Multicopter Design and Control Practice Experiments

RflySim Advanced Courses
Lesson 03: External Control Interface

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Content

1. Configuration of software & hardware
2. MAVLink communication analysis
3. PX4 official controller communication
4. Code generation controller communication
5. Summary

Path of demo source code of this lesson: "RflySimAPIs\SimulinkControlAPI"

1. Configuration of software &

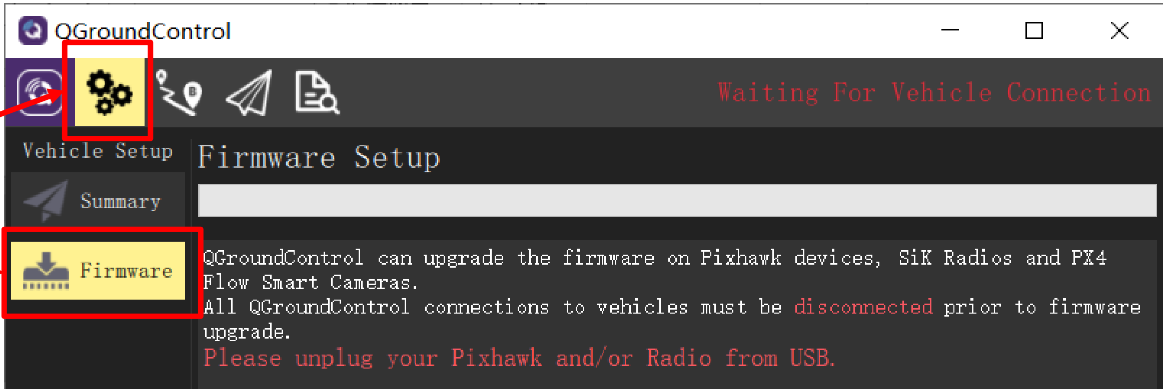
Note: The examples in this section need to use the official firmware of PX4, any version is fine, the latest firmware is selected here

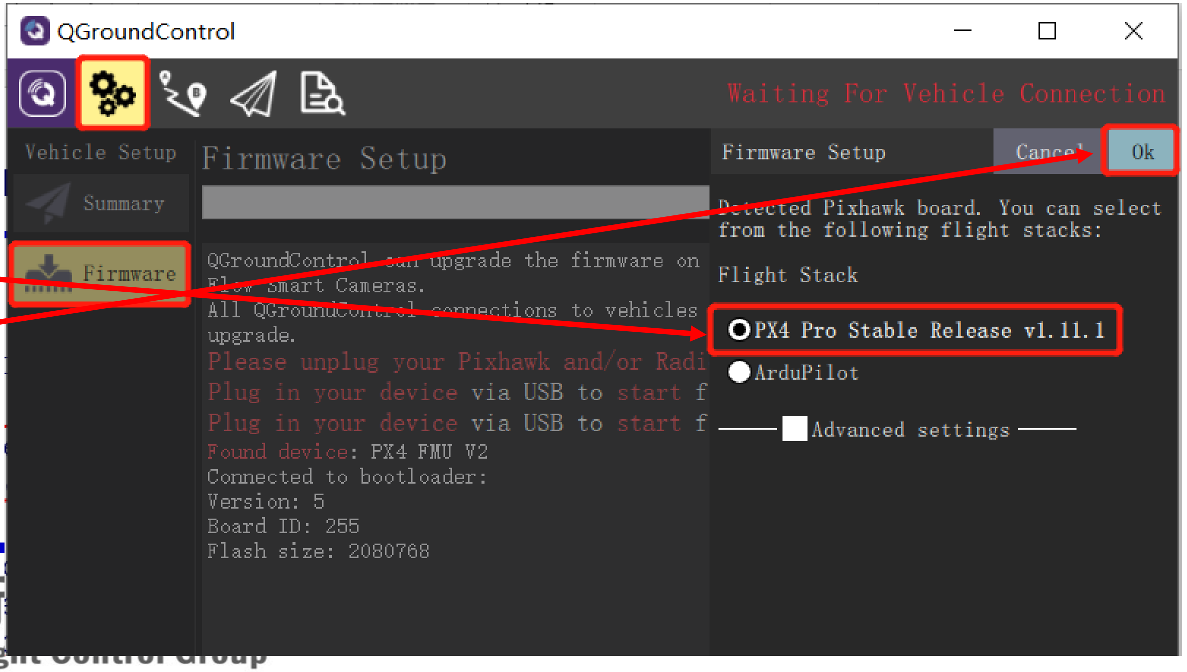
1.1 Pixhawk hardware configuration (1) — online firmware download

1) Open the QGC ground station software;

2) As shown in the figure on the right, click the **gear icon** in the toolbar to enter the settings page, and then click the "**Firmware**" label to enter the firmware burning page;

3) Connect the Pixhawk autopilot to the computer with a USB cable. The software will automatically recognize the Pixhawk hardware, as shown in the lower right figure, the firmware configuration window will pop up on the right side of the interface, check "**PX4 *****", and then click " **OK**", QGC will start to download automatically (Internet connection is required; if no internet, please refer to the next page to use the local firmware file) and install the latest PX4 firmware into Pixhawk;





1. Configuration of softv

Note: If there is no required firmware file in the folder, please visit https: //github.com/PX4/Firmware/releases to download and upload to Pixhawk

1.2 Pixhawk hardware configuration (2) — offline firmware download (when the firmware cannot be downloaded online due to the network)

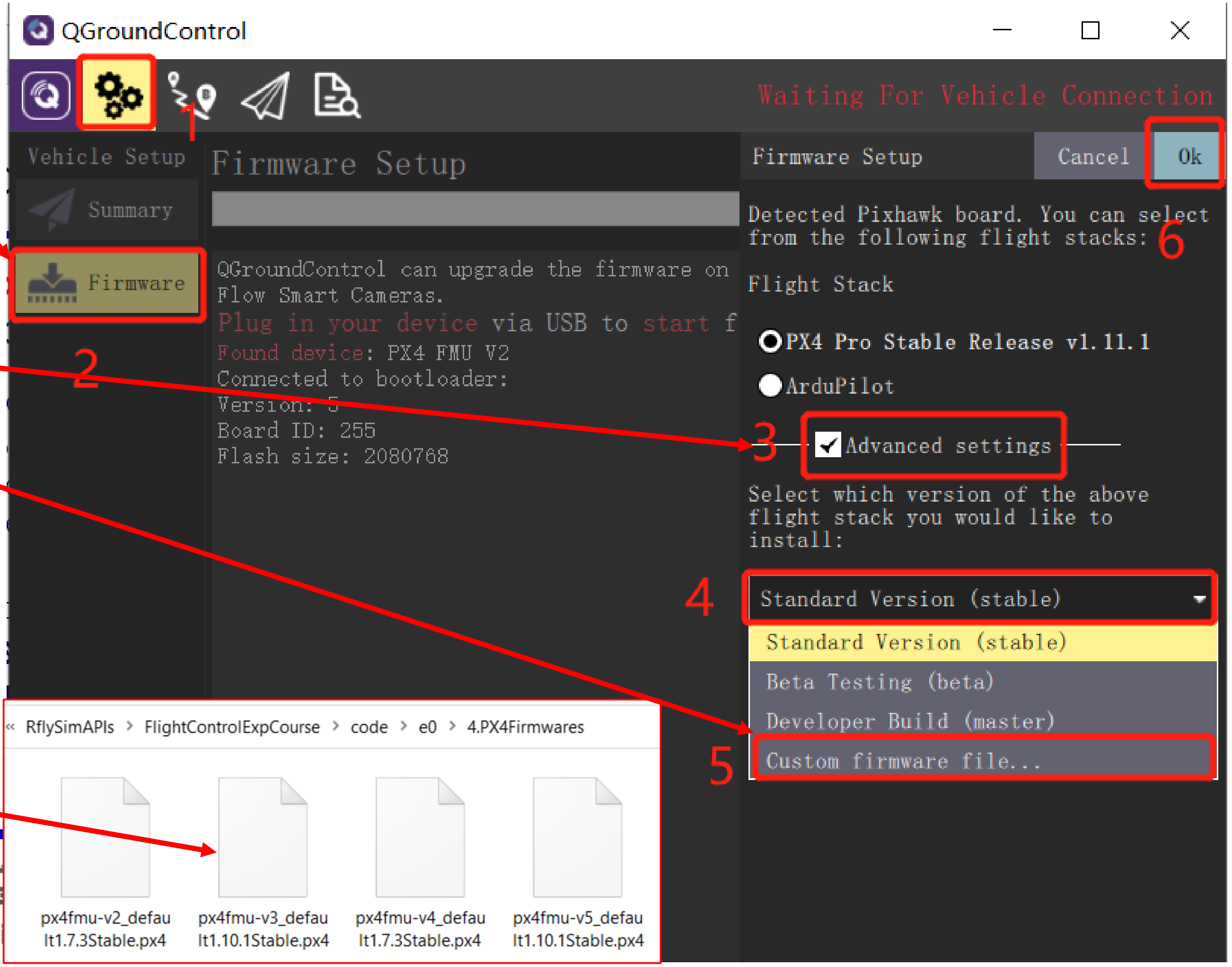
1) Open the QGC ground station software;

2) Click the "**Firmware**" tab, and connect the Pixhawk autopilot with the USB data cable. The ground station will automatically detect the autopilot

3) Check the "**advanced settings**" checkbox;

4) Click **triangle icon** besides the “**Standard Version (stable)**” tab – “**Custom firmware file**”, then click “**OK**”;

5) In the file selection page that pops up, if you use Pixhawk1 flight control, select "**RflySimAPIs\FlightControlExpCourse\code\e0\4.PX4Firmwares\px4fmu-v3_default1.10.1Stable.px4**", if you use Pixhawk 4, select **fmu-v5** firmware

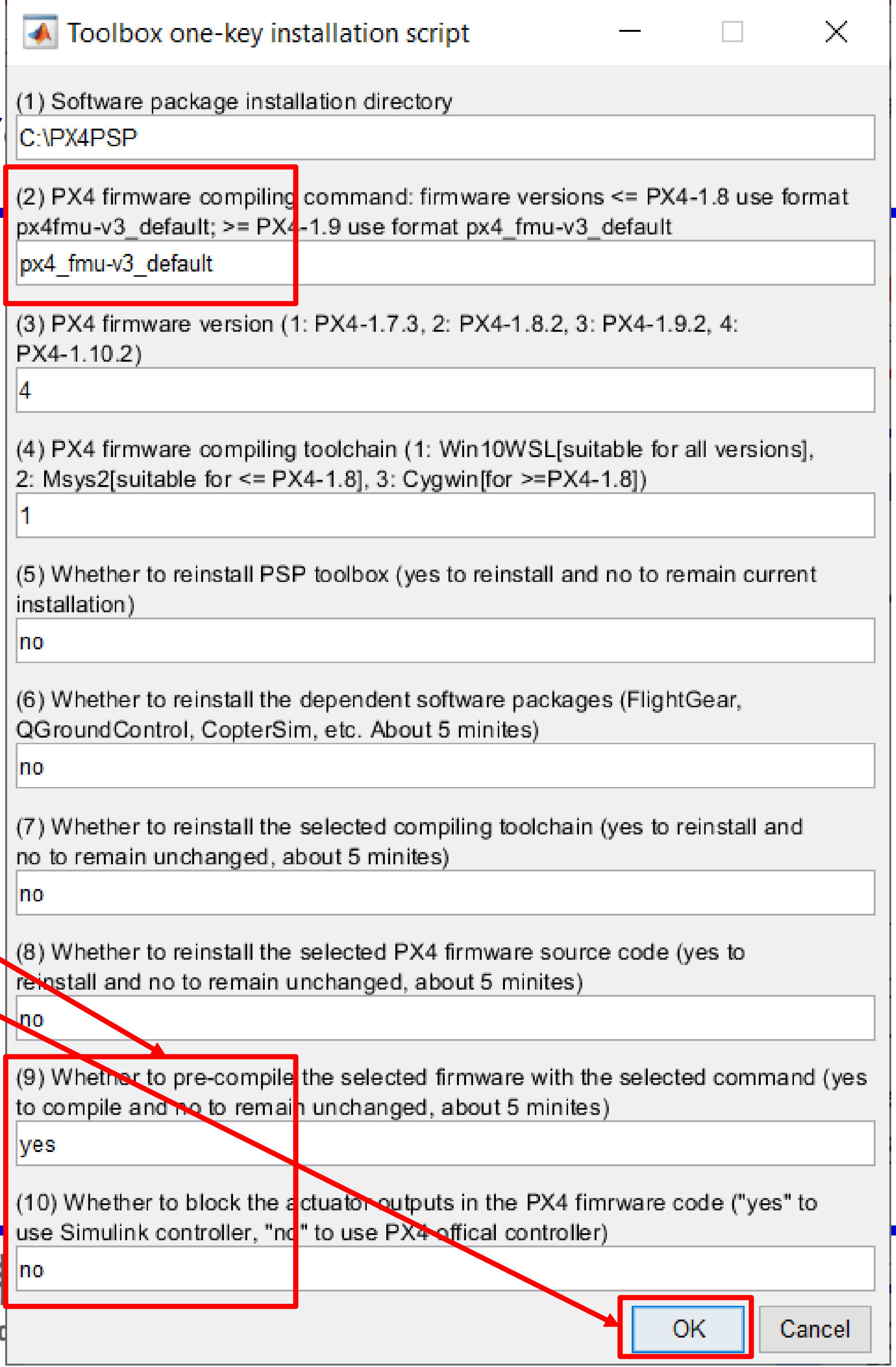


1. Configuration of software

1.3 Pixhawk hardware configuration (3) — offline firmware generation

- Re-run the "**OnekeyScript.p**" script in MATLAB;
- Enter "**px4_fmu-v3_default**" on the second line (here for Pixhawk 1, please select the compilation command according to your flight control hardware)
- As shown in the figure on the right, set the 9th and 10th items to "**yes**" and "**no**" respectively, and keep the other options as default. Click the "**OK**" button to compile the official PX4 firmware without blocking the output of the PX4 itself.
- Run the "**PX4Upload**" command in MATLAB to pop up the firmware burning page. At this time, insert the Pixhawk flight controller to burn the official firmware.

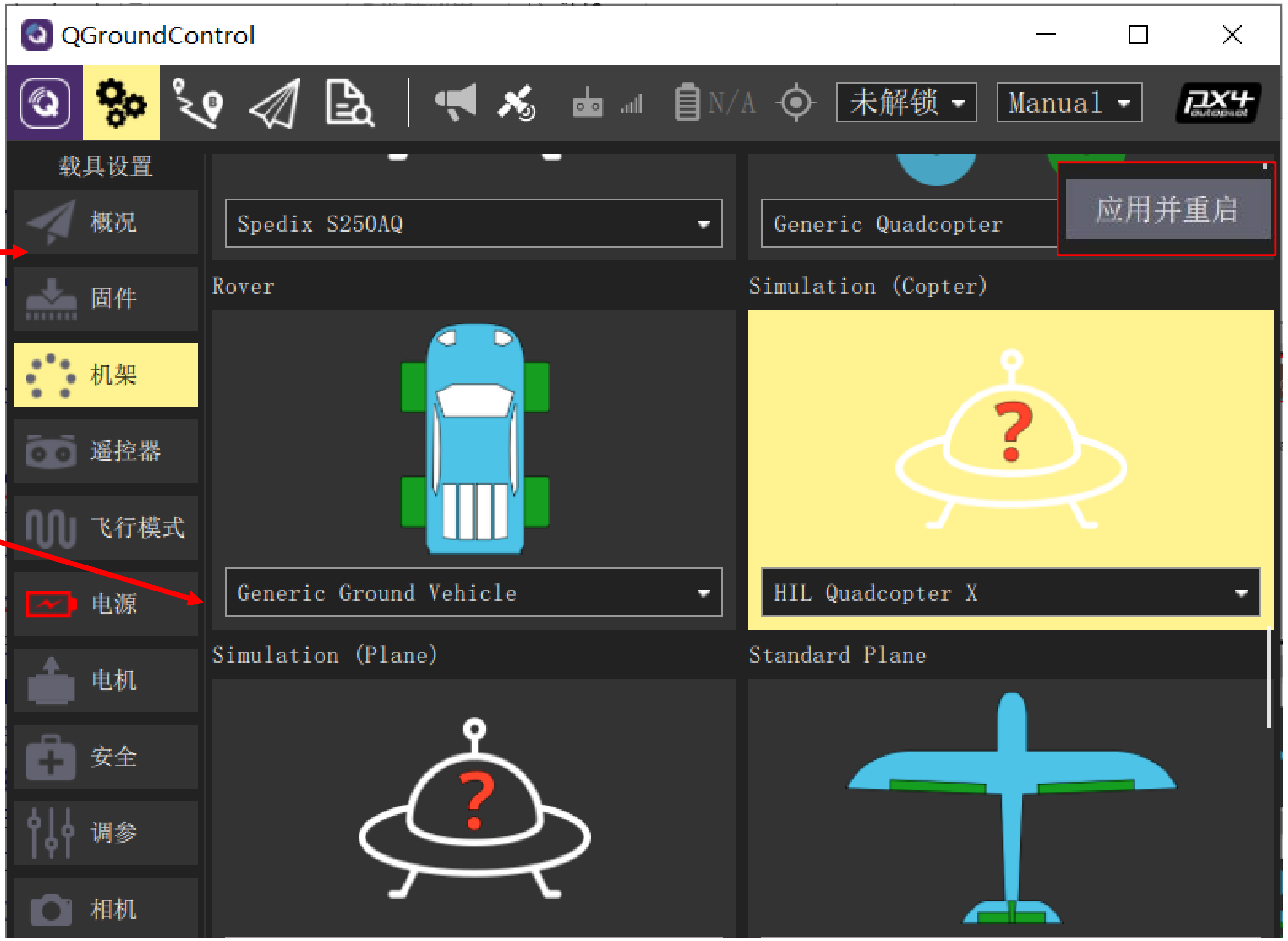
Note: Try this method only when the first two methods are invalid; the following figure is for the advanced version of RflySim, if it is the basic version of RflySim, please use the default firmware and compiler version.



1. Configuration of software & hardware

1.4 Pixhawk HIL simulation mode

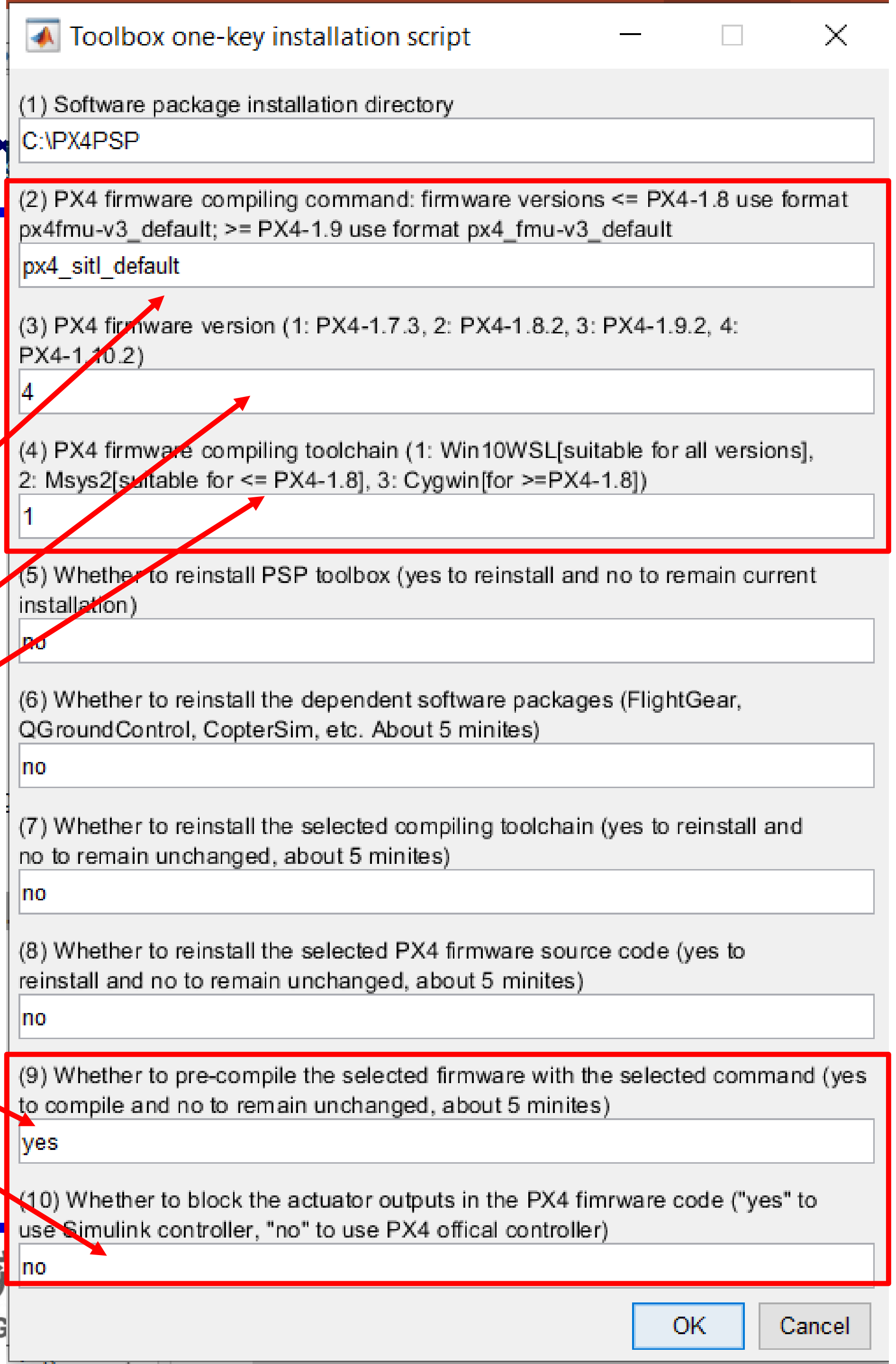
- After the firmware is uploaded, the autopilot will automatically restart and re-connect to the QGC; at this time, as shown on the right, enter the "**Airframe**" tab, select the airframe as "**HIL Quadcopter X**", and then click on the " **Apply and Restart**" button, the autopilot will restart automatically at this time;
- After restarting, QGC will automatically look for the serial port and connect to Pixhawk. At this time, check each configuration page to ensure that Pixhawk enters hardware-in-the-loop (HIL) simulation mode.
- After finishing the radio control (RC) transmitter calibration and mode setting, unplug the RC receiver on Pixhawk, this course does not need to connect the RC receiver



1. Configuration of software &

1.5 PX4 SITL configuration（only for RflySim advanced version）

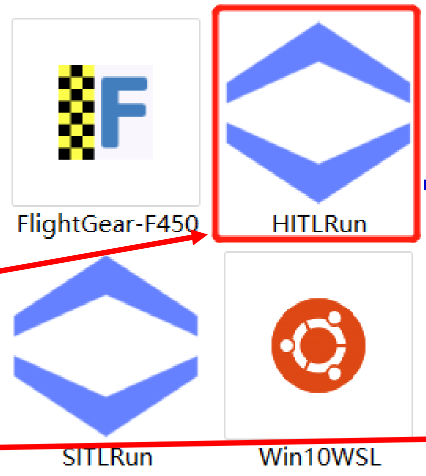
- Re-run the "**OnekeyScript.p**" script, configure it as shown on the right, and click "**OK**"
- This configuration is used to run the SITL simulation mode of PX4, so that we can run a complete PX4 controller under Windows, so that it can be simulated without Pixhawk hardware. The key configuration is as follows:
- Compile command: "**px4_sitl_default**"
- Firmware version: "**4**" - "**PX4 1.10.2**"
- Compiler: "**1**" — "**Win10WSL**"
- Whether to pre-compile the firmware: "**yes**"
- Whether to block the PX4 control output: "**no**"— here the official PX4 firmware is used for top-level external control

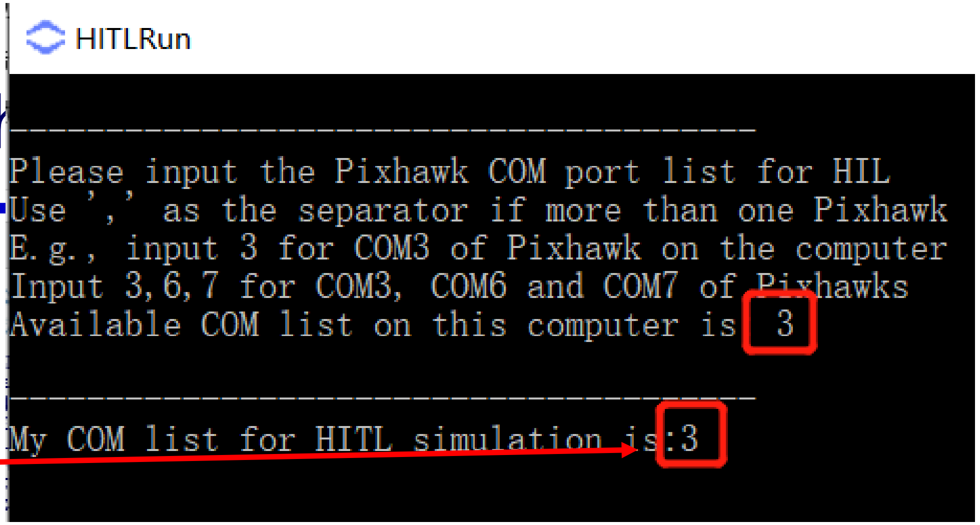


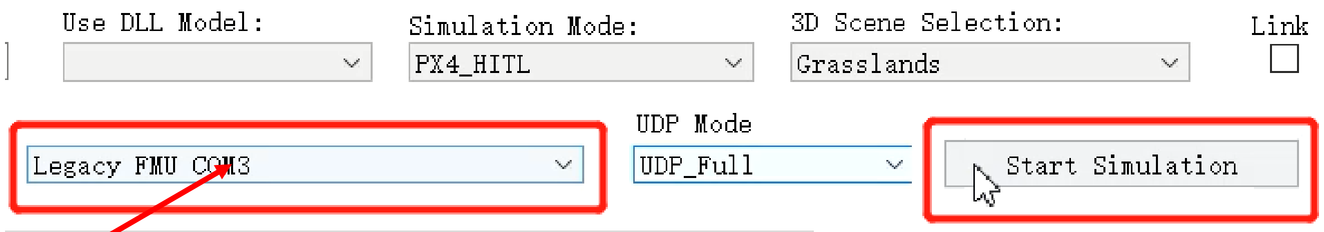
1. Configuration o

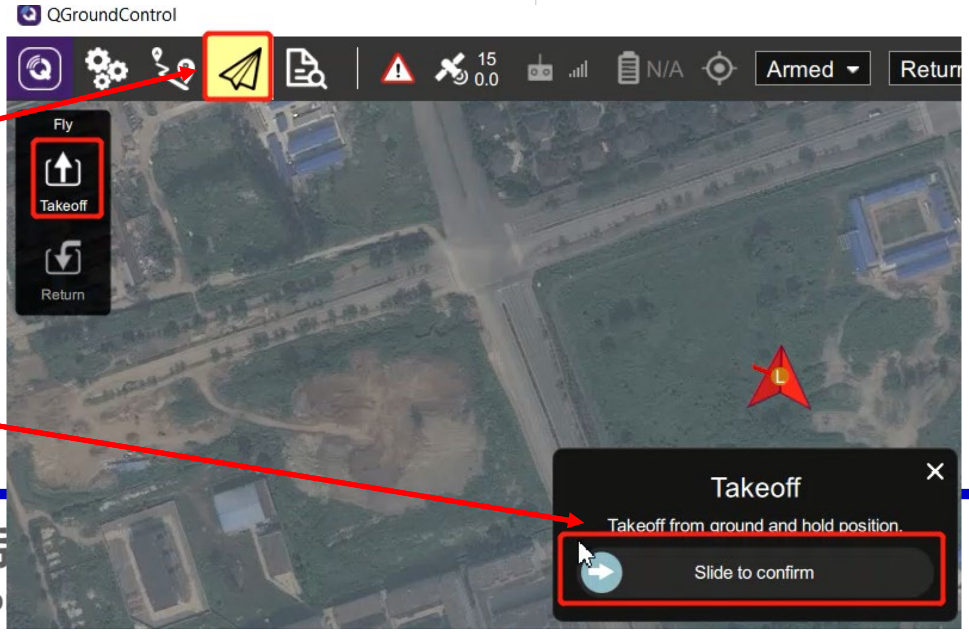
1.6 PX4 HITL simulation test

- If you use RflySim Advanced Edition, please insert Pixhawk, and then directly run the **HITLRun** shortcut on the desktop, enter the **serial port number** in the pop-up window, and press Enter to start the hardware-in-the-loop(HIL) simulation system
- If you use RflySim basic version, please insert Pixhawk, open the CopterSim software, select the flight control serial port in the “**Select Pixhawk Com.**" drop-down box, and click “**Start Simulation**", and then manually open QGC and 3DDisplay
- In QGC, click the **paper plane icon** - **Takeoff** - **Slide to confirm**, you can see that the drone takes off automatically in the view, indicating that the HIL configuration is correct.







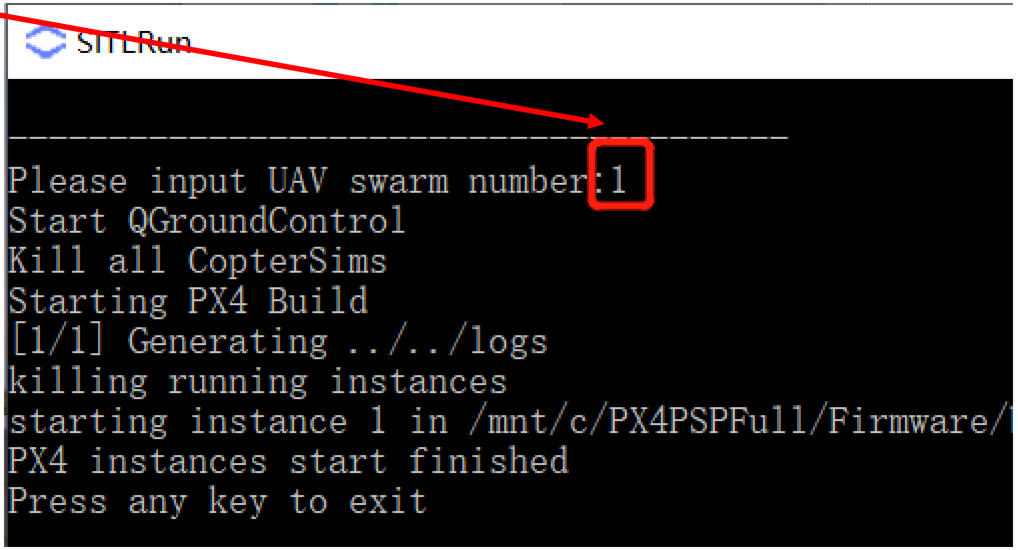


Note: no matter SIL or HIL simulation, you should wait until CopterSim show message “** EKF initialization finished” on the UI, then you can use QGC/Simulink/Python to control the drone.

1. Configuration of software & hardw

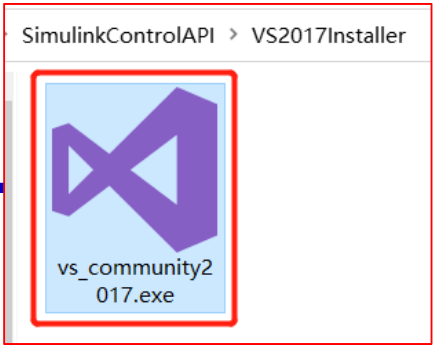
1.7 PX4 SITL simulation (Pixhawk hardware is not required)

- This function is only available in the advanced version of RflySim (corresponding to the setting in **Section 1.5**)
- Double-click the "**SITLRun**" shortcut on the desktop and enter the number "**1**" to start one vehicle SIL simulation system
- Same as the previous page, control the drone to takeoff in QGC. If it can takeoff automatically, it means that the platform is configured correctly.
- **Principle**: PX4 SITL is a real-time operating system that simulates Pixhawk in the Ubuntu environment of Win10WSL, thereby running a complete PX4 controller, and connecting with CopterSim through the network to realize the interaction of sensors/control commands, forming a control simulation closed-loop system, and inserting Pixhawk HITL by hardware has the same effect
- **Note**: Under PX4 SITL simulation, QGC can also be used to configure participation and obtain log files (stored in the installation directory: **Firmware\build\px4_sitl_default\instance_1**)



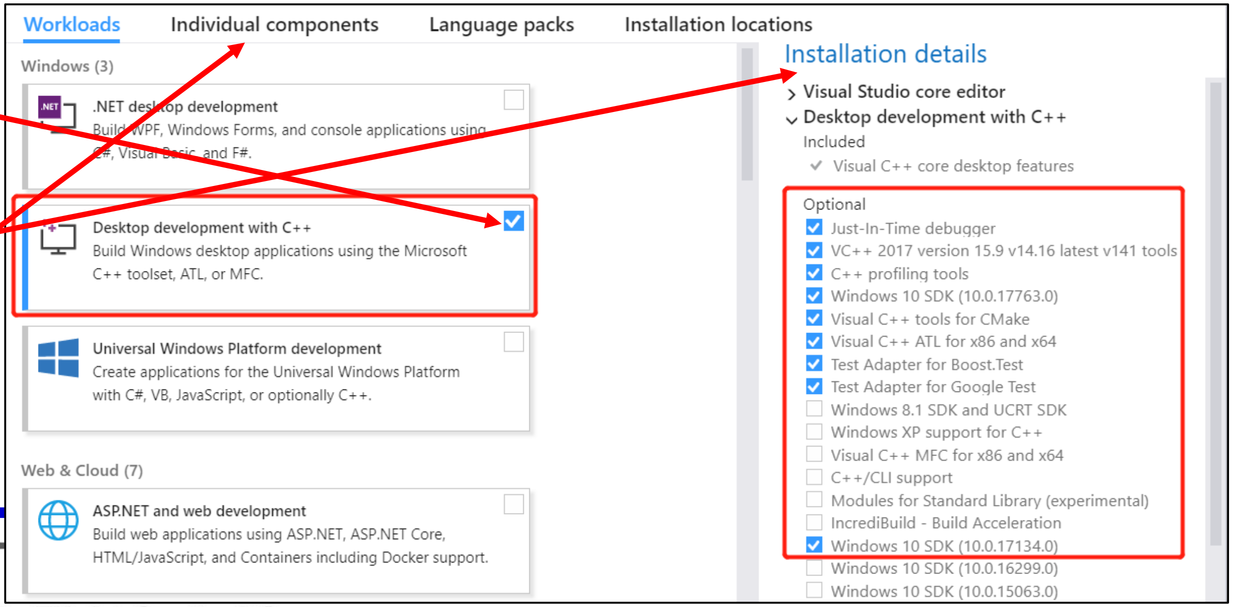
1. Configuration of sof

Note: Visual Studio compiler is needed in many examples in this section, please install in advance



1.8 Install Visual Studio 2017 (other versions can also be used, MATLAB can recognize it)

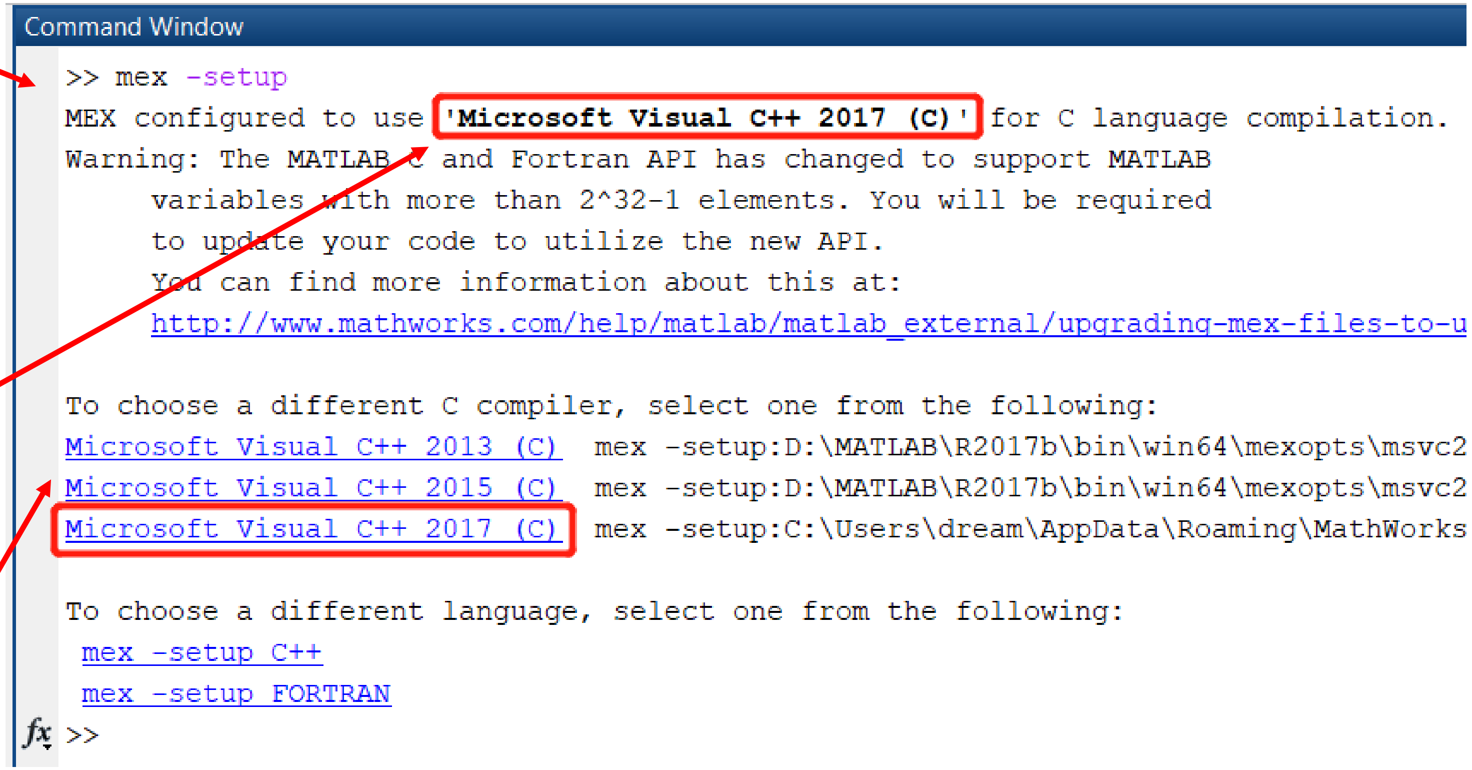
- The Visual Studio compiler is needed in many places in subsequent courses, such as MATLAB
- The use of S-Function Builder module, Simulink automatically generates C/C++ model code, etc.
- It is recommended to install Visual Studio 2017. The online installation steps (internet required) are as follows:
- Double-click "**RflySimAPIs\SimulinkControlAPI\VS2017Installer\vs_community2017.exe**"
- This course content only needs to check the "**Desktop development with C++**" on the right.
- **Note**: If you want to use UE4 C++ development in the future, you can also check the latest Window 10 SDK in the "**Installation details**" on the right; then click the "**Individual components**" tab and check **.NET 4.7.2** (or the latest version) and the corresponding pack package. Click install again.



1. Configuration of software & hardware

1.9 Configure C++ Compiler for MATLAB

- Enter the command "**mex -setup**" in the MATLAB command line window
- Generally speaking, the VS 2017 compiler will be automatically recognized and installed. As shown in the right figure, "MEX configured to use ‘Microsoft Visual C++ 2017’ for", indicating that the installation is correct
- This page can also switch to other compilers such as Visual Studio 2013/2015/2017



content

1. Configuration of software & hardware
2. MAVLink communication analysis
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Path of demo source code of this section: “RflySimAPIs\SimulinkControlAPI\MavlinkDemo”

2. MAVLink communication analysis

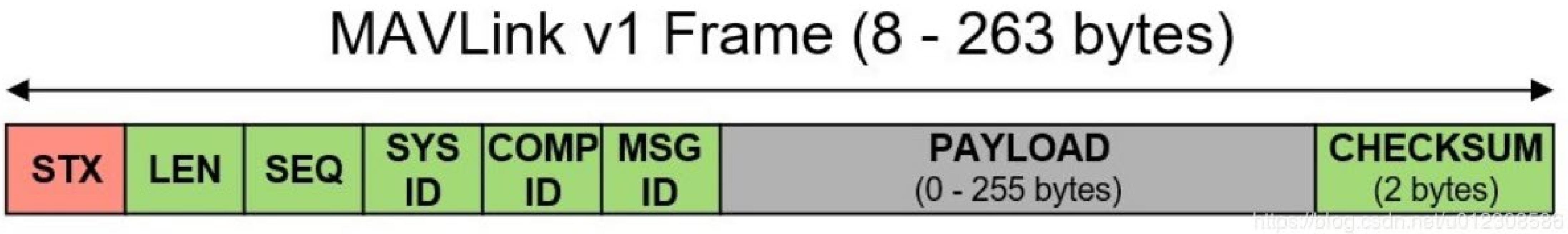
2.1 MAVLink (Micro Air Vehicle Link)

- It is a communication protocol for small unmanned vehicles, first released in 2009. This protocol is widely used in the communication between Ground Control Station (GCS) and Unmanned vehicles, as well as in the internal communication between the onboard computer and the Pixhawk. The protocol is defined in the form of a message library rules for parameter transmission. The MAVLink protocol supports a variety of vehicles such as unmanned fixed-wing aircraft, unmanned rotorcraft, and unmanned vehicles.
- Official use file website: https: //mavlink.io/en/messages/common.html
- MAVLink source code: https: //github.com/mavlink/mavlink
- QGroundControl ground station source code based on MAVLink: https: //github.com/mavlink/qgroundcontrol

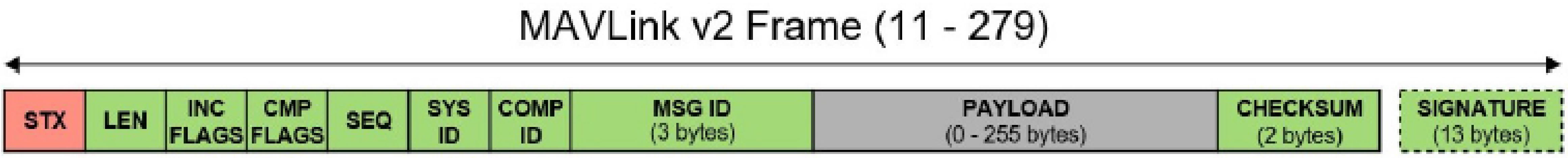
2. MAVLink communication analysis

2.2 The essence of MAVLink

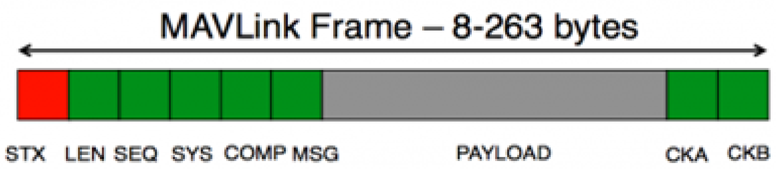
- It is the encapsulation and analysis protocol of byte stream
- The packet format of MAVLink 1 shown as follow:



- The packet format of MAVLink 2 shown as follow:



2. MAVLink cor



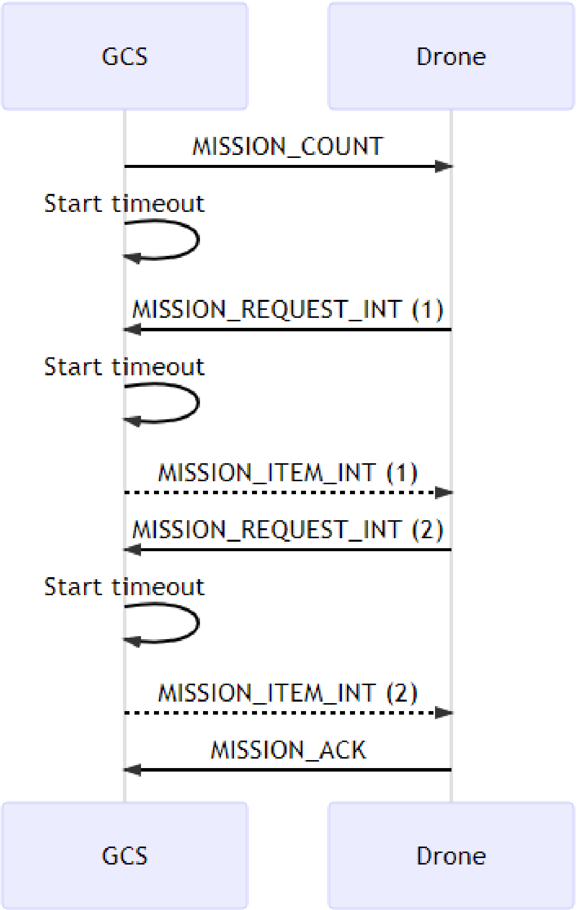
- Definition of bytes in the MAVLink 1 package.
- **STX** → Packet start sign
- **LEN** → Payload Length
- **SEQ** → Packet sequence
- **SYS** → System ID
- **COMP** → Component ID
- **MSG** → Message ID
- **PAYLOAD** → Data
- **CKA** → Checksum A
- **CKB** → Checksum B

Byte Index	Content	Value	Explanation
0	Packet start sign	v1.0: 0xFE (v0.9: 0x55)	Indicates the start of a new packet.
1	Payload length	0 - 255	Indicates length of the following payload.
2	Packet sequence	0 - 255	Each component counts up his send sequence. Allows to detect packet loss
3	System ID	1 - 255	ID of the SENDING system. Allows to differentiate different MAVs on the same network.
4	Component ID	0 - 255	ID of the SENDING component. Allows to differentiate different components of the same system, e.g. the IMU and the autopilot.
5	Message ID	0 - 255	ID of the message - the id defines what the payload "means" and how it should be correctly decoded.
6 to (n+6)	Data	(0 - 255) bytes	Data of the message, depends on the message id.
(n+7) to (n+8)	Checksum (low byte, high byte)	ITU X.25/SAE AS-4 hash, **excluding packet start sign, so bytes 1..(n+6)** Note: The checksum also includes MAVLINK_CRC_EXTRA (Number computed from message fields. Protects the packet from decoding a different version of the same packet but with different variables).	

2. MAVLink communication analysis

2.3 Analysis principle

- **Read**: All byte streams are stored in the buffer, and the byte data in the buffer is read sequentially. When the STX flag bit is encountered (the flag bit of MAVLink v1 is **0xFE**, the flag bit of v2 is **0xFD**), it starts to recognize a message until the end of the message. If the message verification is correct, send the message to the handler
- **Send**: follow the previous page to convert the message into a byte stream



2. MAVLink communication analysis

2.4 receive analyze source code analysis

Given a byte stream buffer of a certain length, the length simply called length, with the following script analysis, the **onMavLinkMessage** function will execute every time a MAVLink packet is parsed.

```
 for(int i = 0 ; i < length ; ++i){
	msgReceived = mavlink_parse_char(MAVLINK_COMM_1, (uint8_t)buffer[i], &message, &status);
	if(msgReceived){
		emit onMavLinkMessage(message);
	}
 }
```

Among them:

```
void onMavLinkMessage(mavlink_message_t message);
```

It is the processing function after a MAVLink message package is obtained. Users need to identify the purpose of the current package (heartbeat package, GPS location, posture, etc.) according to its ID, and extract the important data.

2. MAVLink communication analysis

2.4 receive analyze source code analysis

The analysis function is implemented as follows, jump to the corresponding _decode function according to message.msgid, and decode the data

```
void onMavLinkMessage(mavlink_message_t message){
  switch (message.msgid){
   case MAVLINK_MSG_ID_GLOBAL_POSITION_INT: {
     mavlink_global_position_int_t gp;
     mavlink_msg_global_position_int_decode(&message, &gp);
     outHilData.time_boot_ms = m_LastReceiveMavMsg;
     outHilData.GpsPos[0]=gp.lat;
     outHilData.GpsPos[1]=gp.lon;
     outHilData.GpsPos[2]=gp.alt;
     outHilData.relative_alt = gp.relative_alt;
     outHilData.GpsVel[0]=gp.vx;
     outHilData.GpsVel[1]=gp.vy;
     outHilData.GpsVel[2]=gp.vz;
     outHilData.hdg = gp.hdg;
     break;
   }
  }
}
```

2. MAVLink communication analysis

2.5 Send source code analysis — send a MAVLink_hil_actuator_controls message

```
void sendHILCtrlMessage(uint8_t modes, uint64_t flags, float ctrl[])
{
    mavlink_hil_actuator_controls_t hilctrl;
    hilctrl.mode = modes;
    hilctrl.flags = flags;
    for(int i=0;i<16;i++){
        hilctrl.controls[i]=ctrl[i];
    }
    mavlink_message_t mess;
    mavlink_msg_hil_actuator_controls_encode(SystemID, TargetCompID, &mess, &hilctrl);
    char buffer[500];
    memset(buffer,0,500);
    unsigned int length = mavlink_msg_to_send_buffer((uint8_t*)buffer, & mess);
    udp.writeDatagram(buffer,length);//send the buffer out through USP or interface is ok
}
```

2. MAVLink communication analysis

2.6 MAVLink ID list of message package

- https: //mavlink.io/en/messages/common.html

HEARTBEAT (#0)

Heartbeat package, ID = 0

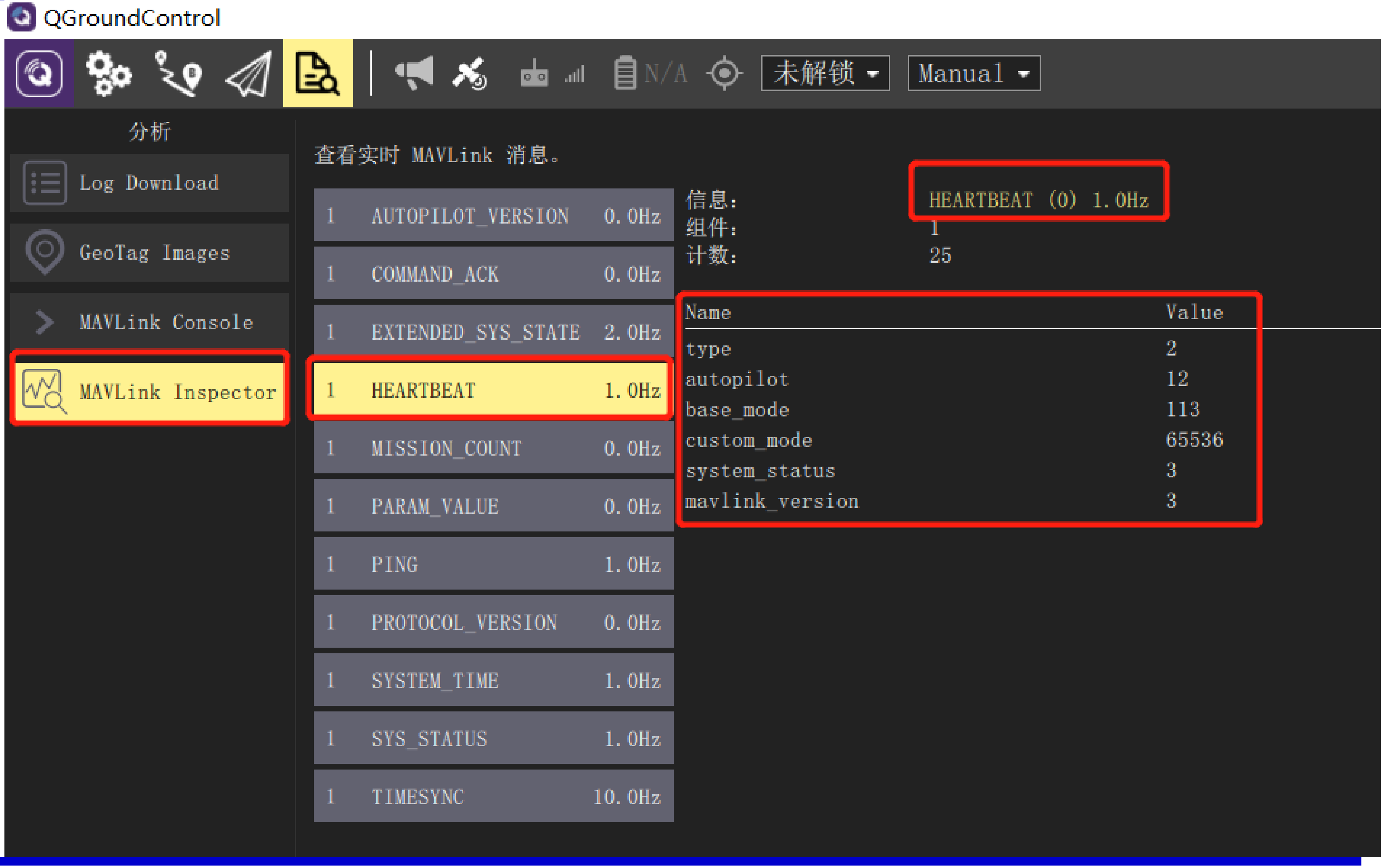
[Message] The heartbeat message shows that a system or component is present and responding. The type and autopilot fields (along with the message component id), allow the receiving system to treat further messages from this system appropriately (e.g. by laying out the user interface based on the autopilot). This microservice is documented at https://mavlink.io/en/services/heartbeat.html

Field Name	Type	Values	Description
type	uint8_t	MAV_TYPE	Vehicle or component type. For a flight controller component the vehicle type (quadrotor, helicopter, etc.). For other components the component type (e.g. camera, gimbal, etc.). This should be used in preference to component id for identifying the component type.
autopilot	uint8_t	MAV_AUTOPILOT	Autopilot type / class. Use MAV_AUTOPILOT_INVALID for components that are not flight controllers.
base_mode	uint8_t	MAV_MODE_FLAG	System mode bitmap.
custom_mode	uint32_t		A bitfield for use for autopilot-specific flags
system_status	uint8_t	MAV_STATE	System status flag.
mavlink_version	uint8_t_mavlink_version		MAVLink version, not writable by user, gets added by protocol because of magic data type: uint8_t_mavlink_version

2. MAVLink communication analysis

2.7 QGC ground station view MAVLink messages

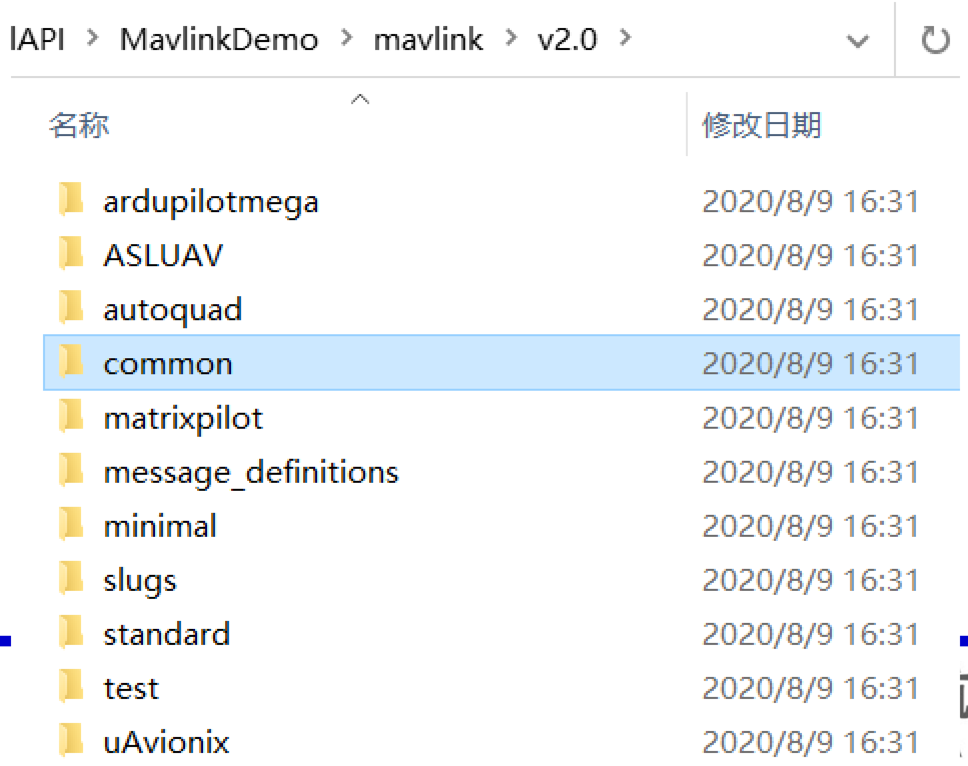
On the MAVLink Inspector page of QGC, you can browse all the MAVLink packages sent by Pixhawk, check the frequency and specific values of each package

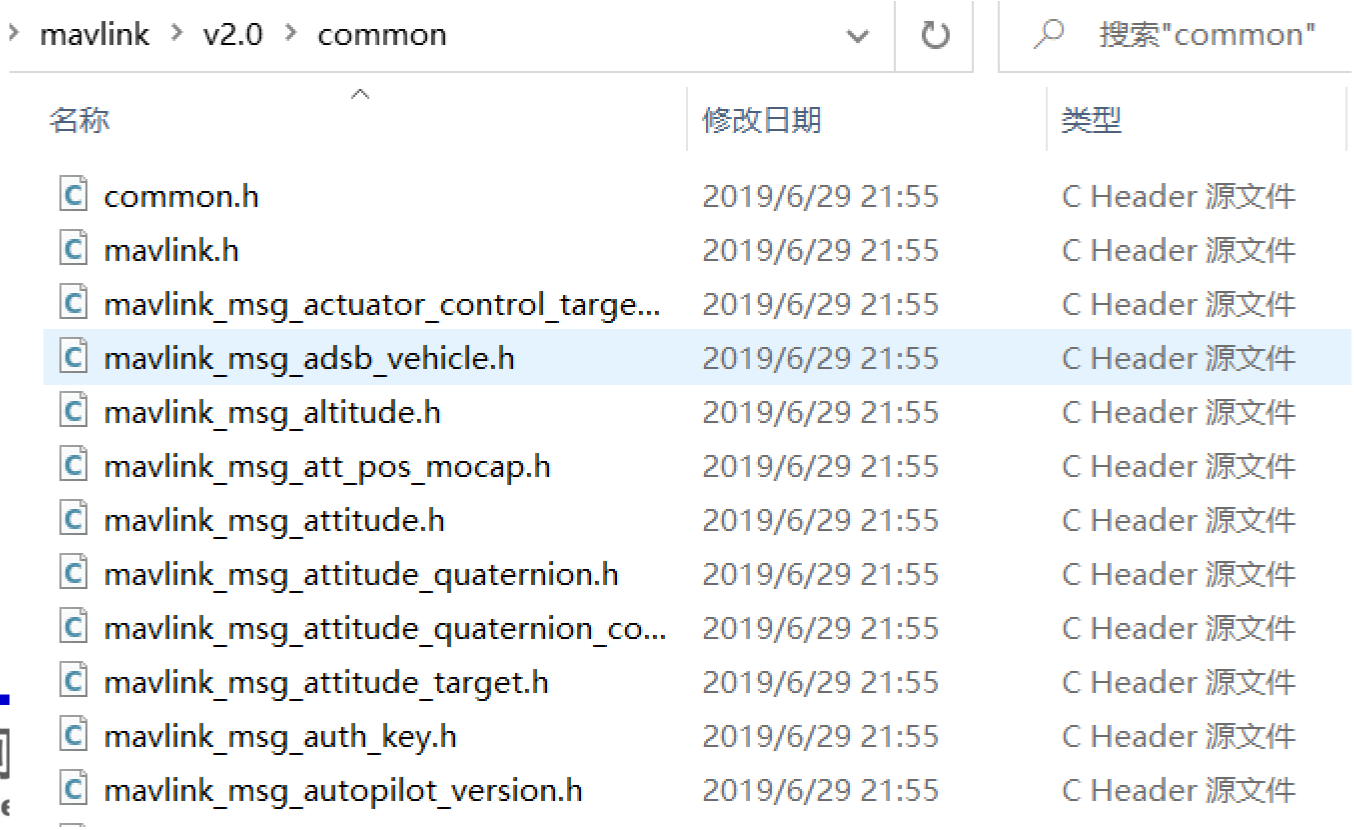


2. MAVLink communication analysis

2.8 Source code of MAVLink 2

Open folder '**RflySimAPIs\SimulinkControlAPI\MavlinkDemo\mavlink\v2.0\common**'. You can see C++ source code of MAVLink, including all definition of all message package.

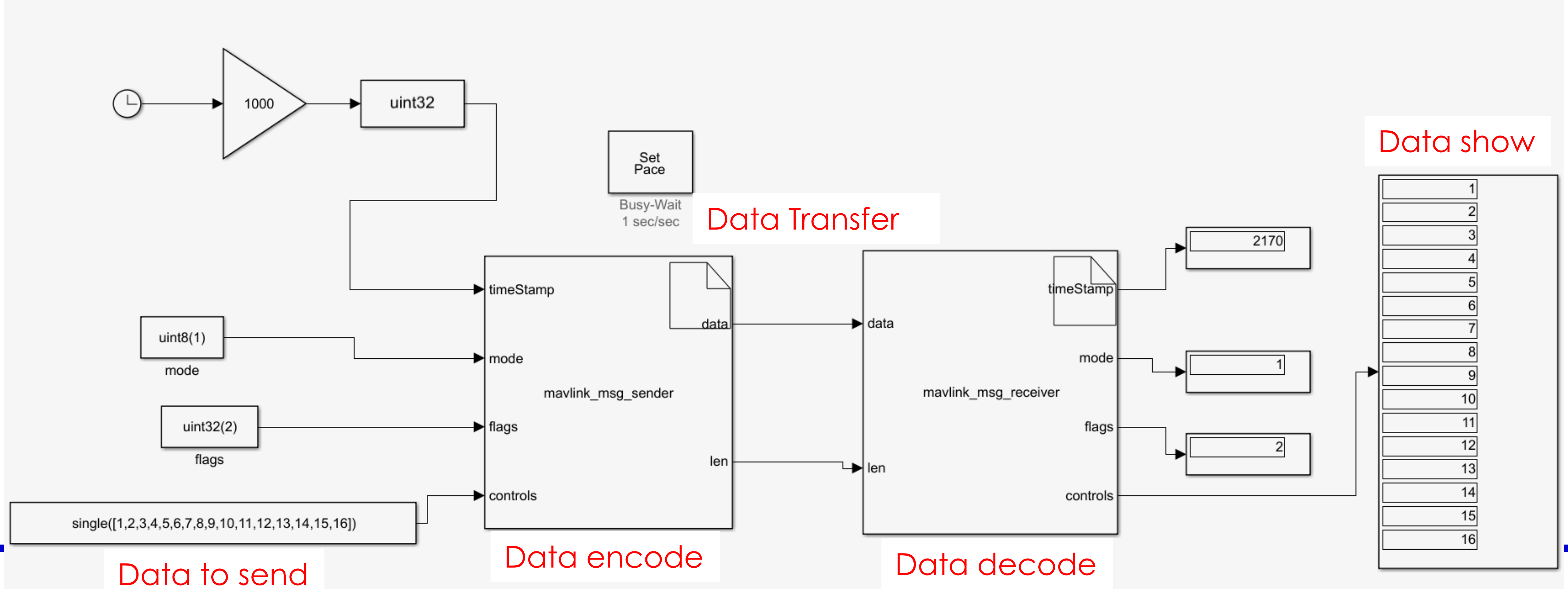




2.9 Simulink Encapsulation and Analysis Implementation of MAVLink Protocol

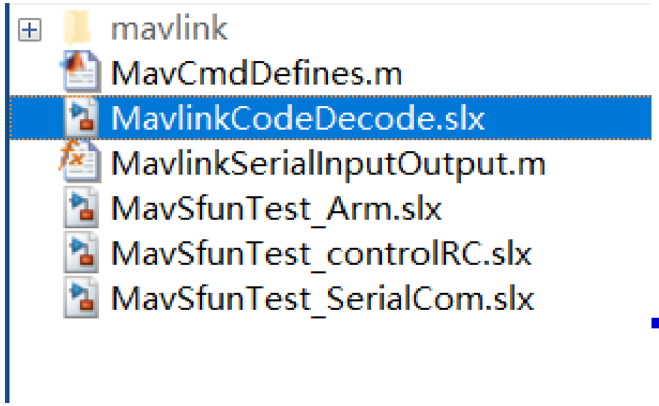
Open demo

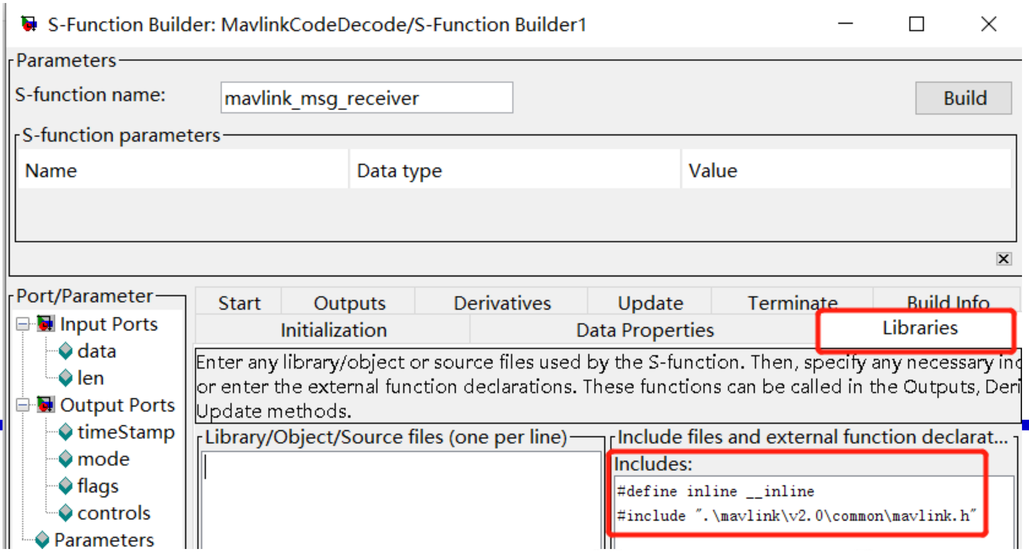
“**RflySimAPIs\SimulinkControlAPI\MavlinkDemo\MavlinkCodeDecode.slx**”

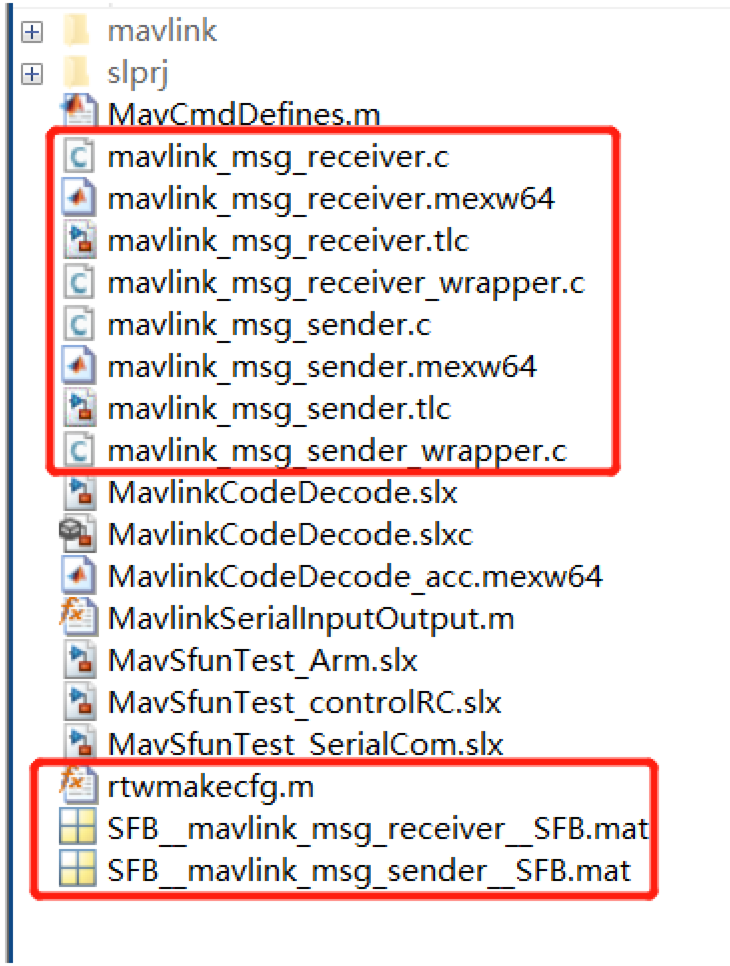


2. MAVLink communication analysis

- After clicking Run, we can see that we encapsulate the data into byte stream data (uint8 byte stream) and len (byte stream length) in Simulink, and then pass a parsing function to parse the byte stream into sending data.
- This example is implemented by **S-Function Builder**, it will automatically call the MAVLink header file when it is running, and compile it into the **.c/.mexw64/.tlc** files shown on the right
- This demo can teach you how to call external C/C++ header files in Simulink to implement your own algorithms.



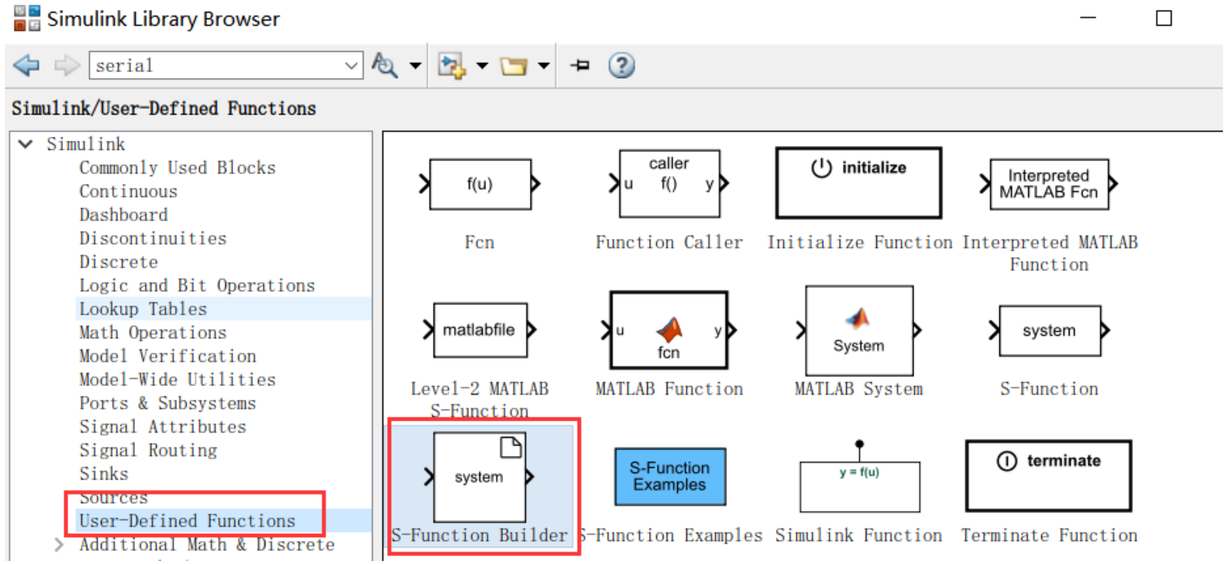


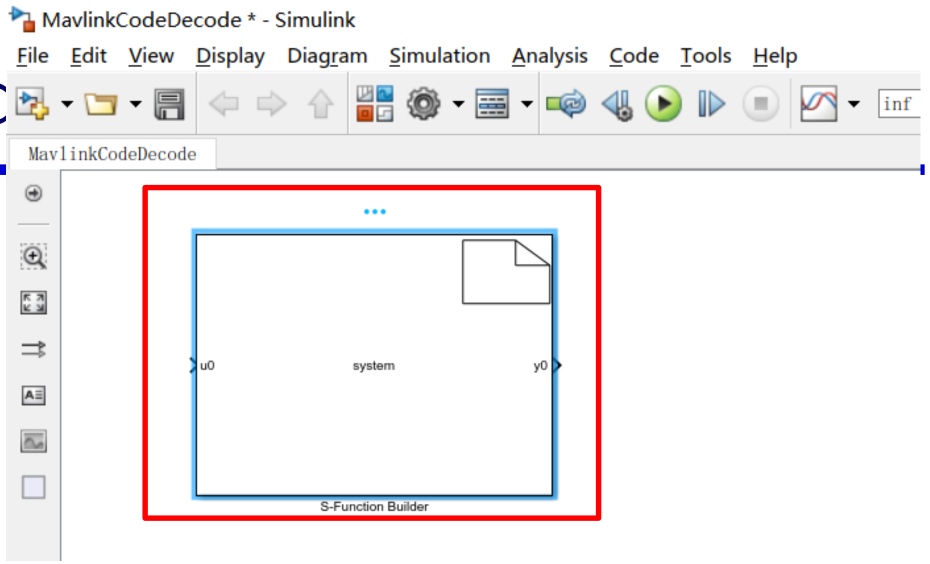


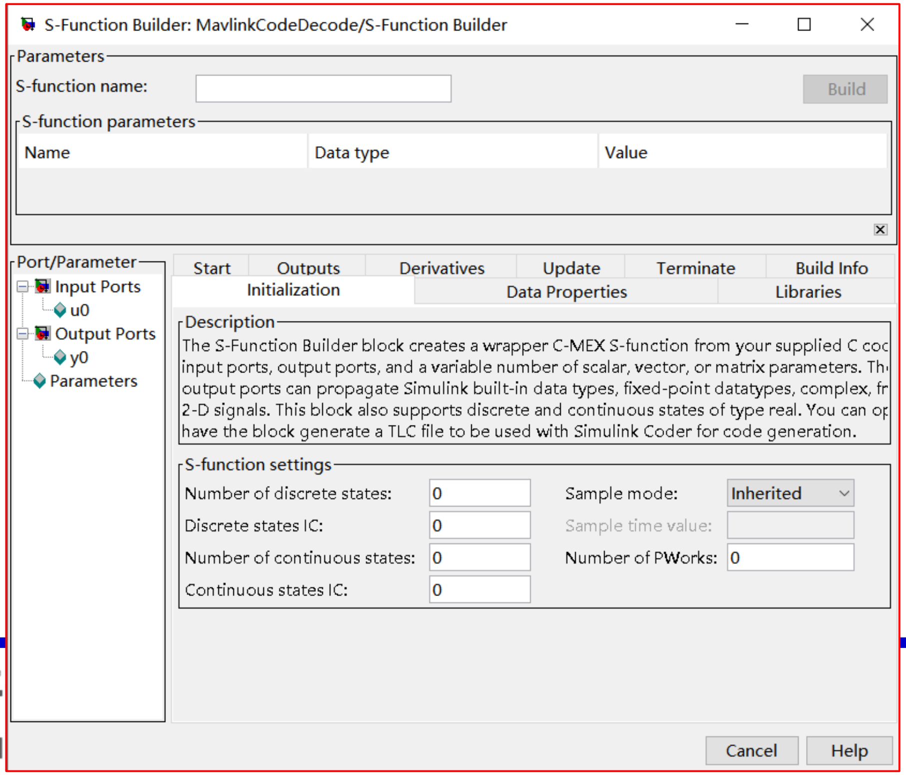
2. MAVLink communication c

2.10 Simulink S-Function program method

- Open the .slx file and drag in an S-Function Builder module from Simulink-User-Defined Functions, double-click it to get the picture on the right



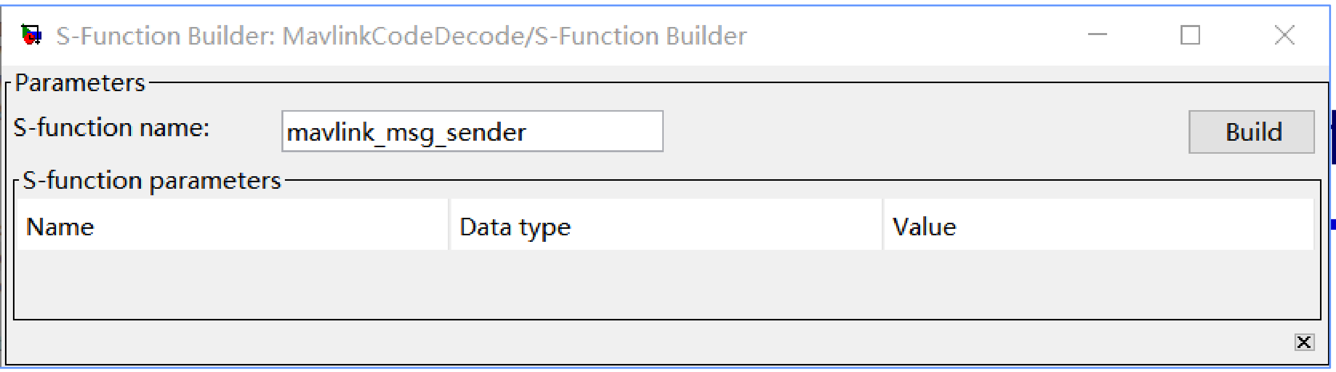


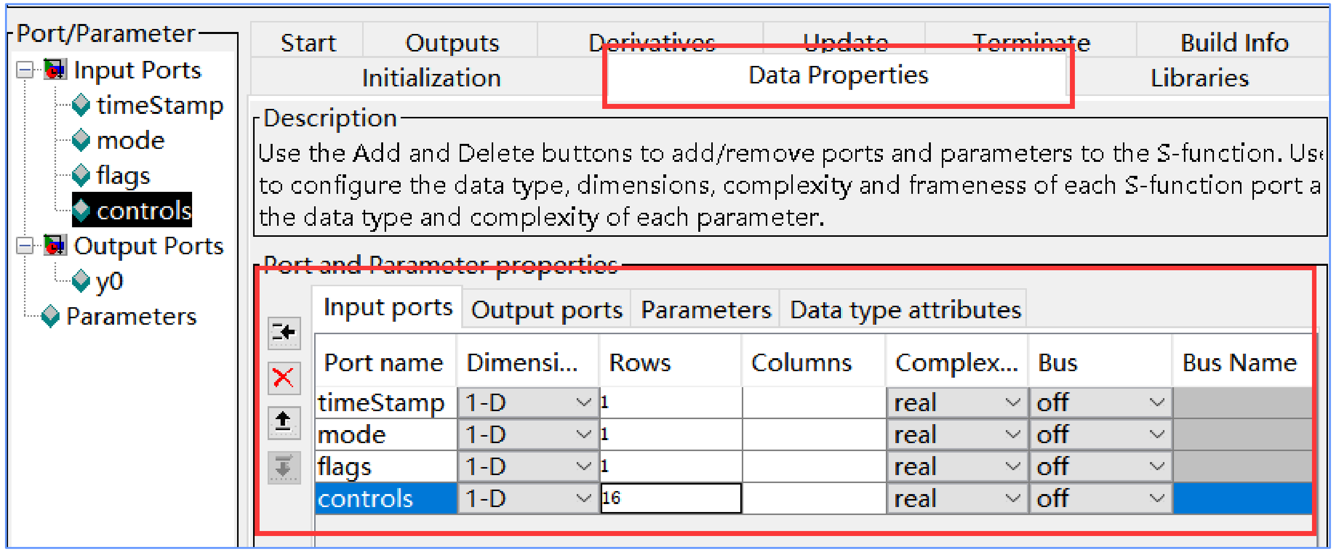


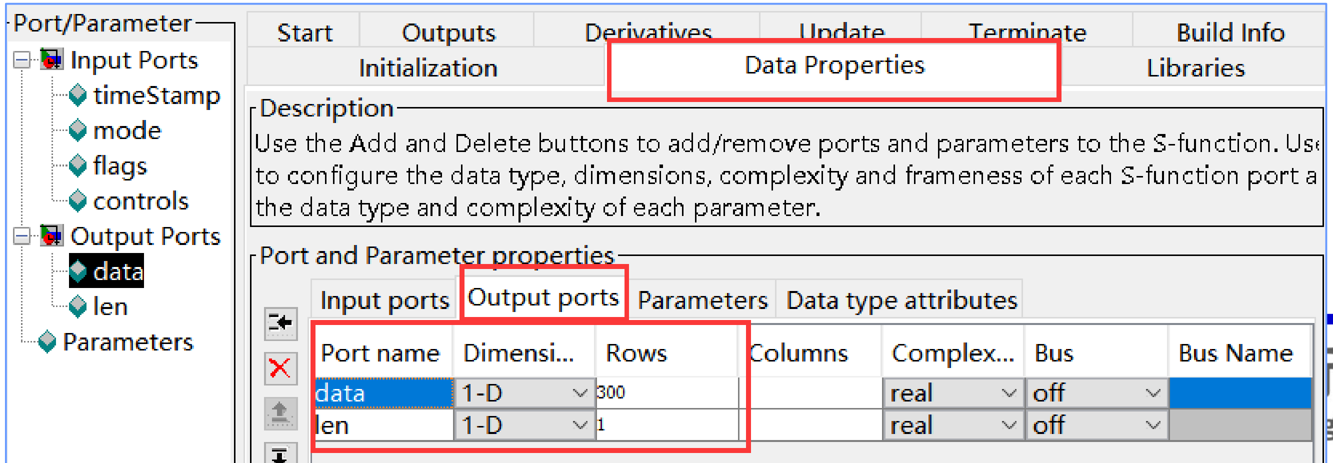
- Below picture shows how to use this module to generate the MAVLink message mentioned above: **MAVLINK_MSG_ID_HIL_ACTUATOR_CONTROLS**

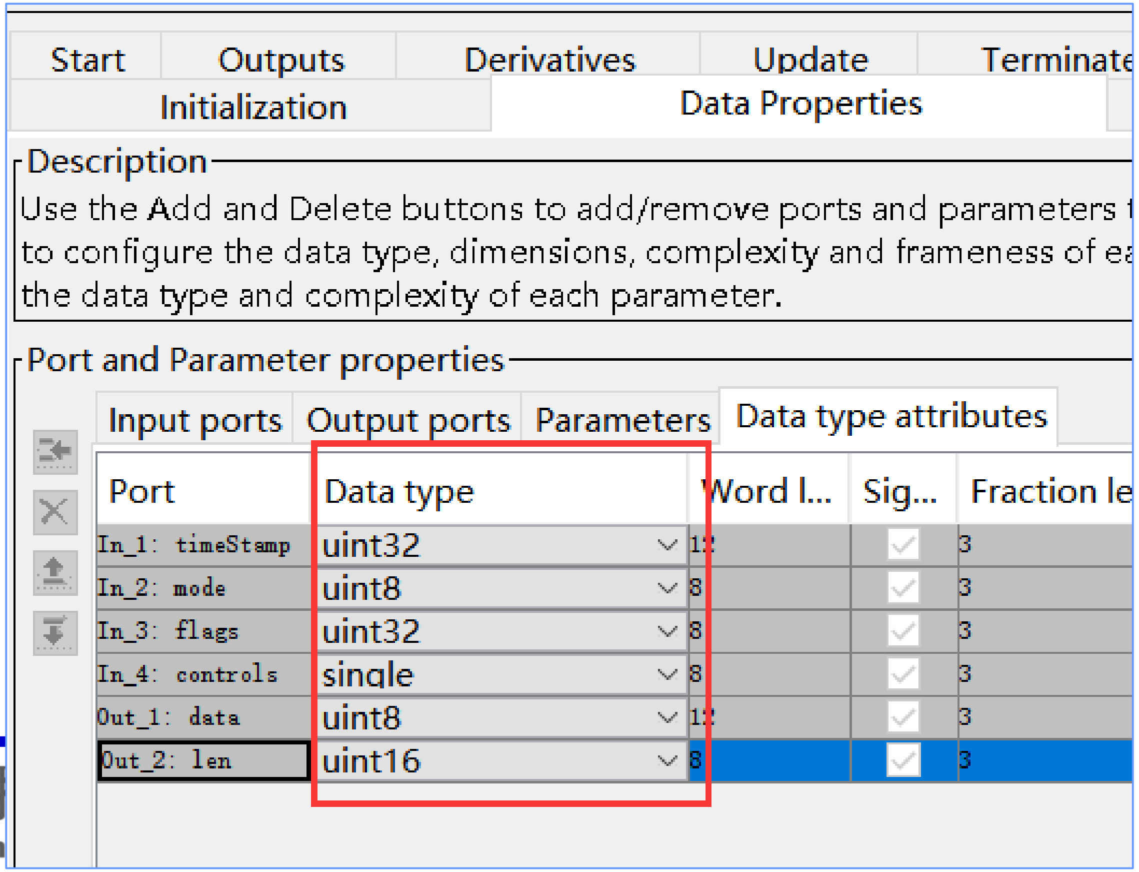
tion analysis

- Name the module and set the input and output parameter names, dimensions, and data types on the Data Type page



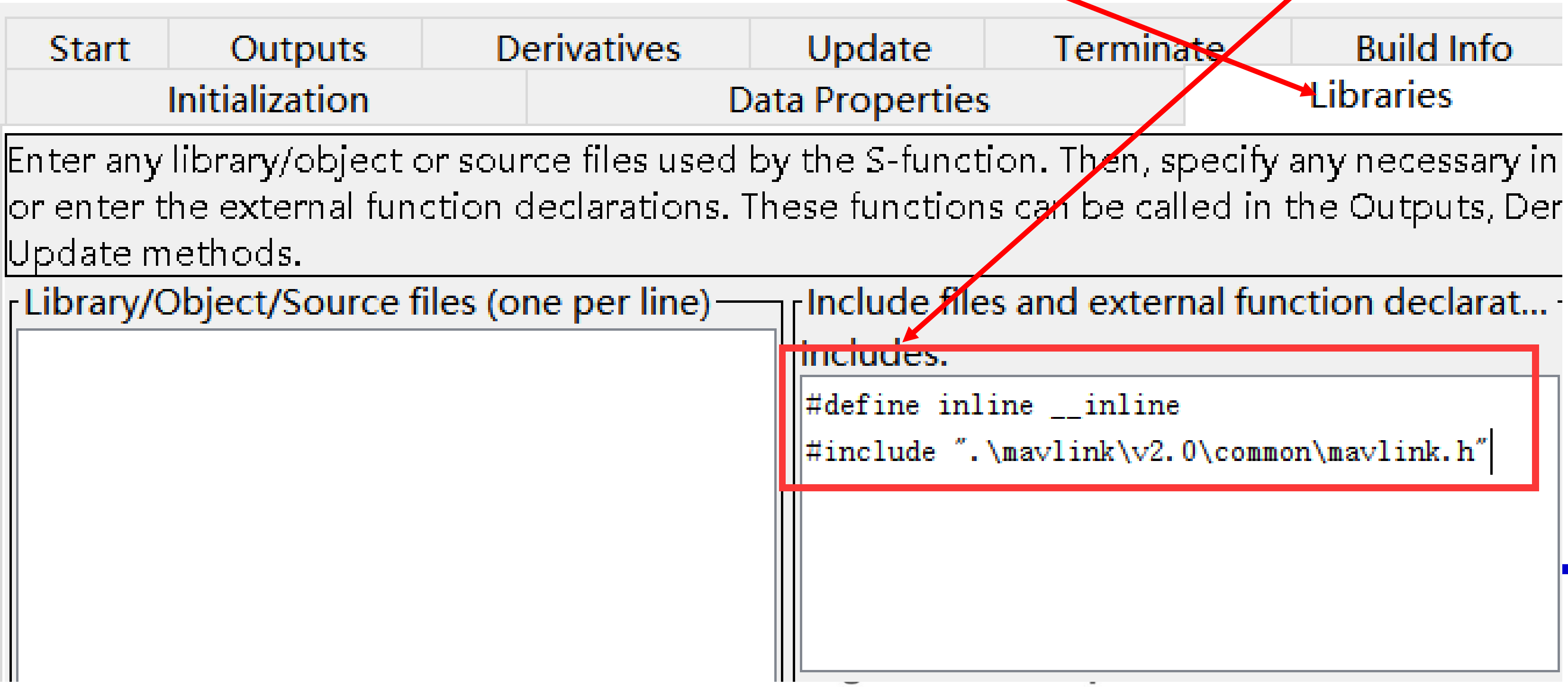






2. MAVLink communication analysis

- Import the MAVLink header file
- Enter the “**Libraries**” tab, and add the following code in the “**includes**” box
- #define inline __inline
- #include ".\mavlink\v2.0\common\mavlink.h"



2. MAVLink communication analysis

- In the **Outputs** tab, add the C/C++ code that obtains the input data and packs it into a MAVLink message, and puts it in the output ports data and len. Where data is the uint8 matrix, and len is the effective length of the data.
- **Note**: Simulink S-function signals have no concept of scalar, and all input/output signals are vectors. Therefore, although an output “**len**” is an one-dimensional scalar, the assignment statement of "**len=*****" is wrong, so use "**len[0]=*****“ instead.

Initialization | Data Properties | Libraries | Start | Outputs | Derivatives | Update | Terminate | Build Info

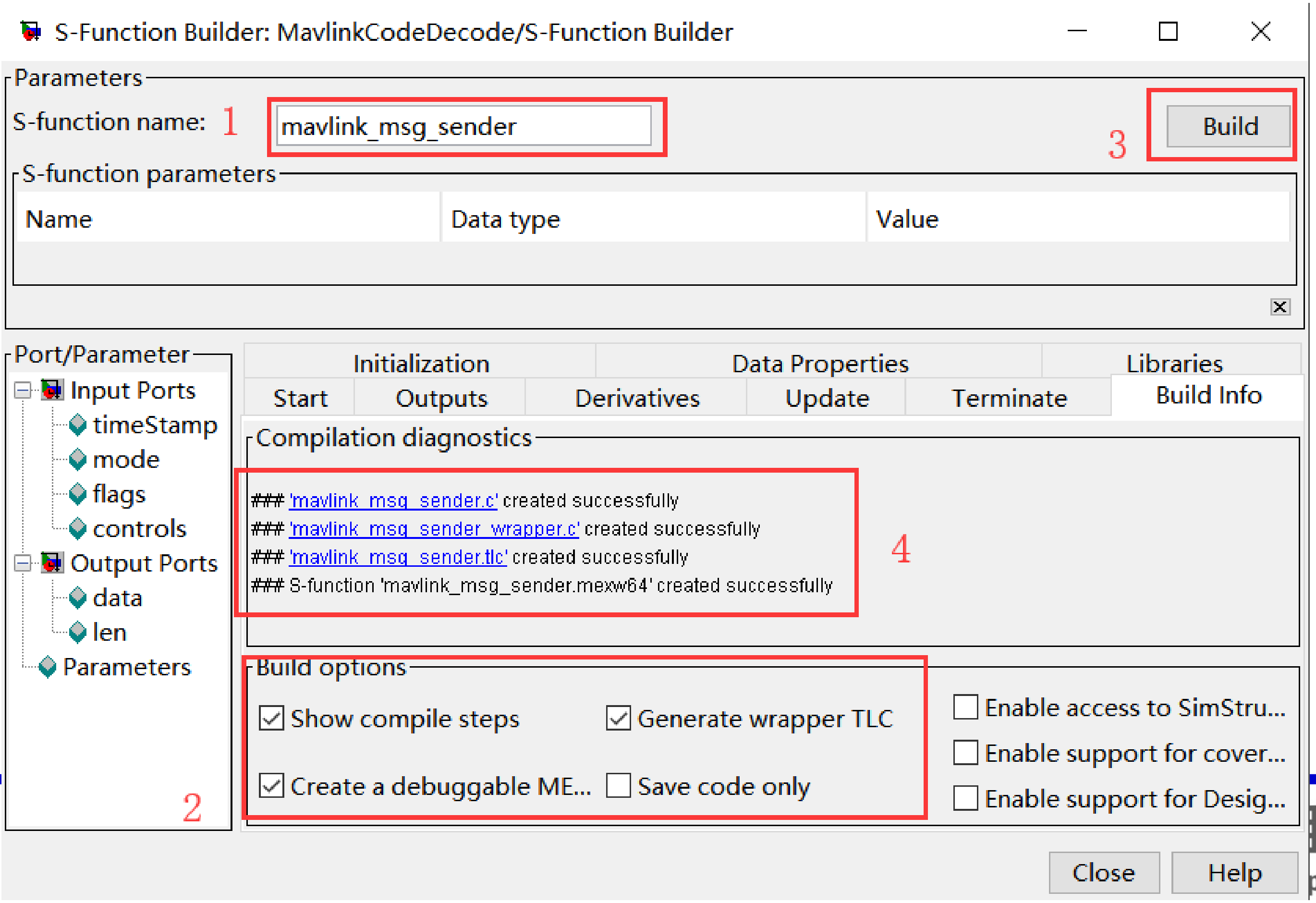
Code description

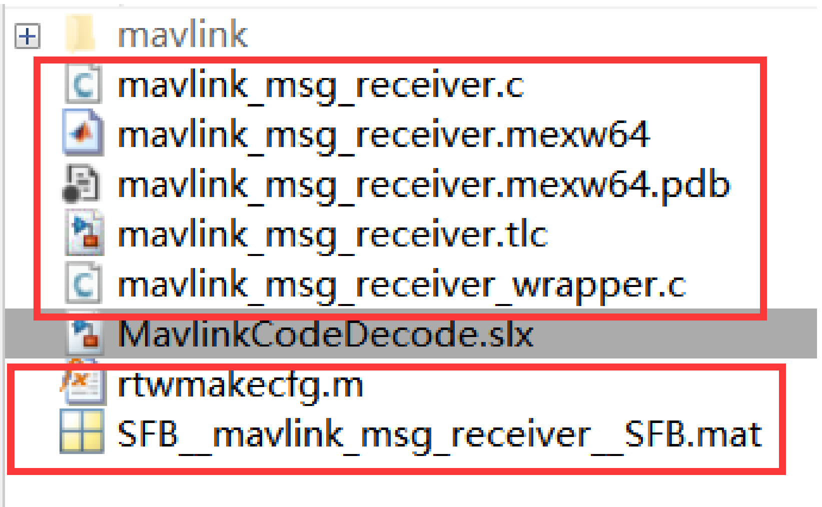
Enter your C-code or call your algorithm. If available, discrete and continuous states should be referenced as xD[0]...xD[n], xC[0]...xC[n] respectively. Input ports, output ports and parameters should be referenced using symbols specified in Data Properties. These references appear directly in the generated S-function.

```
uint8_T out_msg[MAVLINK_MAX_PACKET_LEN]={0};
mavlink_message_t out_msg_m1;
uint8_T sysid = 1;
uint8_T compid = 0;
mavlink_msg_hil_actuator_controls_pack(sysid, compid,  &out_msg_m1, timeStamp[0], controls, mode[0], flags[0]);
uint16_t MavlinkMessageSizes = mavlink_msg_to_send_buffer(out_msg, &out_msg_m1);
len[0] = MavlinkMessageSizes;
for(int i=0;i<MavlinkMessageSizes;i++){  data[i]=out_msg[i]; }
```

2. MAVLink communication analysis

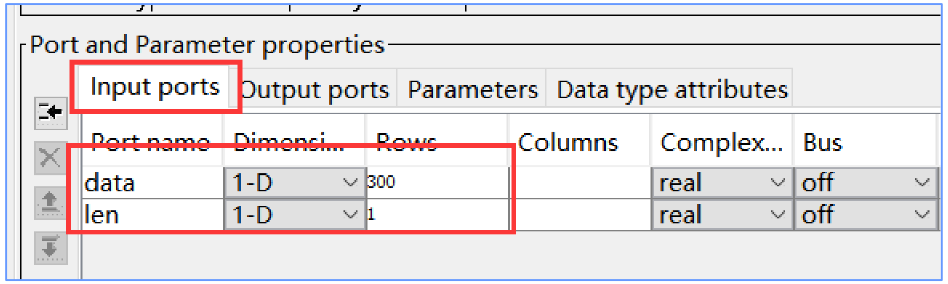
- Check the option to generate **TLC** and **MEX**-file, and then click the compile button, you can get the file that can be called by Simulink as shown on the right.

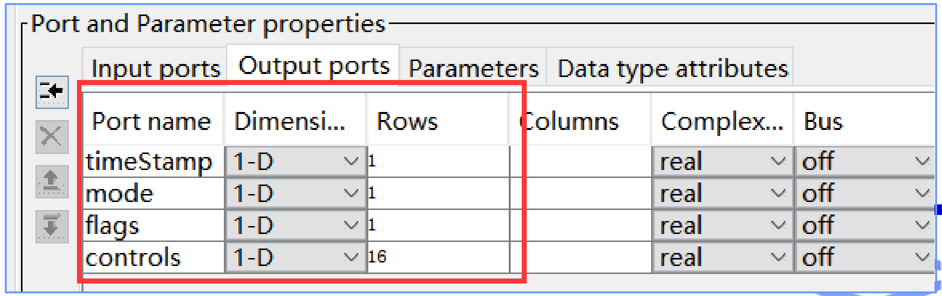


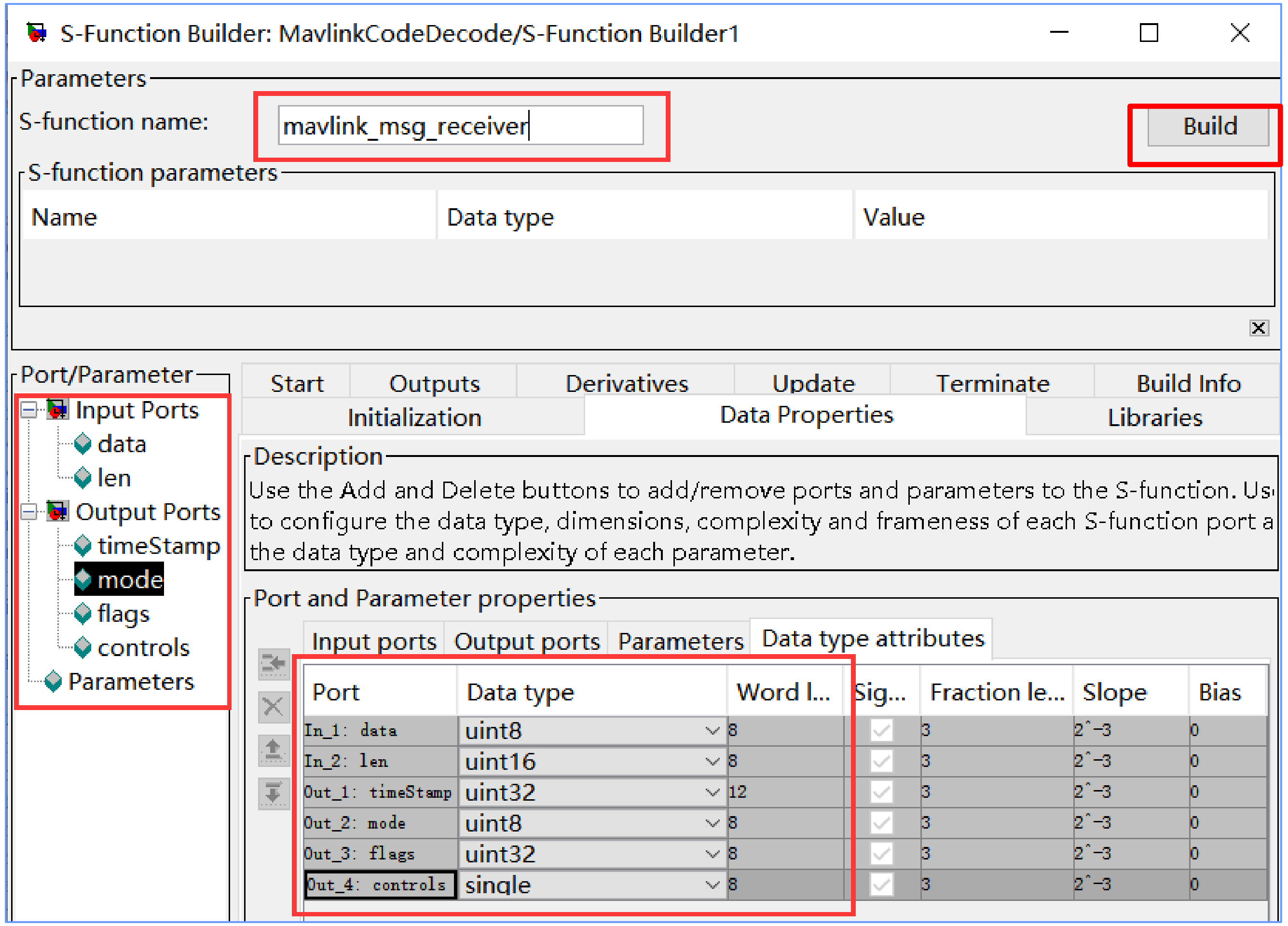


2. MAVLink communication analysis

- Let's build a decoding module for MAVLink messages
- Name it "**mavlink_msg_receiver**"
- Input and output ports, completely opposite to the previous module

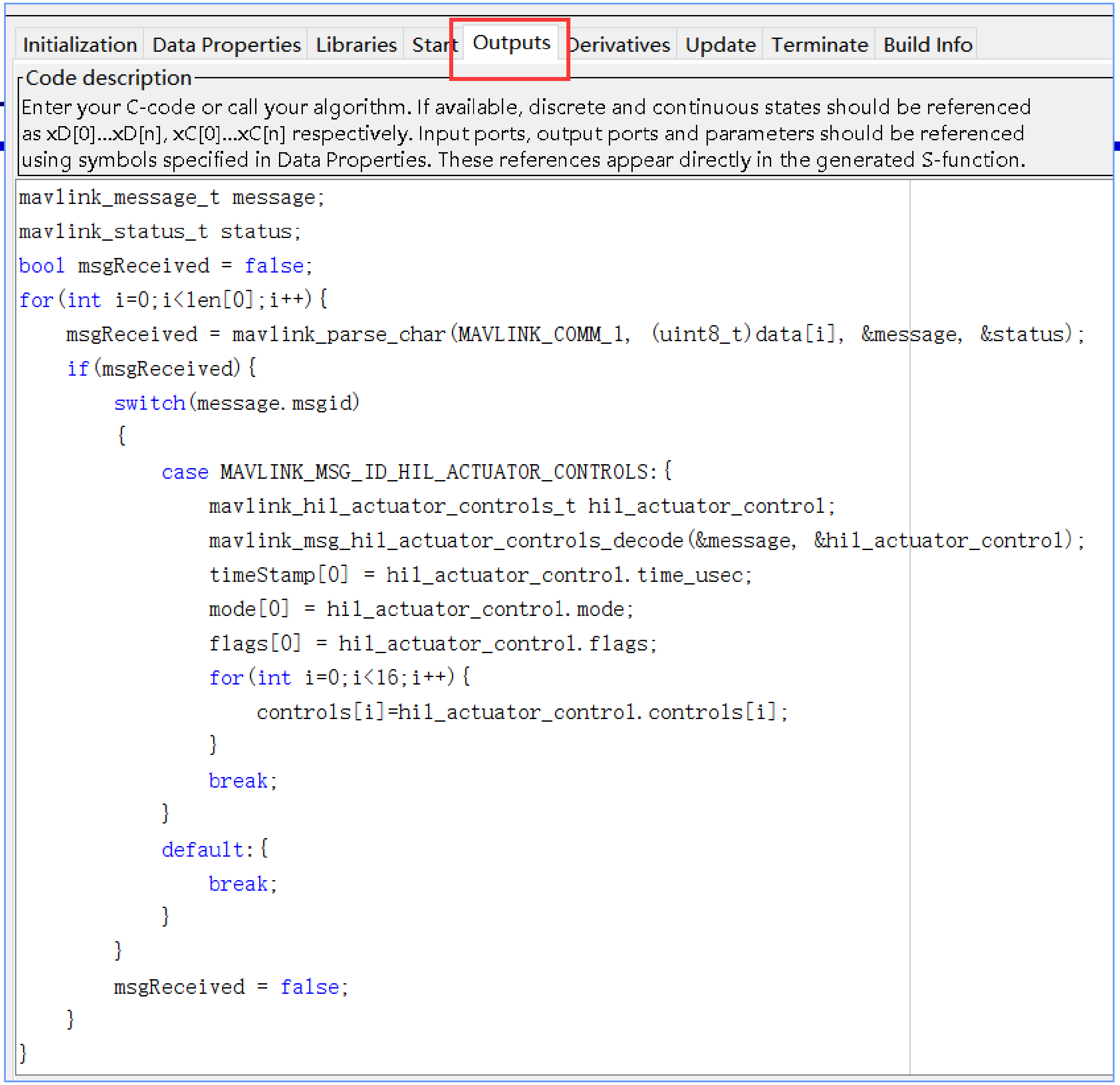






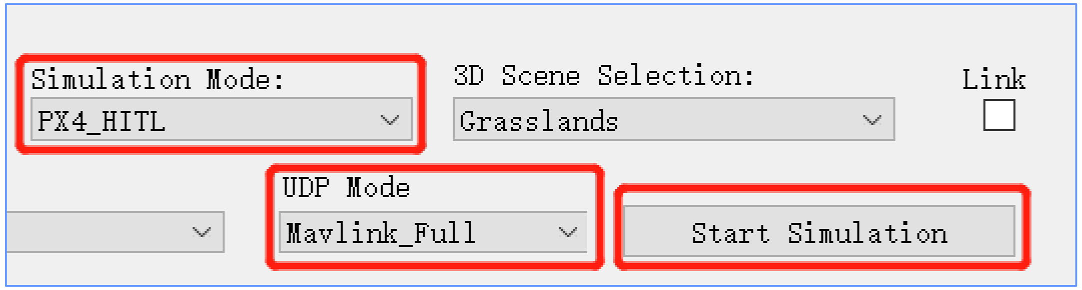
2. MAVLink commu

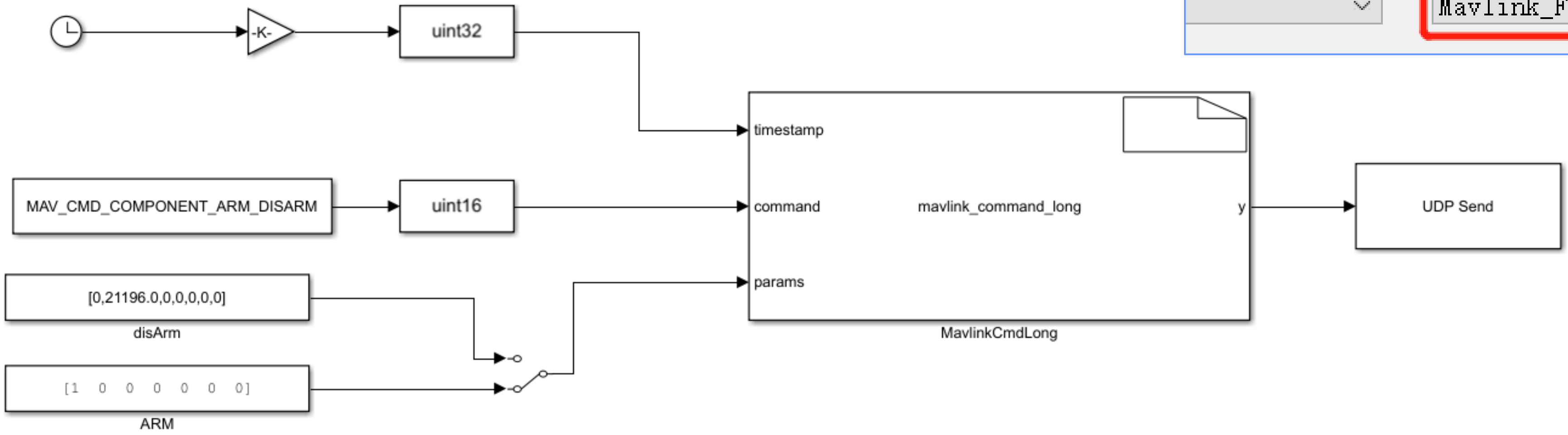
- As shown in the figure on the right, set the decoded byte stream in the Outputs tab and parse out the code of the MAVLink message.
- In the same way, on the library file page, import the MAVLink library file
- After setting the compilation options, click the "**build**" button to check whether the tlc and **mex** files can be generated correctly.



2.11 Send arm command to the flight controller via Simulink/MAVLink (*RflySim Advanced* Version only)

- Plug in Pixhawk, open CopterSim, set HITL simulation, set **UDP_Mode** to **Mavlink_FULL** (*RflySim Advanced* version only), and click the "**Start Simulation**" button
- Open the demo "**MavlinkDemo\MavSfunTest_Arm.slx**" and run it, you can see "**Command ARM/DISARM ACCECPTED**" in the message box of CopterSim, indicating that the experiment was successful

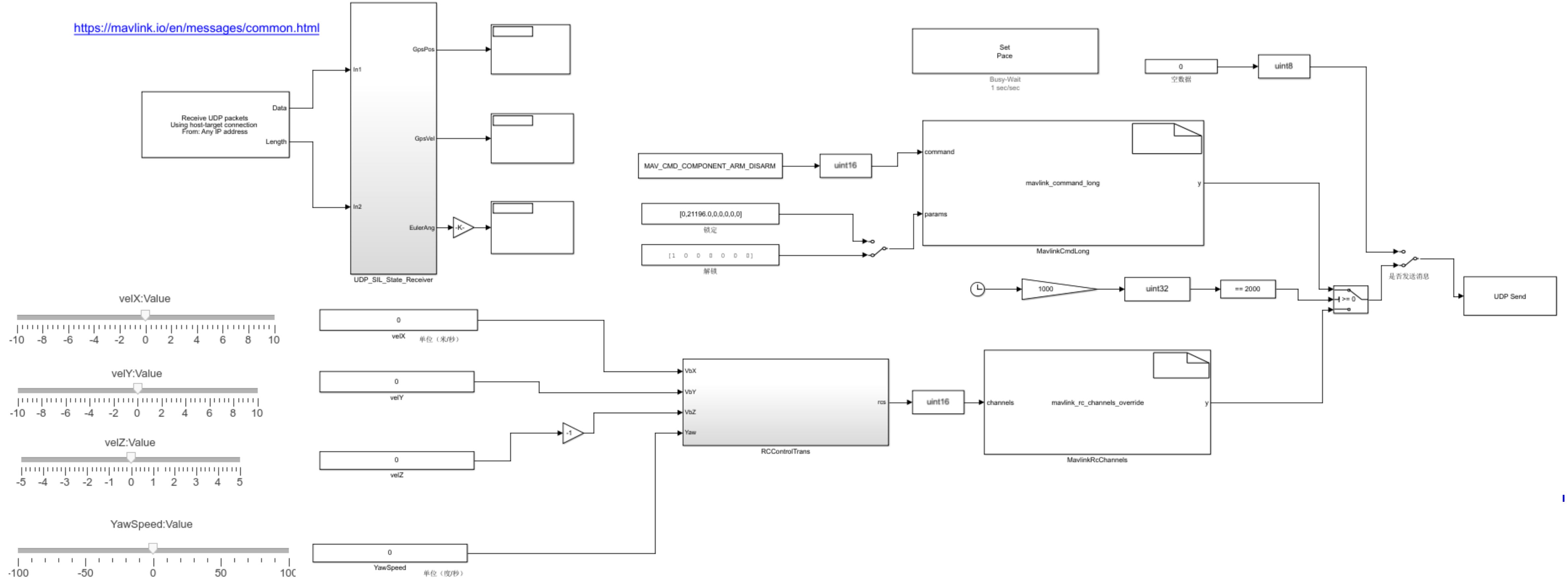




2. MAVLink communication analysis

2.12 Simulate sending RC data via MAVLink (RflySim advanced version only)

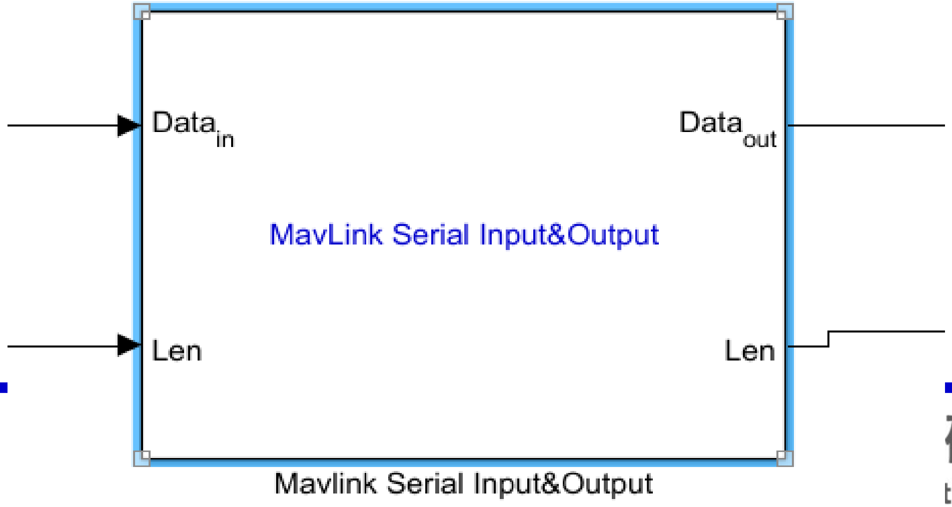
Same as the previous step, open CopterSim hardware-in-the-loop, and run the "**MavlinkDemo\MavSfunTest_control RC.slx**" demo to control the arming of Pixhawk and send RC data to control drone take-off and landing, flight, etc.

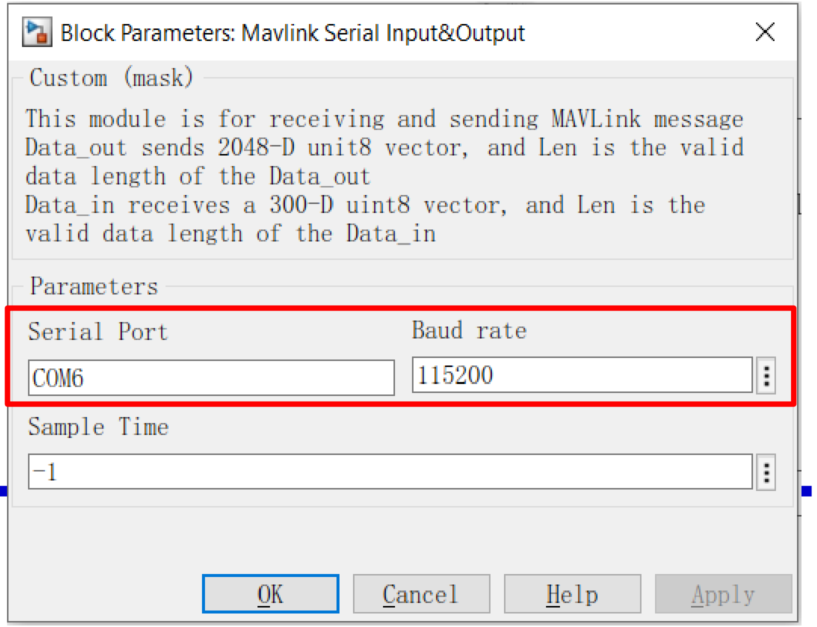


2. MAVLink communication analysis

2.13 Simulink sends and receives MAVLink messages through the serial port

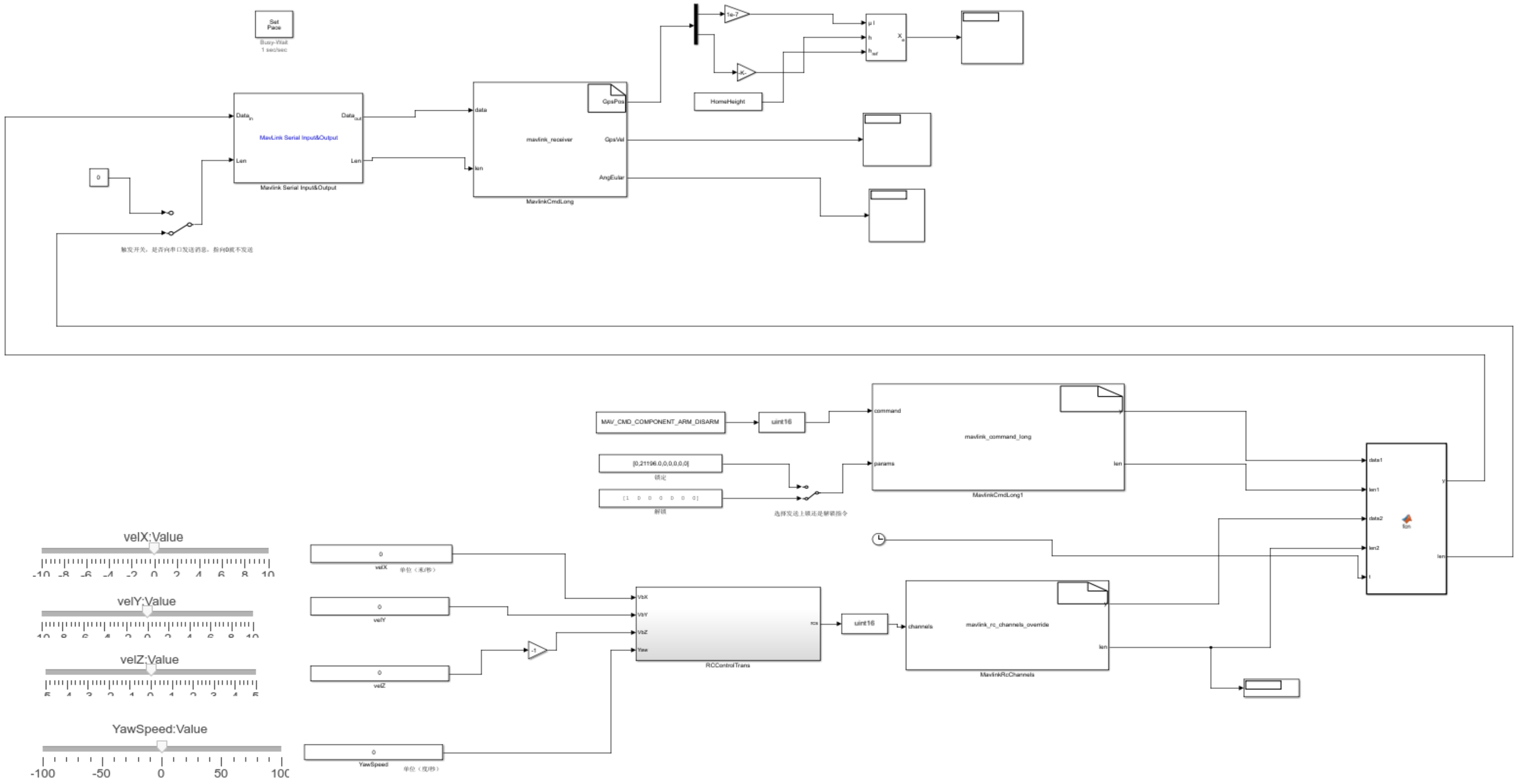
- Connect Pixhawk to computer, use CopterSim to start HIL simulation (you do not need to set **UDP_Mode** so the basic version of RflySim is also applicable), use a digital transmission (radio telemetry) module to connect Pixhawk to the computer, remember the serial number of the radio telemetry module (if you don't have a radio telemetry, you can plug in Pixhawk directly without opening CopterSim, and enter the serial port number of Pixhawk here). **Note**, the Baud rate of a radio is usually 57600.
- Open "**MavlinkDemo\MavSfunTest_SerialCom.slx**", double-click "**Mavlink Serial Input&Output**", and enter the serial port number in it





2. MAVLink communication analysis

- In this example, you can obtain Pixhawk data through the serial port and send control commands. This example can be directly used for real-time (through data transmission) control of the Pixhawk multicopter real vehicle.



Content

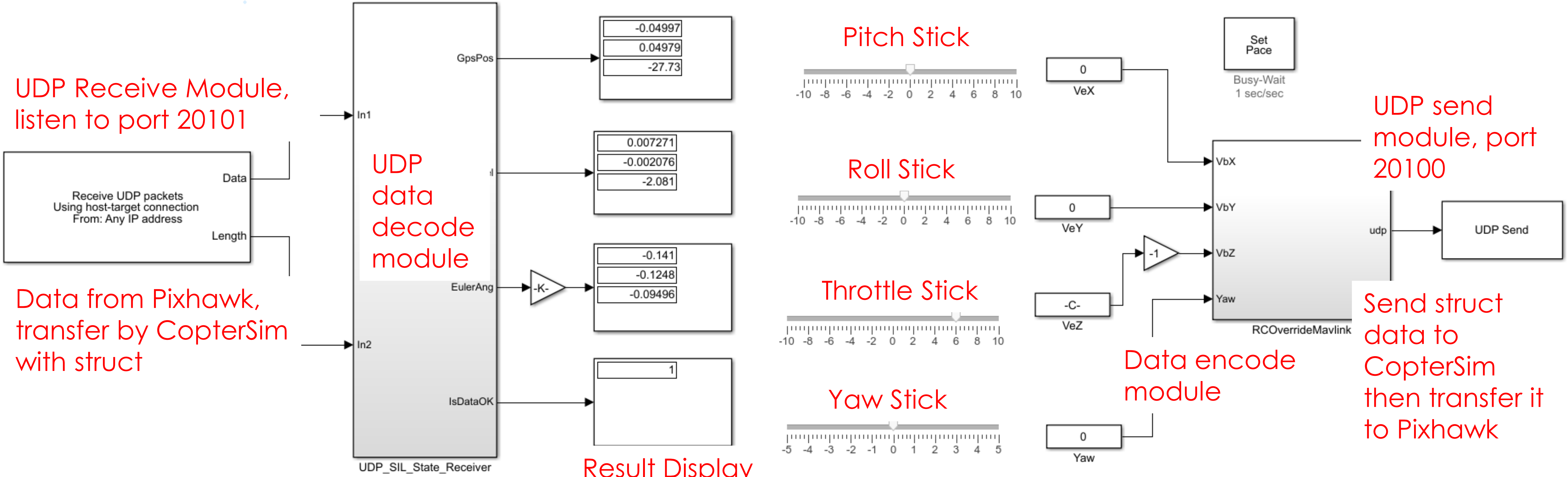
1. Configuration of software & hardware
2. MAVLink communication analysis
3. PX4 official controller communication
4. Code generation controller communication
5. Summary

Path of demo source code of this section: “RflySimAPIs\SimulinkControlAPI”

3. PX4 official controller communication

3.1 Simulink simulates sending the raw data of the RC to control the drone

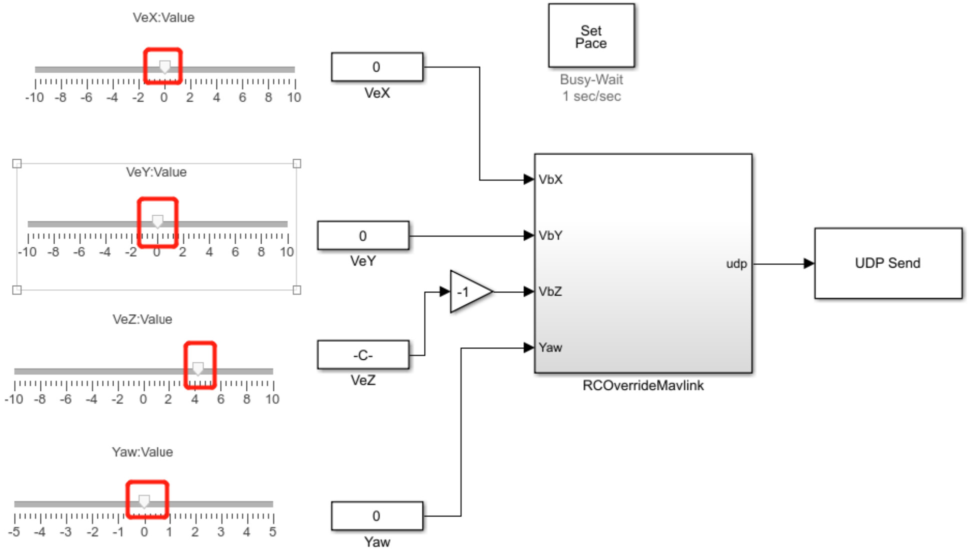
First connect Pixhawk with CopterSim and start HIL simulation and open the 3D software at the same time (RflySim Advanced version can directly run the Desktop **HITLRun** to quickly open the HIL simulation, or run **SITLRun** to open the SIL simulation), and then open "**RflySimAPIs\SimulinkControlAPI\RadioControlAPI.slx**" through MATLAB and run.



3. PX4 official controller communica

3.1 Simulink simulates sending the raw data of the RC to control the drone

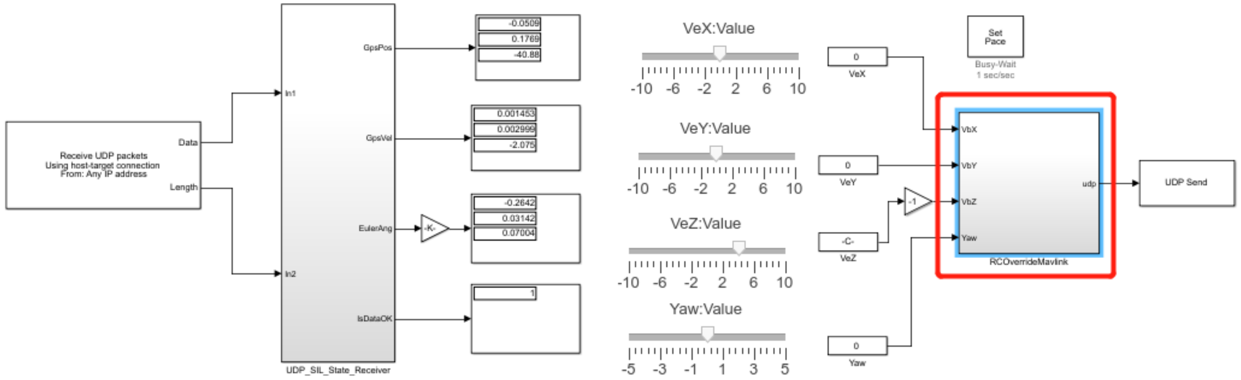
- First, drag the **VeZ** slider to the right (simulating pushing up the throttle to pass the midpoint), you can control the speed of the drone in the Z direction and make the drone take off vertically;
- Then, drag the **VeX** (simulate forward and backward pitch stick) and **VeY** (simulate left and right roll stick) sliders to achieve forward and backward movement,
- Similarly, drag the **Yaw** slider (simulating the left and right yaw sticks) to control the yaw speed and the drone deflection.

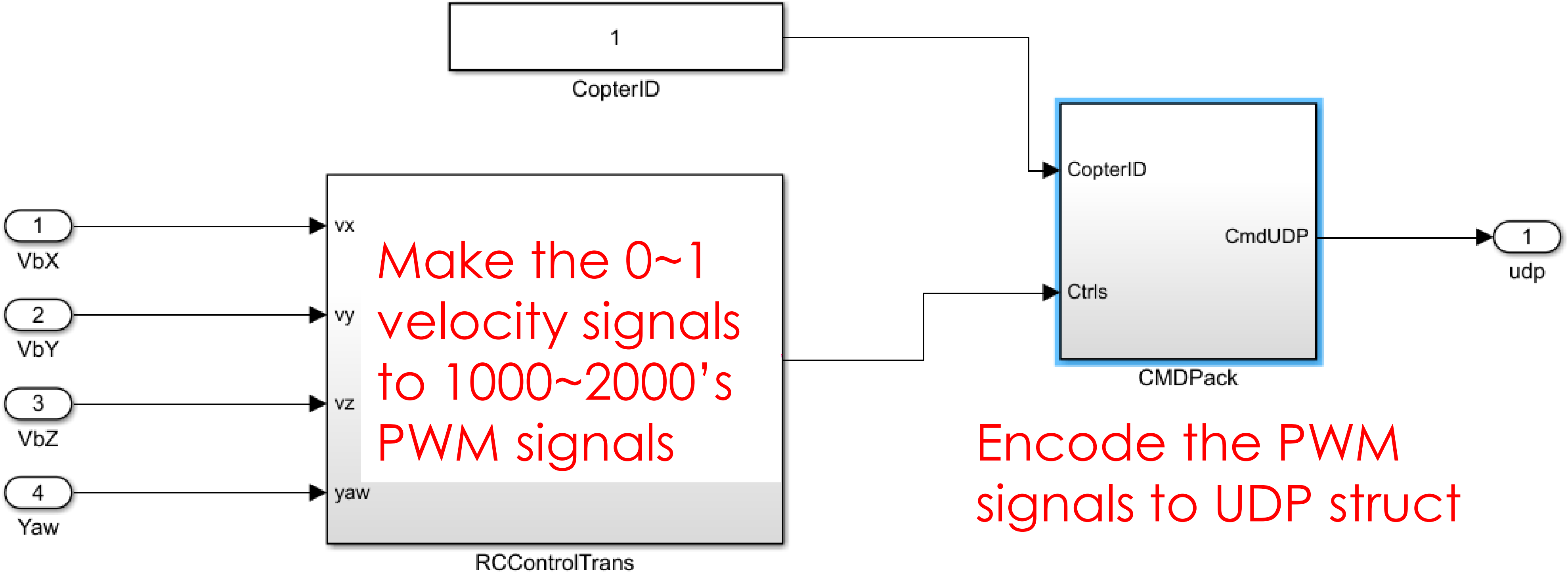


3. PX4 official controller communication

3.1 Simulink simulates sending the raw data of the RC system

- Double-click the "**RCOverrideMavlink**" module, you can see the internal information shown in the figure below



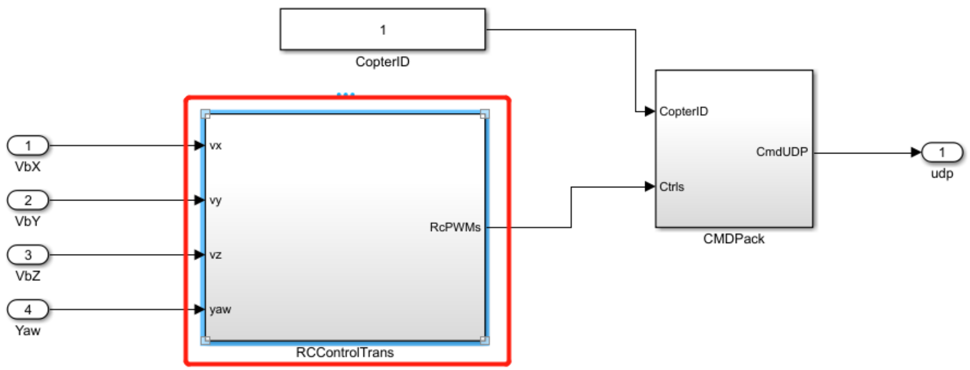


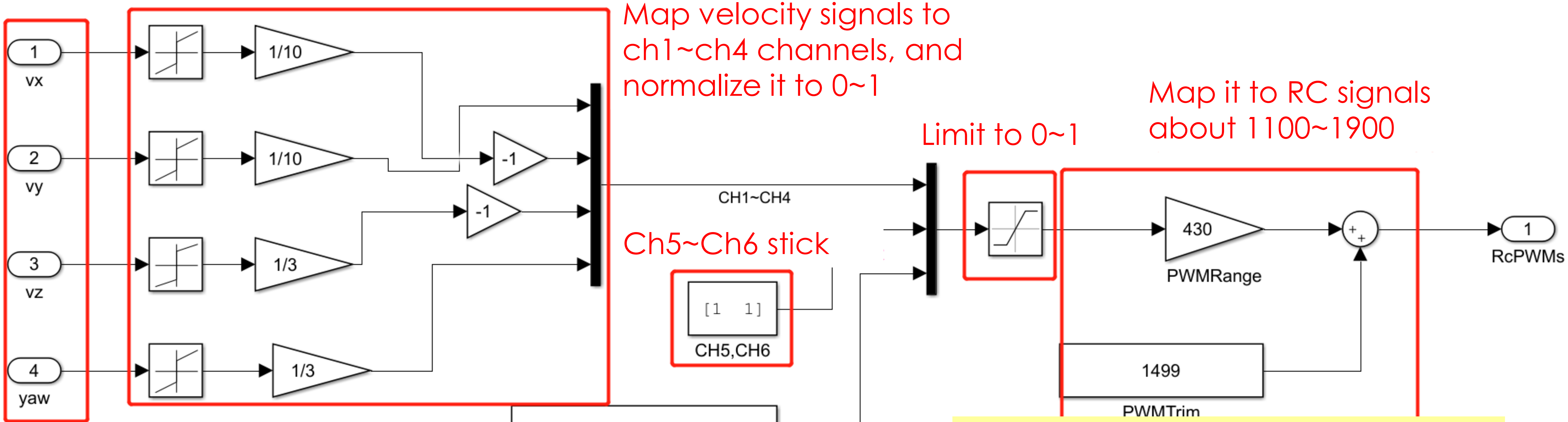
Encode the PWM signals to UDP struct

3. PX4 official controller comm

3.1 Simulink simulates sending the raw data of the RC to control the drone

- Double-click the "**RCControlTrans**" module, you can see the internal information shown below





Map velocity signals to ch1~ch4 channels, and normalize it to 0~1

Limit to 0~1

Map it to RC signals about 1100~1900

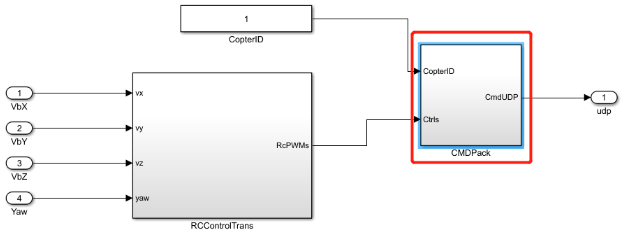
Ch5~Ch6 stick

Body velocity Vx,Vy,Vz,yaw

Fill CH7~CH16 channels

This should be set to be consistent with the RC calibration value, otherwise there will be a response deviation problem

3. PX4 official controller communication

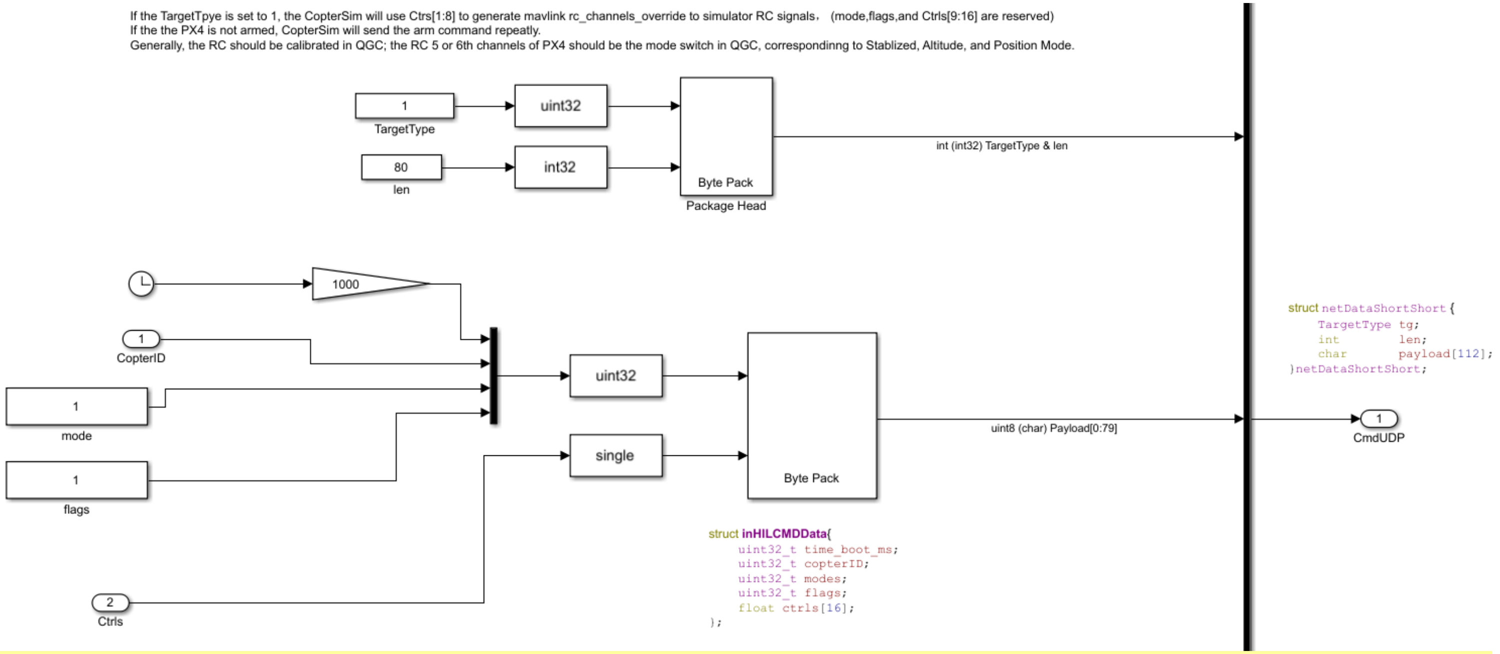


3.1 Simulink simulates sending the raw data of the RC to control the drone

- Double-click to enter the "**CMDPack**" module, you can see the internal information shown in the figure below
- Two-layer encapsulation (to ensure data security)

```
struct inHILCMDData{
    uint32_t time_boot_ms;
    uint32_t copterID;
    uint32_t modes;
    uint32_t flags;
    float ctrls[16];
};

struct netDataShortShort {
    TargetType tg;
    int        len;
    char       payload[112];
}netDataShortShort;
```



Set here to be consistent with the calibration value of the RC system, otherwise there will be a problem of response deviation. First, send the data amplitude to the **inHILCMDData** structure, and then store the structure data in the payload data segment of the **netDataShortShort** structure, and finally send the data.

3. PX4 official controller communication

3.1 Simulink simulates sending the raw data of the RC to control the drone

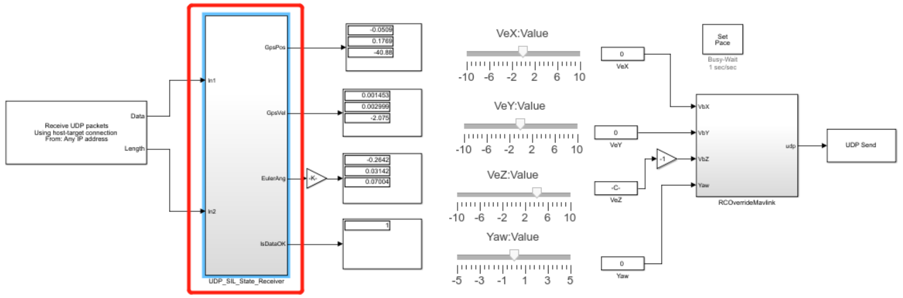
- After CopterSim receives the UDP message from Simulink, it will generate the MAVLink message **RC_CHANNELS_OVERRIDE** (RC channel coverage), and forward it to the Pixhawk module that implements the **RC** signal

RC_CHANNELS_OVERRIDE (#70)

The RAW values of the RC channels sent to the MAV to override info received from the RC radio. A value of UINT16_MAX means no change to that channel. A value of 0 means control of that channel should be released back to the RC radio. The standard PPM modulation is as follows: 1000 microseconds: 0%, 2000 microseconds: 100%. Individual receivers/transmitters might violate this specification.

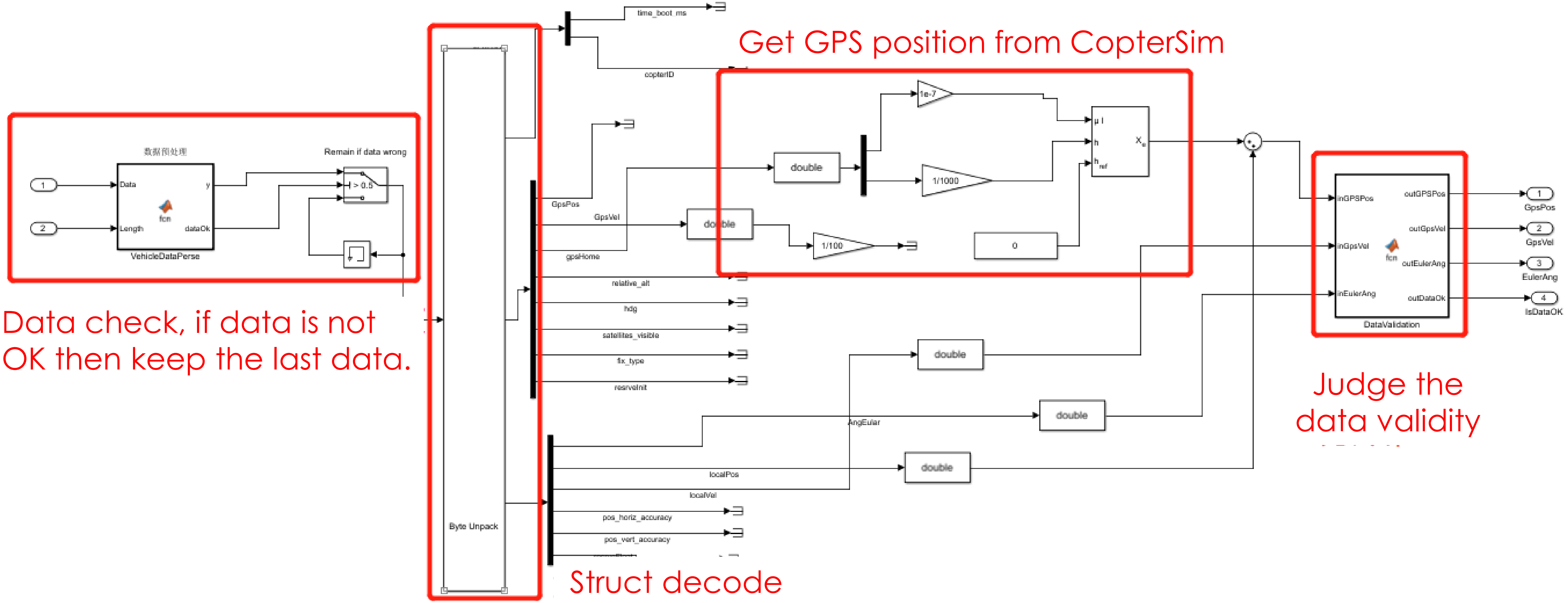
Field Name	Type	Units	Description
target_system	uint8_t		System ID
target_component	uint8_t		Component ID
chan1_raw	uint16_t	us	RC channel 1 value. A value of UINT16_MAX means to ignore this field.
chan2_raw	uint16_t	us	RC channel 2 value. A value of UINT16_MAX means to ignore this field.
chan3_raw	uint16_t	us	RC channel 3 value. A value of UINT16_MAX means to ignore this field.
chan4_raw	uint16_t	us	RC channel 4 value. A value of UINT16_MAX means to ignore this field.
chan5_raw	uint16_t	us	RC channel 5 value. A value of UINT16_MAX means to ignore this field.
chan6_raw	uint16_t	us	RC channel 6 value. A value of UINT16_MAX means to ignore this field.
chan7_raw	uint16_t	us	RC channel 7 value. A value of UINT16_MAX means to ignore this field.
chan8_raw	uint16_t	us	RC channel 8 value. A value of UINT16_MAX means to ignore this field.
chan9_raw **	uint16_t	us	RC channel 9 value. A value of 0 or UINT16_MAX means to ignore this field.
chan10_raw **	uint16_t	us	RC channel 10 value. A value of 0 or UINT16_MAX means to ignore this field.
chan11_raw **	uint16_t	us	RC channel 11 value. A value of 0 or UINT16_MAX means to ignore this field.

3. PX4 official controller commur



3.1 Simulink simulates sending the raw data of the RC

- Go back to the outermost layer and click to enter the "**UDP_SIL_State_Receiver**" module



Get GPS position from CopterSim

Data check, if data is not OK then keep the last data.

Judge the data validity

Struct decode

3. PX4 official controller communication

3.1 Simulink simulates sending the raw data of the RC to control the drone

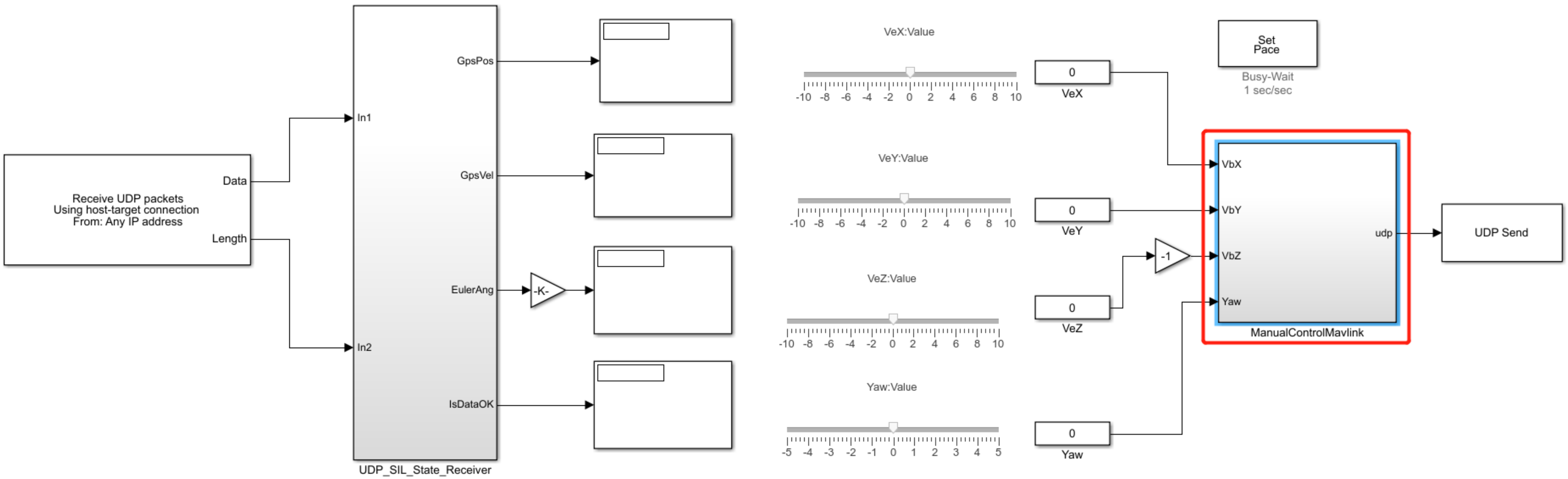
- **Principle:** Receive the data of the **outHILStateData** structure sent by CopterSim via UDP, and extract the value of interest from it
- **CopterSim data resource:** forward MAVLink message from Pixhawk, including **LOCAL_POSITION_NED**, **ATTITUDE**, **HOME_POSITIONE**, **STIMATOR_STATUS**, and etc.

```
struct outHILStateData{ // mavlink data forward from Pixhawk
    uint32_t time_boot_ms; //Timestamp of the message
    uint32_t copterID;    //Copter ID start from 1
    int32_t GpsPos[3];    //Estimated GPS position，lat&long: deg*1e7, alt: m*1e3 and up is positive
    int32_t GpsVel[3];    //Estimated GPS velocity, NED, m/s*1e2->cm/s
    int32_t gpsHome[3];     //Home GPS position, lat&long: deg*1e7, alt: m*1e3 and up is positive
    int32_t relative_alt;  //alt: m*1e3 and up is positive
    int32_t hdg;          //Course angle, NED,deg*1000, 0~360
    int32_t satellites_visible; //GPS Raw data, sum of satellite
    int32_t fix_type;     //GPS Raw data, Fixed type, 3 for fixed (good precision)
    int32_t resrveInit;      //Int, reserve for the future use
    float AngEular[3];    //Estimated Euler angle, unit: rad/s
    float localPos[3];    //Estimated locoal position, NED, unit: m
    float localVel[3];    //Estimated locoal velocity, NED, unit: m/s
    float pos_horiz_accuracy;   //GPS horizontal accuracy, unit: m
    float pos_vert_accuracy; //GPS vertical accuracy, unit: m
    float resrveFloat;      //float,reserve for the future use
}
```

3. PX4 official controller communication

3.2 Simulink simulates sending a normalized RC signal to control the drone

- The previous example sent the raw data of the RC system, so the PWM output value needs to be consistent with the RC calibration value, otherwise control deviation may occur
- Open "**RflySimAPIs\SimulinkControlAPI\ManulControlAPI.slx**", and get a demo with the same function as the previous example. The experiment process is the same, but this demo doesn't need to focus on the RC calibration value



3. PX4 official controller communication

3.2 Simulink simulates sending a normalized RC signal to control the drone

This message is a MAVLink message that implements **MANUAL_CONTROL**. In actual flight, the signal can also be sent through digital transmission to reproduce the control command.

MANUAL_CONTROL (#69)

This message provides an API for manually controlling the vehicle using standard joystick axes nomenclature, along with a joystick-like input device. Unused axes can be disabled an buttons are also transmit as boolean values of their

Field Name	Type	Description
target	uint8_t	The system to be controlled.
x	int16_t	X-axis, normalized to the range [-1000,1000]. A value of INT16_MAX indicates that this axis is invalid. Generally corresponds to forward(1000)-backward(-1000) movement on a joystick and the pitch of a vehicle.
y	int16_t	Y-axis, normalized to the range [-1000,1000]. A value of INT16_MAX indicates that this axis is invalid. Generally corresponds to left(-1000)-right(1000) movement on a joystick and the roll of a vehicle.
z	int16_t	Z-axis, normalized to the range [-1000,1000]. A value of INT16_MAX indicates that this axis is invalid. Generally corresponds to a separate slider movement with maximum being 1000 and minimum being -1000 on a joystick and the thrust of a vehicle. Positive values are positive thrust, negative values are negative thrust.
r	int16_t	R-axis, normalized to the range [-1000,1000]. A value of INT16_MAX indicates that this axis is invalid. Generally corresponds to a twisting of the joystick, with counter-clockwise being 1000 and clockwise being -1000, and the yaw of a vehicle.
buttons	uint16_t	A bitfield corresponding to the joystick buttons' current state, 1 for pressed, 0 for released. The lowest bit corresponds to Button 1.

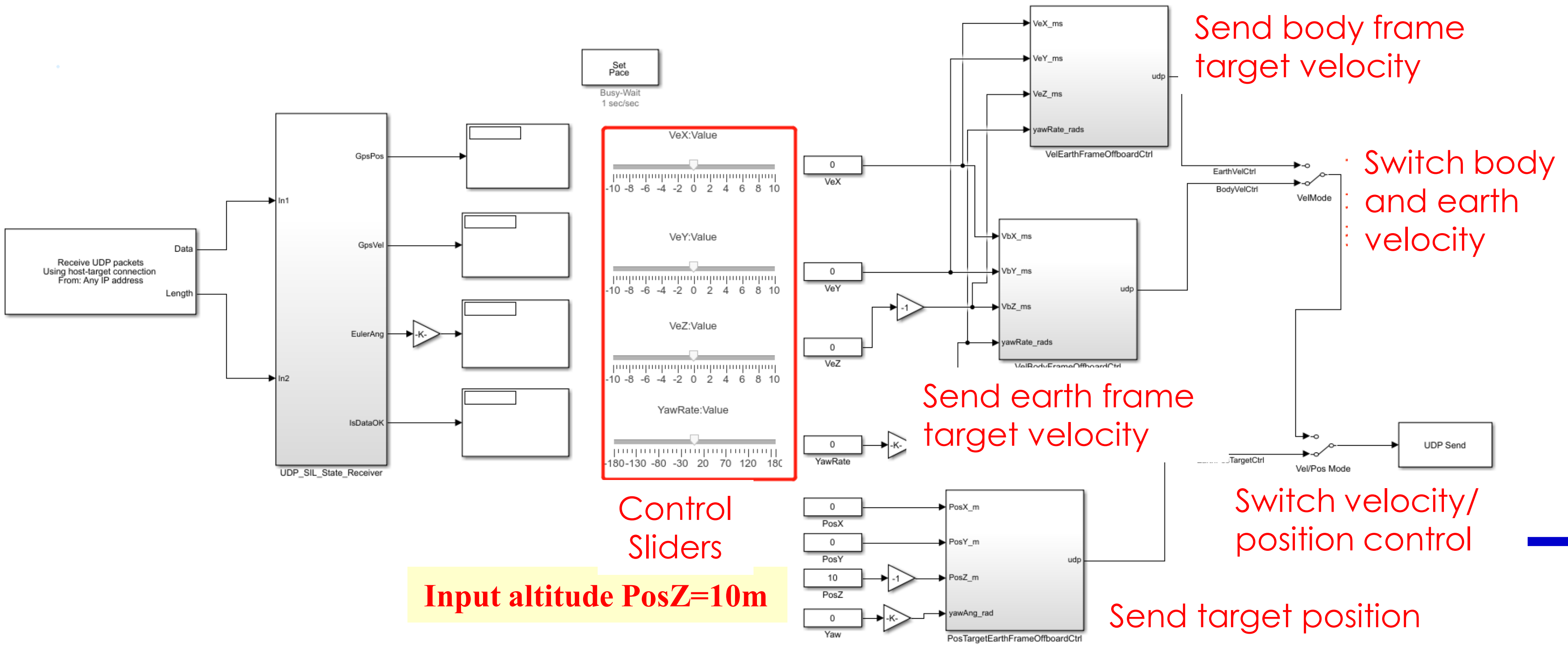
3. PX4 official controller communication

3.3 Simulink simulates sending a controlled drone using Offboard mode

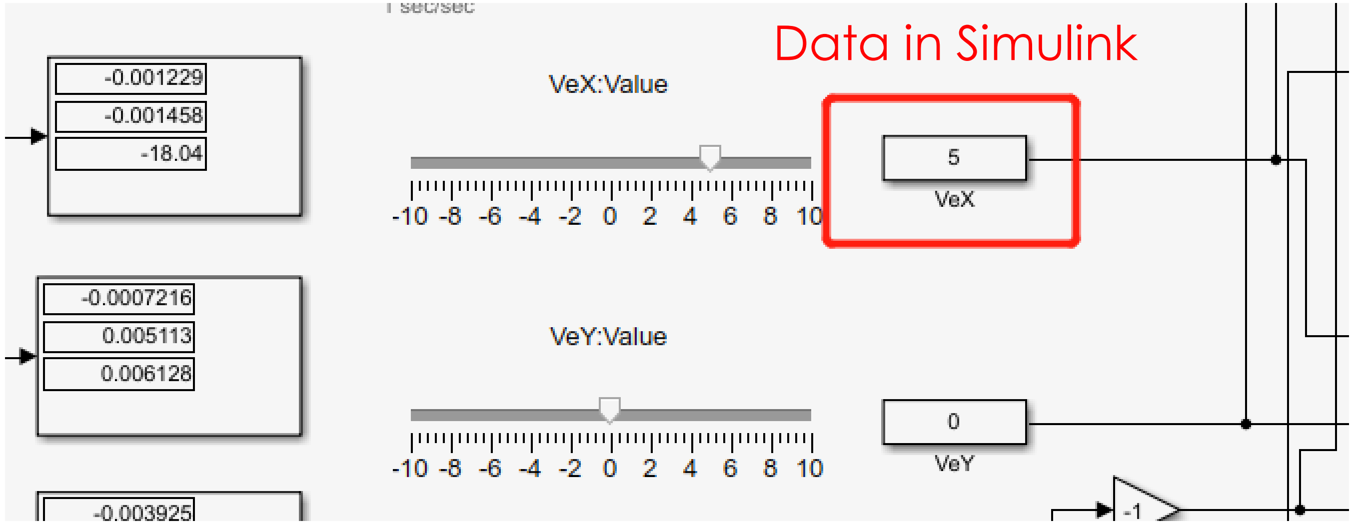
- Offboard mode is a control mode of drones. Usually the onboard computer or ground computer (host computer) is used to control the speed, position, attitude of the drone in real time. The drone can be treat as a whole object, focusing on the top-level vision and swarm algorithm development.
- The RC signal control cannot quantitatively control the speed of the drone, so it is not convenient to use the Offboard control mode, but the RC signal control mode is the closest way to human operation, and it has better effects in some high-maneuver performance control.
- The follow-up experiments of this course are all to see the drone as a whole sub-object (receive and implement speed/position/acceleration/route and other commands), so the subsequent series of experiments will mainly use the Offboard mode to control the drone. Since the Offboard mode is a function provided by the official PX4 controller, you need to make sure that Pixhawk is running the official firmware (mentioned in the previous settings).

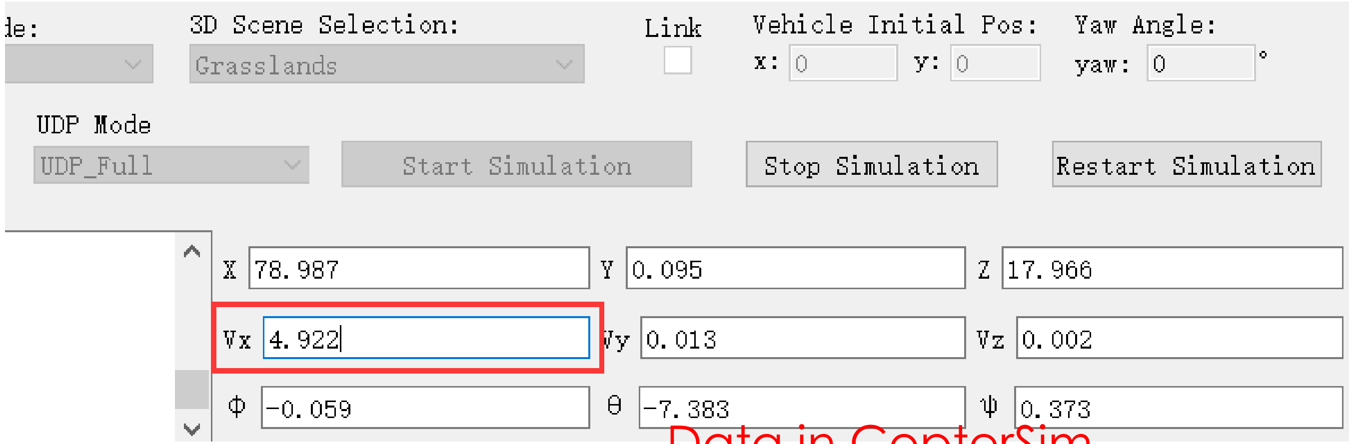
3.3 Simulink simulates sending a controlled drone using Offboard mode

- Enable CopterSim's HIL (or SIL) simulation system
- Open "**RflySimAPIs\SimulinkControlAPI\OffboardAPI.slx**" to run, you can see that the drone will automatically take off to a height of 10m at first, then switch the "**speed/position control**" switch, drag the slider, you can enter speed 5m/s on direction X (or drag Slider **VeX** to the desired value), observe whether the speed is consistent with the given speed in QGC



3. PX4 official controller comm





3. PX4 official controller communication

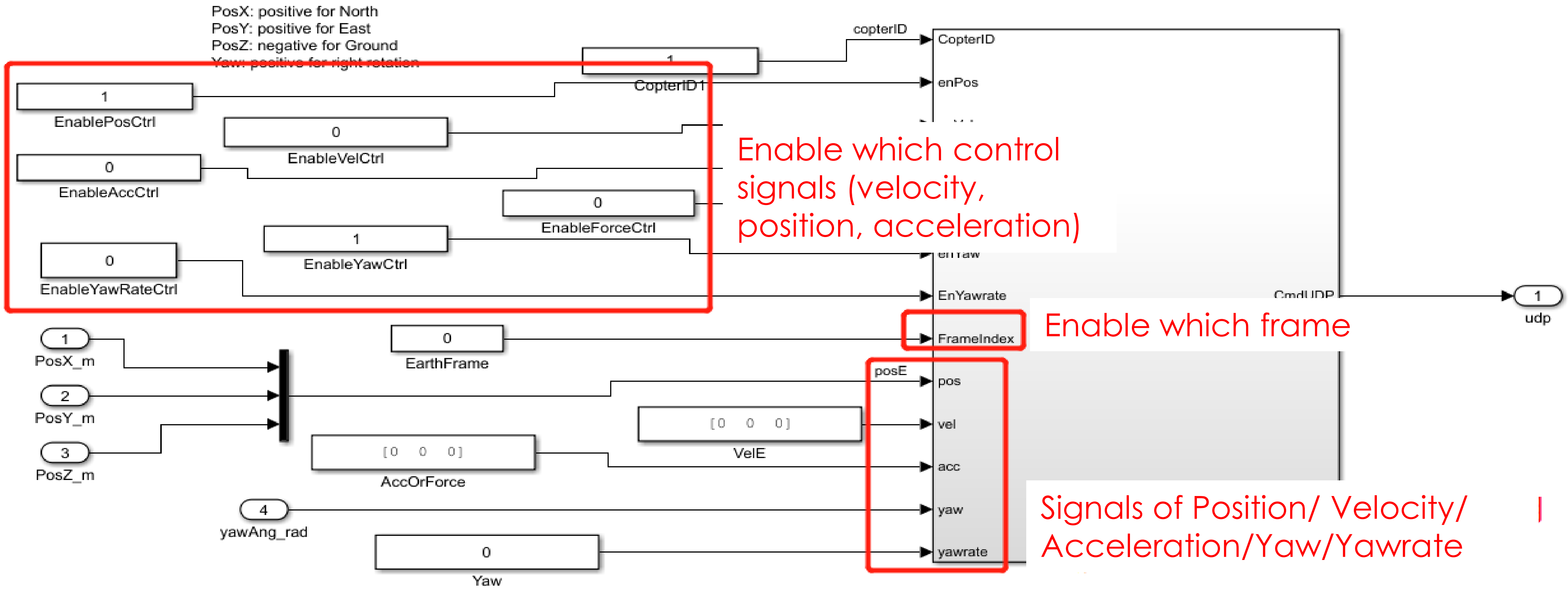
3.3 Simulink simulates sending a controlled drone using Offboard mode (recommended)

- **Principle**: This example will make PX4 enter the Offboard mode, then send a MAVLink message of **SET_POSITION_TARGET_LOCAL_NED** to control the speed, position, and angle of the drone. This command does not require the drone to perform RC calibration or modal settings, just specify the specified speed or position directly.
- Three module examples are shown in the **OffboardAPI.slx** file. **VelEarthFrameOffboardCtrl** is the speed control module in the earth coordinate system
- **VelBodyFrameOffboardCtrl** is the speed control in the body coordinate system
- **PosTargetEarthFrameOffboardCtrl** is the position control module in the earth coordinate system (given the relative take-off point x, y, z coordinates, the drone will automatically fly to this point and hover).
- The implementation methods of the three modules are exactly the same, except that several parameters of the Offboard message (position/speed control mode & body/earth coordinate system) are different. The Offboard control command is based on the disarmed position as the **Home_Position** coordinate as the origin relative coordinate (**Local_Position**), so the position command sent refers to the relative coordinate value of flying to the relative armed position.

3. PX4 official controller communication

3.3 Simulink simulates sending a controlled drone using Offboard mode (recommended)

- The Offboard mode interface of Simulink is shown in the figure below, you can combine the commands that need to be controlled by yourself



3. PX4 official controller communication

3.3 Simulink simulates sending a controlled drone using Offboard mode https://mavlink.io/en/messages/common.html#SET_POSITION_TARGET_LOCAL_NED achieve method of MAVLink message shows as below picture

SET_POSITION_TARGET_LOCAL_NED (#84)

[Message] Sets a desired vehicle position in a local north-east-down coordinate frame. Used by an external controller to command the vehicle (manual controller or other system).

Field Name	Type	Units	Values	Description
time_boot_ms	uint32_t	ms		Timestamp (time since system boot).
target_system	uint8_t			System ID
target_component	uint8_t			Component ID
coordinate_frame	uint8_t		MAV_FRAME	Valid options are: MAV_FRAME_LOCAL_NED = 1, MAV_FRAME_LOCAL_OFFSET_NED = 7, MAV_FRAME_BODY_NED 8, MAV_FRAME_BODY_OFFSET_NED = 9
type_mask	uint16_t		POSITION_TARGET_TYPEMASK	Bitmap to indicate which dimensions should be ignored by the vehicle.

3. PX4 official controller communication

x	float	m		X Position in NED frame
y	float	m		Y Position in NED frame
z	float	m		Z Position in NED frame (note, altitude is negative in NED)
vx	float	m/s		X velocity in NED frame
vy	float	m/s		Y velocity in NED frame
vz	float	m/s		Z velocity in NED frame
afx	float	m/s/s		X acceleration or force (if bit 10 of type_mask is set) in NED frame in meter / s^2 or N
afy	float	m/s/s		Y acceleration or force (if bit 10 of type_mask is set) in NED frame in meter / s^2 or N
afz	float	m/s/s		Z acceleration or force (if bit 10 of type_mask is set) in NED frame in meter / s^2 or N
yaw	float	rad		yaw setpoint
yaw_rate	float	rad/s		yaw rate setpoint

Content

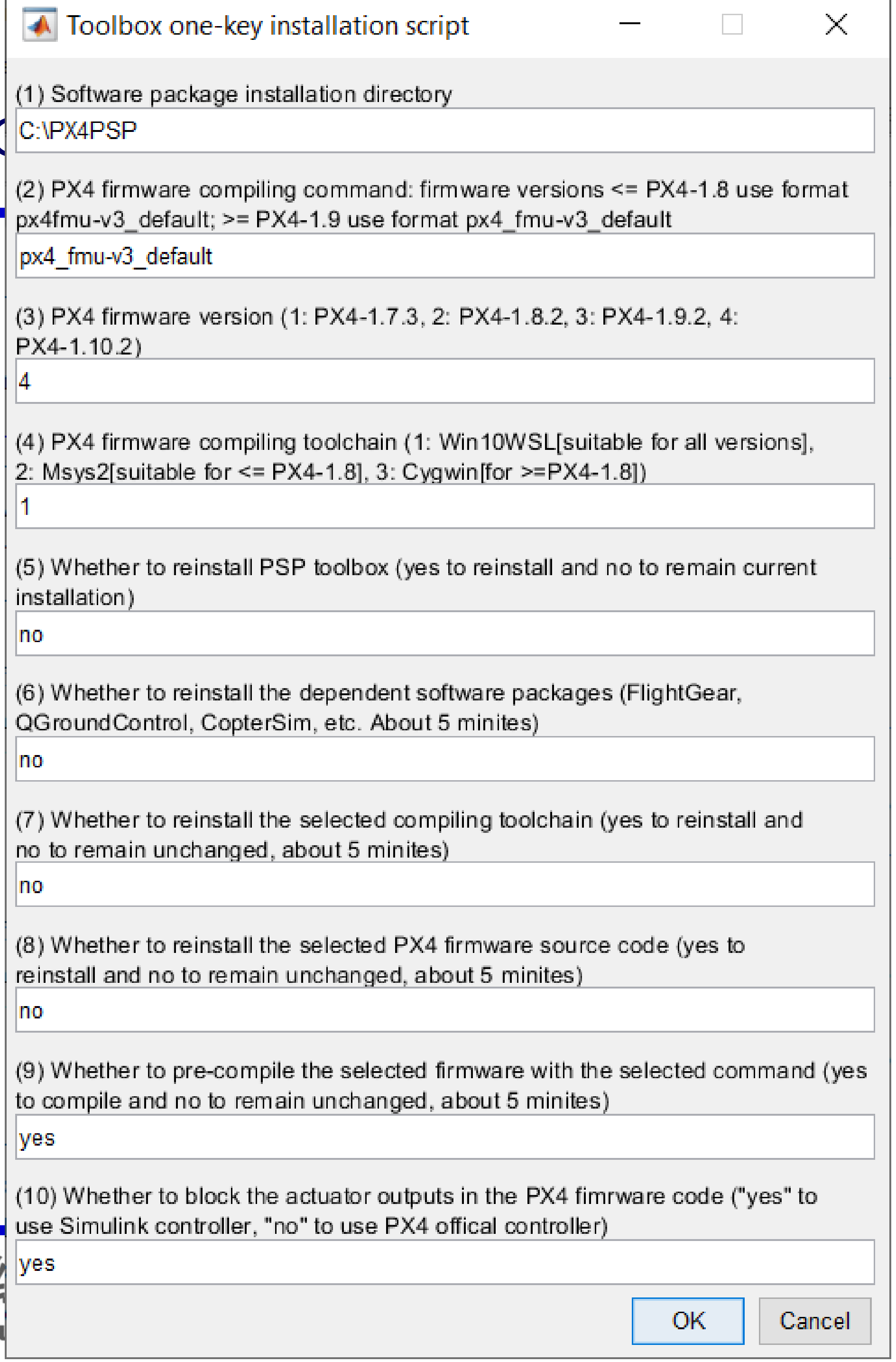
Path of demo source code of this section: “RflySimAPIs\SimulinkControlAPI\Rfly_API_CTRL”

4. Code generation controller c

4.1 Automatic code generation environment configuration

- The Pixhawk control algorithm generated for Simulink can also be controlled through the QGC/Simulink API. To run the example in this section, you need to use Simulink code to generate the controller, so you need to re-run the installation script, as shown in the right figure (RflySim Advanced Edition) to block the PX4's own output. **Note**: Please use **px4fmu-v3_default**, **PX4-1.7.3** firmware, and **Msys2** compiler for RflySim basic version
- **Note**: The compilation command needs to be modified according to your own hardware
- **Note**: The code automatically generated by Simulink currently does not support the **px4_sitl_default** compilation command, so it does not support PX4 SITL simulation. The examples in this section need to use Pixhawk hardware for HIL simulation.

Note: The content of this section is mainly aimed at the external communication problem of the controller developed with Simulink in the course "RflySim_Lesson_02_Flight_Control_Experiments.pdf" (i.e., the series of experiments in the book "Multcopter Design and Control Practice").



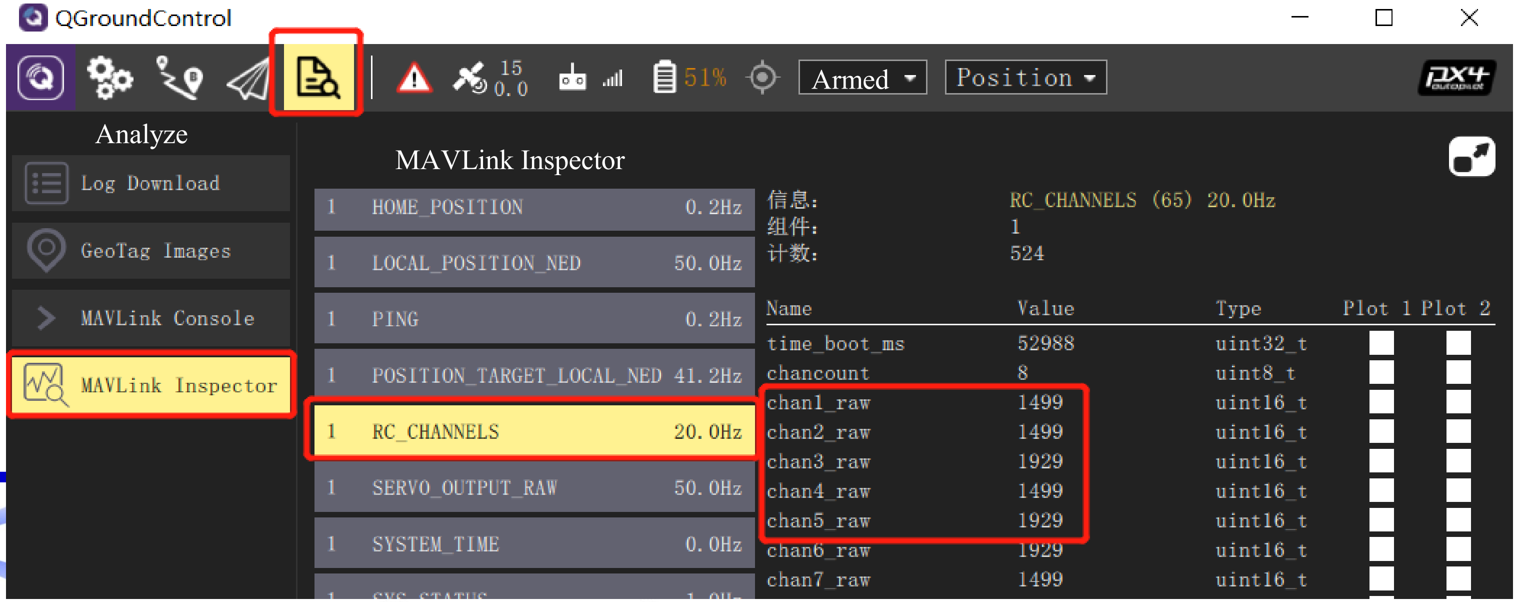
4. Code generation controller communication

4.2 Use the RC signal generated by Simulink to control the controller designed by Simulink

You can use the RC signal output by Simulink to control our own designed attitude controller, such as "**RflySimAPIs\FlightControlExpCourse\code\e0\3.DesignExps\Exp4_AttitudeSystemCodeGen_old.slx**"

First, open "**Exp4_AttitudeSystemCodeGen_old.slx**" to compile the firmware and burn Pixhawk, then use CopterSim to connect to Pixhawk and start the HIL simulation (the advanced version can directly run the desktop **HITLRun** and quickly open the HIL).

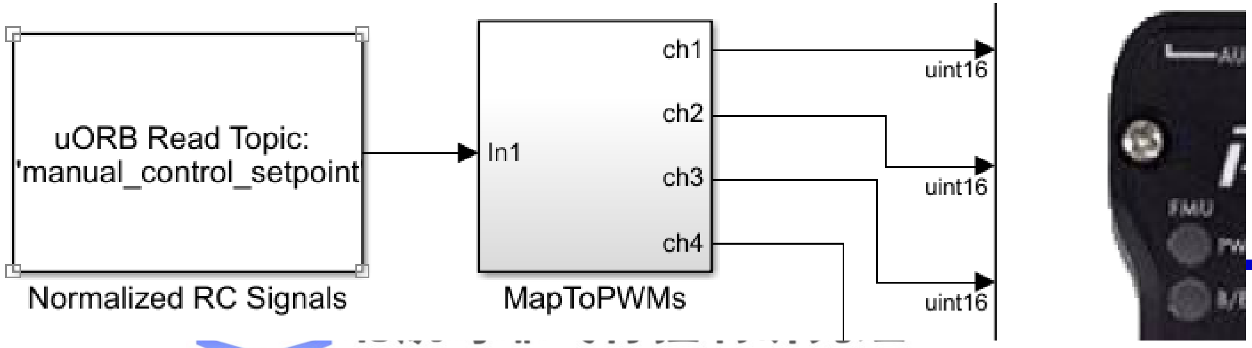
- Open and run the "**RadioControlAPI.slx**" file, you can control the drone to take off and move forward and backward. Data can also be observed in QGC



4. Code generation controller communication

4.2 Use the RC signal generated by Simulink to control the controller designed by Simulink

- **Principle**: To further explain the principle, the **RadioControlAPI.slx** file sends the MAVLink message of **RC_CHANNELS_OVERRIDE** to Pixhawk, and the RC module used in **Exp4_AttitudeSystemCodeGen_old.slx** will receive the MAVLink message, so it can respond.
- Similarly, if you need your own generated code to respond to the input in **ManulControlAPI.slx** and **OffboardAPI.slx**, you need to receive the corresponding uORB messages in the Simulink controller respectively. Among them, **ManulControlAPI.slx** corresponds to the uORB message of "**MANUAL_CONTROL_SETPOINT**", and **OffboardAPI.slx** corresponds to the uORB message of "**POSITION_SETPOINT**".
- **Note**: **ManulControlAPI.slx** corresponds to the demo of "**Exp4_AttitudeSystemCodeGen.slx**" code generation, and can respond to the "**MANUAL_CONTROL_SETPOINT**" message.



4. Code generation controller communication

4.3 Send and receive customized messages using Simulink

- The RflySim platform also provides an external program to communicate with its Simulink controller. It sends uORB messages of **rfly_ctrl.msg** (see **Firmware\msg** folder). It is defined as follows:

```
uint64 timestamp                        # time since system start (microseconds)
uint64 flags                            # control flag
uint8 modes                   # mode flag
float32[16] controls                    # 16D control signals
```

- The uORB message can be sent by an external program to send MAVLink messages to achieve the "**HIL_ACTUATOR_CONTROLS**" message, and its 16-dimensional control amount corresponds to the following definition.

HIL_ACTUATOR_CONTROLS (#93)

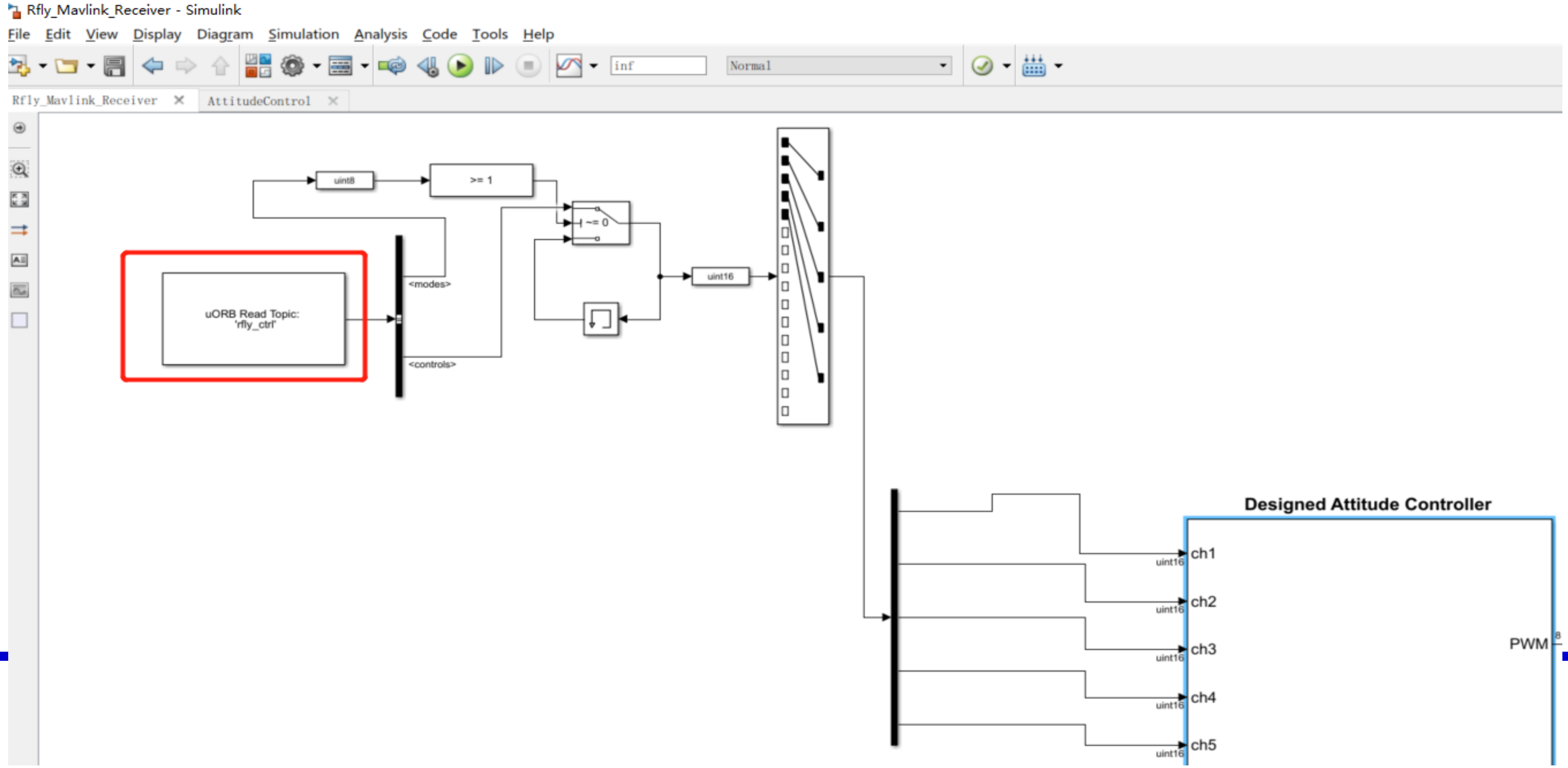
Sent from autopilot to simulation. Hardware in the loop control outputs (replacement for HIL_CONTROLS)

Field Name	Type	Units	Values	Description
time_usec	uint64_t	us		Timestamp (UNIX Epoch time or time since system boot). The receiving end can infer timestamp format (since 1.1.1970 or since system boot) by checking for the magnitude the number.
controls	float[16]			Control outputs -1 .. 1. Channel assignment depends on the simulated hardware.
mode	uint8_t		MAV_MODE_FLAG	System mode. Includes arming state.
flags	uint64_t			Flags as bitfield, reserved for future use.

4. Code generation controller communication

4.3 Send and receive customized messages using Simulink

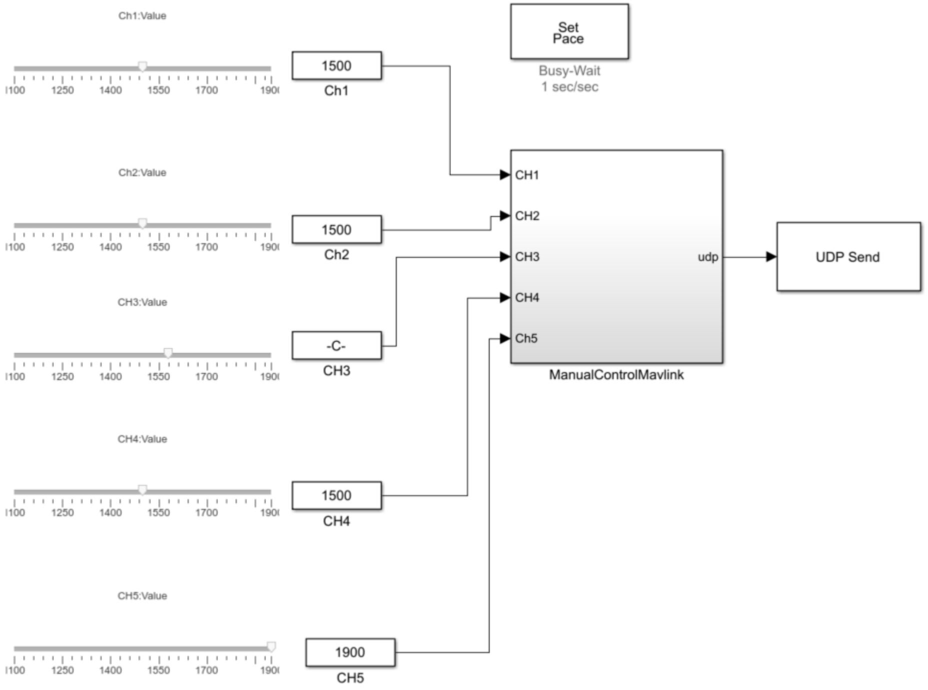
- Open **RflySimAPIs\SimulinkControlAPI\Rfly_API_CTRL\Rfly_ Mavlink_Receiver.slx** with MATLAB, compile the generated code, and burn it to Pixhawk. As shown in the figure below, it received the uORB message of **rfly_ctrl**, replacing the original RC signal.



4. Code generation controller communication

4.3 Send and receive customized messages using Simulink

- Enable the hardware-in-the-loop simulation of CopterSim and Pixhawk, run the "**Rfly_API_CTRL\Rfly_Mavlink_API_Sender.slx**" file, which can send control signals to CopterSim, and CopterSim will forward the "**HIL_ACTUATOR_CONTROLS**" MAVLink message to Pixhawk, and then Pixhawk will publish it to '**rfly_ctrl**' in the pool, used by the px4_simulink_app generated by the code in the above figure. As shown in the figure below, this slx demo simulates the RC data of CH1~Ch5 and sends it to the rfly_ctrl message.
- The experimental effect of this demo is consistent with the operation process of the analog RC signal control PX4 official controller in **Section 3.1**
- The experimental phenomenon is the same as the effect of sending the RC signal to the Simulink code generation controller in **Section 4.2**, because the two examples both send the RC signal, but the communication path is different.
- **Note**: In the case of real flight, just use MAVLink to send **HIL_ACTUATOR_CONTROLS** message to the flight controller, this module can send data to the control



Thanks