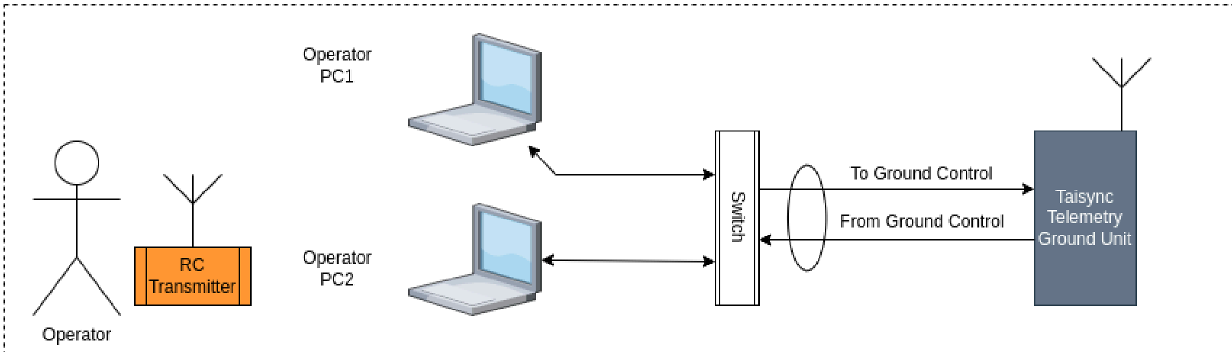
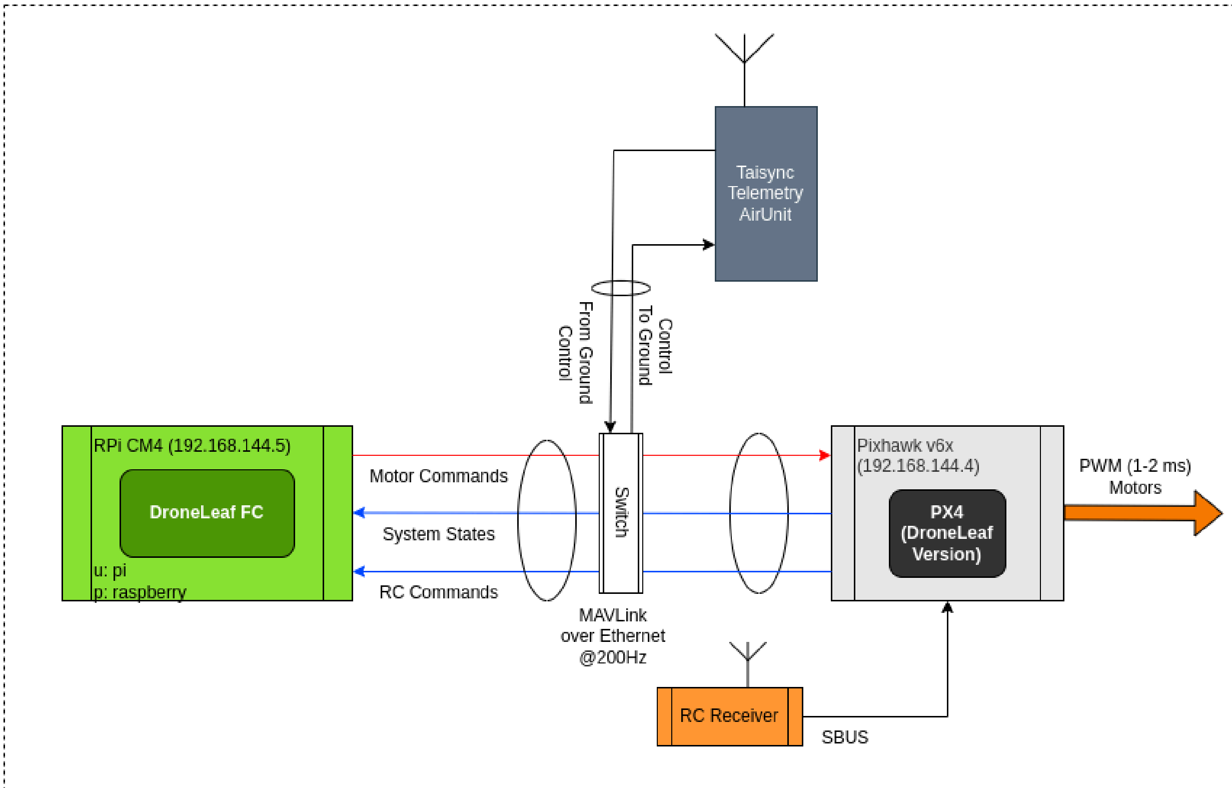
System Overview

Architecture

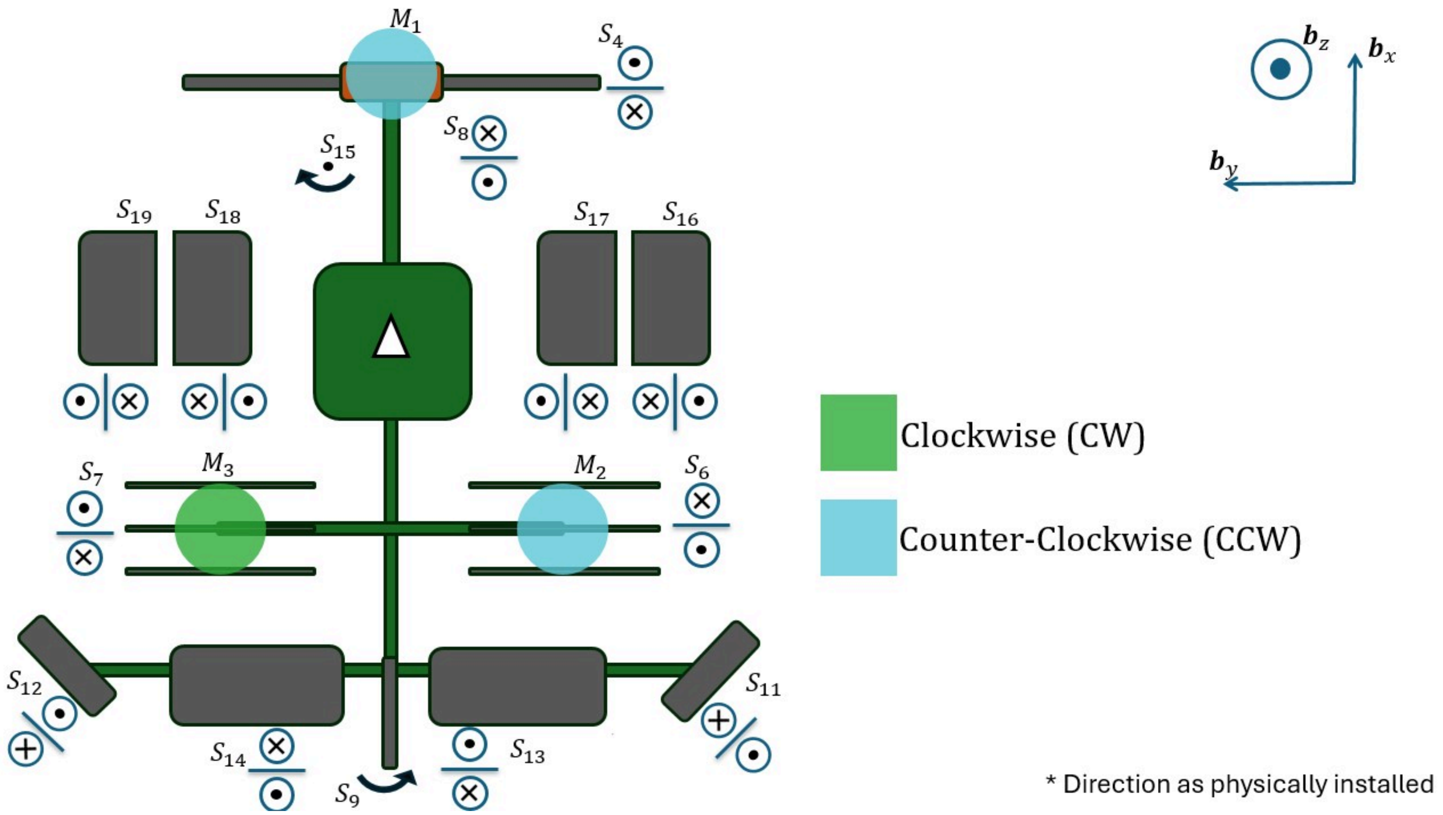
The general system archetichture is given as follows:





Convention

This convention is what to expect when moving knobs in QGroundControl after performing all PX4 settings mentioned below.



Note: Additional actuators not used in the most recent design might be present in the diagram. We keep them their

PX4 Settings

Custom PX4 Firmware and Parameters

Request the latest PX4 firmware from DroneLeaf. Once uploaded through QGC, you need to set the `SYS_AUTOSTART` parameter to `4999` .

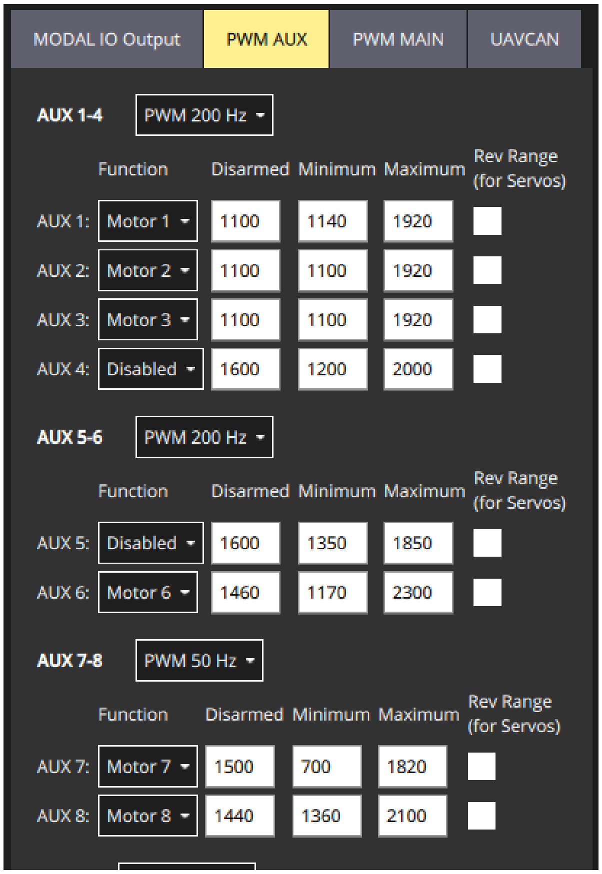
Physical Asset assignment

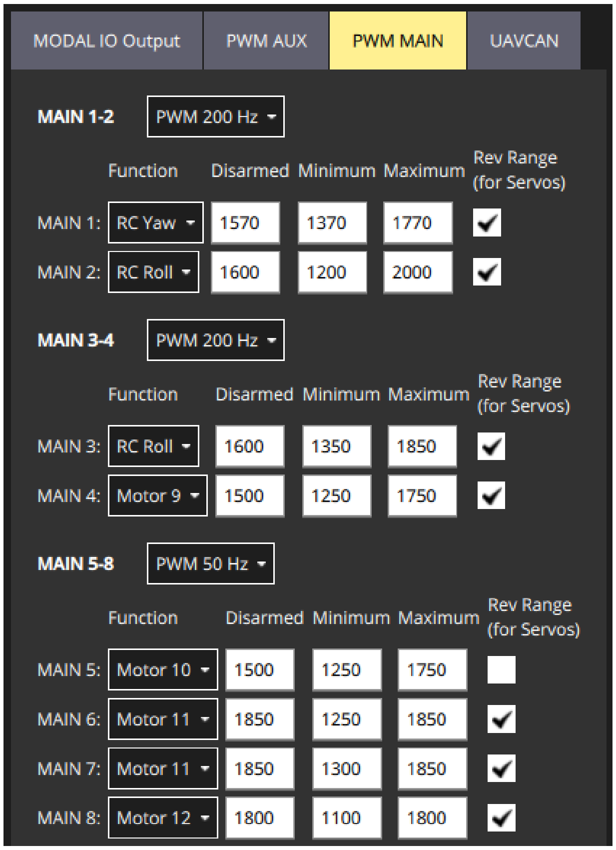
Reference	Function	Pixhawk Pin	Signal Source
M1	Front Motor	AUX 1	OFFBOARD MAVLink 1
M2	Rear Motor R	AUX 2	OFFBOARD MAVLink 2
M3	Rear Motor L	AUX 3	OFFBOARD MAVLink 3
S4	Canard	AUX 4	OFFBOARD MAVLink 4
S5	--------	AUX 5	OFFBOARD MAVLink 5
S6	Vane R	AUX 6	OFFBOARD MAVLink 6
S7	Vane L	AUX 7	OFFBOARD MAVLink 7
S8	M1 Tilt Servo	AUX 8	OFFBOARD MAVLink 8
S9	Rudder	MAIN 1	RC Yaw
S10	--------	MAIN 1	RC Yaw
S11	Aileron R	MAIN 2	RC ROLL
S12	Aileron L	MAIN 3	RC ROLL

Reference	Function	Pixhawk Pin	Signal Source
S13	Elevator R	MAIN 4	OFFBOARD MAVLink 9
S14	Elevator L	MAIN 5	OFFBOARD MAVLink 10
S15	Steering	RC Direct	RC AUX 1
S16	Door R/R	MAIN 8	OFFBOARD MAVLink 12
S17	Door R/L	MAIN 6	OFFBOARD MAVLink 11
S18	Door L/R	MAIN 7	OFFBOARD MAVLink 11
S19	Door L/L	MAIN 8	OFFBOARD MAVLink 12

Actuation PX4 settings

Maximum/Minimum limits for each actuator are set in the QGC. See QGC screenshots below.





RC Settings

Used Controller is Futaba T18SG. ID: T18SG-01.

RC Channel assignment

See `Systems/RC/general.json` for updated HEAR configuration.

RC Channel	PX4 Assignment	Used in HEAR FC	Futaba T18SG Assignment
CH1	RC ROLL	Yes	J1
CH2	RC PITCH	Yes	J2
CH3	RC THROTTLE	Yes	J3
CH4	RC YAW	Yes	J4
CH5			
CH6		Yes (CH_number_for_forward_motion)	RS
CH7			
CH8	RC AUX 2	Yes (CH_number_for_switch_vtol_mode)	SA
CH9			
CH10	RC AUX 1		LD
CH11	Kill switch		SF
CH12			

RC Switches Settings

RC Switch/Knob	Max Val	Min Val	Max Val Pos	Min Val Pos
CH1	+100	-100	West	East
CH2	+100	-100	North	South
CH3	+100	-100	North	South
CH4	+100	-100	West	East
CH6	+100	-100	South	North
CH8	+140	0	South	Middle
CH10	+100	-100	East	West
CH11	+100	-100	South	North

- Top of the RC points north

Surfaces and Servos calibration

Calibration values

Actuator	Positive Set Angle Limit	Negative Set Angle Limit	Positive Mechanical Limit	Negative Mechanical Limit	PWM at the Positive Set Angle	PWM at the Negative Set Angle	PWM at the Positive Mechanical Limit	PWM at the Negative Mechanical Limit	Zero Angle Reference wrt datum
S4	15	15							
S6	40	40							
S7	40	40							
S8	10	70							
S9	45	45							
S13	40	40							
S14	40	40							

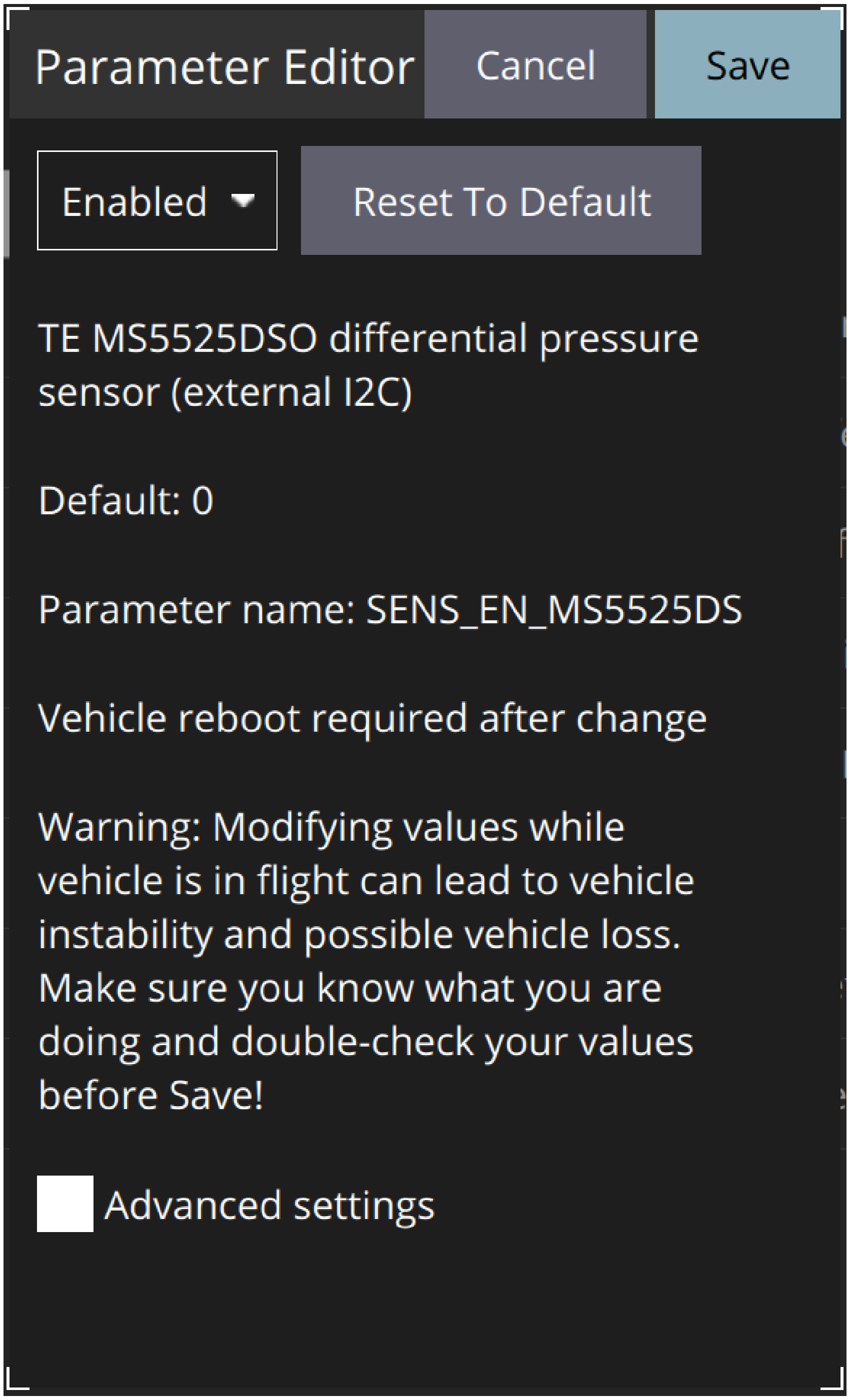
- For PWM limits corresponding to the physical angle limits, refer to the PX4 actuator settings panes above.
- All angles are in degrees.

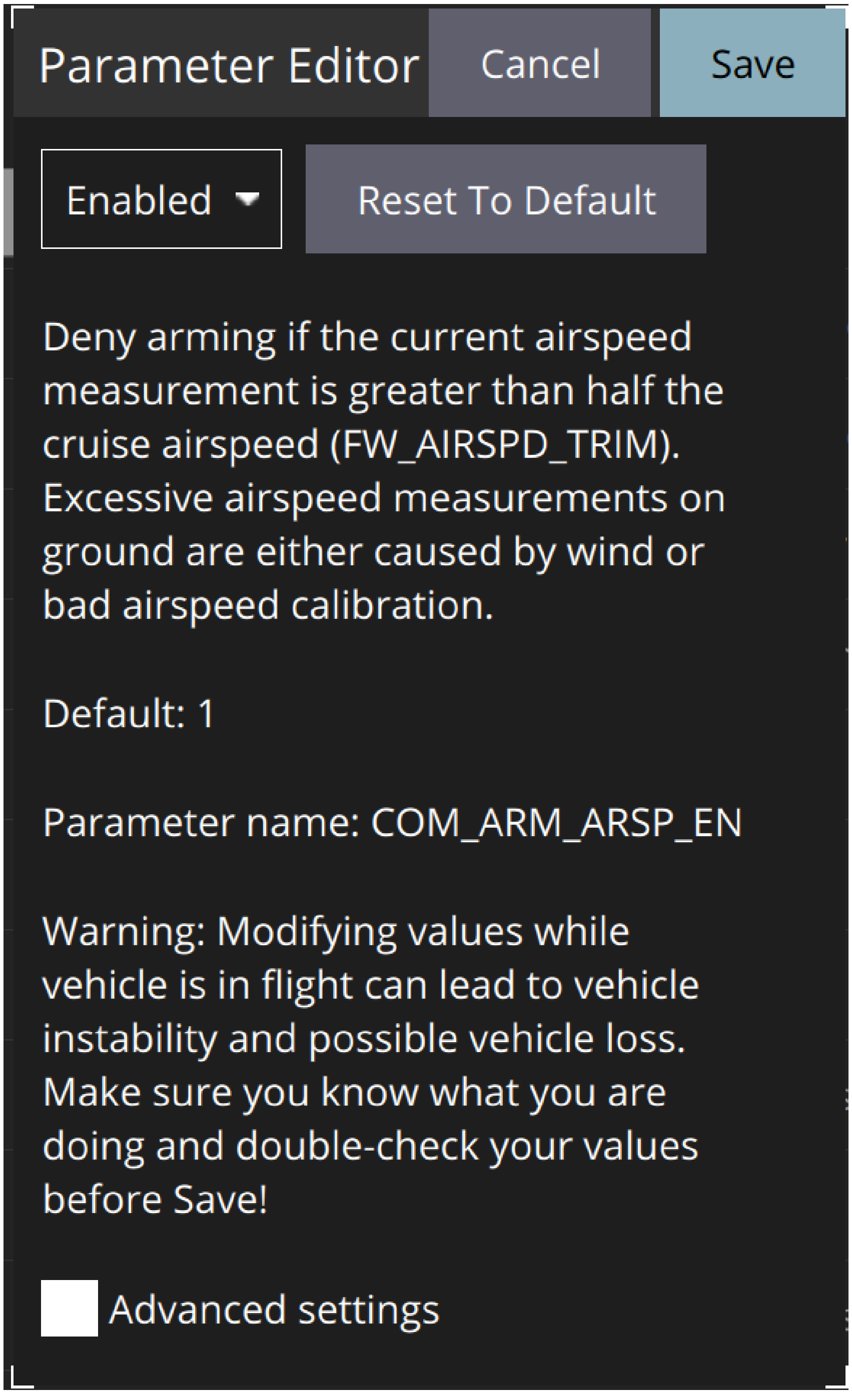
Other Components

Airspeed sensor

airspeed_selector start
ms4525do start -X
SENS_EN_MS4525DO 1
SYS_HAS_NUM_ASPD 1

calibration:
ASPD_SCALE_1
FW_ARSP_SCALE_EN
CAL_AIR_TUBED_MM
CAL_AIR_TUBELEN
SENS_DPRES_ANSC
SENS_DPRES_OFF





LeafFC

DOT Graphs

The DOT graphs for each of the flight systems are in the `DotGraphs` folder.

There are two graphs characterizing each system in LeafFC:
1- Sync Graph: These are synchronous connections that computes every 5 milliseconds (sampling period).
2- Async Graph: These are asynchronous connections that get called only when needed, e.g. transition event.

An online DOT graph viewer can be used to view these graphs. A viewer we recommend is Edotor.

Topics Inspection

From the DOT graphs, follow the subsystems and look for ROS publisher blocks (have left facing arrow shapes) and listen to them in the CLI. Use `rostopic echo /xyz` where `/xyz` is the topic name.

For array ROS types, it is possible to output a specific array index, e.g. `rostopic echo /KU_TriCopter_vtol_manual_control_01/px4_rc_to_ori_thrust/rc_raw/data[0]` to output the first array element.

Configuration files

LeafFC reads the configuration files at LeafFC boot-up. Hence LeafFC needs to be restarted to apply settings updates.

The configuration files are all located in `HEAR_Configurations` folder in the `home` directory of the Raspberry Pi.

The configurations files relevant to KU Snono VTOL are located in the following files:

1. **RC Settings**: `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/px4_rc_to_ori_thrust/general.json`
2. **VTOL/Fixed-wing Specific Settings**: `HEAR_Configurations/Systems/VTOL/general.json` and `general.json` files in the directory sub-folders.
3. **Snono UAV Type Specific Settings**: `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/general.json` .
4. **Actuation Allocation Settings**: `HEAR_Configurations/Allocation_types/general.json` .
5. **Actuation Post Allocation Bias Settings**: `HEAR_Configurations/Allocation_types/PostAllocationMotorBias/general.json`

Note: Items `3-5` above are based on MATLAB auto-configurations scripts.

MATLAB based auto-configuration

Once the aircraft mechanical trimming and angle measurements has been taken, you could follow these steps to get configuration files updated with the correct allocation and trimming values.

1. Update the input files:
   a. `set_PWM_ranges.m`
   b. The design script in `/Motors_Allocation/designs` (create a new `.m` file for every design).
   c. Change in `main.m` the variable `design_name` to the correct design.
2. Run `main.m` .
3. Copy the generated files to the Raspberry PI and replace the existing ones:
   a. `ToConfigurations/general.json` to `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/general.json` on RPi.
   b. `ToConfigurations/Allocation_types/general.json` to `HEAR_Configurations/Allocation_types//general.json` on RPi.
   c. `ToConfigurations/Allocation_types/PostAllocationMotorBias/general.json` to `HEAR_Configurations/Allocation_types/PostAllocationMotorBias/general.json` on RPi.

Major Subsystems' Settings

PX4 RC to Orientation and Throttle mapping

The RC maps are stored in `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/px4_rc_to_ori_thrust/general.json` .

For example:

1. Roll/Pitch: modify `map_for_roll` and `map_for_pitch` to map from the RC input range to the desired control angle in radians.
2. Yaw rate: modify `map_for_yaw_rate` from the RC input range to the desired control rate angle in radians per second.
3. Forward slider: modify `map_for_fwd` .
4. Select the mapped RC channel from `CH_number_for_x` if needed.

State Estimator

Relays PX4 orientation and orientation rate estimates. See the system DOT graph for available topics

Control System

You can configure the PID parameters. For the current version it is only permissible to change `kp` and `kd` which can be changed in `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/px4_rc_to_ori_thrust/PID/` folder.

1. Pitch controller: change `kp` and `kd` in `pitch.json` .
2. Roll controller: change `kp` and `kd` in `roll.json` .
3. Yaw Rate controller: change `kp` in `yawrate.json` .

Important: The controller gains are loaded from the mission control PC `HEAR_Configurations` , NOT the RPi `HEAR_Configurations` .

VTOL Actuation System

The actuation system has been specifically designed for the Snono VTOL. The actuation system functionalities are detailed below.

Allocation logic

The allocation is performed at two modes:

VTOL:

1. `TriCopterKU_vtol_manual_control_gain_positive` : Applies in the VTOL mode when the input to the allocation matrix is positive.
2. `TriCopterKU_vtol_manual_control_gain_negative` : Applies in the VTOL mode when the input to the allocation matrix is negative.

Fixed Wing:

1. `TriCopterKU_vtol_manual_control_plane_gain_positive` : Applies in the fixed-wing mode when the input to the allocation matrix is positive.
2. `TriCopterKU_vtol_manual_control_plane_gain_negative` : Applies in the fixed-wing mode when the input to the allocation matrix is negative.

The allocation is performed by multiplying the vector consisting of:
[
Roll,
Pitch,
Yaw,
Throttle,
Forward,
Roll Feedforward,
Pitch Feedforward,
Yaw Feedforward
]

by the allocation matrix (Outputs x Inputs), in our case (10 x 8) and the outputs are the motor inputs sent to PX4. Note that in our case we send 12 motor commands to PX4 with 10 comming from allocation and 2 additional for the doors making a total of 12. This is since the doors actuators are not involved in allocation.

The Feedforward signals are not passed by the feedback system.

Example
Let us take for example a throttle value of 0.5 with the following positive VTOL matrix:
[
[
0,

-0.7071,
0,
0.45260087506076807,
0,
0,
0,
0
],
[
-0.7071,
0.63266842105263144,
0,
1,
0,
0,
0,
0
],
[
0.7071,
0.63266842105263144,
0,
1,
0,
0,
0,
0
],
[
0,
0,
0,
0,
0,
0,
0,
0
],
[
0,
0,
0,
0,
0,
0,
0,
0
],
[
0,
0,
0.31944444444444442,

0,
0.11979166666666674,
0,
0,
0
],
[
0,
0,
0.31944444444444442,
0,
-0.12013888888888889,
0,
0,
0
],
[
0,
0,
0,
0,
0.65116279069767469,
0,
0,
0
],
[
0,
0,
0,
0,
0,
-0.489010989010989,
0.510989010989011,
0
],
[
0,
0,
0,
0,
0,
0.50609756097560976,
0.50609756097560976,
0
]
]

Then:

M1 would receive a command of 0.5 x 0.4526= 0.2263 due to throttle command.

M2 would receive 1 x 0.4526= 0.4526 due to throttle command.

M3 would receive 1 x 0.4526= 0.4526 due to throttle command.

S4-S10 would receive zero.

Prioritized allocation

In VTOL mode, prioritized allocation applies for yaw and forward inputs leading to vanes output. With prioritized allocation yaw overrides forward action when vanes reach saturation.

Doors Control

The doors closing sequence is characterized by the parameters in `HEAR_Configurations/Systems/VTOL/general.json` . Door parameters are described here:

1. `DELAY_DOORS_OPENING_CLOSING_SEQ` : Delay of outer doors closing following inner doors closing in seconds.
2. `DOORS_PAIR_OPENING_DURATION` : Duration of opening/closing movement of doors in seconds.
3. `DELAY_VANES_CLOSING_VTOL_TO_PLANE` : Not in effect.
4. `SET_DELAY_M2_M3_SPINUP_VTOL_TO_PLANE` : Sets the delay of M2 and M3 spin-up when transitioning from fixed-wing to VTOL, in seconds. This was introduced to avoid accidental suction of doors by the motors.

Compensation Factors

The compensation against thrust loss due to tilting of motors and control surfaces is detailed in `Scheduling of thrusters against thrust loss` document.

There are three compensation terms in effect.

Front tilt servo compensation

The tilt compensation of the front tilt servo is controlled by the `minimum_angle_deg_vtol` and `maximum_angle_deg_vtol` parameters in the `HEAR_Configurations/UAV_types/TriCopterKU_vtol_manual_control/general.json` configuration file.

But the compensation does kick-in only after the dead-band parameter `FRT_TILT_SERVO_DEADBAND_NORMALIZED` in `HEAR_Configurations/Systems/VTOL/general.json` .

Example

Let the `maximum_angle_deg_vtol` of the front tilt servo be set to `60 deg` and `FRT_TILT_SERVO_DEADBAND_NORMALIZED` be `0.75` . Then at a tilt of `0.75x60=45 deg` we have a compensation multiplier of `1` (i.e. no compensation). But at a tilt of `60 deg` we got a compensation multiplier of `1/cos(60)=2` .

Post Allocation Bias

Allocation is a homogeneous transformation in its essence (i.e. has scaling properties). However, in some cases it is required to have a bias post allocation gains.

Post allocation bias can be configured from `HEAR_Configurations/Allocation_types/PostAllocationMotorBias/general.json` .

Trimming the input independent of RC

Transitioning from VTOL to fixed-wing poses additional challenges not solvable by off-the-shelf configurable hardware. For example, RC units allow trimming but we would have two sets of trims: one for VTOL and the other one for fixed-wing. The pilot cannot switch between two set of trims mid-flight.

LeafFC allows custom trimming and Feedforward gains for VTOL and fixed-wing modes independently allowing trimming of the pilot input. These trims can be configured from the `HEAR_Configurations/Systems/VTOL/*` folder and its sub-folders. The correspondence between the configurations parameters and the system blocks can be found by inspecting the root system DOT graph.

Motor mapping from LeafFC to PX4

By definition, the PX4 receives a MAVLink message of the 12 offboard motor commands (`Motor x` in QGC). The LeafFC sends these commands in the range of `0-1` and PX4 translates them to the minimum and maximum PWM range.

The 12 LeafFC motor commands sent to PX4 can be inspected by the ROS topic `/KU_TriCopter_vtol_manual_control_01/actu_sys/to_px4_cmds` .

Example
Let LeafFC send `0.3` command to M1. Let M1 minimum PWM setting be `1100` and maximum PWM setting be `1900` . Then the PWM command sent to the ESC would be `(1900-1100)x0.3+1100=1340` .

Angles Observer

LeafFC has an angle observer based on mechanical calibration inputs. The observer works based on servo output commands, and hence its ROS topics are under the `actu_sys` path.

Note: Front tilt servo observer is used to provide compensation.