Research on Parameter Identification Algorithm of Updraft Based on Energy Recursion of Unmanned Aerial Vehicle

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Abstract. In this paper, the problem of UAV utilizing updraft energy near flight path is modeled, simulated and analyzed. Firstly, a simplified updraft model is established according to the characteristics of updraft. Then, according to the energy trend of UAV in the updraft, the recursive algorithm of UAV energy and the information acquisition model of UAV in the updraft are designed. Based on Nelder-Mead minimum search algorithm, an updraft parameter identification scheme is designed and simulated. It can be concluded that according to the above design scheme, UAV can basically identify the parameters of the updraft region, and achieve a certain identification accuracy, which provides a reference for future research.

1. Introduction
Long endurance UAVs are unmanned aerial vehicles that last for more than 10 hours, days, or even months. It is very suitable for the task of accomplishing intelligence reconnaissance and surveillance in modern high-tech local wars, as well as aerial photography and surveying and mapping tasks in the civilian field. In addition to its excellent airframe performance and gliding capability, long endurance UAVs can obtain additional extra energy through solar, wind gradients, updrafts, etc. to increase airtime[1~3]. China has a vast territory, diverse geographical features, and rich meteorological resources. Research and exploration of updrafts is very beneficial. It is also an advantageous condition for the study of long endurance drones based on the ascent of rising air currents.

In this paper, we study the characteristics and properties of updraft, then establish the updraft and its measurement model and design its energy estimation and updraft parameter identification algorithm. The structure is organized as follows: Section 2 presents a simplified model of updraft and the algorithm of Updraft intensity estimation based on the recursion of the UAV’s energy. Section 3 gives the simulation and verification of parameter identification of the updraft. Finally, Section 4 concludes the paper and points out further work.

2. Updraft Model and The Energy Recurrence Algorithm

2.1. The Updraft Model
Updraft refers to the situation that the vertical pressure gradient force is greater than the gravity of the air block in the vertical movement of air, that is, the air block moves vertically upward. Thermal
updraft refers to the updraft caused by uneven surface heating and atmospheric instability when the sun shines on the ground. Collecting a large number of updraft data as reference, the following properties of updraft are obtained:

- Most of the thermal updraft flows are similar to a circular platform.
- The closer it is to the center, the stronger the updraft is, and the closer it is to the edge, the smaller the updraft intensity is until it dissipates.
- The higher the altitude, the smaller the horizontal cross section of updraft.

According to the above properties and the research of Gedeon J and Michael J[4~5]. Allen, and neglecting the minor factors, we can get the two-dimensional Gauss distribution of thermal updraft. Furthermore, when the selected height interval is small enough, the vertical distribution of updraft can be neglected, and only the intensity distribution and range parameters on a certain horizontal plane need to be studied.

Because the simplified model considers that the updraft intensity is only related to the horizontal position, and the height does not affect its intensity, the airflow intensity distribution satisfies the following requirements:

\[ E_u(x, y) = K_A f(x, y) \]  

(1)

Where, \( K_A \) is the increase of the center strength of the airflow, and its relationship with the strength of the airflow center \( A \) satisfies the following equation:

\[ A = K_A f(u_1, u_2) \]  

(2)

\( f(x, y) \) is a distribution function of airflow, which satisfies the following equations:

\[ f(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x-u_1)^2+(y-u_2)^2}{2\sigma^2}} \]  

(3)

Where, \((x, y)\) represents the horizontal position of the UAV in the inertial coordinate system, \((u_1, u_2)\) is the horizontal position of the center of the updraft region, \(\sigma\) represents the range of the updraft region, and the relationship with the airflow radius \( R \) satisfies the following equation:

\[ R = 3\sigma \]  

(4)

Therefore, the distribution information of the updraft region can be obtained by identifying the four characteristic parameters of the updraft region by collecting the updraft data from the attitude and energy of the UAV.

2.2. Recursive Algorithm Based on UAV’s Energy

Updraft measurement refers to the information of airspeed, air pressure and other environmental information gathered by airborne measurement elements, and combined with the historical position information of the aircraft to judge the updraft around the aircraft, so as to estimate the updraft information.

At present, the measurement methods of updraft intensity are mainly through airspeed measurement of aircraft, three-dimensional wind speed calculation and updraft calculation. However, due to the limitation of sensor accuracy, it is very difficult to measure updraft by this method. This paper presents a method for estimating updraft by recurrence of UAV energy.

As shown in Fig. 1, the energy obtained by the aircraft from the power battery \( E_b \) is consumed by the sound, light and heat of the airborne circuit \( E_a \) on the one hand, and by the motor on the other. The motor loses part of its energy due to copper loss and iron loss \( E_m \), the rest of the energy transfers to the propeller. On the one hand, the propeller uses part of the energy to work on its own loss \( E_r \), on the other hand, it generates effective pulling force to work \( E_p \) so that the aircraft can fly normally. The pull work makes the UAV move. The effect of the pull work converts the pull work into three parts of
energy, one part into kinetic energy due to the change of speed $E_{a1}$, the other part into gravitational potential energy due to the change of altitude $E_{g1}$, and the other part into energy consumption due to the resistance caused by the movement $E_d$. Circuit loss $E_e$, motor loss $E_m$ and propeller loss $E_t$ are all internal losses of aircraft, so they are collectively referred to as aircraft loss $E_f$.

![Diagram of Energy Conversion Relation of UAV in Updraft](image)

**Figure 1.** Diagram of Energy Conversion Relation of UAV in Updraft. According to the law of conservation of energy, the energy obtained from the power battery and the updraft should be equal to the sum of the kinetic energy and gravitational potential energy converted by the aircraft itself during the flight in the updraft region.

Therefore, the battery energy is transformed into gravitational potential energy, kinetic energy, fuselage resistance work and aircraft loss. The expressions are as follows:

$$E_b = E_{g1} + E_{a1} + E_d + E_f$$  \hspace{1cm} (5)

When the aircraft is flying in the updraft area, it gains some additional energy from the updraft. This part of energy will directly affect the aircraft itself, resulting in changes in the speed and altitude of the aircraft, that is, directly converted into gravitational potential energy and kinetic energy. The expressions are as follows:

$$E_L = E_{g2} + E_{a2}$$  \hspace{1cm} (6)

To sum up, the formula for calculating the energy of updraft is as follows:

$$\begin{align*}
E_b & = \Delta t U_s I_b \\
E_e & = E_{g1} + E_{g2} = mg(h-h_0) \\
E_a & = E_{a1} + E_{a2} = \frac{1}{2}m(v^2-v_0^2) \\
E_d & = Dl = C_D Q S l \\
E_f & = E_e + E_m + E_t \\
E_c & = \sum^n_a E_{a} = \Delta t \sum^n_a U_i I_i \\
E_m & = (1-\eta_m)(E_b-E_e) \\
E_t & = (1-\eta_t)(E_b-E_c)\eta_m
\end{align*}$$  \hspace{1cm} (7)
\[ E_L = E_g + E_n + E_d + E_f - E_u \]  

(8)

\( \Delta t \) represents the sampling time, which is a very short fixed value; \( U_1 \) and \( I_1 \) the average voltage and current of the UAV battery in the sampling time can be measured by the power supply monitoring module. \( m \) denotes the mass of the aircraft and remains constant during flight; \( g \) denotes the local gravitational acceleration of the aircraft and is constant in the short term; \( h \) and \( h_0 \) denote the altitude of the aircraft and the altitude of the last sampling time respectively, which can be measured by accelerometers and barometers. \( v \) and \( v_0 \) represent the current speed of the aircraft and the speed of the last sampling time, which can be measured by GPS and inertial navigation devices. \( C_D \) refers to the drag coefficient of the aircraft; \( Q = \frac{1}{2} \rho v^2 \) refers to the dynamic pressure on the aircraft; \( S \) refers to the area of the aircraft, including the area of the fuselage and the area of the wing; \( l \) refers to the displacement of the aircraft along the flight direction during the sampling time. \( E_{el} \) refers to the energy used by various electrical appliances in the airborne circuit of an aircraft. Its size can be measured by a power supply monitoring module. \( \eta_m \) refers to the energy efficiency of the motor; \( \eta_t \) refers to the energy efficiency of the propeller. All the above parameters can be obtained by looking up tables, calculating or measuring. Therefore, the energy obtained by UAV at a certain time in the updraft can be obtained by formula (7) and (8).

3. Updraft Parameter Identification Algorithm and Its Simulation Analysis

By simplifying the updraft model, the identification of the updraft can be transformed into the parameter identification of the binary Gauss function represented by equation (1), that is, the identification of parameter \((u_1, u_2, \sigma, K_\lambda)\).

3.1. Parameter Identification Algorithm

The direct identification method refers to the parameter identification method which determines the updraft region of two-dimensional Gauss distribution by constructing measurement error function and finding its local minimum by Nelder-Mead algorithm. The function to be estimated is known as follows:

\[ \hat{E}_u(x_i, y_i, \hat{k}) = \frac{\hat{K}_\lambda}{2\pi\sigma^2} e^{-\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma^2}} \]  

(9)

The parameters to be estimated is \( \hat{k} = (\hat{u}_1, \hat{u}_2, \hat{\sigma}, \hat{K}_\lambda) \).

When the UAV flies over the updraft area, the updraft intensity at the track sampling point can be measured by the measurement method described above. The estimated value satisfies the following equation:

\[ E_u(x_i, y_i) = \hat{E}_u(x_i, y_i, \hat{k}) + e_i \]  

(10)

Where, \( e_i \) is the measurement error, so the following measurement error function can be designed:

\[ J(\hat{k}) = \sum_i^n (e_i)^2 = \sum_i^n \left[ E_u(x_i, y_i) - \hat{E}_u(x_i, y_i, \hat{k}) \right]^2 \]  

(11)

Then the Nelder-Mead minimum search algorithm is used to calculate the local minimum of the measurement error function \( J(\hat{k}) \) under the initial value \( \hat{k}_0 = (u_0, u_1, \sigma_0, K_\lambda) \), and the solution of the function at the minimum value is obtained, thus four important parameters of the updraft region are obtained. However, after a large number of simulation and calculations, it can be found that the initial value of the algorithm is more stringent, and in extreme cases, it may not converge to the local minimum. Therefore, in order to solve this problem, rough alignment is needed on the initial value,
which requires the design of reasonable acquisition trajectory and parameter initialization method in
the stage of UAV updraft information acquisition.

![Figure 2. Route sketch of rectangular airflow intensity acquisition.](image)

For the cylindrical two-dimensional thermal updraft region with Gauss distribution, a rectangular airway is proposed to collect
the airflow intensity. The acquisition route is divided into four sections: AB, BC, CD and DA.

As shown in Fig. 2, the acquisition route is divided into four sections. The UAV enters the updraft
area at point A, then flies along a straight line to point B, where the updraft intensity reaches the
threshold. Therefore, the UAV considers this point as the point on the boundary of the updraft area. In
order to collect more information about the updraft area, UAV should turn 90 degrees to continue to fly along the straight line inside the updraft, but UAV can not know whether the center position of the updraft area is on its left or right side, so it can only fly with the default 90 degree left turn. When UAV continues to fly in this direction, it is found that the intensity of updraft decreases or even disappears gradually, which indicates that UAV is far away from the updraft area. Then the center of airflow should be on the right side of AB route. At this time, UAV should turn 180 degrees immediately, turn 90 degrees right along the first route BC, and then turn right twice, and fly back to point A along CD and DA routes.

Up to now, UAV has roughly collected the information of airflow intensity on rectangular ABCD routes, which can be expressed as follows:

\[
\begin{align*}
\text{Data} &= \begin{bmatrix}
\bar{x} \\
\bar{y} \\
E
\end{bmatrix} = \begin{bmatrix}
x_1 & x_2 & \ldots & x_n \\
y_1 & y_2 & \ldots & y_n \\
E_1 & E_2 & \ldots & E_n
\end{bmatrix}
\end{align*}
\]  

Parameter initialization calculations for these information are as follows:

\[
\begin{align*}
u_i &= \frac{1}{n} \sum_{i=1}^{n} x_i \\
u_y &= \frac{1}{n} \sum_{i=1}^{n} y_i \\
\sigma_x &= \frac{1}{3} \max \{(\max(x_i) - \min(x_i)), (\max(y_i) - \min(y_i))\} \\
\sigma_y &= \frac{1}{3} \max \{(\max(x_i) - \min(x_i)), (\max(y_i) - \min(y_i))\} \\
K_{\sigma_x} &= \frac{1}{n} \sum_{i=1}^{n} 2E_i \pi \sigma_y \sigma_x^{n-1} e^{-\frac{(x_i - u_x)^2 + (y_i - u_y)^2}{2 \sigma_x^2}}
\end{align*}
\]

3.2. Simulation and Analysis

Then, under the initial condition of rough alignment, the parameters of the updraft region can be
identified to obtain more accurate parameters information. The simulation results show that Fig. 3 is
the simulated updraft and Fig. 4 is the flight route and sampling point of UAV.
Table 1 is the information of the original airflow parameters obtained by simulation and identified by the algorithm, as well as the accuracy of each parameter. It can be seen that the algorithm is very accurate in estimating the airflow range, accurate in the central position parameters, and slightly worse in estimating the magnification of airflow intensity, but it still meets the accuracy requirements.

| Table 1. Simulation results of direct identification algorithm. |
|-----------------|-------|---------|---------|
|                | X (m) | Y (m)   | sigma   | gain    |
| True value     | 100.00| 205.00  | 20.00   | 25133.00|
| Estimated value| 102.01| 213.28  | 20.36   | 25589.00|
| Deviation      | 2.01  | 8.28    | 1.80%   | 1.81%   |

4. Conclusions
Based on the study and analysis of the properties and characteristics of the thermal updraft, a two-dimensional Gauss distribution updraft model of the same plane airflow intensity is established, and an algorithm for updraft measurement is designed from the angle of UAV energy recurrence. On this basis, a method of updraft region parameter identification is proposed. As a result of the simulation and analysis, it can be concluded that the algorithm can achieve the requirement of the accuracy of the updraft parameters identification. Future research work includes enriching updraft models, such as parameter identification of elliptical updraft clusters. The research of UAV’s capacity trajectory optimization in updraft is also the future research content.

5. References
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