Transmission Line Wire Following System Based on Unmanned Aerial Vehicle 3D Lidar

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Abstract. UAV(Unmanned aerial vehicle) wire checking is an efficient and scientific solution of transmission line operations. Aiming at the existing technology, this paper put forward a kind of based on 3D laser radar and ROS (Robot Operating System) of the UAV wire follow System. In the process of power transmission line inspection of wire, the system capture the wire by 3D laser radar mounted on the UAV and calculate the space distance between UAV and the wire and angle of this distance in 3D laser radar coordinate axis, control drone aircraft by PID(Proportion Integration Differentiation) algorithm in the attitude of UAV and inspection speed by the ROS on the onboard computer system platform for real-time wire following and automatic inspection task. Field experiments show that the system can effectively improve the efficiency and safety of wire inspection, and is conducive to the automation, safety and informatization of transmission line inspection process.

1. Introduction

In order to ensure the normal operation of transmission lines, it is important to detect the fault of transmission lines in time, record the fault location and cause, and make the prevention and solution plan in time[1]. At present, helicopter inspection, robot inspection and UAV inspection are widely used in overhead transmission line inspection. Helicopter patrol is mainly composed of staff in a helicopter flying along the overhead transmission line, observe and record with airborne camera equipment along the fault condition, the helicopter inspection is close to line, improve the inspection accuracy and efficiency of inspection, but its route control, the limitation of factors such as climate change, operation cost, are the reason why this method can’t apply a wide range of promotion[2-3]. Inspection robot is hanging in the overhead transmission lines, crawl along the route, and utilization of its sensors mounted on the tower, lead wire, insulator, line hardware, channel circuit to close inspection, the inspection robot must be installed on the tower in advance hanging in conductor, install and uninstall lead to low efficiency of inspection[4-5]. The inspection of UAV is mainly conducted by inspectors who fly the UAV to the overhead transmission line channel, take video pictures of the channel and analyze them after inspecting[6-7]. In the process of patrol inspection, the UAV still needs to face the environment with limited visual field to avoid the impact of the accident crash of the UAV on the circuit safety, which requires the pilot of the UAV to have sufficient experience and be familiar with the circuit environment. So reducing the inspection time of UAV in the inspection process and the threshold of inspectors are the key issues to improve the operation and maintenance efficiency of transmission lines, reduce the operation and maintenance cost and increase the economic benefits of power enterprises.
In this paper, UAV wire following system based on the ROS UAV technology, wireless communication technology, ROS, PID control algorithm as well as GPS technology combined with 3D laser radar, is used to capture of conductor, and calculate the UAV from the wire distance, control the UAV speed and direction, flying along the wires, which reduces a lot of work and risk for the inspection staff, for the power checking and transmission project to provide reliable technical support, has good application value.

2. ROS Node Structure
In this paper, the system in the use of hardware devices are respectively Velodyne 16 lines laser radar, DJI M210 plane, DJI manifold_2. The Velodyne 16-line 3D radar is lightweight and accurate, and acts as a sensor to capture the wires; DJI manifold_2 with 230g, 3-25w power and NVIDIA Jetson TX2 processor, 8G memory, 32G eMMC, 128G SSD hard disk acts as the system computing terminal; As the control object of the control algorithm in this paper, the M210 aircraft is controlled by the OSDK(Onboard Software Development Kit) provided by DJI, which is programmed on manifold_2. Each node publishes and subscribes to each data topic in ROS, and the specific ROS node structure is shown in figure 1.

![Figure 1. The ROS node structure of the system](image)

3. Basic Principle Three-dimensional Radar Ranging

3.1 Establish Three-dimensional Radar Coordinate Axis
The method of ranging through three-dimensional (3D) radar is more robust than the method of ranging by binocular camera or monocular camera outside[8-9]. 3D laser radar emission range is shown in figure 2. The corresponding vertical angle $\omega$, azimuth angle $\alpha$ and distance $R(\alpha, \omega)$ of the point data were obtained from the original data, $\omega$ set is defined as $Q$, and then its X, Y and Z coordinates were calculated for each laser point, as shown in figure 3.
Three-Dimensional radar lateral view and top view.

\[
X = R \cdot \sin(\omega) \cdot \sin(\alpha) \\
Y = R \cdot \sin(\omega) \cdot \cos(\alpha) \\
Z = R \cdot \cos(\omega)
\]

3.2 Ranging Model
In order to realize automatic conductor following, first of all, it is necessary to solve the problem of how to measure the distance between UAV and conductor through 3D lidar. The 3D lidar mount mode and capture range in azimuth angle is shown in figure 4 and the 3D spatial ranging model in this paper is shown in figure 5.

A circle of 3D radar scanning is defined as a period T, and the wires are captured in the time of T. The capture range in azimuth angle is defined as C. In the T period, the distance between drone and power line is defined as D. Among this, \(x(\alpha, \omega), y(\alpha, \omega), z(\alpha, \omega)\) is the x, y, z value of the point cloud data on the three-dimensional radar coordinate axis.

\[
D = \min_{\omega \in Q} \{ y(\alpha, \omega) \}
\]

When \(D_{OA-OB} < \epsilon\) in the figure 5, the attitude of drone is defined as the state that course angle of the drone is the same as the direction of the power line.

When \(D_{AA'-BB'} < \delta\) in the figure 5, the attitude of drone is defined as the state that the position of the drone is the center of capture range. Among them:

\[
D_{OA-OB} = |OA - OB| \\
D_{AA'-BB'} = |AA' - BB'|
\]

\[
OA = R(\omega_A, \alpha_A) = \min_{\alpha \in C} \{ R(\omega_A, \alpha) \} \\
OB = R(\omega_B, \alpha_B) = \min_{\alpha \in C} \{ R(\omega_A, \alpha) \}
\]
\[ AA' = R(\omega_B, \alpha_B) = \min_{\alpha \in \mathcal{C}} \{x(\omega_A, \alpha)\} \]  
(9)

\[ BB' = R(\omega_B, \alpha_B) = \min_{\alpha \in \mathcal{C}} \{x(\omega_A, \alpha)\} \]  
(10)

So, when \( D_{OA-OB} < \varepsilon \) and \( D_{AA'-BB'} < \delta \), the attitude of drone is defined as the inspecting attitude of drone. In this attitude, the drone is able to follow the power line parallelly which is cambered. This paper uses the PID algorithm to control \( D, D_{OA-OB}, D_{AA'-BB'} \).

4. Fight Control Algorithm

PID control principle:

\[ u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \]  
(11)

In this formula, \( u(t) \) is a controlled quantity, \( e(t) \) is the error between the actual output and the expected value. \( K_p \) is the proportionality factor. \( K_i \) is the integral coefficient. \( K_d \) is the differential coefficient. PID control principle is the feedback control based on the system output value. The key is to take the error between the system output value and the expected value as the control quantity of the control system output value.

Among them: the output of the system such as \( D, D_{OA-OB}, D_{AA'-BB'} \) and the expected value of the inspecting attitude such as \( D^*, D_{OA-OB}^*, D_{AA'-BB'}^* \). PID control is used to adjust the attitude and direction speed of the UAV so that the actual output value of the UAV can reach the expected flight value under the inspecting attitude. The real-time distance measurement by 3D lidar is used to realize the automatic inspecting task of the UAV.

5. The Process of Automatic Inspection

UAV conductor tracking automatic inspection system means that the UAV will capture the conductor with 3D laser radar after manual takeoff. After the capture is successful, the automatic inspection mode will be activated to start ranging. All data will be transmitted to the flight control program through ROS, and the flight attitude will be automatically adjusted to the inspection attitude. After the inspection attitude is completed, the onboard terminal control UAV flies at a certain speed along the direction of the conductor (the direction of the radar z-axis), and meanwhile controls the aircraft to maintain the inspection attitude. The direction of the radar Y-axis is perpendicular to the direction of the conductor, and the radar is in the center of the detection area of the conductor.

6. Experiment

The experiment in this paper consists two parts: one is to verify the feasibility of automatic adjustment of inspecting attitude algorithm; the other is to verify the feasibility of automatic patrol of UAV based on distance measurement.

Firstly, verify the feasibility of the inspecting attitude algorithm. In the field of high-voltage lines, UAV is used to capture the transmission wire with some radian and adjust the attitude. The experiment is to record the RTK course angle information of the aircraft in this process, that is, whether the angle tend to be stable value in a certain time. The experimental results are shown in figure 6.
Secondly, it is to verify the feasibility of UAV automatic inspection after automatic adjustment, start to lead the z axis direction of the radar direction at 0.2m/s, the experiment is in the process to record the value of $D_{AA'-BB'}$ and $D_{OA-OB}$ when aircraft's vertical angle $\omega_A = -5^\circ, \omega_B = +5^\circ$, and distance between UAV and line D, with $D_{AA'-BB'}$ converges to a threshold interval $[-\delta, +\delta]$ and $D_{OA-OB}$ converges to a threshold interval $[-\varepsilon, +\varepsilon]$ think UAV is in the center of the wire line in parallel. In this experiment, it set $\delta = 0.05\text{m}$ and $\varepsilon = 0.05\text{m}$. As D is stabilized at the expected value $D^* = 4\text{m}$ think the algorithm of distance control in the inspection process is stable. The experimental results are shown in figure 7 and figure 8.

7. Conclusion
This paper proposes a system to capture and follow transmission line, and control UAV for automatic patrol operation through 3D laser radar and ROS. In the experiment, it shows that the system in a real environment drones can succeed in finish automatic adjustment of inspecting attitude after takeoff manually within 10s to 15s and following with curved wire while keeping the distance between drone and wire stably. Next, we will improve the speed in the automatic fright under the premise of state that...
the high-speed lead to posture change. Under the condition of high speed, the attitude of the aircraft will have an influence for the capture and positioning the wires by 3D laser radar. In the future we will be to modify the data through access attitude sensor, achieve at high speed under the state of automatic following flight without the influence of posture change.

8. Reference
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