Design of autonomous navigation system for electric patrol Unmanned Aerial Vehicle Based on Beidou Positioning and satellite based enhancement

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Abstract. In order to reduce the deviation of automatic inspection of transmission tower UAV and improve the efficiency of inspection work, the design of autonomous navigation system of electric power inspection UAV Based on Beidou Positioning and satellite based enhancement is proposed. On the basis of Beidou Positioning and satellite based enhancement, the automatic inspection projector and automatic inspection navigator of transmission tower UAV are designed, and the hardware design of the system is completed. This paper analyzes the endurance of UAV, calculates the coordinates of the best shooting point of UAV, and completes the planning of automatic inspection path of transmission tower UAV according to the horizontal offset coordinates of UAV in the process of transmission tower inspection. Combined with the automatic inspection algorithm of transmission tower UAV, the system software design is completed to realize the automatic inspection of transmission tower UAV. The simulation results show that compared with the traditional inspection system, the deviation of the designed UAV automatic inspection system for transmission tower is significantly reduced.

1. Introduction

High voltage transmission line has become the main line of the State Grid, which can not only enhance the power transmission capacity, but also effectively improve the problem of backward transmission tower construction[1]. With the acceleration of transmission tower infrastructure construction, the structural design of transmission tower becomes more and more complex, and many transmission lines pass through areas with relatively bad environment, which has a huge impact on the safe and stable operation of transmission tower. Because the transmission tower is exposed to the air for a long time, it bears the pressure of the power load in the power grid. At the same time, it will often encounter the impact of wind and rain, lightning flashover and other destructive external forces, resulting in the transmission tower wire broken strand, missing and other security risks. If these problems are not found in time, it will seriously affect the safe operation of the power grid[2]. Compared with the
traditional inspection system, it not only reduces the inspection risk and cost, but also improves the efficiency of transmission tower inspection. However, the UAV inspection system will be affected by its own performance when it works, and cannot accurately complete the inspection task[3]. Therefore, in order to improve the efficiency of UAV inspection and the performance of self-service navigation, Beidou positioning and satellite enhancement technology are applied to the design of the UAV inspection system of transmission towers to improve the efficiency and quality of inspection work and ensure the inspection. Safety of inspectors.

2. Autonomous Navigation System of Electric Patrol UAV

2.1. Hardware structure configuration of autonomous navigation system for electric patrol UAV

When the transmission tower UAV patrol operation, it is necessary to timely feed the flight coordinate information to the ground and display it to the technicians through projector mapping. Therefore, the design of automatic inspection projector for transmission tower UAV is the key to ensure the safe flight of UAV[4]. The geographical coordinates of UAV patrol work are spherical coordinates. It is difficult for the geographic coordinate system to realize the planning of UAV patrol path and operation mode. Beidou Positioning and star based enhancement are applied to the design of inspection projector, which makes the coordinates after projection become equator and central meridian[5]. The origin of projection coordinate is the intersection of equator and central meridian. The system uses four rotor aircraft as the basic platform to build UAV inspection system. The basic structure is shown in the figure.

![Fig. 1 Configuration structure of patrol UAV](image)

Among them, the remote controller is used to manually control UAV flight and camera pan tilt three-axis rotation in close special operations. The wireless image transmission system adopts 5.8632 frequency point analog image transmission system[6]. The common effective transmission distance is about 3 km. With external antenna, the image transmission distance can be about 10 km. The wireless data transmission system adopts xtend900m / 1W data transmission radio station, and the maximum transmission distance reaches 64km. The power part adopts Langyu x411os400kv brushless motor, with the maximum continuous current of 26a / 30s and the maximum continuous power of 577w. With 30A brushless electronic governor, the continuous current is 30a, and the short-time current can reach 40A[7]. In the data acquisition system, the inspection mode of visible light camera is adopted, and gopro3 + aerial camera is equipped. The video resolution can reach up to 3840x2160, the frames per second can reach up to 120fps, and the photo resolution can reach up to 40000x3000. The selection of some devices is shown in the table.
| Project          | Model                                      |
|------------------|--------------------------------------------|
| Propeller        | APC1447                                    |
| Electronic governor | 30A brushless electronic governor          |
| frame            | 650 quadrotor frame                        |
| Battery          | 6S lithium battery                         |
| Electric machinery | Langyu x4110s400kv brushless motor        |
| Video camera     | Gopro3 + aerial camera                     |
| GPS              | Neo7 GPS module                            |
| Flight controller| PIXHAWK controller                         |

The difference between Beidou Positioning and satellite based enhanced projectors and ordinary projectors lies in the difference of projection geometry and the reference ellipsoid in the process of projection[^8]. The projector based on Beidou Positioning and satellite based enhanced projectors can ensure the direction and angle of coordinate points and projection points unchanged, which is more suitable for aerial projection. The projection path of transmission tower UAV automatic inspection projector needs to consider the flight direction of UAV[^9]. Therefore, the application of Beidou Positioning and satellite based enhancement technology to the projector design can clarify the flight direction of UAV and improve the navigation quality.

2.2. Software function optimization of autonomous navigation system for electric patrol UAV

The inspection mode of power tower has developed from the original manual inspection to UAV inspection. In the process, it has experienced a series of disadvantages, such as low efficiency, high human cost and high risk coefficient. Based on this, the system adopts the layered way to gradually complete the design of each part, mainly including algorithm layer, software layer and hardware layer. The whole system architecture is shown in the figure.

![Architecture of UAV autonomous inspection system](image)

Fig. 2 Architecture of UAV autonomous inspection system

In order to make the software development of the whole system more organized, the software design framework of the system needs to be completed in advance. The software design framework of the inspection system designed in this topic is mainly divided into three modules: data acquisition and processing, inspection point calculation and optimization, and route planning. Referring to the general form of carrier phase observation equation, the equation of carrier phase observation of satellite I by receivers of mobile station u and reference station r can be obtained as follows:

\[
\begin{align*}
\lambda \phi_n^i &= \rho_n^i - \lambda N_n^i + c \left( \delta t_n - \delta t' \right) + T_{\text{ion}, \mu} + T_{\text{trop}, \mu} + \varepsilon_{\phi,\mu}^i \\
\lambda \phi_r^i &= \rho_r^i - \lambda N_r^i + c \left( \delta t_r - \delta t' \right) + T_{\text{ion}, \mu} + T_{\text{trop}, \mu} + \varepsilon_{\phi,\mu}^i
\end{align*}
\]  (1)

The mobile station can be obtained by subtracting the formula. The carrier phase single difference measurement value of satellite i by the receiver of reference station r is as follows:

\[
\begin{align*}
\lambda \phi_{nr}^i &= \lambda \left( \phi_n^i - \phi_r^i \right) \\
&= \rho_{nr}^i - \lambda N_{nr}^i + c \delta t_{nr} + T_{\text{ion}, \mu} + T_{\text{trop}, \mu} + \varepsilon_{\phi,\mu}^i
\end{align*}
\]  (2)
The software layer is mainly divided into application software and driver software. The application software refers to the software implementation of each part of the algorithm layer. The hardware layer of the system provides the collected data, and the software calculation through the algorithm layer provides the key information to the system for further processing. For software development, a good development environment can improve the efficiency of system software development, and Linux is not only a multi-user and multi-task operating system, but also has the characteristics of high degree of modularity, security and stability, good portability, so the application software is mainly developed in the Linux environment.

2.3. Realization of autonomous navigation of UAV for power inspection

MEMS IMU has the advantages of small volume, light weight, strong shock resistance and low cost. When the pod moves with the UAV, the heading error of IMU output navigation information will be reduced, and it can be used when the error reaches the required accuracy. The whole calibration process is divided into four stages: indoor calibration, outdoor data acquisition, post data processing and calculation, and outdoor accuracy verification. In order to improve the efficiency of automatic inspection of transmission tower by UAV, it is theoretically required that the closer the UAV is to the transmission tower, the better.

\[ D_a = \frac{L}{2} + n \]  \hspace{1cm} (3)

Where, \( D_a \) is the horizontal distance between UAV and transmission tower, unit m, \( l \) is the longest cross arm length of transmission tower, unit m, \( n \) is the safe distance of transmission tower, unit M. The distance between transmission tower inspection UAV and the ground needs to be satisfied.

\[ H_a = H + \left( \frac{L}{2} + n \right) \cot \alpha \frac{\alpha}{2D_a} \]  \hspace{1cm} (4)

Where, \( H_a \) is the distance between the UAV and the ground, unit: m, and \( H \) is the height of the transmission tower, unit: M. According to the horizontal offset coordinates of the UAV in the inspection process of transmission tower, the path planning of automatic inspection of transmission tower is completed. Combined with the transmission tower UAV automatic inspection algorithm, the software design of the system is realized.

3. Analysis of experimental results

In order to complete the inspection system of this project, this paper analyzes the inspection environment of the power tower and the operation requirements of the inspection system in detail. The purpose is to make the designed inspection system fit the actual inspection operation environment and requirements as much as possible. Before the development of the inspection system, we need to consider whether the selected hardware platform matches the inspection system. This is also to better focus on the correctness of the inspection system design. In order to ensure the accuracy of the simulation experiment, the simulation experiment needs to meet the following parameter settings. As shown in the table.

| Parameter  | Type    | Parameter meaning       | Company |
|------------|---------|-------------------------|---------|
| Yaw        | FLOAT   | Flight angle            | rad     |
| Rall       | FLOAT   | Lateral angle           | rad     |
| Pitch      | FLOAT   | Pitch angle             | rad     |
| WorldX     | FLOAT   | X coordinate            | m       |
| WorldZ     | FLOAT   | Z coordinate            | m       |
| VelocityX  | FLOAT   | Velocity in X direction | m/s     |
| VelocityZ  | FLOAT   | Velocity in Z direction | m/s     |
Firstly, the UAV is set as the starting point of flight and overlaps with transmission tower 4. Four transmission towers are set as the target points. Transmission tower 1 and transmission tower 2 are used to test the inspection in the horizontal direction, and transmission tower 3 and transmission tower 4 are used to test the inspection in the three-dimensional direction. Transmission tower 4 and transmission tower 1 are used to test the longitudinal inspection. In order to verify the effectiveness of the improved artificial potential field algorithm, the algorithm is used for simulation. In this paper, two groups of simulation experiments are designed, which are the traditional artificial potential field algorithm and the improved artificial potential field algorithm. As shown in the figure is the simulation result diagram, in which figure (a) is the simulation diagram obtained by using the traditional artificial potential field system. From this diagram, it can be seen that the UAV does not reach the target position after bypassing the obstacle, but hovers near the last obstacle, indicating that there are problems of local minimum point and target unreachable. Figure (b) is the simulation diagram of the system.

![Simulation Diagram](image-url)

**Fig. 3** Comparison of obstacle avoidance effect of patrol navigation

From the simulation diagram, it can be seen that the UAV starts from the starting position, bypasses all obstacles, and finally reaches the target position smoothly, without the problem of traditional artificial potential field algorithm. Through the comparison of the two groups of simulation results, the effectiveness of the system can be illustrated. According to the types of experimental data collected, the collected data are tested when the distance between the red and blue water bottles is L = 3M. As shown in the figure, the error diagram of calculating the coordinates of the red and blue water bottles when L = 3M, the abscissa is the distance d between the UAV and the red and blue water bottles, and the ordinate is the error value between the calculated coordinates and the real coordinates. The blue solid line is the error that has not been optimized by the known structure information in the algorithm for solving the coordinates of inspection points, and the corresponding dotted line is the error that has been optimized by the known structure information.

![Error Diagram](image-url)

**Fig. 4** Error comparison of patrol navigation coordinates
From the error diagram shown in the figure, when the distance between the red and blue water bottles $L = 3M$, as the distance $d$ between the UAV and the two water bottles increases from 3.1m to 9.36m, the maximum coordinate error after optimization is 0.1141m, and the average error is 0.097m, which indicates that the distance between the UAV and the water bottle is within 9.36m, The solution algorithm of the inspection point coordinates in the inspection system does not make the error significantly larger with the increase of $D$. And the two dashed lines in the figure are always under the corresponding solid lines, which shows that it is effective to optimize the coordinates by using the known structure information.

4. Conclusions
In order to realize the self-inspection of the tower, the inspection route of UAV must be planned in advance. This paper describes the experimental platform construction and testing process of the detection system, and validates the effectiveness of the system. According to the development requirements of the detection system, combined with the actual engineering application, the hardware platform is built. Secondly, through the system development platform and the construction of the theory of patrol system, according to the design framework of the system software platform design. After the establishment of the experimental platform, the core part of the detection system is tested by designing the experimental content, and its effectiveness is analyzed according to the test results. Finally, the whole system is used to complete the operation test of the tower, which verifies that the system designed in this paper can accurately and stably complete the task of independent inspection, and fully meet the requirements of inspection. Because of the limited time and the long period of technology research, this research will further improve the navigation command and communication ability in the future research.

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