Classification of helicopter's typical flight state based on threshold

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Abstract. Dividing the 37 flying state of a certain line number helicopter. Firstly, dividing the helicopter rotation and single-engine flight. Secondly, performing preliminary state division for the remaining samples, the specific division of yaw angle, helicopter flight altitude and indicated air speed are different states, the least squares polynomial method is used for smoothing respectively. Calculating the extreme value of each parameter data, with the difference value of the extreme value of the parameter data being less than 10 as the limiting condition, dividing the original data segment into non-turning, level flight and steady speed state. The remaining sampling points are in the state of unsteady turning and non-level flight. Taking the difference value 0 as the limiting condition, further divide the non-steady speed and non-level flight state. Dividing the state of turning and non-turning, level flight, ascent and descent, steady speed, increase speed and deceleration state, which is the preliminary division state. Finally, dividing the near-ground and non-near-ground, classifying the helicopter status according to the height threshold, and analyze the accuracy of the classification results. The results show that this method is versatile, can quickly divide helicopters with different flight complexity, and has high accuracy.

1. Introduction

Helicopters for sightseeing, entertainment and material transportation when disasters occur, environmental monitoring, combat, training, etc. [1-2]. The influence of complex factors such as external airflow, vibration and noise in flight changes the load carrying capacity of mobile components under different flight conditions, causing damage to the mobile components [3]. In the event of an accident, it may cause casualties and damage to the helicopter. Therefore, the classification of helicopter flight status has important practical significance for the fault diagnosis and life prediction of helicopter structural components [4-7].

Liu Yu et al. proposed a method based on support vector machines for state division [8-9]. But in actual operation, the time complexity is not been combined with the research. In practical applications, the use value is low. Wang Jin-sheng uses random forest method to achieve flight status division [9]. However, the accuracy of the pre-classification method is uncertain, needing to verify the accuracy of the actual flight status classification results. This paper uses the least squares polynomial fitting method to smooth the helicopter state parameters on the scientific research flight test data of a certain type of helicopter. Obtaining the extreme value of each parameter and performing the difference to obtain the extreme value difference sequence. When the difference value of the extreme value is less
than 10, it is the limiting condition, considering the time continuity, and finally the corresponding original data segment that meets the above conditions is divided into non-turning, the remaining sampling points are in the state of turning, unstable speed and non-level flight. The remaining yaw angle, altitude, and indicated airspeed are differentiated, and the difference value is 0 as the limiting condition, and the unsteady speed and the non-level flight state are further divided. If the value is greater than 0, the speed is increasing, and the state is ascending. Less than 0 means deceleration and descending state.

Combining the engine torque, main rotor speed, pitch angle and other parameter thresholds to divide the helicopter's 37 flying states. Dividing the flying states of data with different levels of complexity, and the accuracy rate is high. Dividing actual scientific research flight test data, it has certain practical engineering application value.

2. Method: Least squares polynomial
Statistical research and scientific research, Building an approximate expression $y = P(x)$, This requires a lot of experimental data $(x_k, y_k)$($k = 0, 1, ..., m$) to find its functional relationship[10].Measuring the deviation $P(x)$ of a function from the given data, It can be measured by the sum of squares of deviations often used in curve fitting.

For the given data $(x_k, y_k)$($k = 0, 1, ..., m$), in the selected function class $\phi$, Solve $P(x) \in \phi$, Minimize the sum of squares of the deviation $r_i = P(x_i) - y_i (i = 0, 1, ..., m)$.

$$\sum_{i=0}^{m} r_i^2 = \sum_{i=0}^{m} [P(x_i) - y_i]^2 = \text{min}$$

(1)

Geometrically, the so-called least squares curve fitting problem is the problem of finding the minimum curve at a given point in the sum of the square of the distance from the point $x_0, x_1, ..., x_n$[11]. Let the fitting polynomial be

$$P(x) = a_0 + a_1 x + ... + a_n x^n, n < m$$

(2)

Getting the result by finding the partial derivative of the coefficients:
Firstly, finding the partial derivative of $S(a_0, a_1, ..., a_n)$ with respect to the coefficient $(a_0, a_1, ..., a_n)$[12], Easy to get

$$\frac{\partial S}{\partial a_j} = 2 \sum_{k=0}^{m} \left[ \sum_{i=0}^{n} x_i^j a_i - \sum_{i=0}^{n} x_i^j y_i \right], \quad j = 0, 1, ..., n$$

(3)

get:

$$\sum_{k=0}^{m} \left[ \sum_{i=0}^{n} x_i^j a_i - \sum_{i=0}^{n} x_i^j y_i \right] = 0, \quad j = 0, 1, ..., n$$

(4)

Equivalent to:

$$\sum_{k=0}^{m} (P(x_k) - y_k) x_k^j = 0, \quad j = 0, 1, ..., n$$

(5)

Regarding the linear equations of coefficients $a_0, a_1, ..., a_n$, Getting each coefficient by solving the above equation.

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3. Helicopter status classification

3.1 Classification of helicopter hovering, single-engine flight and rotation status
Single-engine flight: When the helicopter is off the ground and one of the left engine torque or the right engine torque is 0, the helicopter is in a single-engine flying state. Rotation decline: The helicopter has a single-phase clutch, which can rotate on its mechanical structure. When the main rotor system and the engine are disconnected, the engine no longer provides
power to the main rotor. The relative airflow drives the main rotor system, and only the airflow passing upwards through the rotor drives the rotor blades.

When the helicopter is off the ground, the left engine torque and the right engine torque are 0 at the same time, and the altitude drops, that is, if the altitude difference value is less than or equal to 0 within a continuous period of time, it is classified as autorotation.

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3.2. Classification of helicopter other status

After the rotation and single-engine flight status are divided, the remaining sampling points will be further divided into the flight status. In the helicopter scientific research flight test data, the state is divided according to the state parameters yaw angle, indicated air speed, and altitude, and the helicopter is preliminarily divided into turning non-turning, level flight non-level flight, steady speed and unsteady speed respectively. In the process of non-level flight and unstable speed, the state is further divided into altitude rise and fall, increase speed and deceleration state. The process of dividing the initial state of helicopter altitude is as follows:

Step 1: Polynomial fitting for smoothing

Through the analysis of the height data, the height data has volatility. Use least squares polynomial to fit height data, and convert the data to matrix form. The polynomial fits each row of data. Due to the volatility in the tail of the fitted data, in order to eliminate the influence of the tail fitting data fluctuation, each row adds m more data for fitting. Take the top 200 data after fitting each row. The best effect is when the order of each line fitting is n to 25.

\[
D_{(r+m)} = \begin{bmatrix}
    t(1) & t(2) & \cdots & t(r) & t(r+1) & \cdots & t(r+m) \\
    t(r+1) & t(r+2) & \cdots & t(2r) & t(2r+1) & \cdots & t(2r+m) \\
    \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\
    t(nr+1) & t(nr+2) & \cdots & 0 & 0 & \cdots & 0
\end{bmatrix}
\]

(6)

The height data is transformed into a matrix form, each row is 200, in order to eliminate the influence of the end of the fitting data fluctuation, each row is added m to 60 data for fitting. Take the top 200 data after fitting each row. The best effect is when the order of each line fitting is n to 25.

Step 2: Take extreme values

Take the maximum value and minimum value for the height data after the least squares polynomial smoothing process. Sort the position numbers of the maximum and minimum sampling points according to the order of the height of the original data sampling points to obtain the extreme point data sequence.

Step 3: Obtain the extreme difference sequence

Difference the extreme value data sequence to obtain the difference value sequence and add 0 in front of the sequence.

Step 4: Classification of non-level flight status

Considering the time continuity of the flight state combined with the characteristics of the altitude data sequence change, when the altitude is within continuous time, the altitude value fluctuates within a stable range, and the fluctuation range is within 10, which is classified as a level flight state.

That is to say, a segment of extreme value difference sequence that meets at least two consecutive points and the absolute value of the extreme value difference sequence is less than 10 is divided into the level flight range in the extreme value difference sequence. The original altitude data corresponding to the extreme difference sequence belonging to the level flight range is further divided into level flight state data, and the remaining altitude sampling points are divided into non-level flight state data.

Step 5: Preliminary classification of helicopter ascent and descent
Divide the ascent and descent status for non-level flight data, performing difference calculation on the non-level flight altitude data of step 4. The divided rising state is the height data corresponding to the position where the difference value is greater than 0, and the rest is the falling state data. The ascent, level flight and descent state divided by the original height and the fitted height are shown in Figure 1.

**Figure 1. Helicopter ascent and descent and level flight state diagram**

In the picture, blue is height rise, black is height drop, and red is level flight.

According to the division process from step 1 to step 5, the preliminary state division results of helicopter speed and yaw angle are shown in Figure 2 and Figure 3 below.

**Figure 2. Helicopter speed increase, deceleration and steady speed flight status diagram**

In the figure, blue is increasing speed, black is decelerating, and red is steady speed.

**Figure 3. Helicopter non-turning left turn right turn flight state diagram**

In the figure, blue is increasing speed, black is decelerating, and red is steady speed.
In the picture, blue means left turn, black means right turn, red means non-turning. The near-ground non-near-ground threshold is 50 meters. According to the speed threshold, the speed is divided into different ranges. Excessive speed: 70~90km/h; speed for maximum endurance: 90~130km/h; Speed for maximum endurance: Between Sailing speed: 130~190km/h; Long Sailing speed: 190~215km/h. There are two speed ranges between 130~190km/h cruising speed, 130~170km/h cruising speed and 170~190km/h cruising speed.

3.3 Helicopter status classification rules

The total number of sampling points for a helicopter sampling point is 77334, and each 13 sampling points is 1 second. According to the state parameter threshold and the following rules, the helicopter is divided into 37 flying states, 37 flying states shown in Table 1 below.

| Table 1. Flight status classification criteria |
|------------------------------------------------|
| status                                      | Flight status name                                    | Status label |
| Helicopter ascends and turns in flight      | Ascend to turn or circling ascend                      | 10           |
|                                              | Helicopter turns sharply                              | 13           |
|                                              | (90-130)Helicopter long-range speed horizontal turn   | 17           |
|                                              | (130-170)Helicopter cruise speed horizontal turn      | 21           |
|                                              | (170-190)Helicopter cruise speed horizontal turn      | 23           |
|                                              | (190-215)Helicopter voyage speed horizontal turn      | 25           |
|                                              | Helicopter hovering without ground effect            | 28           |
|                                              | Helicopter speed increase and turn flight             | 12           |
| Helicopter turning and flying              | Helicopter descending and turning flight              | 32           |
| Helicopter turning and descending flight    | Helicopter descends sharply and turns in flight       | 31           |
| Helicopter non-turning ascending flight     | Helicopter climbs obliquely                          | 6            |
|                                              | Helicopter flying vertically                         | 14           |
|                                              | (70-90)Helicopter cruising speed level flight         | 15           |
|                                              | (90-130)Helicopter long-range speed level flight      | 16           |
| Helicopter non-turning level flight         | (130-170)Helicopter cruising speed level flight       | 20           |
|                                              | (170-190)Helicopter cruising speed level flight       | 22           |
|                                              | (190-215)Helicopter voyage speed level flight        | 24           |
|                                              | Helicopter maximum cruising speed level flight        | 26           |
|                                              | Helicopter decelerates horizontally                   | 19           |
|                                              | Helicopter unsteady descending flight                 | 8            |
| Helicopter non-turning down flight          | Helicopter dive flight                                | 29           |
|                                              | The helicopter glide down at a steady speed           | 7            |
|                                              | Helicopter vertical descending flight                 | 35           |
| The flight speed is>270km/h                 | The helicopter flies at an insurmountable speed       | 27           |
| Rise near the ground                        | Helicopter taking off and increasing speed            | 5            |
| Descent near the ground                     | Helicopter vertical landing flight                    | 11           |
| Level flight near the ground                | Helicopter flattened landing flight                   | 37           |
|                                              | Helicopter approach/glide/deceleration flight         | 36           |
|                                              | Helicopter idle status on the ground                  | 1            |
|                                              | Helicopter flying slowly                             | 2            |
|                                              | Helicopter flying at low speed near the ground        | 9            |
|                                              | Helicopter has ground effect hovering flight          | 4            |
Hover: When the helicopter is at a certain height, it can maintain the same state of direction and position. The helicopter is off the ground, but the yaw angle and altitude are fixed, and the speed is about 0, it is hovering.

Helicopter idle status on the ground: When the rotation speed of the main rotor is 127~129, and the speed of the helicopter is about 0 without leaving the ground, it is a slow vehicle on the ground.

Helicopter air slow state: For a certain type of helicopter, when the height of every two sampling points rises by about 5m, and when the height of every two sampling points drops by about 5m, it is dropping sharply, and the yaw angle is turning.

Helicopter ascends, descends and turns to fly: For a certain type of helicopter, when the height of every two sampling points rises by about 5m and when the height of every two sampling points drops by about 5m, it is a sharp drop, and the yaw angle is in a turning state.

Helicopter flattened landing: When the helicopter is landing at altitude, the pitch angle increases monotonously for 4 to 8 seconds.

According to the above rules, the flight process of this sortie divided the 37 flight states of the helicopter, and the flight state changes are shown in Figure 4.

**4. Result**

*In the above figure, the abscissa is the sampling point number, and the ordinate is the flight status number.*

In the result of divided the helicopter flying status obtained, judging the helicopter altitude, speed, and yaw angle according to different status and corresponding limited conditions. When the corresponding yaw angle standard deviation, speed standard deviation, and altitude standard deviation in this segment of data are less than 1, it is non-turning, level flight, and steady speed; otherwise, turning, non-level flight, and unstable speed. Judging each segment of data after segmentation, and marking the sampling start point and ending point of each segment that does not meet the corresponding state determination criteria. Comparing the number of each sampling point divided by the helicopter with the corresponding actual flight status result. The wrong sampling points are as follows.
Table 2. Analysis of the accuracy of flight status division

| Divide the error state | Divide the range of the serial number of the wrong sampling point | Divide the error | Divide the range of the serial number of the wrong sampling point |
|------------------------|---------------------------------------------------------------|------------------|---------------------------------------------------------------|
| State 6                | 46310-46390                                                   | State 8          | 52270-52240                                                   |
|                        | 50610-50590                                                   | State 9          | 39080-39100                                                   |
|                        | 50940-50900                                                   |                  |                                                               |
| State 7                | 49930-49980                                                   | State 12         | 38920-38930                                                   |
|                        | 52380-52340                                                   | State 18         | 52210-52240                                                   |
|                        | 53320-53370                                                   |                  | 60190-60250                                                   |
|                        | 56850-56880                                                   | State 19         | 54020-54070                                                   |
|                        | 60700-60730                                                   | State 21         | 38140-38190                                                   |

Then the number of wrong sampling points is 728. Among them, the number of sampling points in state 0 is 16,207, and state 0 means that the helicopter is not started. The accuracy of the final classification of helicopter flight status is 98.34%.

5. Conclusion
The least squares polynomial fitting method is used to smooth the helicopter state parameters. The extreme value of each parameter data is obtained, and the difference value of the extreme value of the parameter data is less than 10 as the limiting condition, and the corresponding original data segment is divided into non-turning, level flight and steady speed state. The remaining sampling points are turning, unstable speed, and non-level flight. The parameter difference value 0 is used as the limiting condition, and the non-steady speed and non-level flight state are further divided, and finally combined with engine torque, main rotor speed, pitch angle, etc. The parameter threshold divides the 37 flight states of the helicopter. Due to the large fluctuations of the state parameter data, after smoothing the polynomial fitting, there are still large fluctuations, and there is a certain error in the polynomial fitting. The division result is compared with the actual state, and the division accuracy rate reaches 98.34%, which can divide the flight state of helicopters with different flight complexity levels, and has a high accuracy rate.

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