Estimation of Angle of Attack and Angle of Sideslip from Inertial Measurement Unit

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INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have been used for both military and civilian applications. However, expensive single string on-board avionics systems and a poor operating cost performance have limited the utility of these vehicles. This research attempts to reduce the cost and increase the useful payload capacity of the UAVs by using an alternative approach in the calculation of Angle of Attack (AOA) and Angle of Sideslip (AOS) – two important flight parameters that are essential for the development of autopilots and stability augmentation systems.

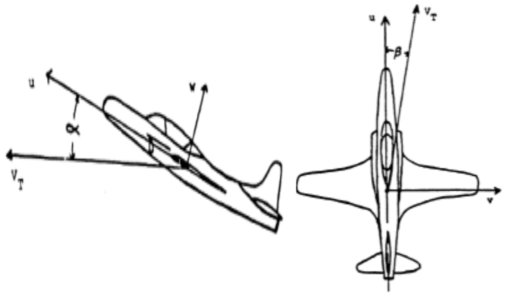

Figure 1: Definition of Angle of Attack (Top) and Angle of Sideslip (Right)

$$\alpha = \tan^{-1}\left(\frac{w}{u}\right)$$

$$\beta = \sin^{-1}\left(\frac{v}{V_T}\right)$$

METHOD

Traditionally, AOA and AOS are calculated using air data probes based on a complex pitot-static system along with an air data computer. However, these probes are expensive, reduce the payload capacity, and are difficult to integrate into UAVs due to space limitation. These probes can also be easily damaged, require power to heat, require calibration, and are prone to mechanical errors. This research tries to address these issues through the estimation of AOA and AOS using data from an inertial measurement unit (IMU), which uses a combination of accelerometers and gyroscopes to provide body accelerations and angular rates.

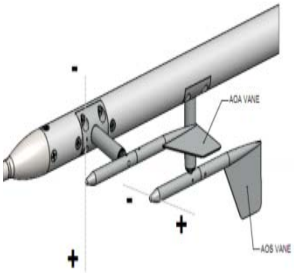

Figure 2: Air Data Probe

Figure 3: Inertial Measurement Unit (IMU)

AIRCRAFT MODEL

A flight dynamics model of the aircraft was developed through the use of Athena Vortex Lattice (AVL), a program for the aerodynamic and flight-dynamic analysis of rigid aircraft that employs an extended vortex lattice model for lifting surfaces. Geometric and mass properties of the aircraft were inputted to yield equations of motion for the rigid body, and simulations were conducted for a variety of cases to produce stability and control parameters that were used to generate a state-space model for the computer algorithm.

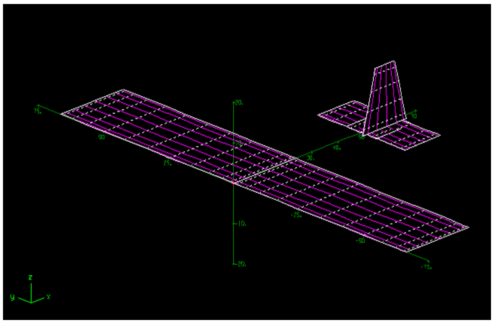

Figure 4: AVL Model of Aircraft (Top) and Dynamic State-Space Model (Bottom)

Longitudinal State-Space Model:

$$\begin{bmatrix} \dot{u}/u_0 \\ \dot{\alpha} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -0.006394 & -0.1358 & 0 & -0.5399 \\ -0.4259 & -3.904 & 0.8717 & -0.07582 \\ -13.43 & -44.62 & -3.513 & 0.004473 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u/u_0 \\ \alpha \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} 0 \\ -0.1152 \\ -8.382 \\ 0 \end{bmatrix} [\delta_e]$$

Lateral-Directional State-Space Model:

$$\begin{bmatrix} \dot{\beta} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} -0.1011 & 0.01862 & -0.9942 & 0.5399 \\ -24.54 & -9.527 & 5.111 & 0 \\ 6.305 & -0.7595 & -0.5306 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \beta \\ p \\ r \\ \phi \end{bmatrix} + \begin{bmatrix} 0 & -0.02518 \\ -0.003774 & -0.309 \\ 0.01624 & 1.291 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta_a \\ \delta_r \end{bmatrix}$$

ANALYSIS

Using the developed model, the stability characteristics of the aircraft during flight were analyzed. The dynamic modes of the aircraft indicate its behavior after being disturbed from steady non-oscillating flight. MATLAB was used to determine the eigenvalues, which in turn were used to identify the longitudinal short period and phugoid modes as well as the lateral-directional roll, spiral, and Dutch roll modes. Open-loop responses for the aircraft were also generated in MATLAB for step inputs in elevator, aileron, and rudder deflection.

POST-PROCESSING

AOA and AOS can be estimated from the velocity components of the IMU (see **Figure 1**). State-space models based on IMU output can be generated for post-processing using a MATLAB-based algorithm. The Kalman filter is an optimal recursive data processing algorithm that combines all available measurement data, plus prior knowledge about the system and measuring devices, to produce an estimate of the desired values in such a manner that the error is minimized statistically.

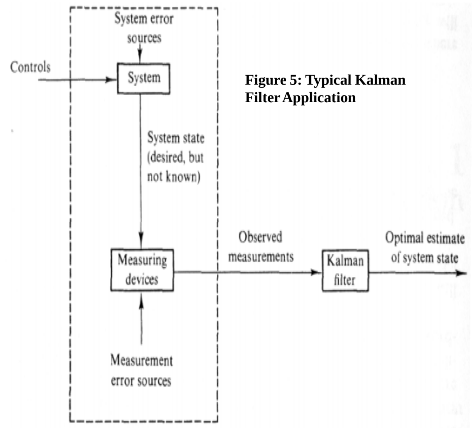

Figure 5: Typical Kalman Filter Application

FUTURE WORK

Flight testing with both the air data probe and IMU will provide data collection for post-processing. Estimated values of AOA and AOS will be compared against those from the air data probe for accuracy. If the comparison is found satisfactory, an algorithm for in-flight processing will be developed to calculate AOA and AOS from inertial data in real time so that these parameters can be used for designing autopilots and stability augmentation systems. This will eventually eliminate the use of air data probes, thus reducing the operating cost and weight of UAVs.

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