

Design of Filter for Airspeed Sensor in Hybrid Vertical Take-Off and Landing (VTOL) UAV

Harish Mahatma Putra, Ghozali Suhariyanto Hadi, Amrinal, Aris Budiarto, and Agus Budiyo
 Bhimasena Research and Technology, Jatinangor, Indonesia

Abstract—In this paper, a digital filter for optimizing airspeed sensor in Hybrid Vertical Take-Off and Landing (VTOL) UAV will be presented. The filter itself is a low-pass filter Infinite Impulse Response that will reduce noise from airspeed sensor readings. The hybrid UAV needs reliable data of airspeed to perform autonomous transition smoothly. The main topic of this paper is about design and implementation of simple first order IIR Filter. This paper also includes the algorithm of the filter which will be implemented in the UAV's autopilot. Therefore, the complex algorithm and the limitation of microprocessor need to be concerned. This filter algorithm theoretically will reduce noise in airspeed data acquisition which disrupt control algorithm in UAV's autopilot without compromising main microprocessor, particularly when the hybrid UAV is in transition state. The algorithm of this filter tested and validated using a model aircraft and compared before and after adding filter. The result also presented in this paper.

Keywords—IIR Filter, Optimized Algorithm, Airspeed Sensor, hybrid VTOL UAV.

Copyright © 2016. Published by UNSYSdigital. All rights reserved.
 DOI: [10.21535/just.v4i2.945](https://doi.org/10.21535/just.v4i2.945)

I. INTRODUCTION

NOWADAYS Unmanned Aerial Vehicle (UAV) has been developed and used for myriad practical purposes [1,2,3]. There are two common configurations of UAV, rotary-wing UAV and fixed-wing UAV [4]. Rotary-wing UAV configuration has advantages such as does not need large area to do take-off and landing. However, Rotary-wing UAV draw much energy. Fixed-wing UAV has advantages such as high endurance, but it will need area for take-off and landing. The Hybrid VTOL UAV was designed to take these advantages [5,6].

The lift of the fixed-wing aircraft is very dependent on airspeed. When the airspeed drops below the stall speed, the aircraft will lose its lift. GPS is reliable speed sensor, but with only GPS, it is hard to estimate actual airspeed especially when in windy situation. The airspeed sensor itself is very noisy without proper filter. Accurate airspeed data is very crucial for hybrid UAV when in transition state, so the autopilot knows when to shut down or decrease the power of vertical motors and control mixing between multicopter and fixed-wing [7]. The autopilot will turn off all the vertical motors completely after the UAV

reaches transition airspeed. When the airspeed sensor is noisy, there will be a spiked reading that makes the autopilot hard to determine whether the transition airspeed has been reached.

II. AIRSPEED ESTIMATION

Airspeed can be estimated through Bernoulli's equation. Stagnation pressure, also known as total pressure, can be written as

$$P_t = P_s + \frac{1}{2}\rho v^2 \quad (1)$$

Solving above equation for flow velocity

$$v = \sqrt{\frac{2 \cdot (P_t - P_s)}{\rho}} \quad (2)$$

where v, ρ, P_t, P_s are airspeed, air density, total pressure, and static pressure, respectively, therefore $(P_t - P_s)$ is pressure difference in pitot tube.

Then that equation can be simplified to

$$v = \sqrt{k \cdot \Delta P} \quad (3)$$

where $v, k, \Delta P$ are airspeed, simplified pressure gain, and pressure difference, respectively.

Equation (3) will be used in airspeed data processing with input from filtered pressure difference. The filter will be added after pressure difference reading.

III. FILTER DESIGN

This filter basically is a low pass filter based on first order Infinite Impulse Response (IIR) Filter. Higher order filter will give better performance but needs more memory and also increase execution time in microprocessor, which will decrease flight performance overall. It also delays data more cycles.

$$\begin{aligned} a_0 y[n] + a_1 y[n-1] + \dots + a_P y[n-P] \\ = b_0 x[n] + b_1 x[n-1] + \dots + b_Q x[n-Q] \end{aligned} \quad (4)$$

Then the above equation can be rearranged to

$$\sum_{i=0}^P a_i y[n-i] = \sum_{j=0}^Q b_j x[n-j] \quad (5)$$

where $x[n]$, a_i , P , $y[n]$, b_i , Q are input signal, feedback filter coefficients, feedback filter order, output signal, feedforward filter coefficients, and feedforward filter order, respectively.

The equation can be simplified because this filter only use first order.

$$a_0 y[n] + a_1 y[n - 1] = b_0 x[n] + b_1 x[n - 1] \quad (6)$$

with $a_0 = 1$, then the equation can be rearranged to

$$y[n] = b_0 x[n] + b_1 x[n - 1] - a_1 y[n - 1] \quad (7)$$

where $x[n]$, $y[n]$, a_0 , a_1 , b_0 , b_1 are raw differential pressure input, filtered differential pressure output, coefficients of feedback filter, and coefficients of feedforward filter, respectively.

IV. ALGORITHM

To implement the algorithm, pressure difference data from airspeed sensor is required. The sensor only provides raw pressure difference data, not the total pressure nor the static pressure. After acquiring the raw data, it is calculated with calibration offset. Next step, the calibrated pressure difference is inserted into that IIR filtering in Eq. (7) to reduce noise. This step is the main filter algorithm. After filtering, clean pressure difference is inserted into airspeed Eq. (3). Then clean airspeed data is ready to be used in main control algorithm.

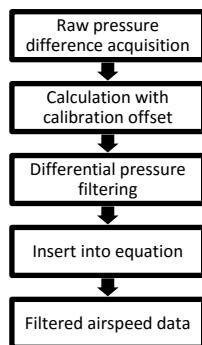


Figure 1 Filtering algorithm flow

V. IMPLEMENTATION

Raw data was acquired using airspeed sensor of Pixhawk flight controller with APM Plane firmware [8]. The airspeed sensor was placed on a manned ground vehicle which then moved at a constant speed. Raw data from internal log was extracted and processed using spreadsheet to simulate the filter algorithm. The coefficients of the filter used in this case was 0.1, 0.1, and -0.8 for b_0 , b_1 , and a_1 respectively. For reference, the ground speed data from GPS is included in graph.

After satisfied with simulation result, the algorithm was implemented to APM Plane source code. The existing airspeed sensor processing code was replaced with this algorithm.

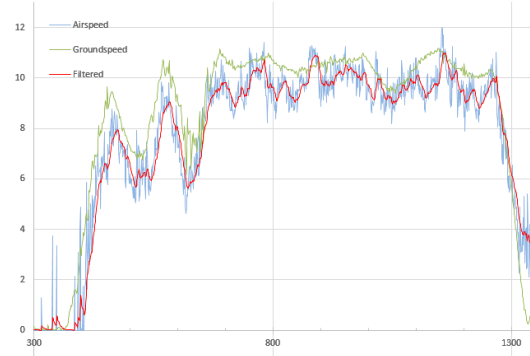


Figure 2 Simulation result using spreadsheet

VI. TESTS AND RESULTS

The filter algorithm was tested using the same method as acquiring raw data. Then, the result was compared with ground speed data as reference.

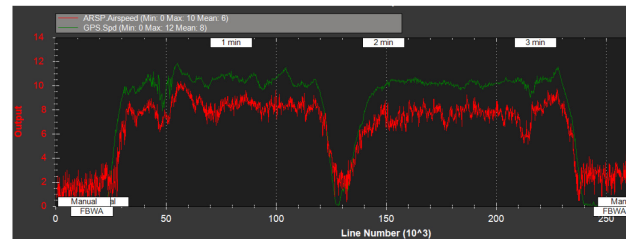


Figure 3 Before adding filter, groundspeed (green) and airspeed (red)

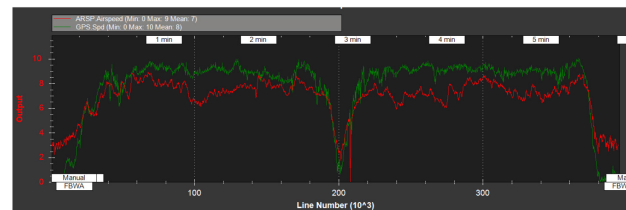


Figure 4 After adding filter, groundspeed (green) and airspeed (red)

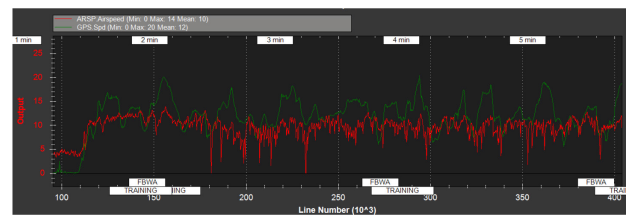


Fig. 5 In flight filter test

Figure 3 and Figure 4 show the airspeed (red) compared to groundspeed (green), before and after adding filter. There is noticeable difference between those figures. Before adding the filter, the airspeed seems noisy, and after filtering, the noise has been reduced.

The algorithm was also tested in flight using FX-61 flying wing. When flying in auto mode, the motor of the UAV sounds more stable as the autopilot automatically adjust the motor power depends on the airspeed.

VII. CONCLUDING REMARKS

The filter for airspeed sensor has been designed and implemented to reduce noise in airspeed readings. This filter also has been tested in flight and gives better performance especially when in autonomous flight. From flight data record, the airspeed data show less noise with this algorithm. One of our future work is to implement the filter into the control system design of our hybrid VTOL UAV.

ACKNOWLEDGMENT

This work was fully supported by Bhimasena Research and Technology, Indonesia.

REFERENCES

- [1] Ghozali Suhariyanto Hadi, Rivaldy Varianto, Bambang Riyanto Trilaksono and Agus Budiyo, "Autonomous UAV System Development for Payload Dropping Mission," *Journal of Instrumentation, Automation and Systems*, vol. 1, no. 2, 2014, pp. 72-77. <https://doi.org/10.21535/jias.v1i2.158>
- [2] Department of Defense USA, *Unmanned Aircraft System Roadmap*, Office of the Secretary of Defense, 2005.
- [3] Ononiwu G. C., Onojo O. J., Chukwuekwa N. and Isu G. O., "UAV Design For Security Monitoring," *International Journal of Emerging Technology & Research*, volume 2, number 2, 2015, pp. 16-24.
- [4] Maddalon, Jeffrey M., Hayhurst, Kelly, J., Koppen, Daniel, M., Upchurch, Jason M., Morris, Allan T., Verstynen, and Harry A., "Perspectives on Unmanned Aircraft Classification for Civil Airworthiness Standards," Virginia: NASA Langley Research Center, 2013.
- [5] Ghozali Suhariyanto Hadi, Muhammad Ramadhan Kusnaedi, Puspita Dewi, Aris Budiarto, Agus Budiyo, "Design of Avionics System and Control Scenario of Small Hybrid Vertical Take-Off and Landing (VTOL) UAV," *Journal of Instrumentation, Automation and Systems*, vol. 2, no. 2, 2015, pp. 67-71. <https://doi.org/10.21535/jias.v2i2.698>
- [6] Alphonsus and Chan Kai Rui, "Unmanned Aerial Vehicle Structure and Propulsion," B.E Thesis, Departement of Mechanical Engineering, National University of Singapore, 2012.
- [7] S. Hansen and M. Blanke, "Diagnosis of Airspeed Measurement Faults for Unmanned Aerial Vehicles," in *IEEE Transactions on Aerospace and Electronic Systems*, vol. 50, no. 1, January 2014, pp. 224-239. <https://doi.org/10.1109/TAES.2013.120420>
- [8] Lorenz Meier, Petri Tanskanen, Friedrich Fraundorfer and Marc Pollefeys, "PIXHAWK: A System for Autonomous Flight using Onboard Computer," *Robotics and Automation (ICRA)*, 2011 IEEE International Conference on, 2011, pp. 2992 – 2997. <https://doi.org/10.1109/icra.2011.5980229>