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Advanced Flight Control Systems: Integration of Pixhawk Pilot Support Package and 6-DOF Dynamic Modeling

Mahabub Sultan*

MS in Data Science, SUNY Buffalo State University, Buffalo, New York, United States

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Author : Mahabub Sultan

Abstract

This report presents a comprehensive study on the implementation and simulation of advanced flight control systems for Unmanned Aerial Vehicles (UAVs). The work is divided into two primary domains: the practical application of the **Pixhawk Pilot Support Package (PSP)** within the MATLAB/Simulink environment and the theoretical construction of a **six-degree-of-freedom (6-DOF)** dynamic model for fixed-wing aircraft. By leveraging the PSP, we demonstrate the integration of hardware-in-theloop (HIL) components, including sensor fusion via uORB and actuator control. Furthermore, a high-fidelity Python-based simulation is developed to validate the 6-DOF equations of motion and control law effectiveness.

Introduction to Pixhawk Pilot Support Package (PSP)

The Pixhawk Pilot Support Package (PSP) serves as a critical bridge between Model-Based Design (MBD) in Simulink and the physical deployment on PX4-based flight controllers. Version 21 of the PSP provides an enhanced suite of blocks that allow for direct interaction with the NuttX real-time operating system (RTOS) underlying the Pixhawk hardware.

Software Environment and Virtual Runtime

The installation of the PSP requires a robust toolchain, including the arm-none-eabigcc cross-compiler, CMake, and Python. A pivotal component is the **virtual runtime library**, which enables the execution of generated C++ code within a simulated environment or directly on the FMU (Flight Management Unit). This environment ensures that the timing constraints of the uORB (Micro Object Request Broker) middleware are met, allowing for asynchronous communication between modules such as the GPS, IMU, and the control mixer.

Simulink Block Library and Experimental Demonstration

The PSP Simulink library is categorized into several functional domains. Our experiments focused on the following key blocks: (Table 1).

Demonstration of Integrated Sensors and Attitude

Using the px4demo_attitude_system.slx model, we demonstrated the fusion of accelerometer and gyroscope data to estimate the aircraft's attitude (Euler angles).

The uORB blocks were utilized to subscribe to the vehicle_attitude topic, providing a seamless flow of data from the sensors to the control logic.

Six-Degree-of-Freedom (6-DOF) Dynamic Modeling

To complement the hardware-centric approach of the PSP, we developed a mathematical model of a fixed-wing aircraft. The 6-DOF model captures the complex interplay between aerodynamic forces, moments, and rigid-body dynamics.

Equations of Motion

The state x vector is defined as: $x = [u, v, w, p, q, r, \phi, \theta, \psi, x, y, z]^T$ *where* [u, v, w] *arebody – framevelocities,* [p, q, r] *areangularrates*, and [\phi, \theta, \psi]$ are Euler angles.

The translational dynamics are governed by: $u=F_x/m-(qw-rv)\ v=F_y/m-(ru-pw)\ w=F_z/m-(pv-qu)$

Aerodynamic Coefficients

Aerodynamic forces and moments are calculated using non-dimensional coefficients (C_L, C_D,

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***Correspondence:**
Mahabub Sultan, MS in Data Science, SUNY Buffalo State University, Buffalo, New York, United States; Tel: +1 412 218 9731;
E-mail: mahabubsultan2@gmail.com/
ORCID: https://orcid.org/0009-0004-8589-3270

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Table 1:

Block Category	**Specific Blocks**	**Functionality**
Sensors	GPS, ADC, Sensor Combined	Real-time acquisition of positional and inertial data
Actuators	PWM Output, AUX Output	Control of ESCs for motor speed and servo positioning
Communication	uORB Read/Write	Inter-process communication within the PX4 firmware
Peripherals	RGB LED, Tone Output	Visual and auditory status indication for the pilot
System	Battery, RC Input	Monitoring power levels and pilot command inputs

C_m, *etc.)*, which are functions of the angle of attack (α) and sideslip angle (β). In a professional PhD-level workflow, these are often derived from **DATCOM** or Computational Fluid Dynamics (CFD) analysis.

Python Simulation and Results

A custom Python simulation was implemented to solve the nonlinear differential equations of the 6-DOF model. The simulation utilizes the scipy.integrate.solve_ivp solver with a Runge-Kutta 4^{th}-order method.

Simulation Configuration

The aircraft was initialized at an altitude of 100 meters with a forward velocity of 20 m/s. A constant thrust and a slight elevator deflection were applied to observe the longitudinal stability and climb performance.

Visual Analysis

The following figures illustrate the simulation results:

- **Altitude and Attitude:** Shows the aircraft's climb rate and the stabilization of pitch and roll angles.
- **3D Trajectory:** Provides a spatial visualization of the flight path, demonstrating the coupling between longitudinal and lateral dynamics.

(Note: Visualizations are attached as simulation_results.png and trajectory_3d.png)

Conclusion and Personal Creativity

The integration of the Pixhawk Pilot Support Package with high-fidelity 6-DOF modeling represents a modern approach to flight control system development. My personal contribution to this work involves the synthesis of these two domains: using the PSP for hardware abstraction and the Python environment for rapid control law prototyping. This dual-track methodology significantly reduces the "sim-to-real" gap, ensuring that control algorithms are both mathematically sound and computationally feasible for real-time deployment.

Appendix: Python Simulation Code

```
import numpy as np

from scipy.integrate import solve_ivp

import matplotlib.pyplot as plt

# [Full code included in the attached aircraft_sim.py file]
```

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