VTOL Controller Design and Simulation

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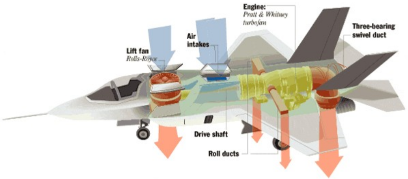
Objective

- Design control systems for aerial vehicles.
- Develop specialized controllers for multicopter and fixed-wing modes and
- fine tune the controllers developed for multicopter and fixed wing fot the two vtol modes
- Implement a switching controller for VTOL mode transitions.

VTOL: Vertical Take-Off and Landing

- VTOL (Vertical Take-Off and Landing) aircraft can take off, hover, and land without a runway.
- They use rotor-based thrust for vertical motion and aerodynamic lift for efficient forward flight.
- VTOL systems blend the advantages of helicopters (maneuverability) and airplanes (speed and range).
- Types include multicopters, tilt-rotor, tilt-wing, and hybrid fixed-wing configurations.
- Applications:
  - Urban air mobility (eVTOL taxis, cargo drones)
  - Search and rescue operations in inaccessible terrains
  - Military missions with rapid deployment needs
  - Environmental monitoring and agriculture



Methodology

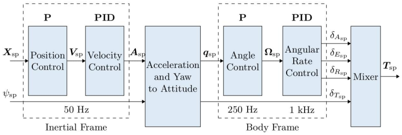
- Separate controllers for:
  - Multicopter (Quadrotor) for takeoff, hover, and landing
  - Fixed-wing for cruising
- Design and integrate a switching controller for smooth transitions.

Quadrotor Controller

- Cascaded PID: Angular rates → Attitude → Velocity → Position → Altitude Control
- PID Equation (Parallel Form):

$$u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}$$

- Tunable via PX4: MC_ROLLRATE_P, MC_ROLLRATE_I, etc.



Motor Mixing in Quadrotors

- Converts control inputs (Throttle, Roll, Pitch, Yaw) into individual motor thrusts.
- Necessary for stabilizing and maneuvering a multicopter.
- Each motor's output is a linear combination of control inputs.

$$\begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix} = \begin{bmatrix} 1 & -1 & -1 & -1 \\ 1 & -1 & +1 & +1 \\ 1 & +1 & +1 & -1 \\ 1 & +1 & -1 & +1 \end{bmatrix} \begin{bmatrix} T \\ \phi \text{ (Roll)} \\ \theta \text{ (Pitch)} \\ \psi \text{ (Yaw)} \end{bmatrix}$$

- CW motors generate negative yaw torque; CCW motors generate positive yaw torque.
- PX4 uses mixing matrices to implement this mapping based on airframe configuration.

Quadrotor Controller: Simulation Results

- Results showing position and attitude stability.
- Performance validated through time-domain plots.

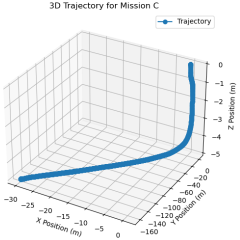


Figure: Outer Loop: Trajectory Control

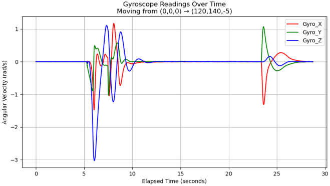


Figure: Gyro Readings

Fixed-Wing Controller

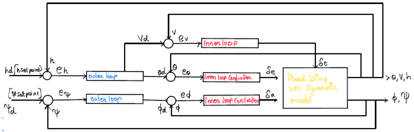
- Controls include pitch, roll, yaw, throttle.
- The lift is given by:

$$L = \frac{1}{2}\rho V^2 S C_L$$

- The drag is given by:

$$D = \frac{1}{2}\rho V^2 S C_D$$

- Adaptive control adjusts control surface deflections and throttle dynamically to respond to changes in mass, wind, and aerodynamic coefficients.



Fixed-Wing Controller: Simulation Results

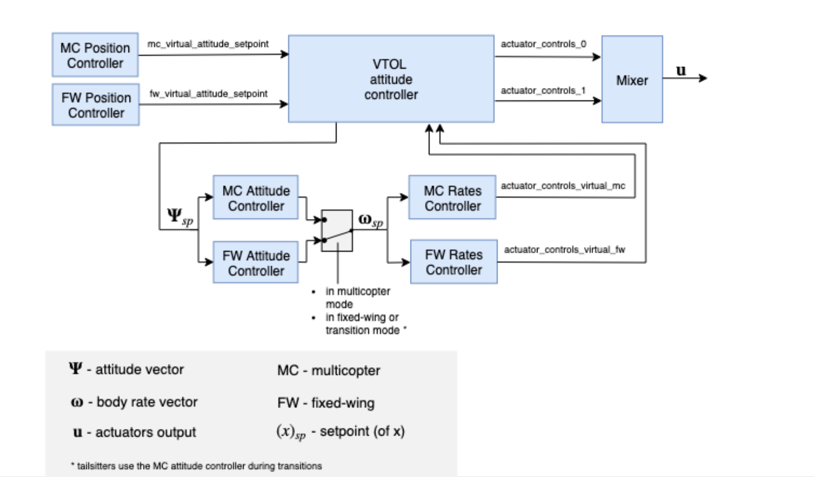
- Results showing altitude and airspeed control.
- Smooth and stable trajectory during cruise phase.

Controller Integration and Tuning

- The quadrotor and fixed-wing controllers are combined for hybrid VTOL operation.
- Quadrotor controller needs retuning due to shifted center of mass.
- Fixed-wing controller requires tuning as the number of control surfaces increases from 2 (basic) to 5 (VTOL design).
- Integrated tuning ensures seamless behavior in transition states.

Switching Controller

- Manages transitions between multicopter and fixed-wing modes.
- Uses state machine logic for mode transitions.
- Ensures actuator and control stability during switching.



Future Considerations

- Improve switching smoothness and robustness.
- Incorporate adaptive control for dynamic environments.
- Integrate motion planning algorithms for fixed-wing trajectory optimization.
- Enhance actuator fault detection and redundancy mechanisms.