Design of Precise Delivery and Recovery System of Unmanned Aerial Vehicle Equipped with Line Patrol Robot

Jie Lu, Jinzhi Guo, Zhaoguang Zhang, Xinli Song, Lifeng Hou, Xuesong Bai, Jian Chen, Guangtao Yang, Ning Ji
(State Grid JiBei Electric Power Co., Ltd. ChengDe Power Supply Company, Chengde, HeBei, 067000, China)
*Corresponding author’s e-mail: lu.jie@jibei.sgcc.com.cn

Abstract. Based on the actual inspection requirements, this paper fully studies the application scenarios of UAV and robot inspection, and develops an intelligent UAV line inspection robot composite system based on UAV, robot, edge computing, machine vision, artificial intelligence and other technologies, which plays a significant role in promoting the application practice of UAV and robot inspection technology.

1. Introduction
Transmission line is an important part of the power grid, and transmission line inspection is an important means to ensure its reliable operation. With the introduction of new technologies, new methods and new management concepts, UAVs and line inspection robots have gradually been paid attention to and began to be applied to transmission line inspection, which makes up for the shortcomings of traditional manual inspection to a certain extent, especially in high mountains and other inaccessible areas, the advantages are more obvious [1-2].

In order to obtain clear images, the distance between the UAV and the tower during patrol inspection basically depends on visual observation and experience. It mainly depends on the airborne visual perception system for measurement and the infrared perception system for obstacle avoidance. However, the obstacle avoidance function does not necessarily take effect on small objects such as branches, conductors and ground wires. The maintenance of safe distance also depends on manual judgment and control [3-4]. The overhead transmission line inspection robot mainly walks on the conductor and ground wire with a cross-sectional area of no less than 50mm², and inspects the transmission line, ancillary facilities and corridors through the carried task load. The robot can go up and down the tower by manual hoisting, supporting up and down line devices, or mechanical arm devices. When walking on the conductor and ground wire, it will cause additional load on the conductor and ground wire, and it is not convenient for transportation and rapid deployment of on-site operation [5-7].

Based on the actual inspection requirements, this paper fully studies the application scenarios of UAV and robot inspection, and develops an intelligent UAV line inspection robot composite system.

2. Real Time Modeling of Transmission Line / Tower
Using UAV combined with lidar slam technology, real-time modeling of transmission line / tower is carried out and fed back to UAV flight control system to realize high-precision obstacle avoidance and conductor identification and positioning. During slam processing, firstly extract the landmarks from the radar scanning data, and then associate and fuse the extracted landmarks with odometer data and IMU
data. After the data association and fusion, update the EKF observation equation, and finally update the
odometer data and the corresponding EKF equation, so as to realize obstacle scanning and accurate
positioning of UAV, as shown in Fig.1 and Fig.2.

The method based on artificial potential field is used to realize automatic path planning and obstacle
avoidance. The schematic diagram of artificial potential field under the simulated narrow channel
scenario is shown in Fig.3. The walls on both sides of the channel will repel the UAV at the same time,
and the closer to the wall, the greater the repulsion, so $F_2 > F_1$. At the same time, in order to prevent the
UAV from colliding with obstacles during its movement, the obstacles will also produce repulsive force
$F_3$ to the UAV; the current target point of the UAV will generate gravity $F_4$ on the UAV, and the magnitude
of gravity is related to the distance. Therefore, the vector sum of repulsion and gravity forms the total
potential field in the current environment. Under the traction of the potential field, no one has the
opportunity to avoid obstacles and fly towards the target point.

In order to solve the problem that the UAV may collide with obstacles when it is far from the target
point, the distance parameter between the UAV and the target point is introduced into the repulsion
function to reduce the repulsion force; Aiming at the problem that the artificial potential field method is
easy to fall into the local optimal solution in the complex environment, the random disturbance method
is introduced to make the object jump out of the local optimal value and realize the global path planning
in the complex environment.

The UAV flight control algorithm part adopts the control structure with attitude control as the inner
loop and position control as the outer loop, as shown in Fig.4, that is, firstly, the desired position
command and altitude command are given externally, the altitude controller carries out altitude control
combined with altitude information feedback, and the altitude controller directly outputs the UAV
throttle signal; The position controller combines the position information feedback for position control,
and its output is transformed into the desired attitude angle command of the UAV, and then combined
with the attitude information feedback for attitude control, while the output of the attitude controller is...
transformed into the control signal of the motor actuator, so as to realize the control of the motor speed, and then realize the control of the UAV.

![Fig.4 Flight control structure of rotor UAV](image1)

![Fig.5 Basic structure of controller](image2)

In each controller, the PID controller based control method is adopted. In order to better eliminate the influence of external interference and system noise on the UAV control system, the active disturbance rejection control theory is also introduced. Fig.5 shows the basic structure of the controller.

The expected command information is first processed through the transition process. The existence of the transition process is mainly to prevent sudden change signals and commands beyond the maneuverability range of UAV, smooth the expected signals, and give appropriate reference commands and their differential signals. The reference command signal and feedback signal enter the PID controller for error control. The PID controller adopts a double closed-loop series structure. The outer loop controls the target physical quantity, and the inner loop controls the rate of the target physical quantity to obtain the PID control output. Disturbance estimation mainly unifies the unmodeled part of the system and noise into the extended state, estimates the defined extended state in real time through the extended state observer, compensates the PID control output, and obtains the final controller output.

### 3. Precise delivery and recovery of robot by UAV

Carrier phase difference technology, called RTK Technology for short, is based on the real-time processing of the carrier phase of two stations. It can provide the three-dimensional coordinates of the station in real time with centimeter accuracy. Different from other differential, the data transmitted by the reference station is the original observation of pseudo range and phase. After receiving the data observed by the reference station and the local machine, the user receiver uses the static relative measurement processing method to solve the baseline, and then calculates the coordinates of the measurement points. Integer ambiguity search based on ambiguity domain is undoubtedly an effective means to solve this problem. Among many algorithms in this field, integer least squares estimation is one of the algorithms with good performance and perfect theoretical system. Firstly, in the integer ambiguity space $Z_m$, a integer ambiguity combination to be selected is fixed $\beta$, then, the minimization problem of the following equation (1) is solved analytically to obtain a solution and a corresponding minimum. Obviously, it can be solved by the standard least square method.

$$
\min_{\alpha \in \mathbb{R}^n} \left\| Z - A\alpha - B\beta \right\|^2
$$

The second step is to change gradually in a certain order $\beta$ by repeatedly solving equation 1, a series of minima will be obtained, and each minima corresponds to an alternative integer ambiguity combination in the integer ambiguity space $Z_m$. Alternative integer ambiguity combinations corresponding to the minimum of these minima $\beta$ is the selected optimal integer ambiguity solution. The above process is equivalent to solving the following minimum problem:

$$
\min_{\beta \in Z^*} \min_{\alpha \in \mathbb{R}^n} \left\| Z - A\alpha - B\beta \right\|^2
$$

Therefore, the floating-point solution of the ambiguity group can be obtained by the standard least square method $\hat{\beta}$ And its covariance matrix $\hat{Q}_{\beta}$. Based on this, the least squares residual of the
minimization problem in the case of floating point can be obtained, that is $\alpha$, $\beta$. The least squares residual when taking the real value, expressed in $\Omega_0$ means, i.e

$$
\Omega_0 = \min_{\alpha \in R^n, \beta \in R^m} \|Z - A\alpha - B\beta\|^2
$$

(3)

Accordingly, it is expressed $\alpha$ in $\Omega$, Take the real value and $\beta$ The least squares residual in the case of rounding, i.e

$$
\Omega = \min_{\alpha \in \ell, \beta \in Z^k} \|Z - A\alpha - B\beta\|^2
$$

(4)

It can be proved that:

$$
\Omega = \Omega_0 + \left(\beta - \tilde{\beta}\right)^T Q^{-1}_\beta \left(\beta - \tilde{\beta}\right)
$$

(5)

Using the floating-point solution of ambiguity and its covariance matrix, we can calculate the integer solution of integer ambiguity.

$$
\min_{\beta} \left(\beta - \tilde{\beta}\right)^T Q^{-1}_\beta \left(\beta - \tilde{\beta}\right), \beta \in Z^k
$$

(6)

In the power line patrol, due to the poor perspective of UAV remote operation, the controller cannot accurately estimate the distance between UAV and the surrounding environment. In addition, there may be signal barrier areas in the power line patrol. Therefore, it is very important to realize the autonomous positioning of UAV. The project plans to use differential GPS for accurate positioning, with an error of centimeter level. At the same time, in the signal barrier area, that is, the area where GPS signal cannot be received, UWB auxiliary positioning system is selected to realize semi-autonomous accurate positioning. The detailed design flow of the system is shown in Fig.6.

The mathematical model of UAV is written in the form of state space description:

$$
\begin{align*}
\dot{v}_x &= v_y \omega_z - v_z \omega_y + F_x / m \\
\dot{v}_y &= -v_x \omega_z + v_z \omega_x + F_y / m \\
\dot{v}_z &= v_x \omega_y - v_y \omega_x + F_z / m \\
\dot{\omega}_x &= c_1 \omega_y \omega_z + c_2 \omega_z + c_3 \omega_x \omega_z + c_4 \left(\omega_z^2 - \omega_y^2\right) + M_1 \\
\dot{\omega}_y &= c_1 \omega_x \omega_z + c_5 \omega_x + c_4 \omega_x \omega_z + c_6 \left(\omega_z^2 - \omega_x^2\right) + M_2 \\
\dot{\omega}_z &= c_1 \omega_x \omega_y + c_10 \omega_x + c_11 \omega_y + c_12 \left(\omega_z^2 - \omega_y^2\right) + M_3
\end{align*}
$$

(7)

Among
\[ c_1 = \frac{J_x (J_y - J_z + J_y)}{J_x J_z}, c_2 = \frac{J_y (J_z - J_x + J_z)}{J_x J_y}, c_3 = \frac{J_z - J_x}{J_y}, c_4 = \frac{J_y}{J_z} \]

\[ c_5 = \frac{J_x (J_y - J_z - J_y)}{J_z J_y}, c_6 = \frac{J_z (J_x - J_y - J_z)}{J_y J_z}, c_7 = \frac{J_x (J_y + J_z - J_y)}{J_z J_x}, c_8 = \frac{J_z (J_x + J_y - J_z)}{J_x J_z} \]

\[ M_1 = \frac{1}{J_x} M_y + \frac{J_y}{J_x J_y} M_z + \frac{J_x}{J_y J_z} M_z \]

\[ M_2 = \frac{J_y}{J_z J_y} M_x + \frac{1}{J_y} M_y + \frac{J_x}{J_y J_z} M_z \]

\[ M_3 = \frac{J_x}{J_y J_z} M_x + \frac{J_y}{J_z J_y} M_y + \frac{1}{J_z} M_z \]

\( F_x, F_y, F_z, M_x, M_y, M_z \) is each component of the resultant force received by the carrier in the inertial coordinate system. The resultant force includes gravity, the lift generated by the rotor, and the force generated by air on the carrier other than the rotor.

After the UAV is started, follow up the account coordinates of the tower and its current RTK coordinates, independently plan the flight route and fly to the launch point. After the aircraft arrives above the launching point, the laser radar carried by the aircraft will slam scan the transmission line / tower at the launching point, calculate the precise position where the robot will hang on the transmission line, and identify the obstacles near the hanging position. The aircraft flight control will gradually guide the aircraft to slowly approach the hanging position while avoiding obstacles with high precision. When the robot reaches the releasable distance, The UAV releases the robot, realizes the accurate suspension of the robot, and the UAV returns. After completing the operation, the robot returns to the starting working position and waits for recovery. The UAV obtains the coordinates of the robot, independently plans the flight route according to the RTK coordinates of the current aircraft, and flies to the recovery point where the robot is located. After the aircraft reaches above the recovery point, the laser radar carried by the aircraft scans the transmission line / tower and robot, accurately calculate the position of the robot and identify the obstacles near the recovery position. While avoiding the obstacles with high precision, the aircraft flight control gradually guides the aircraft to approach the robot slowly. When the UAV reaches the recoverable distance, start the robot recovery device, grab the robot, and the UAV returns. As shown in Fig.7.

4. Conclusion

Combined with the physical, mechanical and electrical characteristics of the line patrol robot, this paper studies the multi rotor UAV platform suitable for carrying, and combined with the placement and
recovery characteristics of the line patrol robot, studies the schemes of automatic identification, automatic docking, automatic placement and automatic recovery. A complex integrated intelligent system has been developed to optimize and improve the automatic identification and control of UAV airborne AI front-end, navigation and precise positioning, UAV platform carrying interface, line patrol robot structure module, patrol scanning device, task autonomous planning and other parts in the whole research and development process, And it ensures good coordination and applicability between structure and function. An intelligent UAV line inspection robot composite system will play a significant role in promoting the application practice of UAV and robot inspection technology.

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