Autonomous Security Evaluation Model for UAV Based on Airborne Information

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***Abstract*—The issue of safety assessment during UAV flight is a core technology for UAV safety regulation. This study establishes an evaluation model for the autonomous safety of unmanned aerial vehicles (UAVs). First, set up a multi-sensor module to measure the UAV airborne data, then filter out the noise of the airborne data based on the Butterworth filter, and then compute and process the collected airborne data based on the UAV security evaluation index. Then, use the Logistic function to normalize the UAV airborne information. Finally, establish the UAV autonomous security evaluation model based on the index selected by the AHP for the UAV security evaluation.**

***Keywords*—UAV, Security Assessment, Logistic Function, AHP, Security Assessment Model**

I. INTRODUCTION

UAV (unmanned aerial vehicle) is a kind of unmanned aerial vehicle that flies by radio remote control or self-contained program [1, 2]. It has the advantages of convenient deployment, high maneuverability and low cost. Compared with manned aircraft, the unmanned aerial vehicle is smaller and more flexible. Since the unmanned aerial vehicle was invented in the 1940s, it has been integrated into national production and life after decades of development. Unmanned aerial vehicles have been widely used in the military [3], civil [4], commercial [5], and many other fields. However, when an unmanned aerial vehicle component fails, severe weather conditions may cause the UAV to fall at high altitudes, causing serious damage or injuries. Safety issues with the flight of unmanned aerial vehicles during the voyage become prominent [6-8]. In the past, whether an unmanned aerial vehicle is in a safe environment is often judged by artificial experience. This method is subjective and has a small audience, which is not conducive to promotion. With the proposal of UAV safety supervision, people put forward higher requirements for UAV quality, flight safety, and stability. Improving the reliability of UAVs in flight has gradually become a frontier and hot issue in the field of UAV scientific research [9-10].

In this work, we set up an evaluation model for UAV autonomous security. The model of UAV autonomous security assessment includes the collection, filtering, calculation, and normalization of UAV atmospheric data. The collection of UAV atmospheric data achieves the collection of multiple UAV airborne information by building different sensor modules. Unmanned aerial vehicle (UAV) atmospheric data calculation establishes the UAV security evaluation index and the information collection processing. Filtering of UAV atmospheric data establishes a Butterworth low-pass filter to filter out Gaussian noise during acquisition. Normalization of UAV atmospheric data enables dimensionless processing of the UAV evaluation index, mapping data to standardized intervals. Finally, an evaluation model of UAV autonomous security is established according to the proposed index.

There are several contributions to our work.

1) The data type of UAV atmospheric data collection is given.

2) Established a multidimensional evaluation index for the safety of unmanned air data.

3) Established a model for the safety assessment of UAV atmospheric data.

II. LITERATURE REVIEW

Currently, the research on UAV security at home and abroad is mainly focused on transmitting the information.

Khan et al. [11] solved the problem of messages unencrypted in MavLink by adding a security layer to encrypt and protect the protocol. Encryption technology was proposed to ensure communication security between the UAV and the ground military system. Zhou et al. [12] designed a low-complexity iterative algorithm to maximize the minimum confidentiality capacity under delay, minimum unload, and total power constraints, which enhances communication security between unmanned aerial vehicles. Mehta et al. [13] handle the real-time dynamic communication requirements of unmanned aerial vehicles based on blockchain technology, providing a strong and secure communication network for unmanned aerial vehicles. Wu et al. [14] Using the unmanned aerial vehicle image to monitor the safety performance of road construction, proposed the safety inclination of the pit slope as the safety monitoring index to ensure construction safety.

A series of UAV safety scoring systems have been set up by relevant domestic and foreign workers, but there are some problems. At present, no specific, simple, and practical UAV safety evaluation system has been formed.

III. ESTABLISHMENT OF UAV SAFETY EVALUATION MODEL

The model of UAV autonomous security evaluation includes measurement, filtering, calculation, and normalization of UAV atmospheric data information. Finally, a security evaluation model is established using normalized data information.

A. Measurement of Data

The airborne data of the UAV is collected by the measuring platform, and the longitude and latitude of the UAV's space position are measured by the GPS positioning module; MPU6050 six-axis attitude sensor module measures the attitude of the UAV fuselage; The barometric pressure sensor module measures the atmospheric pressure of the UAV's space position; The magnetometer module measures the magnetic field intensity of the space where the UAV is located. The structural block diagram of the measuring platform is shown in Figure 1.

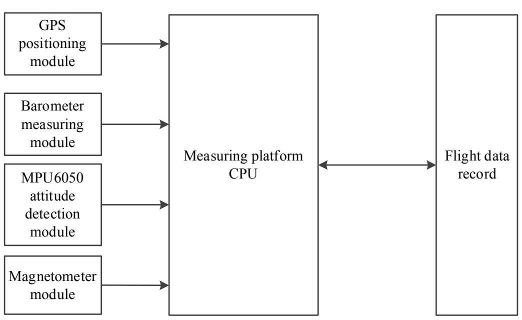

Fig. 1. Structural block diagram of measuring platform

B. Data Filtering

The acquisition and transmission of UAV signals will be affected by the errors of acquisition devices and the interference of the surrounding environment, thus affecting the accuracy of the collected signals. Therefore, the frequency domain noise reduction method is used to process the collected signal, and the frequency domain transformation is used to filter the Gaussian noise of the collected information; The noise is filtered according to the spatial position longitude and latitude information, fuselage attitude information, atmospheric pressure information and magnetic induction intensity information collected by the UAV measurement platform.

1) Fourier transform of discrete signal for collected signal

The Fourier transform formula is shown in the formula (1):

$$F(m) = \sum_{n=0}^{n=N-1} f(n) \bullet e^{\frac{-j2\pi mn}{N}} \tag{1}$$

In the formula(1), N is the number of discrete signals in the time domain, n is the number of discrete signals in the time domain (value range: 0~N-1), m is the number of signals in the frequency domain (value range: 0~N-1), and the number of signals in the frequency domain is also N.

2) Design FIR filter for the collected information

The design FIR filter performance requirements are shown in Table I.

TABLE I. FIR FILTER PERFORMANCE REQUIREMENTS TABLE

Performance Parameter	Set Value
Filter Type	Low Pass Filter
Passband Cut-off Frequency fp	10Hz
Stopband Cut-off Frequency fs	30HZ

3) Design filter function $H(N)$

The function passing through the filter is shown in the formula (2).

$$F = F(m) \bullet H(N) \tag{2}$$

After the inverse Fourier transform of the discrete signal is shown in the formula, the signal is converted from the frequency domain signal to the time domain signal to achieve signal filtering.

C. Data Solving

For the collected atmospheric pressure information, the relationship between atmospheric pressure and altitude can be obtained by using the atmospheric pressure-altitude formula as shown in the formula (3).

$$P = P_0 \times \left(1 - \frac{L*h}{T_0}\right)^{\frac{g*M}{R*L}} \tag{3}$$

In Formula 12, P_0 is the standard atmospheric pressure at sea level, which is; H is the altitude; L is the rate of temperature decrease, about 0.0065K/m in dry air; T0 is the sea level standard temperature; G is the acceleration of gravity on the earth's surface, about 9.8m/s 2; M is molar mass, about 0.0289644kg/mol; R is the universal gas constant, about 8.31447.

For the collected airborne attitude information, the corresponding three-dimensional Euler angle can be solved by the quaternion method to obtain the airborne data of the unmanned aircraft.

The collected magnetic field strength information, it can be obtained by analog-to-digital conversion after collection by the magnetometer sensor. Enables detection of magnetic field interference in the space where the UAV is located.

Navigation height of unmanned aerial vehicle: Atmospheric pressure is measured by a barometer, DFT is transformed by a discrete frequency domain, then filtered by a designed frequency domain filter. Finally, the current space height of the unmanned aerial vehicle can be derived from the pressure formula.

Navigation distance of unmanned aerial vehicle: The longitude and latitude of the unmanned aerial vehicle are measured by the GPS positioning module, DFT is transformed by a discrete frequency domain and then filtered by a designed frequency domain filter. Then two-dimensional plane coordinates of the unmanned aerial vehicle are calculated by the transformation formula of the latitude and longitude coordinate system. The three-dimensional position of the unmanned aerial vehicle can be obtained by combining the altitude information measured by a barometer. Defines the unmanned aerial vehicle navigation distance as a two-norm of the three-dimensional position of the unmanned aerial vehicle. As shown in the formula (4).

$$d = \| s \|_2 = \sqrt{x^2 + y^2 + z^2} \tag{4}$$

Unmanned aerial vehicle vacuum speed: The components of the unmanned aerial vehicle speed in the three-dimensional coordinate system are derived by the first-order difference of the unmanned navigation distance derived from the above sensor measurements. The unmanned aerial vehicle vacuum speed is defined as a two-norm of the three-dimensional velocity component of the unmanned aerial vehicle space. As shown in the formula (5).

$$\begin{cases} v_x(i) = x(i) - x(i-1), i \in (2,n) \\ v_y(i) = y(i) - y(i-1), i \in (2,n) \\ v_z(i) = z(i) - z(i-1), i \in (2,n) \\ v = \| \vec{v} \|_2 = \sqrt{v_x^2 + v_y^2 + v_z^2} \end{cases} \tag{5}$$

Unmanned aerial vehicle navigation load: Unmanned aerial vehicle acceleration component in a three-dimensional coordinate system is obtained by the second-order difference of the unmanned navigation distance derived from the above sensor measurement information, and the unmanned aerial vehicle navigation load is defined as the product of the unmanned aerial vehicle acceleration and mass. As shown in the formula (6).

$$\begin{cases} a = \| \vec{a} \|_2 = \sqrt{a_x^2 + a_y^2 + a_z^2} \\ F = m \times a \end{cases} \tag{6}$$

Mach number of unmanned aerial vehicle: Mach number is the ratio of vacuum speed to sound speed. The vacuum speed has been calculated in the above steps, taking into account that the sound speed is only affected by temperature, which is dependent on altitude. As shown in the formula (7).

$$\begin{cases} A = A_0 \times \sqrt{1 - \dfrac{L}{T_0} \times H} \\ M_a = \dfrac{v}{A} \end{cases} \tag{7}$$

The magnetic field strength of the space in which the UAV is located is measured by a magnetometer sensor, transformed by a discrete frequency domain DFT, and filtered by a designed frequency domain filter to output the measured magnetic field strength.

UAV Attack Angle: Measure the airborne attitude information through the MPU6050 attitude sensor, transform DFT through a discrete frequency domain, and filter through the designed frequency domain filter to output the measured UAV Attack Angle.

D. *Normalization Processing of Signals*

Based on different ranges of atmospheric data information, the unmanned aerial vehicle information is normalized to the [0,1] range by using the Logistic function. Based on the UAV's navigation distance, the UAV's vacuum speed, the UAV's navigation capacity, UAV Mach number, the intensity of the magnetic field in the space where the UAV is located, and the interval of the UAV's angle of attack, the corresponding Logistic functions are established. For a set of data x, the mean and maximum, and minimum values are calculated, respectively, as shown in the formula (8).

$$\begin{cases} Ex = \dfrac{1}{n} \bullet \sum_{i=1}^{n} x(i) \\ \max x = x^{(n)} \\ \min x = x^{(1)} \end{cases} \tag{8}$$

In the formula (8), Ex is the mathematical expectation of x, $x^{(i)}$ is the ith order statistic of x, $\max x$ is the maximum of x, and $\min x$ is the minimum of X.

The standard for building a Logistic function based on this is shown in the formula (9).

$$Q = 1 - \frac{1}{1 + e^{-\frac{(x-Ex)}{\max x - \min x}}} \tag{9}$$

This Logistic function allows monitoring information to be mapped into an interval [0, 1] to normalize the data.

E. *Establishment of Safety Evaluation System*

For the measured atmospheric data system index, the weight between the indexes is determined by the analytic hierarchy process, and then the safety evaluation of the atmospheric data system is realized.

For AI at any given time, the relative importance of AIJ to the rest of the indexes is calculated, as shown in Table II.

TABLE II. EVALUATION INDEX IMPORTANCE COMPARISON RESULT

	A1	A2	...	An
A1	a11	a12	...	a1n
A2	a21	a22	...	a2n
...	...	...	...	...
An	an1	an2	...	ann

The relative importance can be calculated as shown in the formula (10).

$$a_{ij} = \frac{A_i}{A_j} \tag{10}$$

The resulting quantitative judgment matrix is shown in the formula (11).

$$A^{'} = [a_{ij}]_{n\times n} \tag{11}$$

By calculating the relative weights of each hierarchical index through the analytic hierarchy process, the quantitative judgment matrix is normalized column by column as shown in the formula (12).

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{12}$$

The sum vectors added by rows are shown in the formula (13).

$$W_i = \sum_{j=1}^{n} \overline{a_{ij}} \tag{13}$$

Next, the sum vector is normalized to get the weight vector as shown in the formula (14).

$$\overline{W_i} = \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{14}$$

The final UAV system security evaluation score is shown in the formula (15).

$$Value = \sum_{i=1}^{n} W_i \bullet Q_i \tag{15}$$

IV. Evaluation Model Solving

The Logistic function corresponding to the Butterworth filter and the safety evaluation index in the UAV security evaluation model is solved, and the safety evaluation index of the UAV is established.

A. Filter Design and Filtering Results

A Butterworth low-pass filter is designed for the performance parameters shown in Table I as shown in Figure 2.

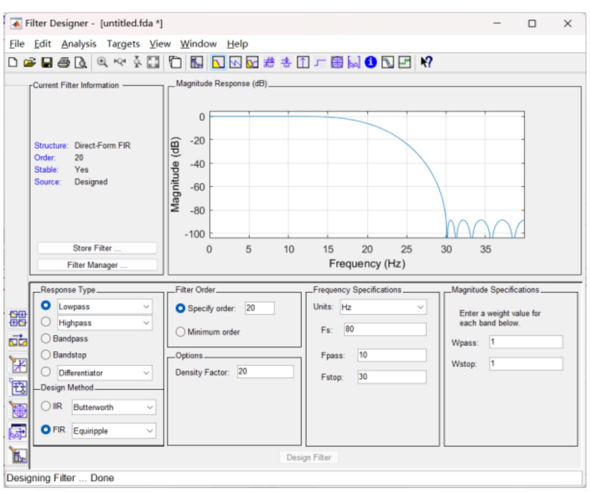

Fig. 2. Butterworth Low-pass Filter Frequency Response Graph

The UAV flight data before and after filtered data processing is shown in Figure 3.

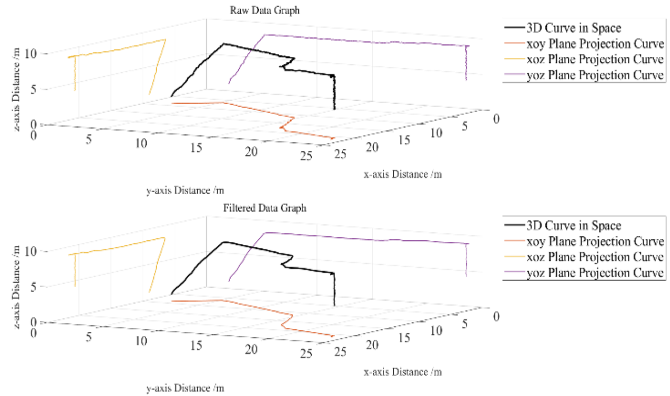

Fig. 3. Filtering result graph

B. Model Data Processing

Take the acquisition of UAV flight data as an example to calculate the corresponding indicators, such as the intervals of the six indicators shown in Table III and the corresponding designed Logistic functions to normalize them.

TABLE III. Intervals of Indicators and Corresponding Logistic Functions

Indicator Name	Interval	Logistic function
Unmanned aerial vehicle navigation distance	[0,500]	$x_0 = 1 - \frac{1}{1+e^{-\frac{(x-250)}{50}}}$ (16)
Unmanned aerial vehicle vacuum speed	[0,40]	$x_0 = 1 - \frac{1}{1+e^{-\frac{(x-20)}{4}}}$ (17)
Unmanned aerial vehicle navigation capacity	[0,10]	$x_0 = 1 - \frac{1}{1+e^{-(x-5)}}$ (18)
Mach Number of Unmanned Aerial Vehicles	[0,0.1]	$x_0 = 1 - \frac{1}{1+e^{-100\bullet(x-0.05)}}$ (19)
Space magnetic field strength of the unmanned aerial vehicle	[0.4,0.6]	$x_0 = 1 - \frac{1}{1+e^{-50\bullet(x-0.5)}}$ (20)
UAV Attack Angle	[0,30]	$x_0 = 1 - \frac{1}{1+e^{-\frac{(x-15)}{3}}}$ (21)

The logistic function normalized by the six indicators is shown in Figure 4.

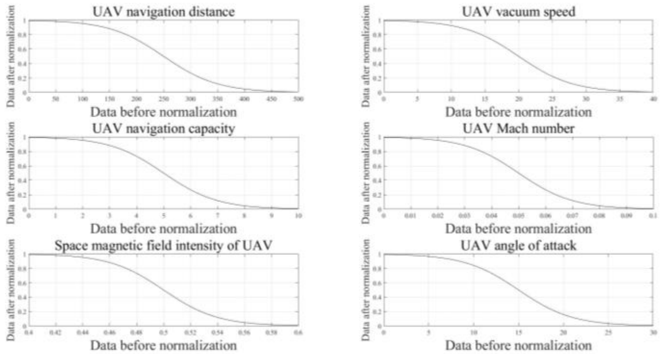

Fig. 4. Logistic Image Normalized by Different Indicators

C. Evaluation System

The autonomous safety system of the UAV is evaluated by six safety evaluation indexes: navigation height, navigation distance, vacuum speed, navigation bearing capacity, Mach number, magnetic field strength in space, and angle of attack. The structure system of UAV autonomous security evaluation is shown in Figure 5.

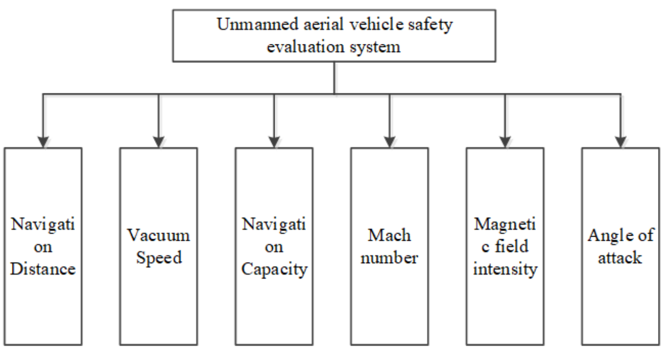

Fig. 5. Autonomous Safety Assessment Structure Diagram for UAV

Comparing the importance of six selected UAV safety evaluation indexes, a pair comparison matrix is constructed, the sum vectors are normalized, and the weight vectors are obtained as shown in the formula (22).

$$\overline{W_i} = \frac{W_i}{\sum_{i=1}^{6} W_i} \tag{22}$$

Finally, the UAV system security evaluation score is the product of six index factors, strength, and corresponding weight factor, as shown in the formula (23).

$$Value = \sum_{i=1}^{6} W_i \bullet Q_i \tag{23}$$

V. Conclusion

Aiming at the problem of autonomous security evaluation for unmanned aerial vehicles, this paper establishes the model of autonomous security evaluation for unmanned aerial vehicles. The CPU of the measuring platform and the filter of the data collected from the UAV are designed, and the structure system of the UAV's autonomous security evaluation is established. This paper mainly contributes to the following three aspects.

1) The data types of UAV atmospheric data collection are given.

2) A multidimensional evaluation index for the safety of unmanned air data was established.

3) A safety assessment model for UAV atmospheric data is established.

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