Research on Locating Algorithm of Unmanned Airport Source Based on Array Detecting Line

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Abstract. In view of the fact that the UAV patrol overhead transmission line cannot accurately locate the patrol UAV, the relative position of the field source cannot be judged, and the problem of autonomous navigation and obstacle avoidance cannot be realized. A field based on electric field information array detection is proposed. Source location algorithm. Firstly, based on the principle of electrostatic induction, the portable power frequency electric field sensor detection plate is designed. The four sensor detection plates are installed on the same horizontal surface of the drone with the coordinate center of the unmanned aerial vehicle center as the fixed coordinate system. By analyzing the geometric relationship of the spatial position of the four sensors and the corresponding output signals, the relative position coordinates of the field source space can be solved, so as to accurately locate the spatial relative position of the field source and the patrol UAV. The UAV can provide a reference for autonomous navigation and obstacle avoidance. The algorithm solves the problem that it is difficult to achieve accurate positioning and navigation due to factors such as too small wire diameter, weather conditions, and sensor limitations when the patrol drone is far away from the operator. At the same time, a reliable method is proposed. The algorithm can restore the trajectory of the UAV in the laboratory environment, and verify the accuracy of the field location algorithm. It provides a theoretical basis for the research of UAV autonomous obstacle avoidance navigation.

1. Introduction

As an important part of the power system, overhead transmission lines are extremely important for the safe and reliable operation of the power system. At the same time, the distribution points of overhead high-voltage transmission lines are wide-ranging, and the coverage areas are mostly mountainous areas, jungles, hills, etc. The natural environment is harsh, the meteorological conditions are complicated, and the power lines, towers and accessories are exposed to the field for a long time, subject to continuous mechanical tension, lightning and strong wind, materials. Damage caused by aging, such as broken strands, abrasion, corrosion, etc. if not discovered and repaired or replaced in time, will result in large-scale power outages, resulting in great economic losses and serious social impact. Therefore, in order to timely grasp the operation of the transmission line, understand the environment around the transmission line and carry out corresponding processing to ensure the safety of the power supply, the transmission line must be regularly inspected. However, the inspection of overhead high-voltage transmission lines is an extremely difficult process, which requires a lot of manpower, material and financial resources. The UAV inspection line has the characteristics of strong maneuverability, simple control, high efficiency and low cost. The UAV are used in the inspection of transmission lines by domestic and foreign power enterprises [1-5].

In the process of conducting inspections on overhead transmission lines by UAV, in order to collect
power line operation and fault information, the UAV needs to be close to the wires and towers to patrol the transmission lines. If the relative space position of field source and line patrol UAV cannot be accurate location and accurate ranging. It will bring big problems to the operation control of the UAV, which will cause the UAV to hit the transmission line or the tower, causing damage to the drone, the transmission line and the tower, and even causing the failure of the power system [6]. Based on this, this paper uses the inherent characteristics of a stable alternating electric field in the surrounding space after the power transmission line is energized [7]. Based on the electric field information array method, the mathematical model of the positioning and distance of the target field source is derived. The solution of the source relative spatial position enables the localization and orientation of the target field source. At the same time, using the stable field strength information around the energized wires, four portable sensing probes are designed based on the principle of electrostatic induction to install the layout on the surface of the UAV. The field source positioning model is established by the relationship between the four sensing probes. The relative position of the space between the field source and the UAV is accurately positioned, which provides a theoretical basis and reference basis for the autonomous aircraft to achieve autonomous navigation and obstacle avoidance.

2. Design based on electrostatic induction sensor probe

The conductor in the alternating electric field has its surface induced charge and the electric field to be measured change with time at the same frequency. For this induced charge treatment, a voltage or current signal proportional to the electric field to be measured can be obtained, thereby realizing the electric field measuring. The schematic structure diagram is shown in Figure 1:

Suppose the in-plane density of the induced charge be \( \sigma \), in the air, the dielectric constant \( \varepsilon_0 \) and the change in the measured electric field strength \( E(t) \) causes a change in the number of \( Q(t) \) induced charges. This relationship can be expressed as [8-9]:

\[
Q(t) = \int \sigma d\mathbf{s} = \varepsilon_0 E(t) S
\]

(1)

Where \( S \) is the effective area of the induction plate.

In order to facilitate accurate positioning of the target field source and simplify the field source to point charge, the field strength at a certain point of the detector plate is detected at a certain time [7,10]:

\[
E(t) = \frac{1}{4\pi \varepsilon_0} \frac{Q_0(t)}{x^2 + y^2 + z^2}
\]

(2)

The equations (1) and (2) can be used to determine the amount of charge on the plate:

\[
Q(t)(Q_0(t), x, y, z) = \frac{(Q_0(t) \cdot S)}{2\pi} \cdot (z / \sqrt{x^2 + y^2 + z^2})
\]

(3)

Where \( S = \pi a^2 \) is the area of the detector plate and \( a \) is the radius of the circular probe plate.

Change equation (3) to the form of spherical coordinate system, and its conversion relationship is shown in equation (4):
\[
\begin{align*}
\begin{cases}
x = r \sin \theta \cos \varphi \\
y = r \sin \theta \sin \varphi \\
z = r \cos \theta
\end{cases}
\end{align*}
- \frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}, \quad -\pi < \varphi < \pi
\]

(4)

Then equation (3) can be expressed as:

\[
Q(Q_0, x, y, z) = \left( \frac{Q_0 \cdot S}{2\pi} \cdot \sin \theta \right)
\]

(5)

It can be seen from equation (5) that the amount of charge induced by the sensor detecting plate is related to the amount of charge of the target field source, the distance \( r \) between the field source and the detecting plate, and the pitch angle \( \theta \) of the target with respect to the plate. Therefore, equation (5) is the localization equation of the field source.

3. Research on field source localization algorithm based on electric field information array

In order to accurately locate the relative position between the patrol UAV and the field source, a field strength information array based method is used to locate the field source. A detector array based on electrostatic induction was established\(^{[1]1}\). Combined with the analysis of equation (3), it can be known that the location of the field source requires four unknowns of \( Q_0, x, y, z \) to be solved. Therefore, four equations need to be established to solve the field source information. Let \( N=4 \) in equation (6), namely:

\[
\begin{align*}
Q_1 &= \frac{Q_0 \cdot S_1}{2\pi} \cdot \frac{z_0}{r_1^3} \\
Q_2 &= \frac{Q_0 \cdot S_2}{2\pi} \cdot \frac{z_0}{r_2^3} \\
Q_3 &= \frac{Q_0 \cdot S_3}{2\pi} \cdot \frac{z_0}{r_3^3} \\
Q_4 &= \frac{Q_0 \cdot S_4}{2\pi} \cdot \frac{z_0}{r_4^3}
\end{align*}
\]

(6)

Where \( Q_1, Q_2, Q_3, Q_4 \) represents the amount of induced charge on the 4 detector plates; \( S_1, S_2, S_3, S_4 \) represents the area of the 4 plates; \( Q_0 \) represents the charge of the target; \( \theta_1, \theta_2, \theta_3, \theta_4 \) represents the pitch angle of the target field source relative to the detector plate; \( r_1, r_2, r_3, r_4 \) represents the target and detection the distance between the centers of the plates.

Thus, the layout of the coordinate system and the sensor detector plate array is as shown in the following figure, where the coordinates of the target in this coordinate system are assumed to be \((x_0, y_0, z_0)\).

![Figure 2. Sensor detection plate array layout](image-url)
Assume that the center coordinates of the four sensing probes are (0,0,0), (L,0,0), (0,L,0), (L/2,L/2,0) and each detecting plate is a circle with an area S, the distance between the field source and each detecting plate, and the following equation can be obtained by solving the geometric relationship:

\[ r_1 = \sqrt{\frac{2 + 2 \cdot L}{\frac{Q_1^2}{Q_2^2} + \frac{1}{L} \left[ L^2 + 2 \cdot \left( \frac{Q_2^2}{Q_3^2} + \frac{1}{L} \right) \cdot (1 + L) \right]}} \]  

(7)

\[ r_2 = \sqrt{\frac{Q_2}{Q_1} \cdot r_1} \]  

(8)

\[ r_3 = \sqrt{\frac{Q_3}{Q_1} \cdot r_1} \]  

(9)

\[ x_0 = \frac{1}{2} \left( L^2 + r_1^2 - r_2^2 \right) \]  

(10)

\[ y_0 = \frac{1}{2} \left( L^2 + r_1^2 - r_3^2 \right) \]  

(11)

\[ z_0 = \frac{1}{2} \left( -2L^2 + 2L^2 \cdot r_1^2 - 2r_1^2 + 2r_2^2 r_3^2 - r_2^4 + 2L^2 \cdot r_3^2 - r_3^4 \right)^{\frac{1}{2}} \]  

(12)

It can be seen from the above equations (10-12) that the positioning and orientation of the field source target can be achieved by reading the four electrostatic detecting plates.

4. Analysis of the experiment and results

The algorithm was verified by the power frequency field source location experiment in the laboratory environment. The high-voltage experimental platform is adjusted to a fixed voltage level of 10kV, and a spatial rectangular coordinate system is established with the position of the field source as the coordinate system origin, and a trajectory is randomly arranged within the safety range of the coordinate system, as shown in the layout of the experimental scene, take 10 sampling points on the trajectory curve (as shown in Figure 3). At the same time, the portable power frequency electric field sensing plate for the UAV inspection line is arranged on the four wings of the UAV, and data is collected for different points. The wing length L is 0.6m, and the sensor is round. The radius of the sensing plate is 0.015 m, and the collected data is transmitted back to the host computer through the Bluetooth module. The schematic diagram of the experimental layout corresponding to the test scene layout is shown in Figure3:

![Figure 3. Schematic diagram of the experimental data acquisition system](image)

![Figure 4. Field source motion trajectory coordinate fitting curve](image)

The UAV sensor system is placed at 10 sampling points to collect the electric field information, and the output voltage value of each sensor under each point is recorded. The voltage value of the corresponding point is input into the mathematical model to solve the problem at this point. Accurate
positioning of the field source can be achieved by the spatial coordinates of the coordinate origin field source. And record the position of each coordinate, because during the experiment, the drone is placed on the ground, the field source height is low, so the z coordinate of the solution is basically unchanged and can be ignored. In order to facilitate the representation, the z coordinate value is omitted. The coordinate points (x, y) of the solution are fitted and analyzed by MATLAB, and the analysis results are shown in Figure 4.

5. Conclusion
At present, when the line patrol UAV is far away from the operator, due to the weather conditions, the power line diameter is too small or the limitations of the commonly used sensors, and can not be accurately controlled. In this paper, a method that based on the electric field information array is proposed for accurately locating the target field source. In the laboratory environment, the flight control center is taken as the coordinate origin, each sampling point is sampled, and the collected data is input into the field source to locate the mathematical model. The curve after fitting the output coordinate values is shown in Figure. 4. Combined with the experimental trajectory analysis in Figure. 3, it can be seen that the trajectory fitted by the positioning algorithm can restore the real experimental sampling trajectory better, which means that the algorithm can realize the positioning of the target field source by the UAV. The algorithm provides a theoretical basis for the autonomous navigation and obstacle avoidance of the UAV patrol transmission line, and has certain practical significance.

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