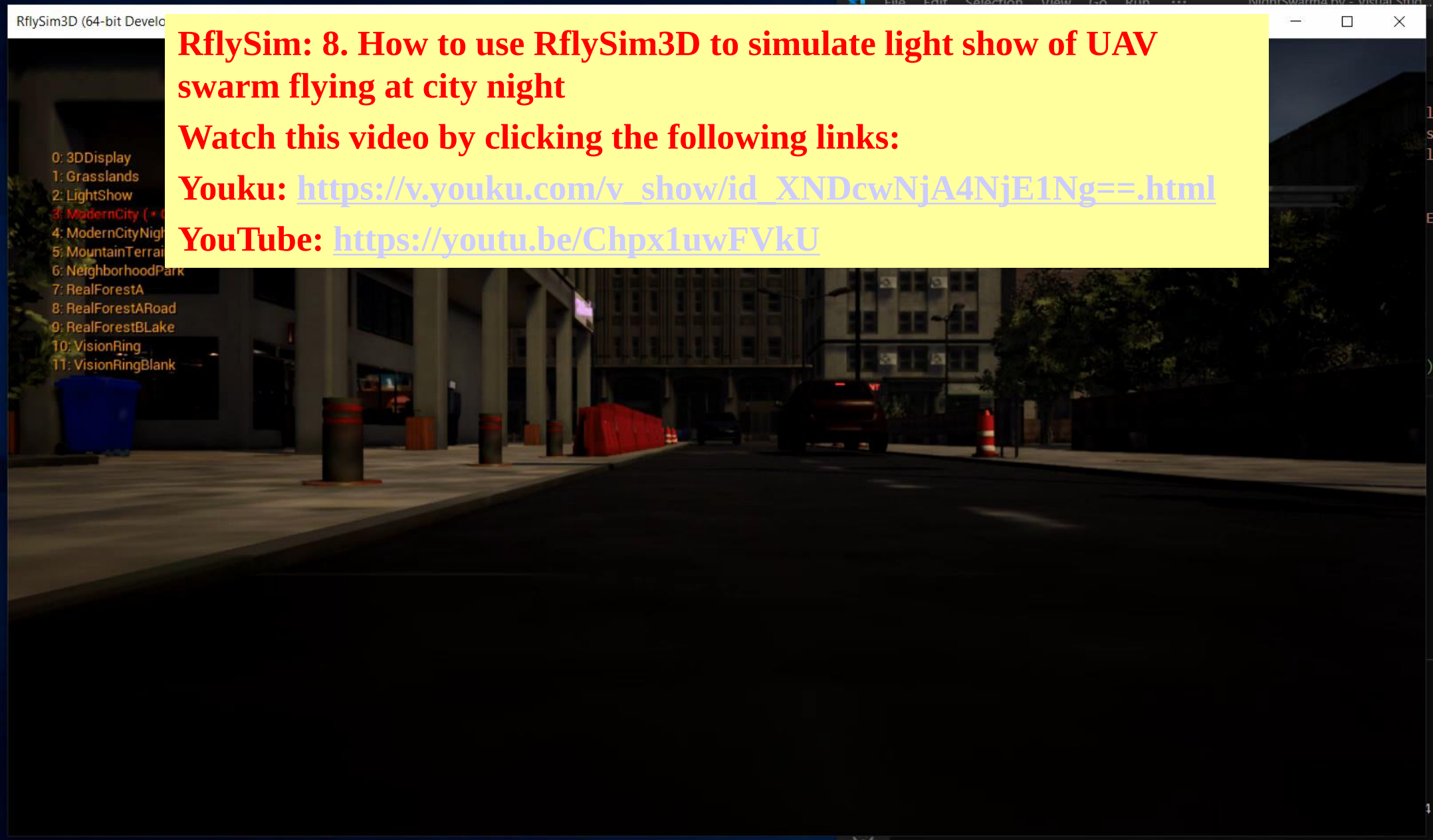



RflySim: 8. How to use RflySim3D to simulate light show of UAV swarm flying at city night

Watch this video by clicking the following links:

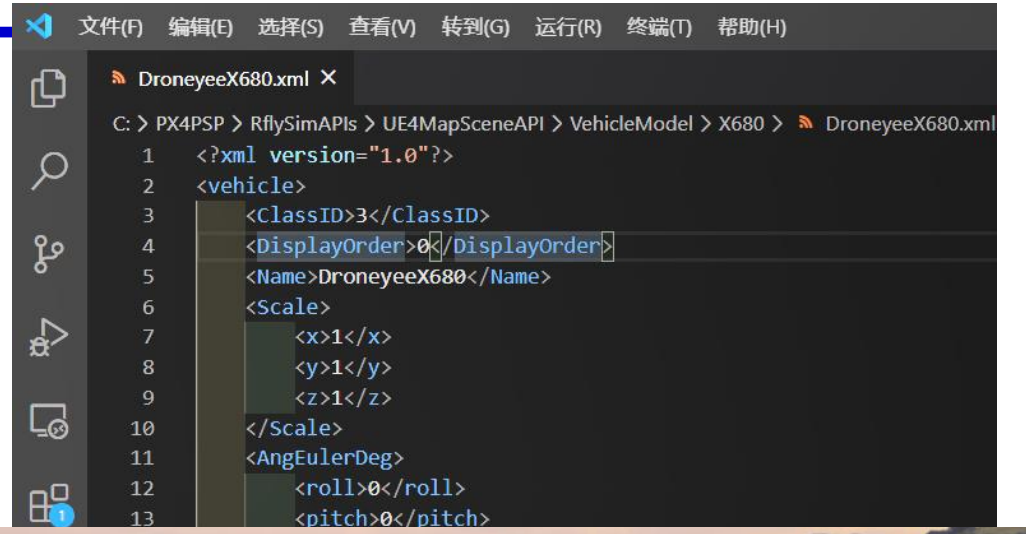
Youku: https://v.youku.com/v_show/id_XNDcwNjA4NjE1Ng==.html

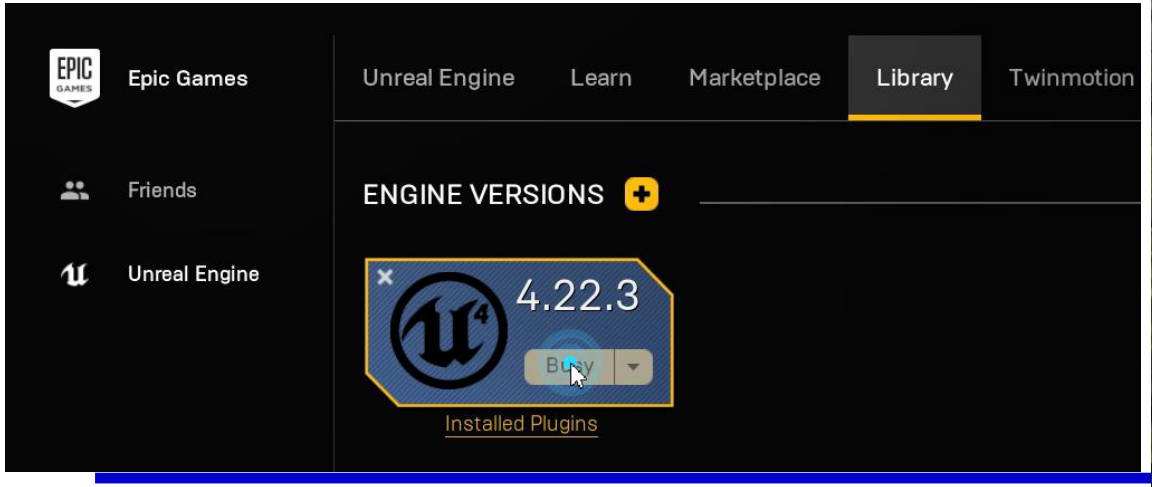
YouTube: https://youtu.be/Chpx1uwFVkU



2.9 How to import your vehicle's 3D model to RflySim3D

- Support to import all vehicle/target/people/obstacle in UE4 → RflySim3D will detect and import UE4 model file and XML configuration file
- Create a 3D model in 3Ds Max (or imported from AutoCAD, SketchUp by fbx file) → imported to UE4 → imported to RlfySim3D

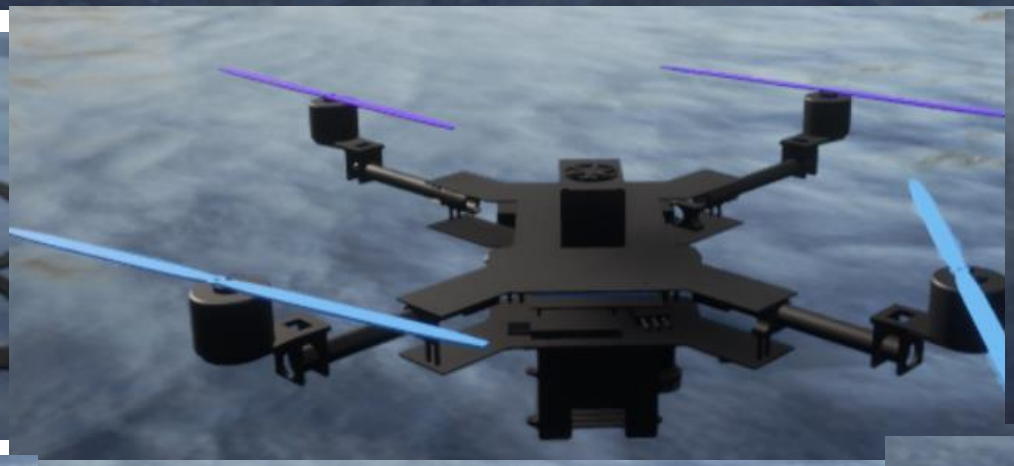
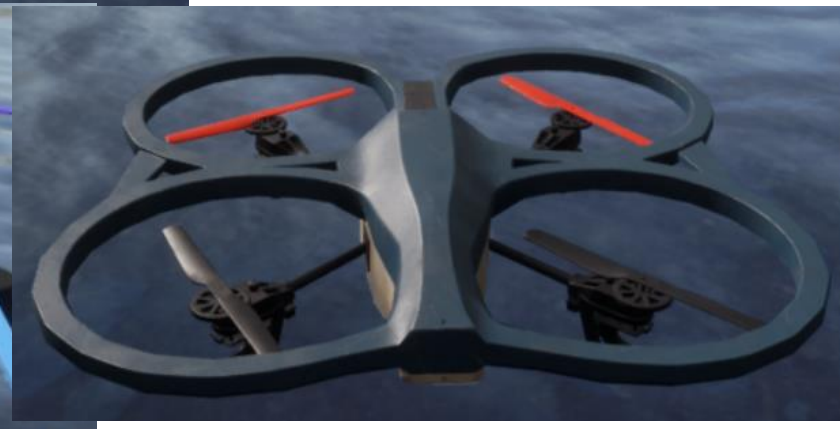


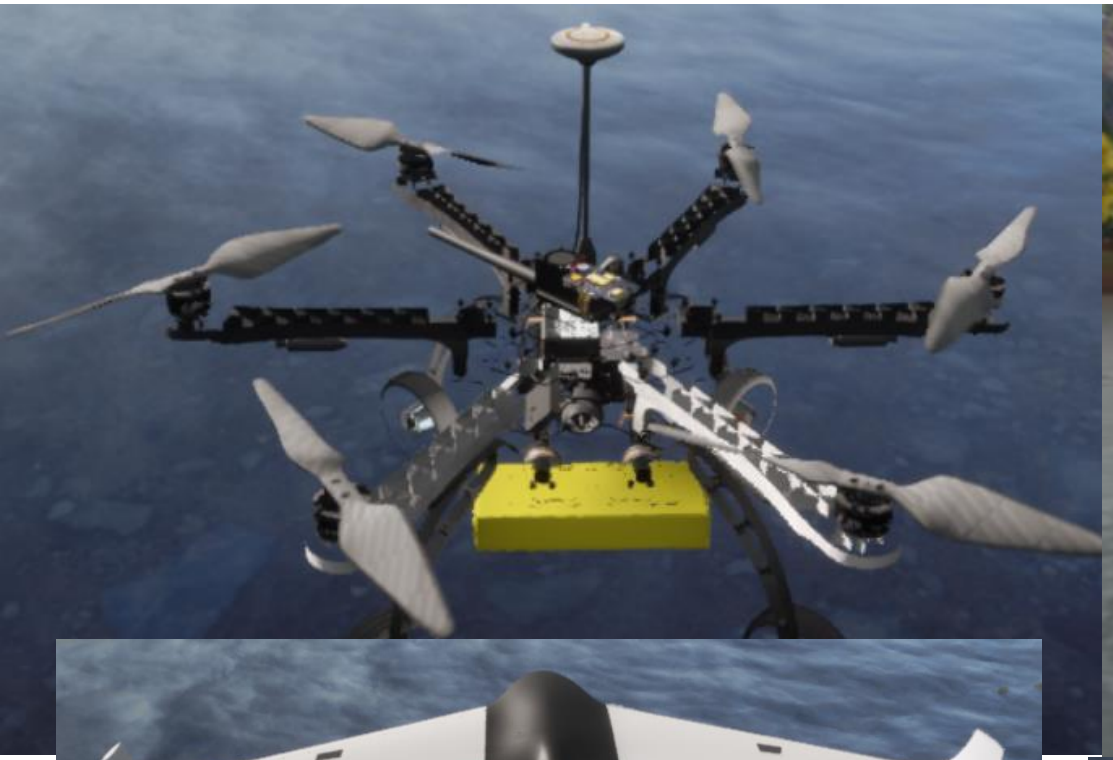



DroneyeeX680.max - Autodesk 3ds Max 2020
RflySim: 9. How to import your own 3D vehicle models to the UE4-based RflySim3D program
Watch this video by clicking the following links:
Youku: https://v.youku.com/v_show/id_XNDcwNjA4NzIxMg==.html
YouTube: https://youtu.be/mKUehJwqqsU
[+] [Left] [Standard] [Wireframe]
[+] [Perspective] [Standard] [Default Shading]
Open a 3D model from 3Ds Max






Front camera view
Vehicle chase view
Fixed monitoring view
Indoor Scenes

Switch to altitude mode


Car chase view
Street Scenes
for cars


Arm the drone and take off
Forest Scenes for
Multicopters

Futaba


Mountain Scenes
for Fixed-wing

Outline

1. Ideas and Goals of RflySim Platform

2. Single Vehicle Control and Test Framework

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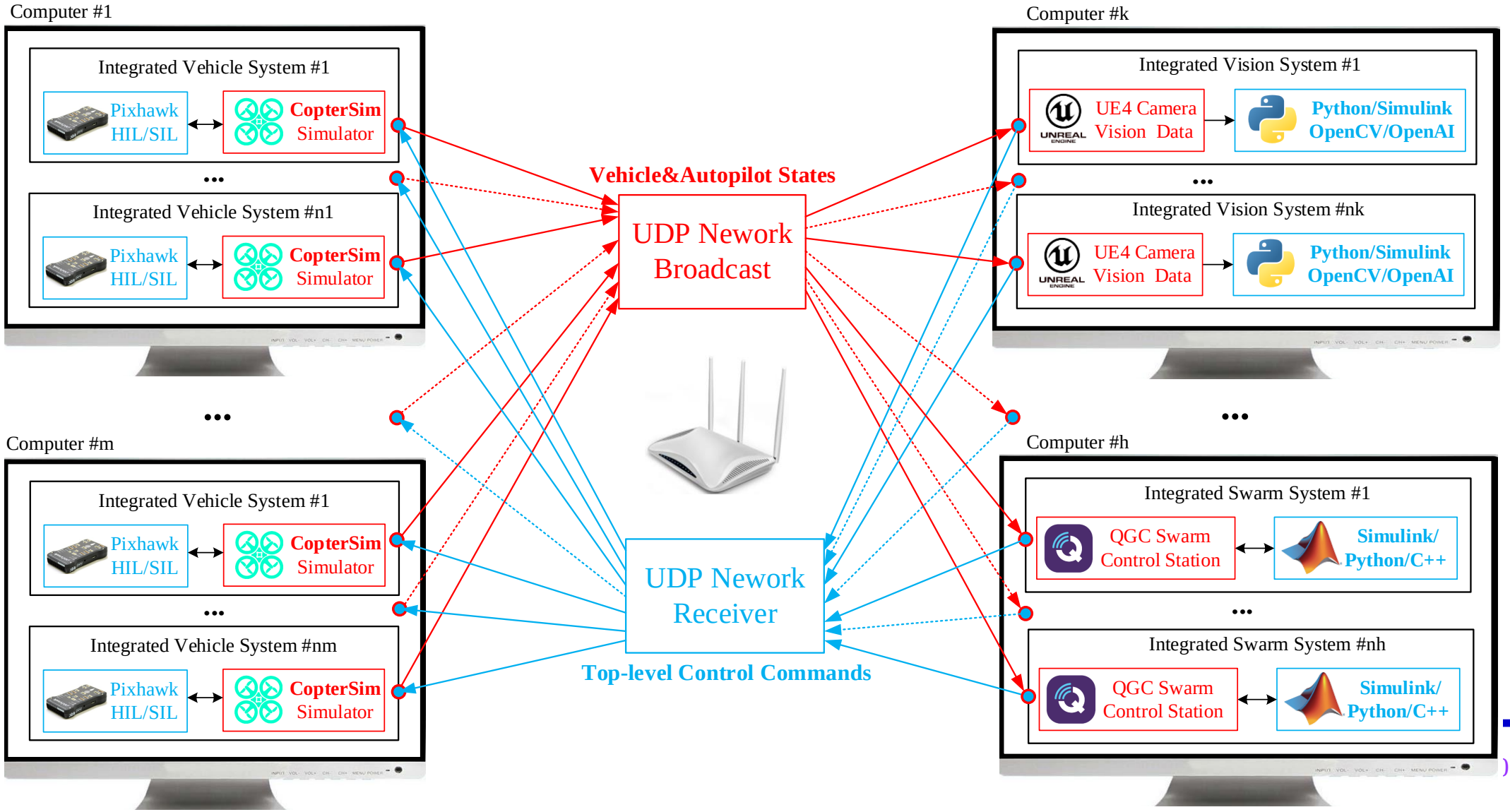
4. Vision/AI-based Control and Test Framework

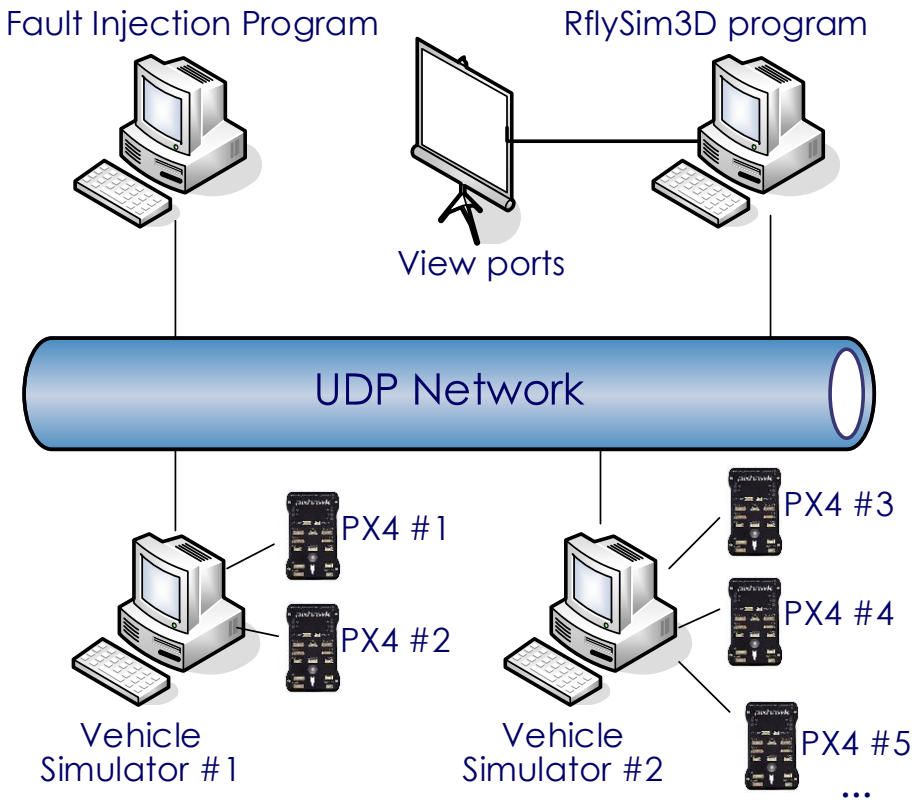
5. Summary

3.1 System Structure

Totally distributed framework, you can extend to any number of computers, vehicles, observation views, etc.



3.2 Distributed framwork

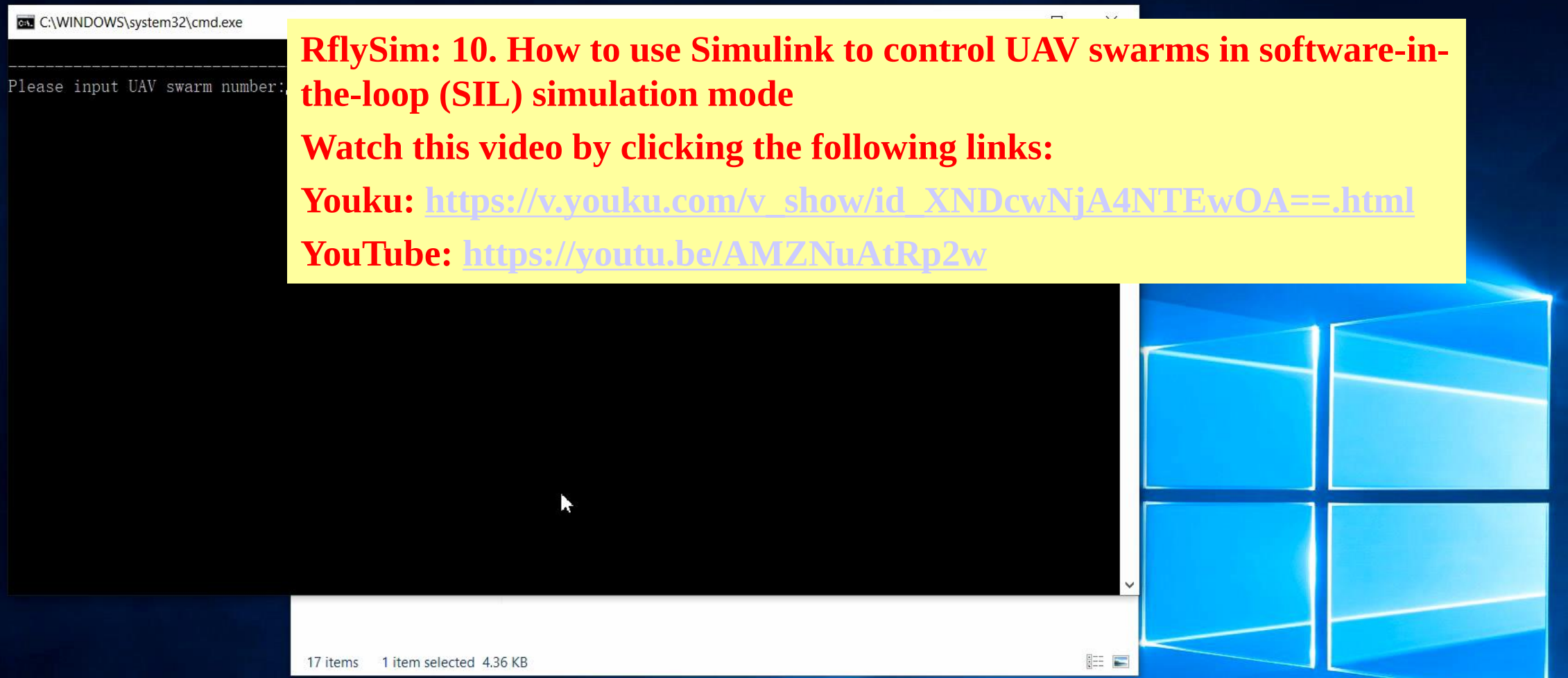


Distributed framework in LAN

Real UAV Swarm system

3.3 Key problems and solutions for UAV Swarm simulation

- Problem 1: it is ineffective to create simulated vehicles&Pixhawks one by one
- Solution: One-key script to start and initialize all programs and parameters
- Problem 2: How to display all vehicles in the same 3D program
- Solution: we use UDP network to broadcast vehicle states, and RflySim3D dynamically create vehicle 3D model when receiving new data. Users can also create other 3D models such as obstacle, people, tracking target, checker board .
- Problem 3: The network become congested when vehicle number is too large
  Solution: we have multiple communication protocols, simplified message can be applied when vehicle number is large to improve the real-time performance of communication.
- Problem 4: It is too costly and inefficient to perform large scale swarm simulation with Pixhawk hardware.
  Solution: we provide PX4 SITL simulation mode, under which the PX4 Autopilot software is running in the windows instead of Pixhawk hardware.
- Problem 5: How much vehicle can be simulated on one computer?
- Answer: the QGroundControl and RflySim3D occupy most of the computing resource, and the CopterSim + PX4 SILT only need few computing resources. For normal high-performance PCs, we can run at least 15 vehicles with CopterSim + PX4 SITL, and at least 30 vehicles with CopterSim + PX4 HITL. The number will increase if the QGroundControl, RflySim3D, and MATLAB are not running on this computer

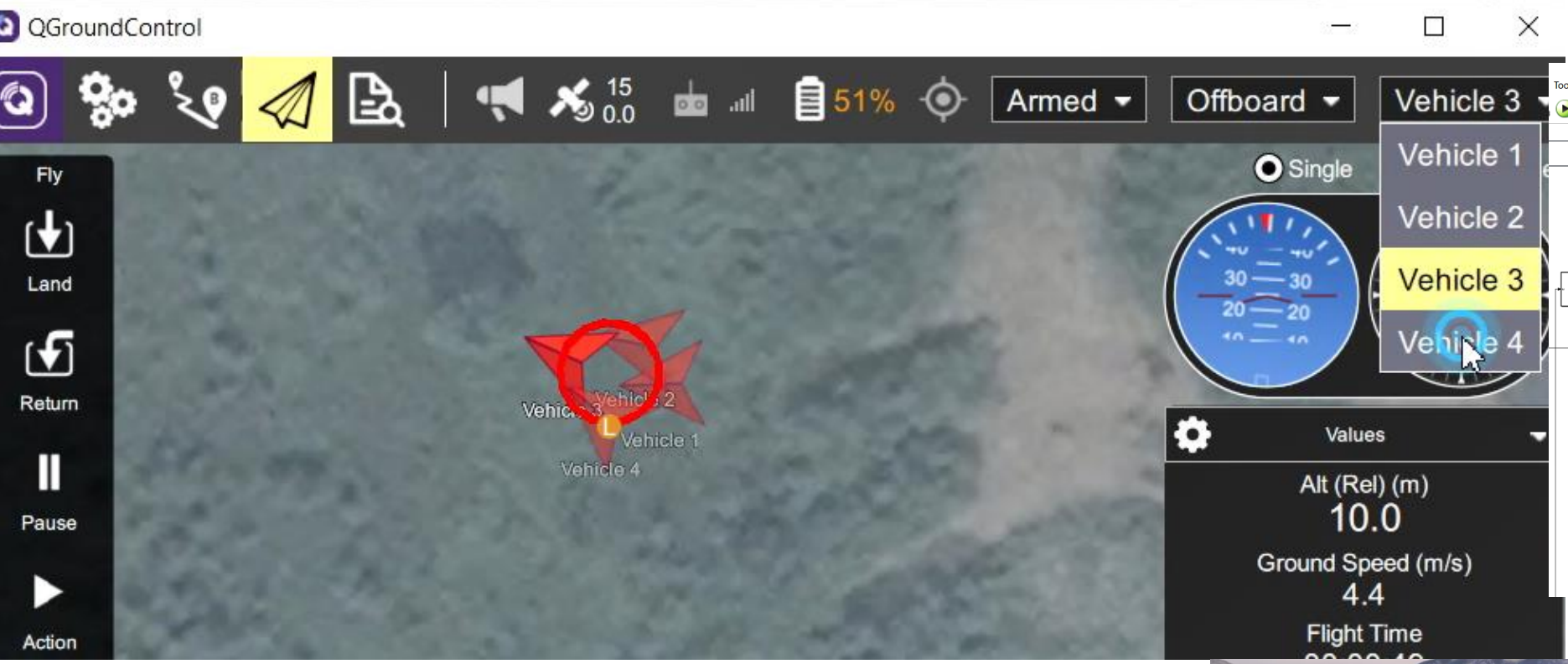


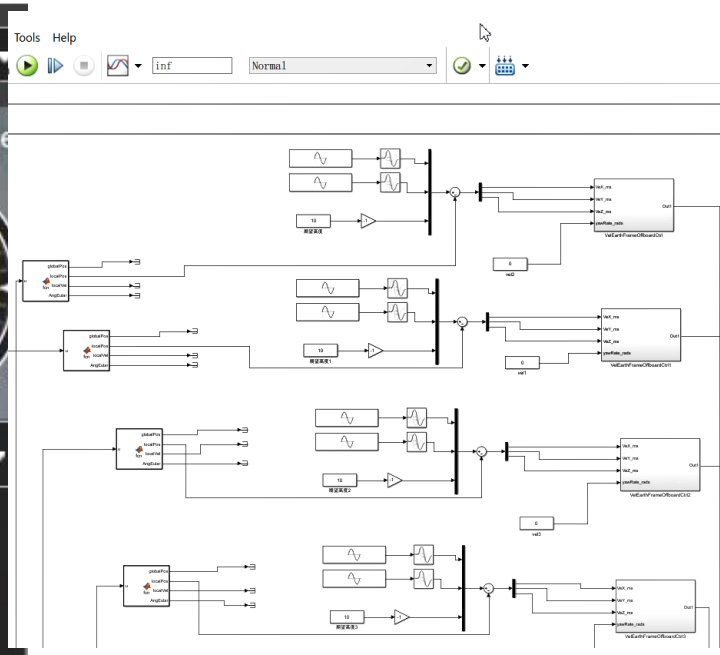
RflySim: 10. How to use Simulink to control UAV swarms in software-in-the-loop (SIL) simulation mode

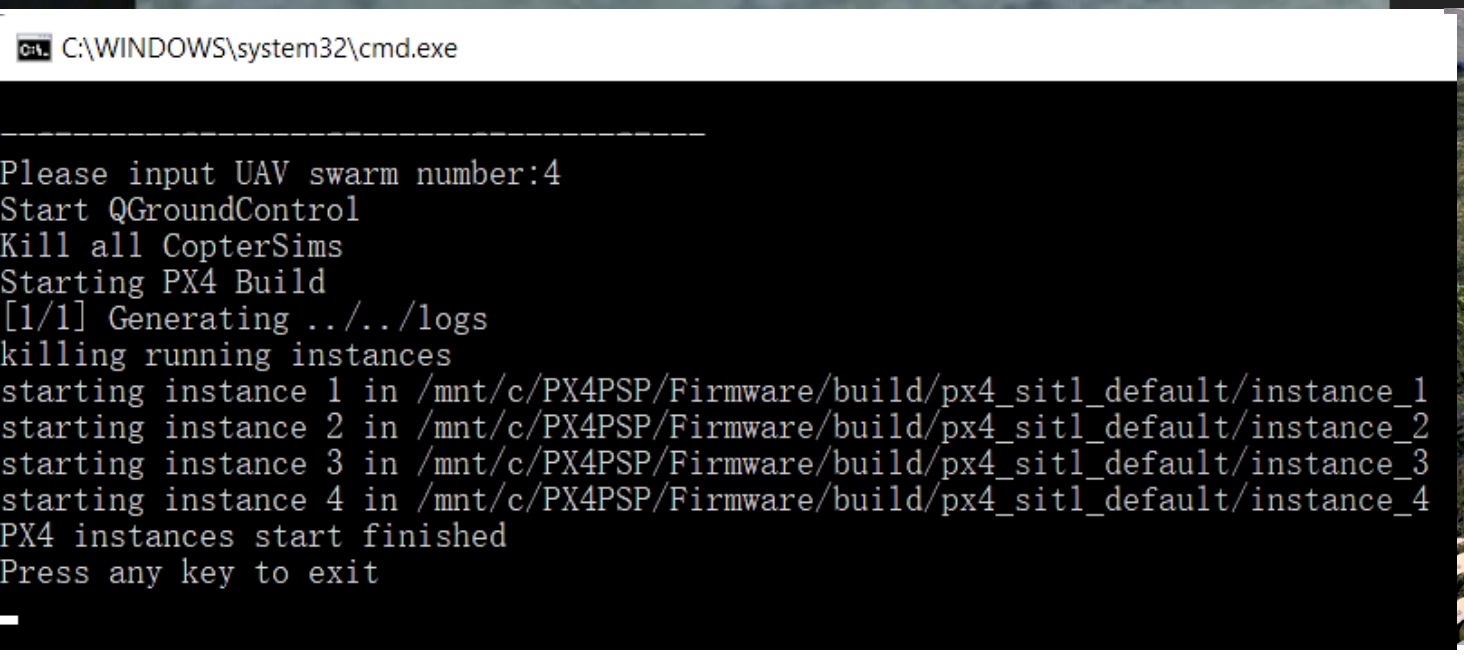
Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4NTEwOA==.html

YouTube: https://youtu.be/AMZNuAtRp2w


QGroundControl
15
0.0
51%
Armed
Offboard
Vehicle 3
Vehicle 1
Vehicle 2
Vehicle 3
Vehicle 4
Single
Fly
Land
Return
Pause
Action
Values
Alt (Rel) (m)
10.0
Ground Speed (m/s)
4.4
Flight Time


Tools
Help
inf
Normal


C:\WINDOWS\system32\cmd.exe
Please input UAV swarm number:4
Start QGroundControl
Kill all CopterSims
Starting PX4 Build
[1/1] Generating ../../logs
killing running instances
starting instance 1 in /mnt/c/PX4PSP/Firmware/build/px4_sitl_default/instance_1
starting instance 2 in /mnt/c/PX4PSP/Firmware/build/px4_sitl_default/instance_2
starting instance 3 in /mnt/c/PX4PSP/Firmware/build/px4_sitl_default/instance_3
starting instance 4 in /mnt/c/PX4PSP/Firmware/build/px4_sitl_default/instance_4
PX4 instances start finished
Press any key to exit


1
2
3
4

3.4 Key problems and solutions for UAV Swarm simulation

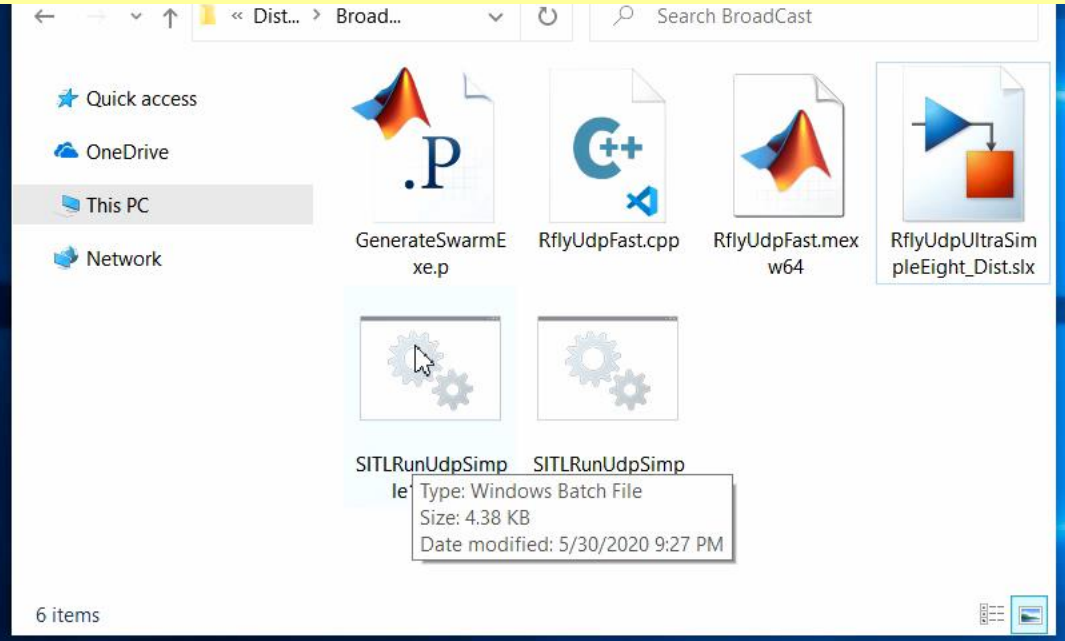
- Problem 6: Simulink will significantly slow down when too much vehicles to be controlled, which may affect the real-time performance
  Solution: we provide script to compile Simulink controller to exe file, which can control large-scale UAV swarm simulation system with few computing resource
- Problem 7: How to ensure controller can work in real system as in simulation
- Solution 1: All vehicle data received by Simulink is the actual data from Pixhawk through Mavlink instead of ideal data from simulator, and the output of Simulink is also Mavlink message to Pixhawk.
- Solution 2: Our swarm communication interfaces ensure the Simulink can control actual UAV swarm system when each UAV is connected to the same LAN through WIFI or radio telemetry. User can also generate the Simulink to C/C++ code to developing a swarm ground control system.

RflySim: 11. How to quickly perform distributed software-in-the-loop simulation (SIL) for UAV swarm with multiple computer

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4NDE2OA==.html

YouTube: https://youtu.be/fmzYADSQyj0

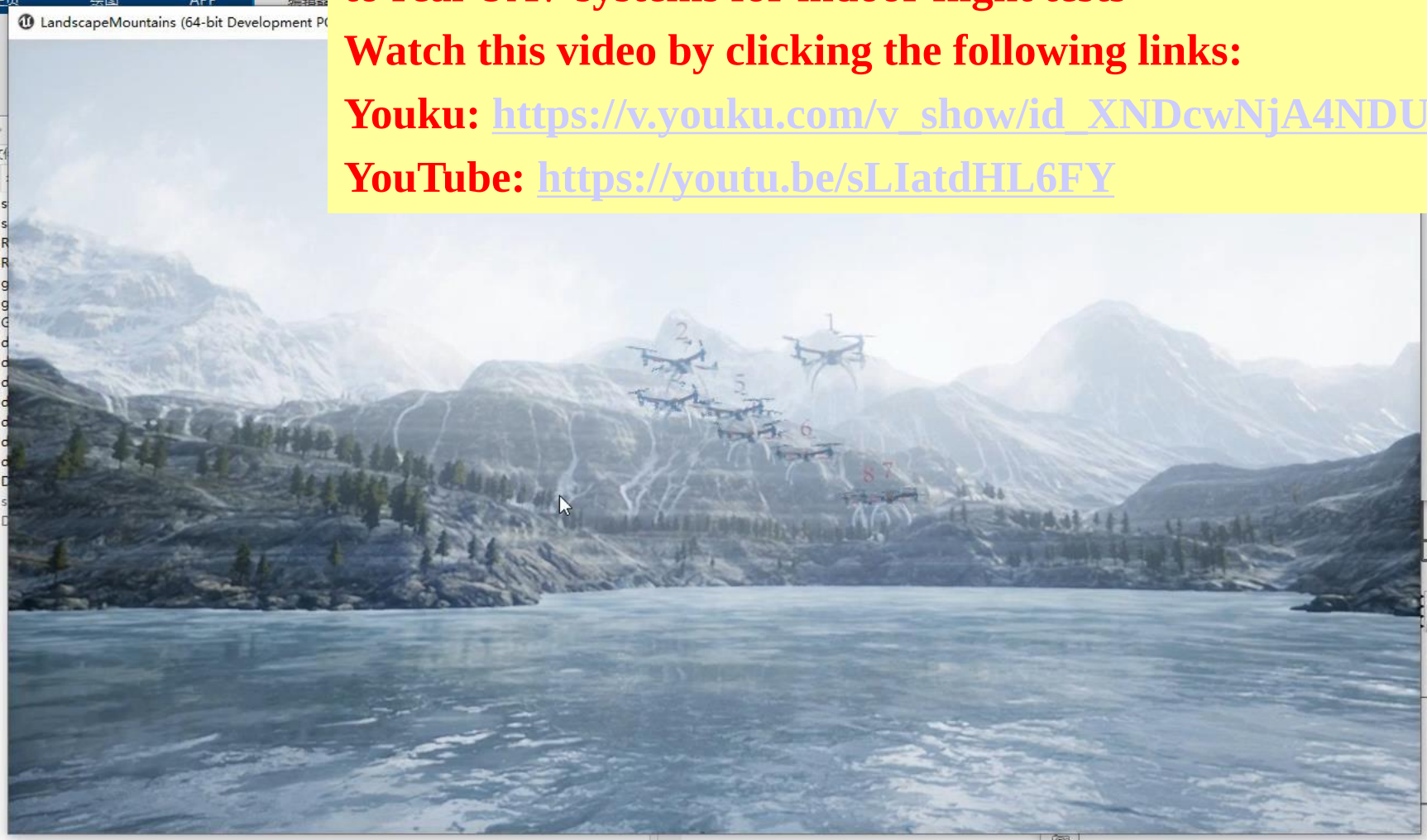


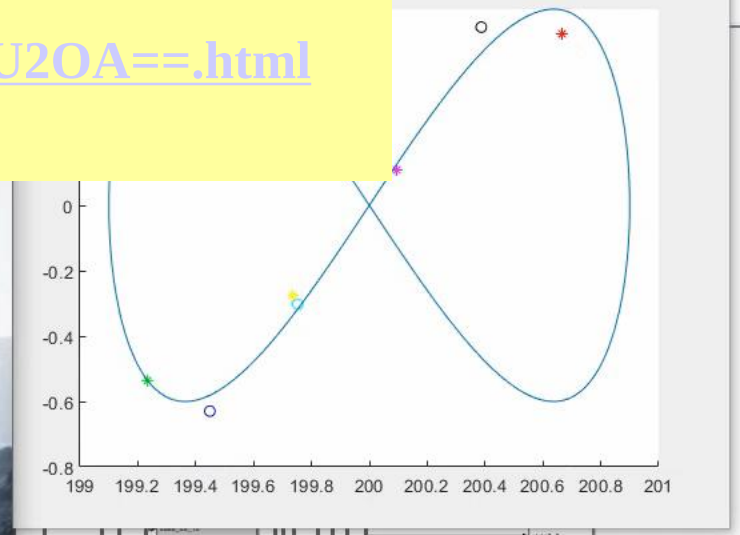
RflySim: 12. How to quickly apply the UAV swarm control algorithms to real UAV systems for indoor flight tests

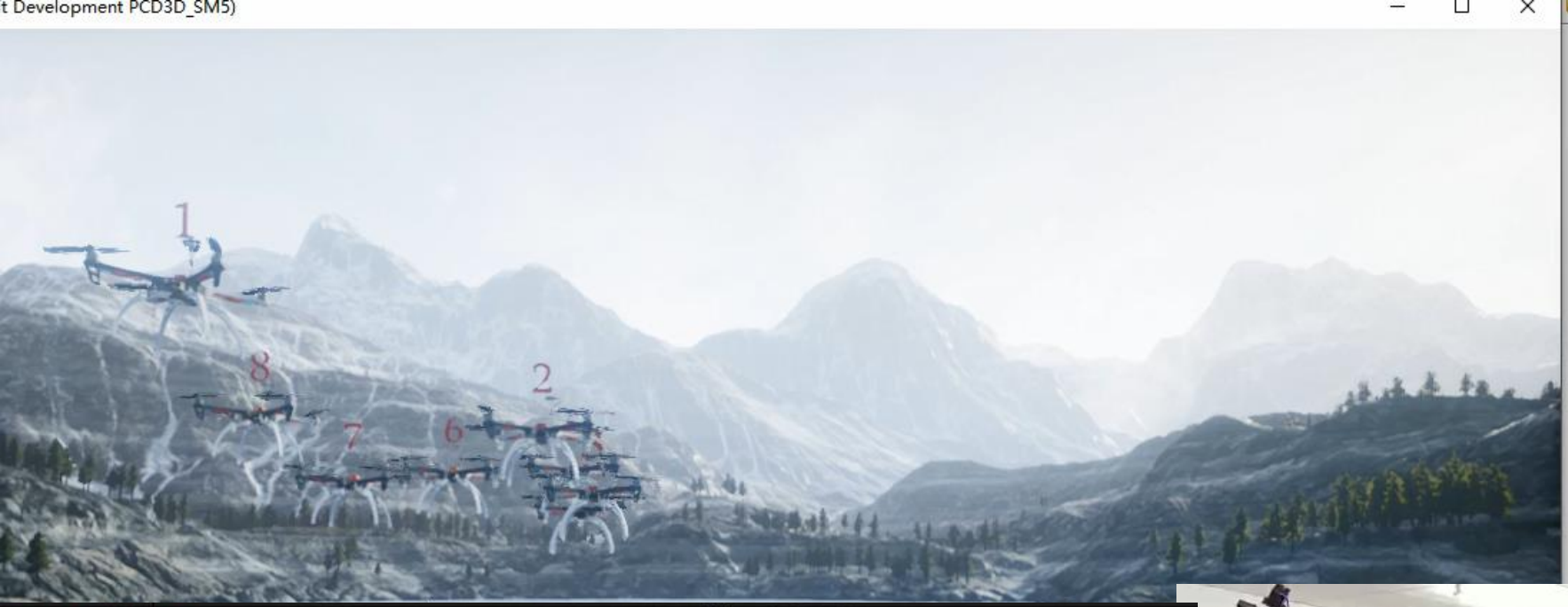
Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4NDU2OA==.html

YouTube: https://youtu.be/sLIatdHL6FY






t Development PCD3D_SM5)
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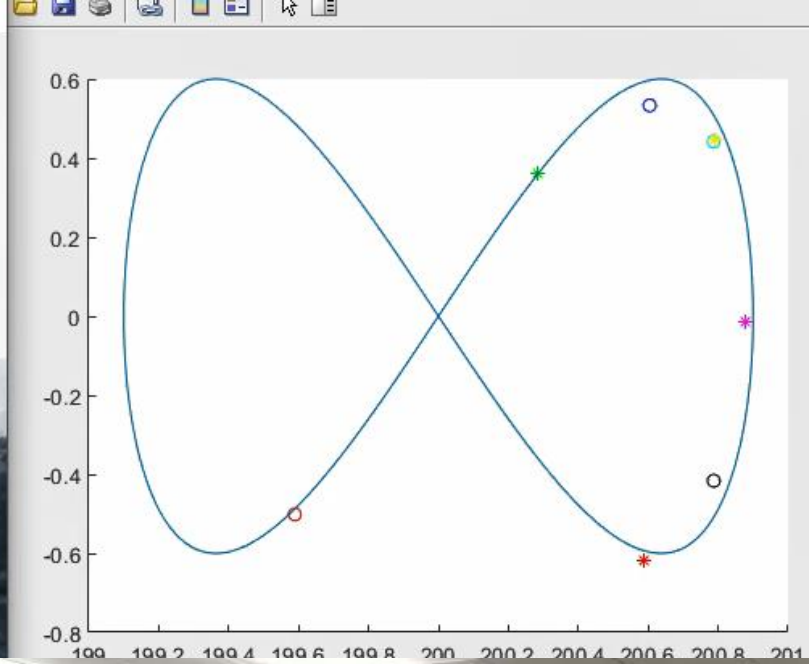
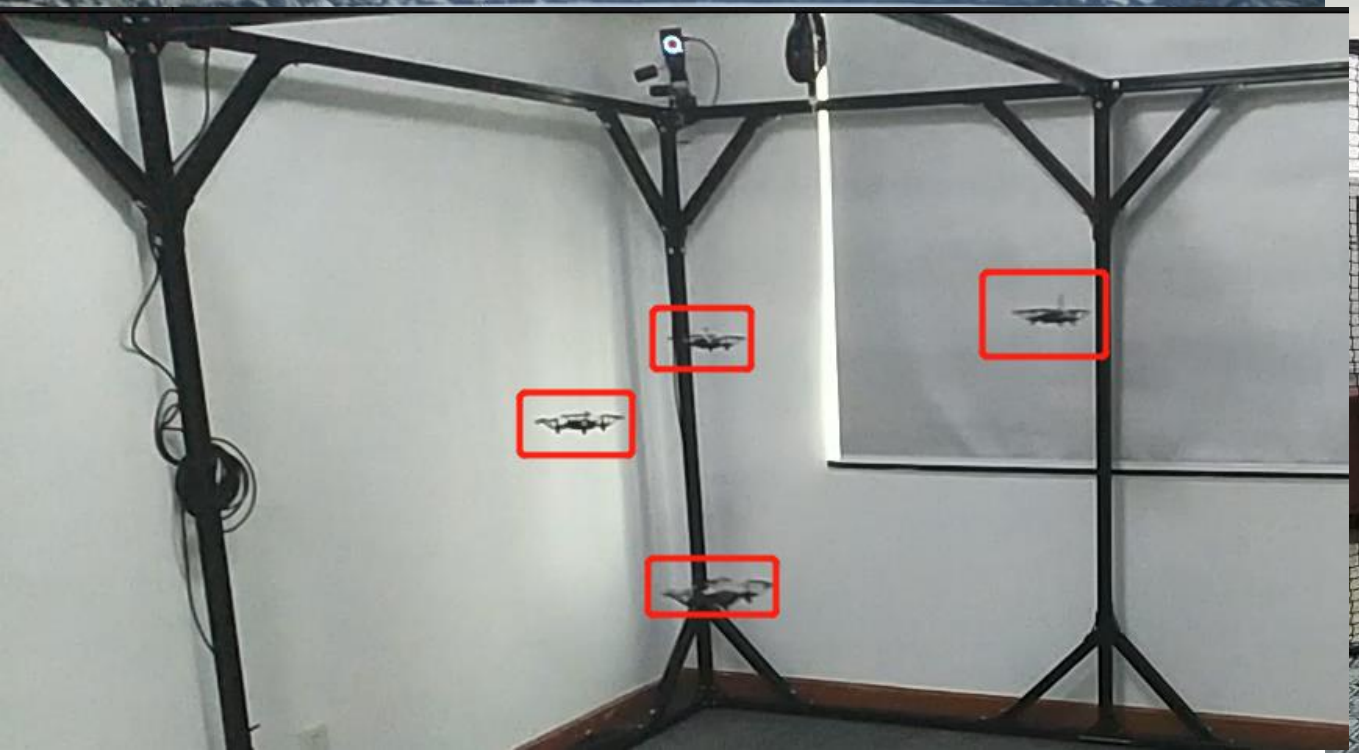
7
6


0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8



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4.1 Key Problems and Solution for UAV Vision Simulation

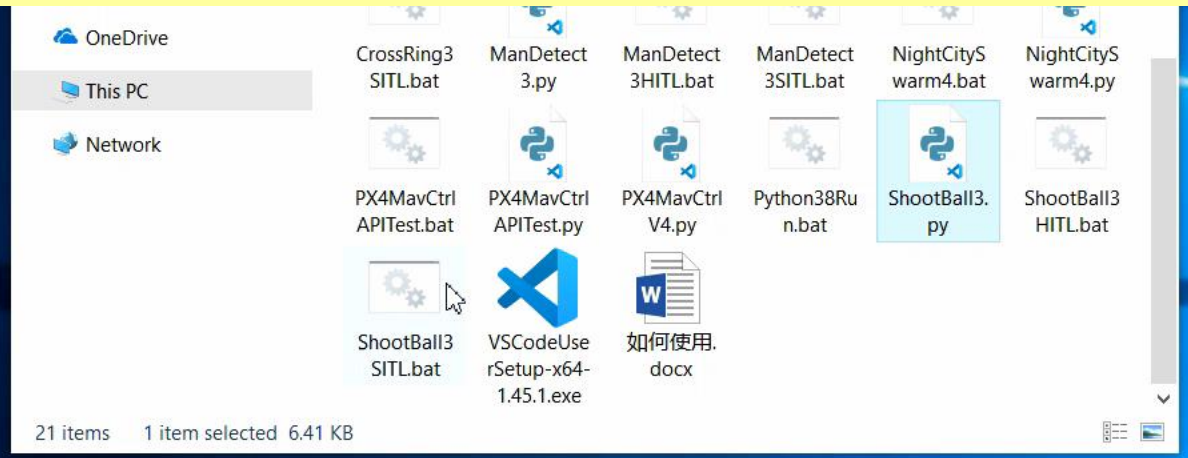
- Problem 1: How to capture images from UE4-based program RflySim3D with high frame rate
- Solution: we use Python/C/Simulink to directly read screen images from windows API which is independent from RflySim3D, so our interface will not slow down the efficiency of RflySim3D, and we can read the images with a very high frame rate (within 5ms, more than 200Hz)
- outside the RflySim3D
- Problem 2: How to obtain multiple camera views in the same time
  Solution: users can open multiple RflySim3D windows to display different views.
- Problem 3: How to change the image size, camera position and angle, and select cameras on the desired vehicles.
  Solution: users can set these parameters through mouse and keyboard, or send commands through our UDP interface
- Problem 4: How to ensure the algorithm can run successfully on real vehicles？
  Solution: Our programming language is Python (we will support MATLAB soon) which is cross-platform, and our communication interface is based on Mavlink which can be processed by Pixhawk directly. So the algorithms can run on onboard computer without modification

RflySim: 13. How to use Python/OpenCV to perform vision-based control of a multicopter UAV

Watch this video by clicking the following links:

Youku: https://v.youku.com/v_show/id_XNDcwNjA4NTYwNA==.html

YouTube: https://youtu.be/PvxEfY7oMq4



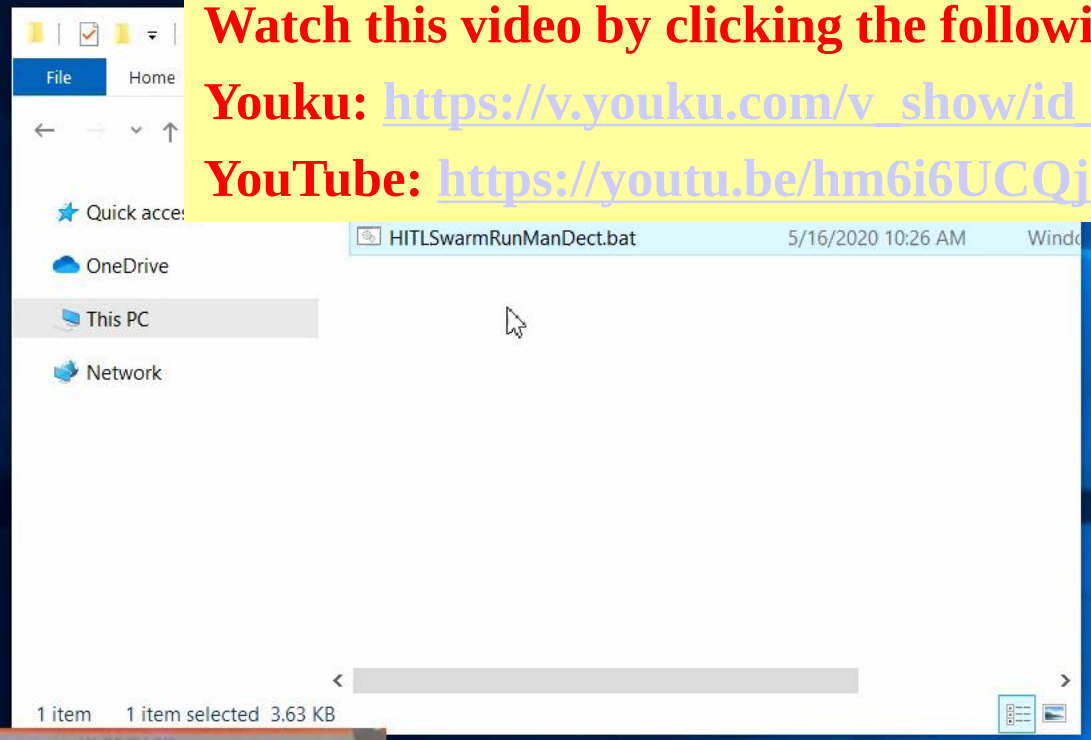
Use demo bat script to quickly create a SITL vehicle

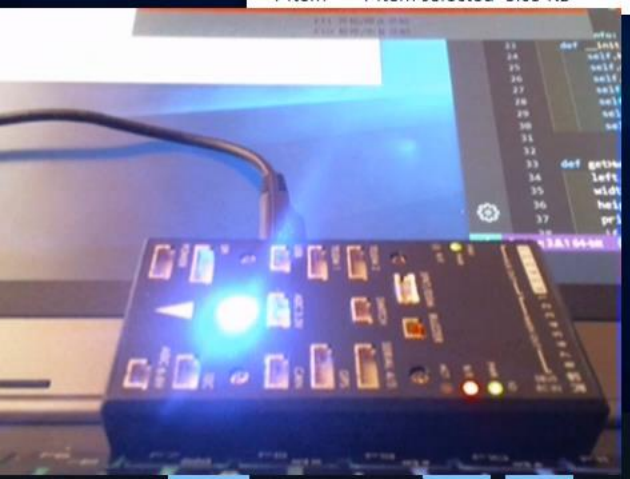
RflySim: 14. How to perform binocular vision control and apply to real multicopter system

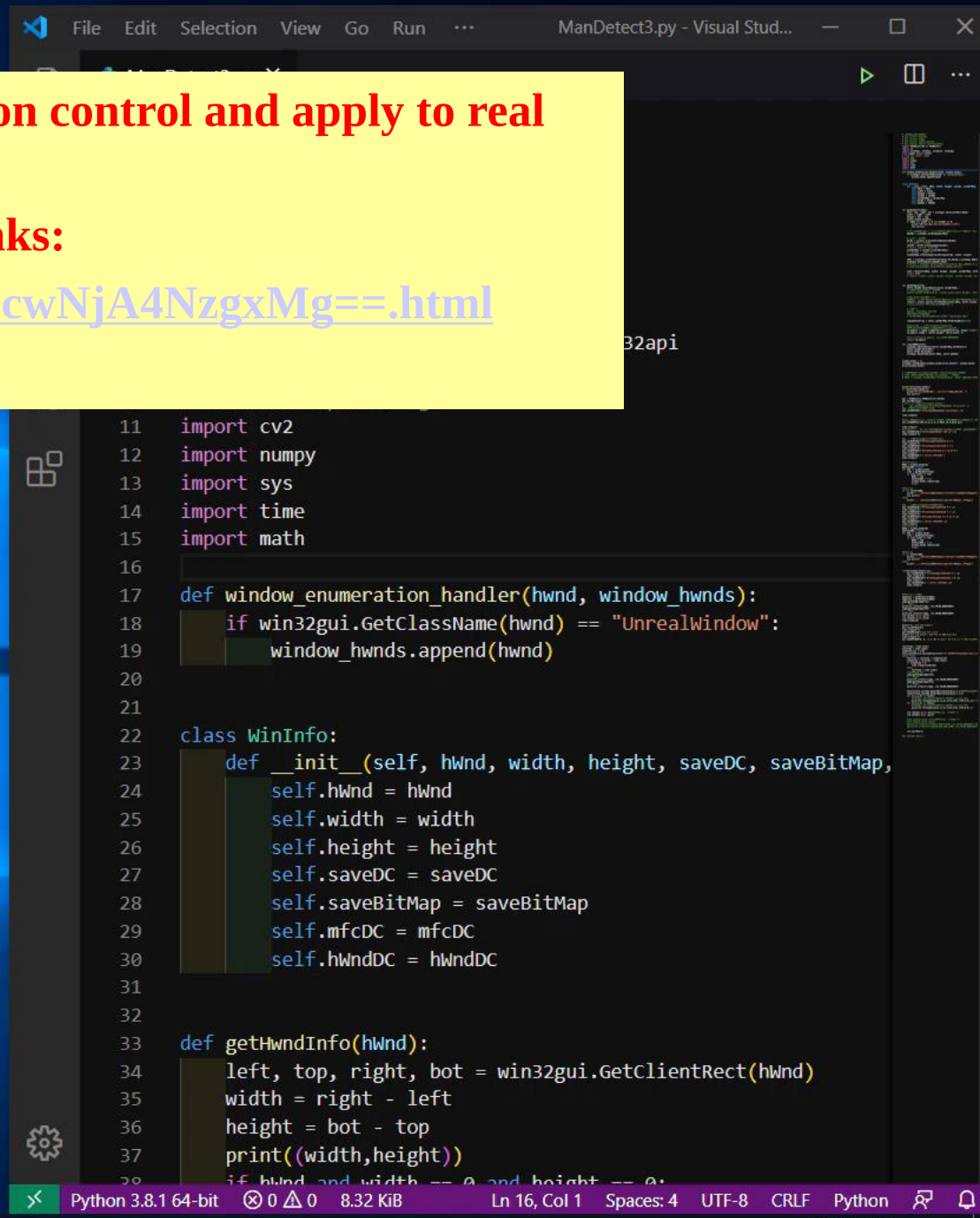
Watch this video by clicking the following links:

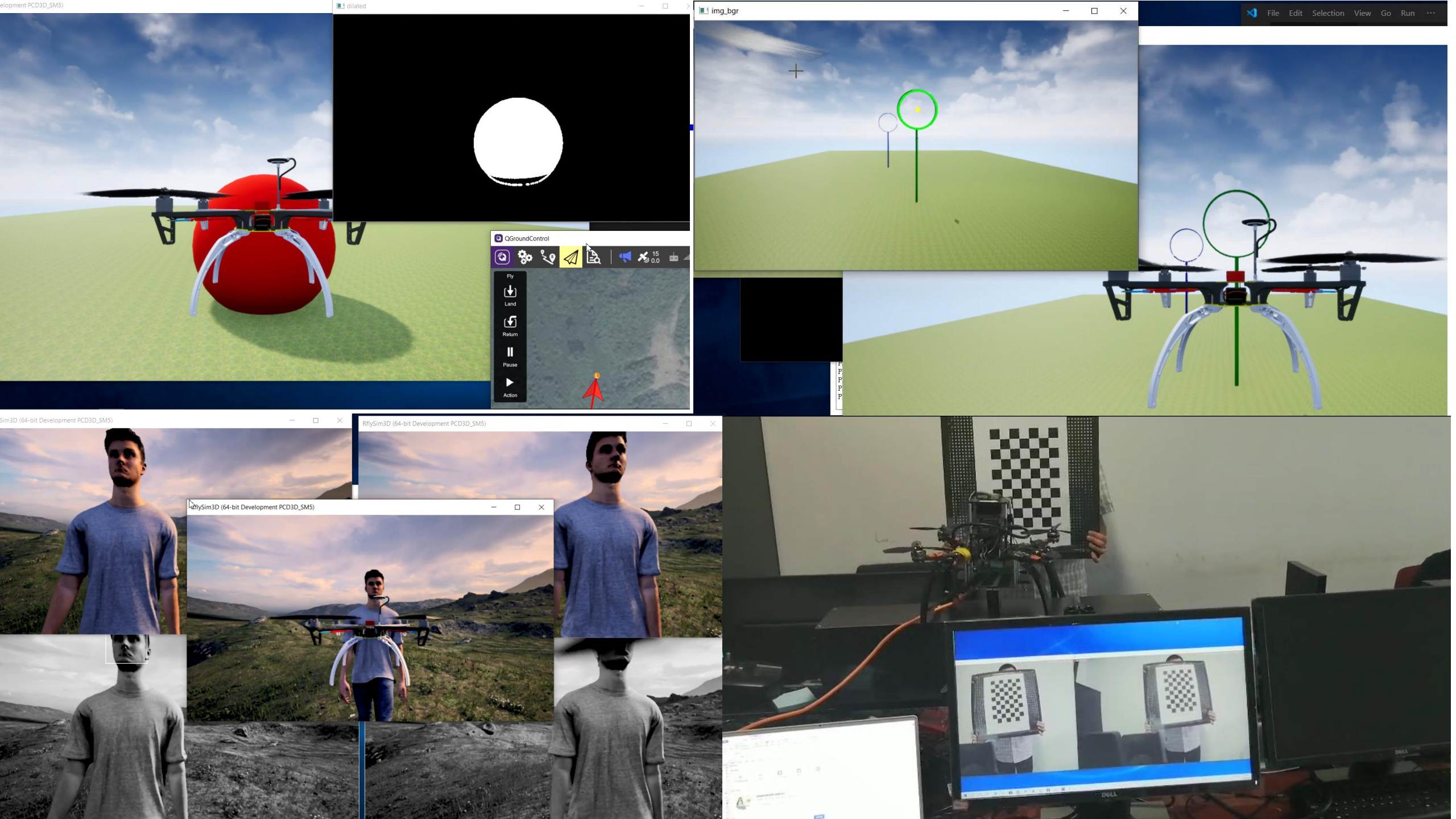
Youku: https://v.youku.com/v_show/id_XNDcwNjA4NzgxMg==.html

YouTube: https://youtu.be/hm6i6UCQjCI








dilated
QGroundControl
Fly
Land
Return
Pause
Action
img_bgr
File
Edit
Selection
View
Go
Run
RflySim3D (64-bit Development PCD3D_SM5)

F450机架

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Summary

RflySim provide a unified solution for development, test and assessment of unmanned control systems, and we have more wonderful features are coming soon:

1. More high-fidelity 3D scenes and vehicle models will be released on our website with control demos for users.
2. More sensors will be supported, e.g., Lidar, depth cameras.
3. Simulink interface for computer vision and machine learning, so users can train their vehicle control algorithms on RflySim
4. More types of vehicle to be supported, e.g., driverless cars, fixed-wing aircraft, VTOL, unmanned boat, etc.
5. Standard modeling module database to quickly develop vehicle model
6. More experimental courses will be released on our website

How to get RflySim advanced version?

Visit our website: https://rflysim.com

Contact our email: rflysim@163.com

Thanks