Adaptive Extended Kalman Filter Based on SOA Algorithm for UAV **Attitude Solution**

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ABSTRACT

Aiming at this problem of the inertial measurement unit has high noise, low precision and large error in traditional attitude calculation methods, an Extended Adaptive Kalman Filter algorithm was proposed to optimize attitude data. The algorithm first builds a state equation model based on sensors such as gyroscope, accelerometer, and magnetometer, with gyroscope data as prediction data, accelerometer and magnetometer measurement values as observation data, and performs error compensation and filtering on the collected raw data. The Seagull Optimization algorithm (SOA) is used to optimize the process noise covariance and measurement noise covariance of the Extended Kalman Filter. Finally, a high-precision aircraft attitude estimation is obtained after Adaptive Extended Kalman Filter algorithm (AEKF) filtering. Both static and dynamic experiments are carried out on the flight experiment platform based on INS-DH-OEM inertial navigation system. Comparing and analyzing the filter effect of the traditional extended Kalman filter algorithm and the adaptive extended Kalman filter algorithm proposed in the paper. Through the experimental results, the algorithm proposed in this paper can suppress the drift of attitude angle, filter out noise and accurately track the attitude change. In the static test, the accuracy of the three attitude angles can be controlled within 0.1°. Compared with the traditional EKF algorithm, the proposed algorithm has better stability and higher accuracy. In the dynamic experiment, the gyroscope has good dynamic performance but with the passage of time, it will produce integral drift, and in this paper, the accelerometer is used to carry out a real-time drift correction of the gyroscope. The roll Angle error and pitch Angle error of this algorithm are within 0.5 °, which is higher than that of the traditional EKF algorithm.

Keywords: Adaptive Extended Kalman Filter, attitude estimation, inertial navigation system, Seagull Optimization algorithm (SOA)

1. INTRODUCTION

Inertial measurement systems are widely used due to their wide application range, good dynamics, and high accuracy of data acquisition. For example, in small aircraft, they are used to obtain aircraft attitude information. With the development trend of society, small unmanned aerial vehicles (UAVs) are playing a huge role in surveying and mapping, three-dimensional real scene, land planning, public security maintenance, disaster monitoring, forestry investigation, smart water conservancy, digital city, emergency rescue and other fields. ^{[1][2]} Due to the wide application of UAVs, it is inevitable that they will be used in the harsh environment with extremely poor signals and low visibility, such as high altitude, fog, heavy rain, heavy snow, etc., which leads to the low operation efficiency of UAVs. Therefore, higher requirements are put forward for the attitude information of the UAV. Usually, a filter algorithm is used to solve the attitude information to obtain high-precision, high-reliability and high-stability attitude information.

Julier et al. (2000)^[3] used a filter better than extended Kalman filter for filtering, and the accuracy effect is easier to achieve than EKF or Gaussian second-order filter. However, this method requires a lot of computation and is not easy to implement. Shin et al. (2004)^[4] developed a low-cost unscented Kalman filter, a quaternion-based UKF method, which allows a large initial attitude error. For the inertial navigation system with a fast increase in heading error, the processing result is better, but the calculation is large and EKF is better than UKF when the initial attitude error is small. Sabatini et al. (2006)^[5] designed and tested a quaternion-based orientation filter, established a specific state vector model, and introduced the measurement noise covariance matrix to prevent the influence of magnetic field disturbance on the measurement accuracy, thus improving the accuracy of positioning estimation. Rong Zhu et al. (2007)^[6] proposed a novel estimation method based on the Kalman fusion algorithm, which adopts a new state vector containing three

> SPIE-CLP Conference on Advanced Photonics 2022, edited by Xu Liu, Anatoly Zayats, Xiaocong Yuan, Proc. of SPIE Vol. 12601, 126010J © 2023 SPIE · 0277-786X · doi: 10.1117/12.2666214

orthogonal components of magnetic field and gravity, replacing the traditional Quaternions and Euler angles, thus establishing a simple linear Kalman model, the method is greatly simplified in computational complexity, and can be executed at a faster speed using an inexpensive microprocessor, which verifies the effectiveness of the method. Silson et al. (2011)^[7] proposed a new fast initial coarse alignment estimation method for ship strapdown inertial attitude reference system. The advantage of this method is that it can deal with attitude errors effectively. The disadvantage is that only inertial measurement units are used for alignment, and sensor errors are not considered. Zou et al. (2014)^[8] design of the improved Extended Kalman Filtering algorithm, using the fourth order runge kutta method to correction of gyro Angle, so as to correct the error of accelerometer and magnetometer data, estimate the process noise covariance of Kalman Filtering, so as to accurately locate gesture, but ignored the interference of the acceleration of gravity. Julier et al. (2014) ^[9] surveyed the state of the art in unscented techniques for nonlinear estimation and provided a number of examples to verify its advantages over the traditional linearization method, but there is a lack of certain experiments and evidence. Sheng et al. (2015)^[10] proposed an algorithm for fusion of Multi sensor data, which was implemented by the strapdown AHRS hardware platform. The attitude angle can be corrected by PID control parameters and the attitude estimation is processed by the direction cosine matrix model. Zhao et al. (2015)^[11] proposed the CKF algorithm, which uses the noise statistical estimator and has high adaptive robustness, this algorithm solved the problems of accuracy degradation and divergence under the condition of model uncertainty or prior noise statistics, and improved the robustness and adaptability of SCKF algorithm. Wang et al. (2017)^[12] proposed a volumetric Kalman filter algorithm and deduced an augmented volumetric Kalman filter to deal with the strong nonlinearity of the INS model, effectively reducing the nonadditive value in inertial measurement. The method is better than the traditional EKF/UKF method. Lu et al. (2020)^[13] proposed an aircraft attitude information fusion method based on Extended Kalman Filter (EKF) to eliminate the influence of magnetic interference on attitude and heading estimation, but in the process of attitude determination, the linearization step of the system equation uses the Jacobian matrix to update the state transition matrix and the observation matrix, which has poor stability and large estimation deviation. Liu et al. (2022) ^[14] proposed an Adaptive Unscented Kalman Filter (AUKF), which uses the gradient descent method to optimize the key parameters of the unscented Kalman filter and without calculating the Jacobian matrix. The convergence speed is strengthened, and the attitude calculation accuracy and stability are very good, but the calculation amount is large, and the estimation accuracy is also greatly affected in complex working environments. G. Zhou ^[15-20] has also done a lot of research in this field.

Considering the accuracy of attitude calculation, the influence of sensor errors and the algorithm requirements, a SOAoptimized Adaptive Extended Kalman Filter algorithm is proposed. This method optimizes the parameters R and Q of the filter, and finds the exact values of the two parameters, so as to achieve the purpose of solving. The algorithm has the advantages of the fast global convergence, the fast operation speed and the simple implementation. Through the static and the dynamic experiments, the advantages of the algorithm and the traditional Kalman filter algorithm are compared and analyzed. The algorithm improves the accuracy and performance of attitude solution.

2. OVERALL IMPLEMENTATION METHOD

The SOA genetic algorithm is used to adaptively adjust the noise model parameters of the extended Kalman filter system to meet the requirements of the EKF algorithm model for accurate modeling. Since the model parameters of this filter are constantly changing over time, the optimization period of the genetic algorithm can be appropriately selected to reduce the calculation amount to a certain extent and optimize the filtering accuracy; through optimizing the function of SOA genetic algorithm, the optimal large-scale variation of parameters can be found, so as to achieve high-precision attitude calculation.

The SOA genetic algorithm can iteratively obtain accurate parameters, which are the two key values R and Q of the extended Kalman filter, that is, the measurement noise value and the system noise value. Of course, all of these require repeated debugging and research through programming to get better results. The idea flow of the whole attitude calculation is shown in the following Fig. 1.



Fig. 1. Flow chart of attitude solution based on AEKF

3. EXPERIMENT AND RESULT ANALYSIS

This experiment is based on the Seagull Genetic algorithm ^[21] using the Extended Kalman Filter to solve the adaptive filtering. In the Windows 10 environment, the experiment is carried out through MATLAB R2014b, and the experimental situation is as follows.

3.1 Experimental Platform

In order to illustrate that the method proposed in this paper has certain advantages, the accuracy of attitude calculation is improved to a certain extent. In this paper, a flight experiment platform based on the INS-DH-OEM inertial navigation system is built, and the UAV dynamic flight experiment is carried out outdoors. This experiment uses the INS-DH-OEM inertial navigation system, which uses an advanced dual-antenna GNSS receiver, Honeywell HG4930 IMU, advanced MEMS accelerometer with 3-axis calibration full operating temperature range and a new generation of tactical grade MEMS gyroscope. The parameters of the inertial measurement unit are as follows: the serial port baud rate is 115200bps, the data output rate is 1~200HZ, the pitch/roll accuracy (static) is: 0.05 RMS, and the pitch/roll accuracy (dynamic) is: 0.5 RMS. High-precision inertial measurement unit (including gyroscope and accelerometer), as shown in the following Fig. 2.



Fig. 2. Honeywell HG4930 IMU

3.2 The Experiment

The data of this experiment is from June 25, 2022, in front of the library of Yanshan Campus of Guilin University of Technology, Guilin City, Guangxi Zhuang Autonomous Region. using an octa-rotor UAV equipped with INS-DH-OEM sensor to carry out the flight experiment, data collection is read by the INS-DH-OEM high-precision inertial navigation system, and the data read by the sensor system within a certain period of time is selected for comparison with the attitude data obtained by the experimental method.

3.3 Static Experiment

The eight-rotor UAV is placed on the level ground, and the ideal value of the pitch angle and roll angle is 0°, as shown in the following Fig. 3.



Fig. 3. Octopteral drone with IMU

This experiment outputs normalized acceleration data, and the angle data is converted into radians and angles. After the Adaptive Extended Kalman Filter processing, the curve change graph of the attitude angle within 180 seconds is output. The actual attitude curve of the three axes is shown in the following Fig. 4.



Fig.4. Three-axis actual attitude curve

Through the Adaptive Extended Kalman Filter processing of the attitude data collected in the static state, it is found that compared with the ideal value of the roll angle of 0°, the actual roll angle deviation is 0.09°, and the algorithm has higher Compared with the ideal value of the pitch angle of 0°, the actual pitch angle deviation is 0.045°, and the calculation accuracy of the algorithm is high; since the magnetometer data is not included in the POS, the attitude calculation of the heading angle depends on Accelerometer and gyroscope, but between 20 seconds and 40 seconds, the error of accelerometer and gyroscope fluctuates greatly, so the calculated heading angle fluctuates greatly around 20 seconds, and basically remains stable in other time periods.

3.4 Dynamic Experiment

Let the UAV equipped with the POS experimental platform change its attitude, and select the attitude measurement data under dynamic conditions.

Experiment: collect the dynamic POS data within 100 seconds, use the Adaptive Extended Kalman Filter algorithm to calculate the attitude, and compare the three-axis attitude angle calculated within 100 seconds with the error of the real three-axis attitude angle obtained by the UAV with the SOA platform installed, as shown in Fig.5.





Analysis: Comparing the calculation result of the Adaptive Extended Kalman Filter algorithm with the real attitude angle, the deviation between the filter angle of roll and the real angle is within 0.2 °, the deviation between the filter angle of pitch and the real angle is within 0.5 °, and because of the POS does not contain magnetometer data, so the magnetic field data cannot be obtained. The true heading angle of the magnetic field is obtained by the fusion of the three-axis accelerometer and the gyroscope. The yaw filtering angle calculated by the Adaptive Extended Kalman Filter algorithm is not representative and cannot be compared. Therefore, in general, the real attitude angle curve changes can be accurately tracked by the Adaptive Extended Kalman Filter algorithm, but the value of the heading angle is very drifting and is not representative.

4. CONCLUSION

Aiming at the attitude solution problem of octopteral drone, in order to solve the low cost and high precision requirements of attitude sensor installed on UAV, in this paper, an attitude solving algorithm based on SOA algorithm and Adaptive Extended Kalman Filter is proposed. The method uses the SOA algorithm to adjust the parameters R and Q of the Extended Kalman Filter, optimizes the state prediction and estimation, and effectively reduces the sensor drift and noise errors in the attitude solution process. Through the static data and dynamic data collected by the UAV platform equipped with imu, the attitude accuracy of the proposed method is verified, and the experimental results are analyzed and compared in detail. Experimental results show that, compared with the traditional algorithms, the algorithm improves the long-term stability and accuracy of attitude solution.

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