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Research Paper

Dynamic gyroscope sensors fusion and calibration using Kalman filter

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Abstract

The stability of an Unmanned Aerial Vehicle (UAV) during actual flight conditions is one parameter that is very important in systems design in Avionics. In this research, two sensors, the autopilot microcontroller and the smartphone gyroscope sensing mechanism, are fused together and calibrated to monitor the flying behavior of the UAV prior to actual test flights. The two fused sensors and installed inside the UAV for relatively increased sensing accuracy and best flight monitoring capabilities. A Kalman filter is used as fusion technique and a Stewart Motion tracker is also used to test the ruggedness and accuracy of the fused sensor system. Experiment results show that fused system can give an overall mean square error or 1.9729.

Keywords: *Unmanned Aerial Vehicle, Sensor Fusion, Kalman Filters, Microcontrollers, Smartphone*.

1. Introduction

The study and analysis of Unmanned Aerial Vehicles (UAV) is a very hot topic in research nowadays. UAVs are commonly used in both the military and police forces in situations where the risk of sending a human piloted aircraft is unacceptable, or the situation makes using a manned aircraft impractical. Due to a large number of researches for UAV, some focus on the review and investigation of the capabilities and performances of UAVs. Examples of these studies are discussed in research papers [1, 2, 3].
The use of smartphones as sensors incorporated in UAVs is also another topic of interest. Smartphones have inertial sensors that can be useful in monitoring important system parameters for UAVs such as location and orientation. Aside from the sensors bundled on smartphones, several hard wired sensors are also available and are normally installed in UAVs. Because of this reason, multi-sensor fusion arises. The fusion system gives additional reliability and accuracy in sensing critical parameters of the UAV. Increased accuracy means better systems monitoring on the conditions and flight performance of the UAV. Several articles regarding sensor fusion are discussed in papers [4, 5, 6, 7, 8,9].
The popularity of multi-sensor fusion has grown enormously, giving topics of interests for the researchers to identify and evaluate the best fusion techniques that can be used. The most common method of multi-sensor fusion is the kalman filtering as evaluated in papers [10, 11].
Lastly, the test for ruggedness and stability of the UAV can be done using a popular Stewart Motion Tracker platform [12]. This is used in this research to test the stability of the UAV and the accuracy of the fused gyroscope sensors.

2. Problem Statement

The ruggedness of the unmanned aerial vehicle (UAV) needs prior tests and analysis even before the actual flight activities. The behavior of the UAV during flight is one measure of the stability of the UAV as it experiences environmental obstacles such as dragging and spinning. In this aspect, the accurate orientation of the UAV must be monitored at all times.
These orientation parameters involve the roll, pitch and yaw of the system. Normally, UAVs have built in gyroscope system that can monitor these parameters. The gyroscope system is usually incorporated in an autopilot system so that remote maneuvering can be done easily. Even if the gyroscope system exists in the autopilot, a more accurate measurement of the orientation is needed to properly monitor the performance of the UAV. An additional gyroscope system can still be used. Modern smartphone have built in gyroscope system inside their board mechanisms.
This paper proposes the fusion of the autopilot gyroscope system and the smartphone gyroscope system to provide a more reliable and accurate orientation data from the UAV.

3. Methodology

This study aims to accomplish two phases of research.as shown in figure 1 below

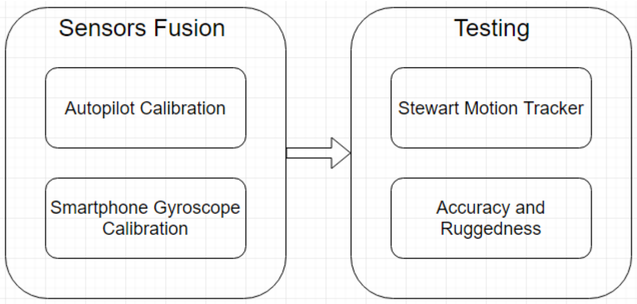

Fig 1: Phases of the Sensors Fusion Study

Fig. 1 shows the two phases of this research. Phase 1 involves the calibration of both the autopilot system and the smartphone gyroscope mechanism so that both of them will give the same data format for the orientation. After the calibration process, the two sensors will be fused using kalman filter.

The fused sensor system will be tested prior to actual flight activities. The ruggedness of the UAV and the accuracy of the fused sensors will be tested and analyzed using a Stewart motion tracker to control the orientations of the UAV. The orientation data from the motion tracker will serve as the ground truth in computing for the accuracy of the fused sensors.

Fig. 2 below shows the proposed flowchart for the fusion process of the autopilot gyroscope and the smartphone gyroscope.

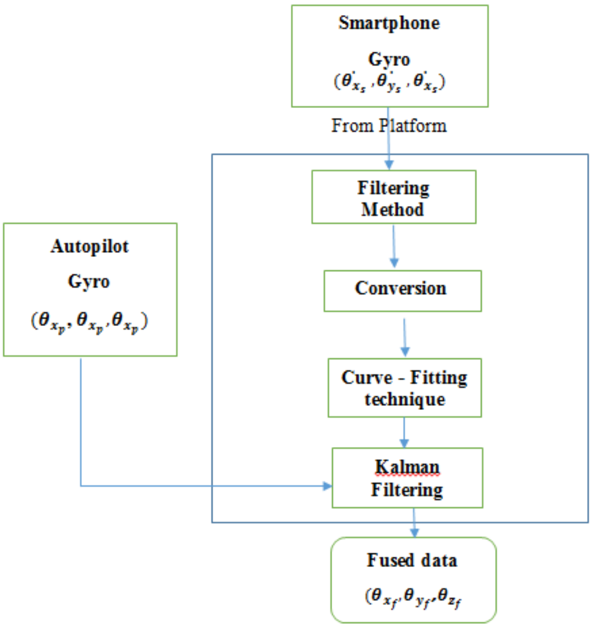

Fig. 2: Flowchart of Sensors Fusion Process

Fig. 2 shows the fusion process of the two sensors, the autopilot gyroscope and the smartphone gyroscope system. Both sensors need to be filtered out to remove the noise variations present on both signals. The smartphone gyroscope system needs to undergo unit conversion so that both sensors have the same data format. The unit of the orientations from the autopilot is terms of degrees while the unit from the smartphone gyroscope is in degrees per second. The two sensors will be fused using Kalman Filtering.

The smartphone gyroscope data needs a process called unit conversion. Filtered raw data from Smartphone IMU **Gyro** $(\dot{\theta}_{x_s}, \dot{\theta}_{y_s}, \dot{\theta}_{x_s})$ is in rotation rate degree per second unit. ArduPilot's rotation angle is in $degree$ unit. The filtered rotation rate should be converted into filtered rotation angle. Fig. 3 below illustrates the process of unit conversion.

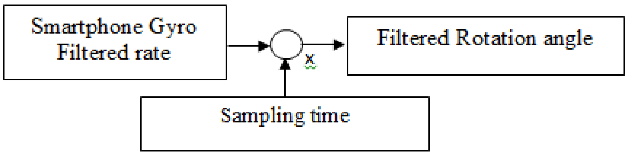

Fig. 3: Smartphone Gyroscope Board Mechanism

The pseudo code used for unit conversion is also shown in fig. 4 below

```
for smartphone_gyro_data  = 1 to 156,000:

start

    rotation_ angle_gyro_θxs  = rotation_ rate_gyro_θxs  * sampling time
    rotation_angle_gyro_θys   = rotation_ rate_gyro_θys  * sampling time
    rotation_ angle_gyro_θzs  = rotation_ rate_gyro_θzs  * sampling time

end.
```

Fig. 4: Pseudo code for Conversion Method

Fig. 4 shows the pseudo code used to convert the unit from the smartphone gyroscope which is degrees per second to be uniform to the unit of the autopilot gyroscope which is n degrees. The unit conversion is done by sampling method.

4. Discussion of results

All the results including material selection are discussed in this chapter.

A. Material selection

The choice of the sensors to be fused and will be used to test the ruggedness of the UAV is presented here. Two sensors are considered in this research, the smartphone gyroscope mechanism and the autopilot system mechanism.

For the smartphone sensor, the board containing the gyroscope mechanism is used and installed in the UAV. The board measures the orientations such as roll, pitch and yaw and has unit of degrees per second.

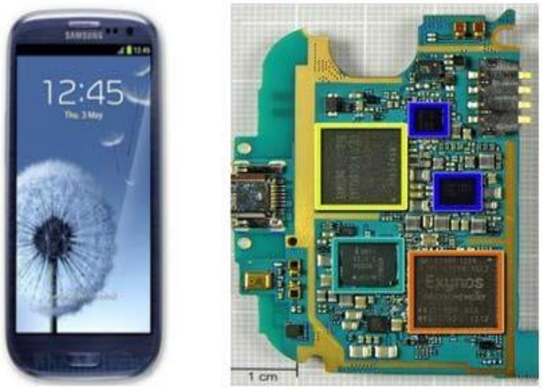

Fig. 5: Smartphone Gyroscope Board Mechanism

Fig. 5 shows the gyroscope board from Samsung Galaxy Note III. This is one of the sensors that will be used for in this research.

The second sensor to be used in this research is the autopilot system as shown in fig. 6 below.

Fig. 6: Autopilot System Gyroscope Sensor

Fig. 6 shows the autopilot gyroscope sensor that uses the ArduPilot 2.6 microcontroller based system. This sensor is able to give the orientation of a body in degrees.

The autopilot gyroscope sensor and the smartphone gyroscope mechanism are fused together to give one fused data. After the pre-processing needed by each sensor, a kalman filter is implemented to fuse the sensor data together. Examples of the results from kalman filter are shown on the figures below.

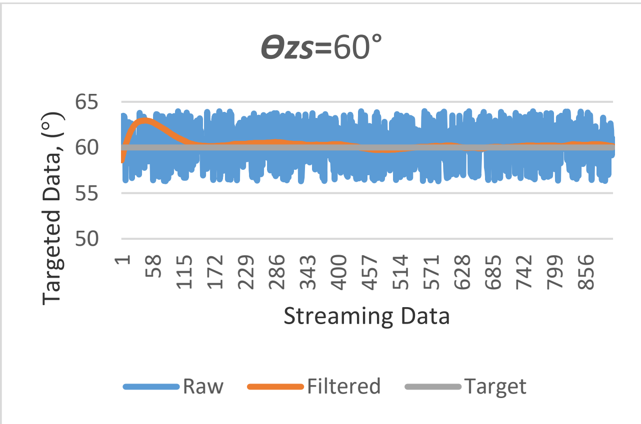

Fig. 7: Filtered Output of Gyroscope Data for 60° yaw

Fig.7 above shows the output of the kalman filter as it approaches the test yaw value of 60 degrees. The noise coming from the raw data from the sensors are filtered out. It can be seen that the fused data value approaches that of the target or assigned value of the motion tracker. This gives a clear proof of the effectiveness of the kalman filter in fusing two sensor data in one.

B. Testing and calibration

The second part of this study is the test and further calibration of the fused sensors system. The UAV will be mounted above the Stewart motion tracker and will be subjected to different flight conditions. The series of tests will be done to test the ruggedness of the UAV prior to actual flight activities. The fused sensor system will also be further calibrated using the motion trackers orientation as the ground truth. This is done to improve the accuracy of the fused sensors. Figure 8 below shows the Stewart motion tracker.

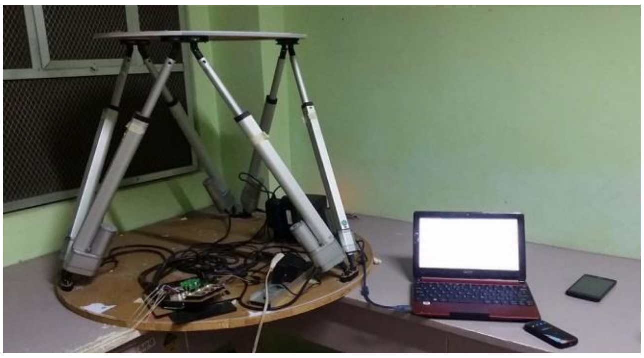

Fig. 8: Stewart Motion Tracker Platform

Fig. 8 shows the Stewart motion tracker platform that will be used to test the ruggedness of the UAV and the accuracy of the fused sensors. This platform is connected to a laptop as a console in controlling the desired orientations of the platform.

Table 1: Average filtered data for roll used as inputs for curve fitting

Stewart Platform Orientation	Fused Sensors Orientation
60	58.781040
40	38.672110
20	18.859467
0	-0.021862
-20	-18.343039
-40	-38.403634
-60	-58.860434

Table 1 shows some samples of the results in comparing the roll orientation between the Stewart motion tracker and the fused sensor. For the roll orientation, the mean square error is 1.5919.

Table 2: Average filtered data for pitch used as inputs for curve fitting analysis

Stewart Platform Orientation	Fused Sensors Orientation
60	58.67989618
40	38.26450601
20	18.6080363
0	-0.41387
-20	-18.343039
-40	-38.130696
-60	-58.633961

Table 2 shows some samples of the results in comparing the pitch orientation between the Stewart motion tracker and the fused sensor. For the pitch orientation, the absolute mean square error is 2.1385.

Table 3: Average filtered data for yaw used as inputs for curve fitting analysis

Stewart Platform Orientation	Fused Sensors Orientation
60	58.79816385
40	37.98938968
20	18.80641563
0	0.030961885
-20	-18.314693
-40	-37.993599
-60	-58.759394

Table 3 shows some samples of the results in comparing the yaw orientation between the Stewart motion tracker and the fused sensor. For the yaw orientation, the mean square error is 2.1882.

The overall accuracy of the fused sensor system is shown in table 4 below.

Table 4: Overall Accuracy of the Fused Sensor System

Parameter	MSE
Roll	1.5919
Pitch	2.1385
Yaw	2.1882
Overall	1.9729

5. Conclusions

The ruggedness of the UAV is tested successfully using the Stewart motion tracker. The UAV was subjected to different desired orientation as controlled by the computer interfaced in the platform.
The autopilot gyroscope and the smartphone gyroscope mechanism were successfully fused together using Kalman filters. The accuracy of the fused sensor system in terms of the data for different orientations such as the roll, pitch and yaw is computed and analyzed using the Stewart platform data as the ground truth for the computation. The overall mean square error for the fused sensor system is found to be 1.9729. Due to the success of the sensor fusion, the UAV is now equipped with a more reliable and accurate sensor mechanism that can be used during the actual flight activities of the UAV.
The sensor fusion technique can be further improved by a better filtering and calibration process for the sensors and good calibration parameters for the Kalman Filtering. Other fusion techniques can also be used in integrating multiple sensor systems.

Acknowledgement

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