Sensor Integration and Filtering Technique for Autopilot UAV

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1. Introduction

Satellites may allow us to obtain images of wide areas, but they can only provide images with low spatial resolution and manned aircrafts which are needed for imaging are operated at higher acquisition costs. On the other hand, with UAVs, allow users to obtain accurate, high-resolution data within a desired timeframe, and since they fly at lower altitudes, they tend to be minimally affected by clouds [1]. However, UAVs flying at lower altitudes have a greater likelihood to overturn than manned aircrafts. This issue has been addressed by the advancement of wireless communication and development of MEMS, which eventually led to the development of low-cost autopilot UAVs. It should be emphasized that what we need is a flawless autopilot system for aircrafts, and to achieve this, an accurate and stable state estimation must be made through processing signals by using various combinations of sensors and filtering techniques.

Nagai et. al. designed an autopilot system by combining sensors such as CCD, IMU, GPS, and mini laser,[2] while Coopmans proposed an architecture for a sensor package, autopilot device, and embedded software that can be used to build an autopilot system for a small UAV[3]. Until now, studies on filters that process signals from sensors have been conventionally performed by using a Kalman filter and an extended-Kalman filter. However, recent studies tend to focus more on using extended-Kalman filters [3-5]. Although an improved extended Kalman filter can be a burden on the processor itself, as it is believed to be flawless, it is now being studied in various ways, taking into account additional factors. This study aims to compare and analyze different architectures for sensors used in autopiloted UAVs and filtering techniques based on a preliminary study.

2. Sensor Integration Architecture

The factors that are required to fly on autopilot are listed in Table 1. Among those, a sensor that can detect the position, speed, altitude, and heading of an aircraft should be prepared. This study used a 3D IMU, GPS, and magnetometer to integrate a sensor. Fig.1 illustrates a processor, autopilot device, and hardware integration. A Gumstix onboard computer is a backbone that controls the data flow and the process of the entire system, and it communicates with a Paparazzi TWOG Autopilot over a TTL UART. Meanwhile, an autopilot system connects with a 900MHz Modem and RC receiver, which are communication devices, and controls a servo that maintains predetermined flight paths. In addition, the onboard computer is connected to the GPS and IMU sensor, and a Wi-Fi module that can communicate with the console is mounted on it. A multi-spectral camera that is used for obtaining geospatial information is connected to the computer via a USB port.

[Table 1] Hardware and software for Autopilot UAV development

Hardware	Return Value
• GPS receiver	• absolute position(N,E,H), ground speed(v_n, v_e, v_d)
• Rate gyro	• angular rate(p, q, r)
• Accelerometer	• acceleration(a_x, a_y, a_z)
• Magnetometer	• heading correction (Ψ)
• Pressure sensor	• air speed(relative pressure), altitude(h)
• Ultrasonic sensor	• relative height above ground.
• Image sensor	• RGB, NIR, Thermal

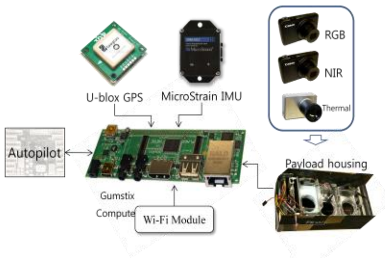


Fig. 1 Hardware integration architecture

3. Filtering Techniques

3.1. Filtering algorithm for sensor integration

Despite the fact that a Kalman filter needs to perform a large number of calculations and thus can place a burden on the processer, many still choose to use it, because it is highly reliable. In this study, a GPS-EKF (GPS aided Extended Kalman Filter) which is made by adding GPS data to an extended Kalman filter was used. This filter is an algorithm that combines a quaternion-based extended Kalman filter that uses four factors, including the ax, ay, and az values obtained from the accelerometer and the yaw angle obtained from the magnetometer[7], with a Euler Anglesbased extended Kalman filter that uses the system's state values φand θ as well as the ax, ay, and az values obtained from the accelerometer. The observation equation is replaced by the measured GPS ground speeds (V_g), in order to obtain a more accurate estimate of the gravity vector (Eq.1).

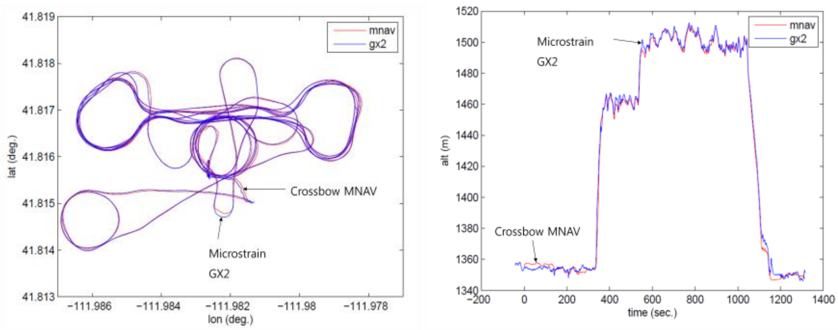
$$\dot{q} = \frac{1}{2}\left[\begin{array}{ccccccc} 0 & -\hat{p} & -\hat{q} & -\hat{r} & 0 & 0 & 0 \\ \hat{p} & 0 & \hat{r} & -\hat{q} & 0 & 0 & 0 \\ \hat{q} & -\hat{r} & 0 & \hat{p} & 0 & 0 & 0 \\ \hat{r} & \hat{q} & -\hat{p} & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right] q + w_k, \qquad \begin{bmatrix} \hat{a}_x \\ \hat{a}_y \\ \hat{a}_z \end{bmatrix} = \begin{bmatrix} 2g(q_1q_3 - q_0q_2) \\ 2g(q_2q_3 + q_0q_1) \\ g(q_0^2 - q_1^2 - q_2^2 + q_3^2) \end{bmatrix} + v_k \quad (1)$$

$$\text{where} \begin{bmatrix} \hat{a}_x \\ \hat{a}_y \\ \hat{a}_z \end{bmatrix} = \begin{bmatrix} a_x \\ a_y - rV_g + g\sin\phi_{t-1} \\ a_z + qV_g + g\cos\phi_{t-1} \end{bmatrix}.$$

$\hat{a}_x, \hat{a}_y, \hat{a}_z$	*: acceleration from accelerator*	v_k	*: velocity*
V_g	*: ground speed from GPS*	g	*: acceleration of gravity*
ϕ	*: roll angle*	$q_0 \sim q_3$	*: unit quaternion*
r	*: rate gyro, angular velocity*		

3.2. GPS-EKF Test

In order to validate the reliability of the developed GPS-EKF, we flew a UAV built with a Microstrain GX2 IMU, LEA-5H GPS, and Paparazzi TWOG autopilot while applying the EKF and GPS-FKF developed by Jang (200)[8]. The UAV's mission was to pass the waypoint 1 and 2, make a circle with a radius of 70 m, and then come back. All data on the internal sensors and time-stamped data from the Gumstix are stored by the Gumstix itself at 50 Hz, whereas data from the GPS sensor were saved at 4 Hz. However, the GPS-EKF was implemented separately using Matlab.



(a) Latitude and Longitude plot (b) Altitude plot

Fig.2 UAV trajectory for sensor data collection

4. Conclusions

Through this study, a hardware architecture for an autopilot, onboard computer, IMU & GPS sensor-based UAV has been established. Furthermore, by applying an EKF (Extended Kalman Filter) using GPS data, the accuracy has improved by approximately twenty percent, which will contribute to more accurate autopilot control over aircraft's flight paths.

5. References

[1] Han Seunghee(2013), "A design proposal for economical autopiloted UAVs for acquiring geospatial information(I)", ISGIS Proceeding, pp.156-157.

[2] Masahiko Nagai, Tianen Chen, Afzal Ahmed, Ryosuke Shibasaki, UAV BORNE MAPPING BY MULTI SENSOR INTEGRATION, pp.1215-1221, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing 2008.