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UAV Altitude Measurement Method Based on Data Fusion and Kalman Filter

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Abstract. Accurate altitude measurement of UAV is very important for its flight mission. Based on the analysis of the measurement performance of different altitude measurement sensors, this paper designs a multi-altitude measurement sensor fusion filtering structure, and then describes the fusion filtering method. This method mainly provides weighted fusion of data from various altitude measurement sensors to obtain altitude information with higher accuracy than any sensor. Through Kalman filtering of the fusion data, more accurate flight altitude data of UAV can be obtained. The method is validated by a typical example. The results show that the proposed method can solve the problem of precise measurement of altitude data in UAV flight process, and has certain theoretical significance and good application value.

1. Introduction

In order to perform different tasks, UAVs need to fly under various complex terrain conditions. Flight altitude measurement is very important for UAV terrain matching and tracking, and it is a key part of UAV flight control system. At present, the flight altimeter of UAV mainly consists of barometric altimeter, global positioning system (GPS), radio altimeter and inertial measurement unit (IMU). Different height measuring devices have both advantages and disadvantages. In order to accurately measure the height information of unmanned aerial vehicles, many scholars have made useful explorations [1-5]. Based on the theory of optimal weighted fusion of multi-sensor data and Kalman filtering method, the altitude information measured by different sensors is fused by optimal weighted fusion firstly to improve the accuracy of UAV altitude measurement information initially, and then Kalman filtering is used to further improve the accuracy of UAV altitude measurement so as to satisfy the altitude information accuracy requirements in the process of UAV flight control.

2. Fusion Filtering Model

2.1. Fusion Filter Structure

In order to improve the altitude measurement accuracy of UAV flight control system, the advantages and disadvantages of barometric altimeter, global positioning system, radio altimeter and inertial measurement module should be considered comprehensively. The barometric altimeter mainly uses the relationship between air pressure and altitude to calculate the altitude (absolute altitude) of the UAV through the barometric value of its altitude, which is greatly affected by the changes of atmospheric temperature and isobaric surface, and the measurement error increases with the decrease of altitude; the GPS system mainly uses the distance difference between the receiver and multiple navigation satellites to achieve altitude measurement. The measurement accuracy is high when it is far from the ground or sea surface; the radio altimeter calculates the flight altitude (relative altitude) mainly by the time difference between transmitting and receiving radio waves from the radio equipment, and the measurement error is greatly affected by the fluctuation of the reflector; the inertial measurement unit mainly measures the inertial parameters of the carrier through the measurement carrier. The acceleration of the test system is used to integrate the time and obtain the parameters of the carrier. The measurement error will accumulate with the time.

Combining the advantages of the above four sensors for UAV altitude correlation parameter measurement, a fusion filter structure for UAV altitude measurement is designed as shown in figure 1.

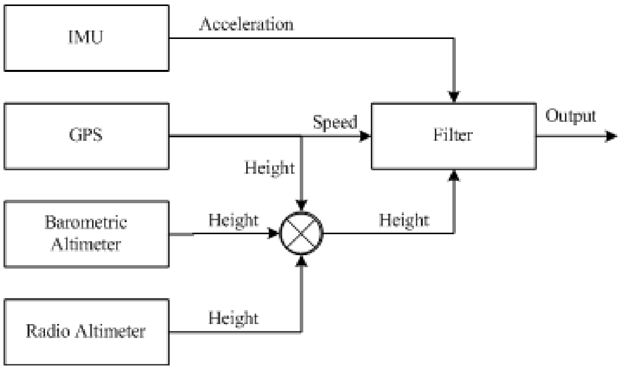

Figure 1. The structure of fusion filter.

In figure 1, the input information of the filter includes UAV altitude, vertical velocity and acceleration. Among them, height information is weighted by height information provided by GPS, barometric altimeter and radio altimeter. Vertical velocity information is provided by GPS, and vertical acceleration information is provided by IMU.

2.2. Sensor Measurement Model

2.2.1. GPS Measurement Equation

$$\begin{cases} h_{GPS} = h + \delta_{GPS} \\ v_{GPS-Z} = v_Z + \delta^v_{GPS-Z} \end{cases} \tag{1}$$

where h_{GPS} is the altitude measured by GPS, h is the true altitude of UAV, δ_{GPS} is the noise measured by GPS altitude, the variance is σ^2_{GPS} v_{GPS-Z} is the velocity measured by GPS, v_Z is the real velocity, δ^v_{GPS-Z} is the noise measured by GPS vertical velocity, and the variance is $\left(\sigma^v_{GPS-Z}\right)^2$.

2.2.2. Barometric Altimeter Measurement Equation

$$h_{ba} = (1+\lambda)h + b_h + \delta_{ba} \tag{2}$$

where h_{ba} is the measurement height of the barometric altimeter. λ is the scale factor deviation of the barometric altimeter, and its variance is $\sigma^2_\lambda . h$ is the true height of the UAV. b_h is the error of the UAV system, and its variance is $\sigma^2_b . \delta_{ba}$ is the measurement noise of the barometric altimeter and its variance is σ^2_{ba}.

2.2.3. Radio Altimeter Measurement Equation

$$h_{ra} = h + \delta_{ra} \tag{3}$$

where h_{ra} is the altitude measured by radio altimeter, h is the true altitude for UAV and δ_{ra} is the noise measured by radio altimeter with variance of σ_{ra}^2.

2.2.4. IMU Measurement Equation

$$a_{IMU-Z} = a_Z + \delta_{IMU-Z}^a \tag{4}$$

where a_{IMU-Z} is the acceleration value measured by IMU in the vertical direction, a_Z is the real acceleration value in the vertical direction of UAV, δ_{IMU-Z}^a is the measurement noise in the vertical direction of IMU, and the variance is σ_{IMU-Z}^2.

3. Fusion Filtering Algorithm

3.1. Space-Time Unification of High-Altitude Information

Due to the different sampling periods of different altitude measurement sensors, it is necessary to align the data in time and space when processing the data from different sensors, so as to avoid the errors caused by the inconsistency of time and space.

3.1.1. Unification of Time. Assuming that Q_{t_a} is the altitude measured by a height measurement sensor at the moment t_a and Q_{t_c} is the altitude measured at the moment t_c, the altitude of the moment t_b is

$$Q_{t_b} = Q_{t_a} + t_b \cdot \left(Q_{t_a} - Q_{t_c}\right) / \left(t_a - t_c\right) \tag{5}$$

In order to reduce the introduction of new errors in space-time alignment, the measurement time of sensors with large sampling period is taken as the benchmark.

3.1.2. Unification of Space. Assuming that the altitude measurement datum of one sensor is sea level and that of another sensor is $Q_{sealevel}$ above sea level, when the altitude measurement value of the sensor is Q, its relative altitude value Q_{real} to sea level is

$$Q_{real} = Q + Q_{sealevel} \tag{6}$$

3.2. Highly Information Weighted Fusion

Assuming that the output data of an UAV altimeter sensor is $\mathrm{x_i}(\mathrm{k})$ ($\mathrm{i} \in \{\text{GPS}, \text{Barometric Altimeter, Radio Altimeter}\}$) at the time k and the weight value in the data fusion process is ω_{i}, the fusion result of the altimeter sensor combination at the time k is as follows:

$$\mathrm{y}(\mathrm{k}) = \sum_{\mathrm{i} \in \{\text{GPS}, \text{Barometric Altimeter}, \text{Radio Altimeter}\}} \omega_{\mathrm{i}} \cdot \mathrm{x_i}(\mathrm{k}) \tag{7}$$

In a certain period of time T, the altitude information output by the combination of altimeter sensors is as follows:

$$\begin{cases} X = [x_{GPS}, x_{BA}, x_{RA}] \\ W = [\omega_{GPS}, \omega_{BA}, \omega_{RA}] \\ \mathrm{Y} = WX^T \end{cases} \tag{8}$$

where x_{GPS} represents all the measurement data of GPS in that time period T, and x_{BA} represents all the measurement data of barometer in that time period T, x_{RA} represents all the measurement data of radio altimeter in that time period T.

Because the measurement data of each height measurement sensor are independent and obey normal distribution $\mathrm{N}(\mu_i, \sigma_i^2)$, the fusion results obey normal distribution $\mathrm{N}\left(\sum_{i=1}^{n}\omega_i\mu_i, \sum_{i=1}^{n}\omega_i^2\sigma_i^2\right)$.

If and only then $\omega_{\mathrm{i}} = \left[\sigma_i^2 \sum_{i=1}^{n}\left(1/\sigma_i^2\right)\right]^{-1}$, the fusion accuracy σ_Y is the smallest, and $\sigma_Y = \left[\sum_{i=1}^{n}\left(1/\sigma_i^2\right)\right]^{-1/2}$ [6].

3.3. Kalman Filter

Based on the above analysis, it is assumed that the state of the height measurement fusion filtering system is $\Omega(k) = [y(k), v(k), a(k)]^T$ at the time k.When the process noise of the system is neglected and the interval between adjacent time is equal to t, the state transition matrix A and observation matrix H and observation quantity $\Psi(k)$ and observation noise $\delta(k)$ of the system are as follows:

$$\begin{cases} A = \begin{bmatrix} 1 & t & t^2/2 \\ 0 & 1 & t \\ 0 & 0 & 1 \end{bmatrix} \\ H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \\ \Psi(k) = H \cdot \Omega(k) + \delta(k) \\ \delta(k) = \begin{bmatrix} \sigma_y & \delta_{GPS-Z}^v & \delta_{IMU-Z}^a \end{bmatrix}^T \end{cases} \tag{9}$$

The Kalman filter equation of the system can be expressed as follows:

$$\Omega(k+1 \mid k) = A \cdot \Omega(k) \tag{10}$$

$$P(k+1 \mid k) = A \cdot P(k \mid k) \cdot A^T \tag{11}$$

$$K(k+1) = P(k+1 \mid k) \cdot H^T \cdot \left[H \cdot P(k+1 \mid k) \cdot H^T + \Delta(k)\right]^{-1} \tag{12}$$

$$\Omega(k+1 \mid k+1) = \Omega(k+1 \mid k) + K(k+1) \cdot \left[\Psi(k+1) - H \cdot \Omega(k+1 \mid k)\right] \tag{13}$$

$$P(k+1 \mid k+1) = \left[I - K(k+1) \cdot H\right] \cdot P(k+1 \mid k) \tag{14}$$

4. Simulation Verification

In order to verify the effectiveness of this method, simulation parameters are set to simulate the flight altitude of UAV. The simulation conditions are as follows:

4.1. UAV Flight Parameters

The flight time of UAV is 420 seconds. The reference altitude of UAV is sea level. The process includes three stages: climbing (A1), cruising (A2) and descending (A3). Among them, 0-180 s is the climbing stage, in which the vertical direction of UAV accelerates with the acceleration of 0.2 m/s^2. After the vertical direction speed reaches 12 m/s, the UAV climbs uniformly in the vertical direction, then slows down with the acceleration of -0.2 m/s^2 in the vertical direction until the vertical direction speed is 0 m/s; 181-240s is the cruise stage, in which both of the vertical direction speed and the vertical direction speed of UAV are equal to 0; 241-420 s is the downward phase. In this phase, the UAV accelerates downward with the acceleration of -0.2 m/s^2 in the vertical direction. After the vertical velocity reaches - 12 m/s, the UAV decreases uniformly in the vertical direction, and then slows down with the acceleration of 0.2 m/s^2 in the vertical direction until landing.

4.2. Height Measurement Sensor Parameters

The height measurement error of GPS is 30 m, and the velocity measurement error is 0.2 m/s, and the sampling period is 100 ms; barometric altimeter does not exist scale factor error, and its measurement error is 20 m, and sampling period is 10 ms; The measurement error of radio altimeter is10 m, and the sampling period is 200 ms; The acceleration measurement error of IMU is 0.01 m/s^2.

According to the fusion filtering algorithm mentioned above, the sampling period of radio altimeter is the largest, and the information of altitude information provided by radio altimeter is used to unify the time. According to the concept of reference standard deviation, the fusion filtering accuracy as follows:

$$\sigma = \sqrt{\frac{1}{M-1}\sum_{p=1}^{M}\left(h_{FusionFilter}(p) - h(p)\right)^2} \tag{15}$$

where σ is the precision of fusion filtering, and M is the number of samples, and $h_{FusionFilter}(p)$ and $h(p)$ are the fusion filtering data and the real height data of UAV respectively at the sampling time p.

According to the above simulation conditions, 500 Monte Carlo experiments are carried out, and the comparison of measurement accuracy curves between three height measurement sensors and fusion filtering is shown in figure 2.

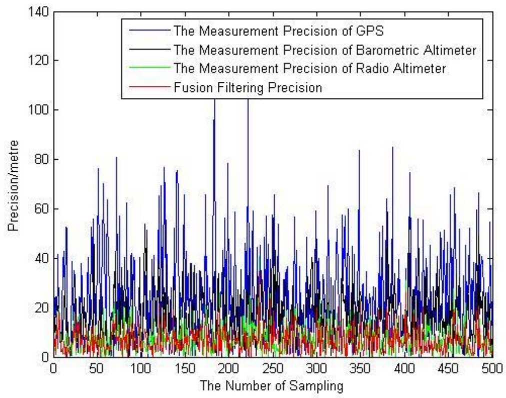

Figure 2. Accuracy curve of height measurement in different ways.

The simulation results of 500 times Monte Carlo are that the flight altitude track accuracy of fusion filtering is 499 times better than that of GPS and 491 times better than that of barometric altimeter and 388 times better than that of radio altimeter.

5. Conclusion

In this paper, the problem of precise measurement of flight altitude of UAV is studied. Findings from the study are that Using multi-altitude measurement sensor combination measurement and data filtering by weighted fusion, we can get more accurate altitude data and through Kalman filtering of multi-sensor altitude fusion data, more accurate flight altitude data of UAV can be obtained.

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