Design and Implementation of Ground Terminal for Aerial Radio Monitoring System Based on UAV

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Abstract. The electromagnetic environment is becoming increasingly complex, and frequent radio interference to civil aviation has seriously affected the safe operation of civil aviation systems. In this article, the team designed a ground terminal system for an aerial radio monitoring system based on UAVs (Unmanned Aerial Vehicles), which was redeveloped based on the Mission-Planner open source ground station platform. The system used UAVs as flight platform, and used antennas, radio receivers and other hardware equipment for monitoring. The system could control UAVs and monitor radio signals. Tests such as frequency band scanning and two-point cross positioning show that the terminal system can implement the functions of controlling UAVs and radio monitoring, while effectively streamlining the number of workers and effectively improving the efficiency of detection.

Keywords: Civil aviation; Radio interference; UAV; Aerial monitoring; Ground Terminal.

1. Introduction

The electromagnetic interference of civil aviation radio frequency is regarded as the “invisible killer” of flight safety[1]. The statistical results show that the number of radio interference reports received by civil aviation in East China in 2017 was 399 times, and 439 times in 2016, 334 times in 2015, 400 times in 2014, 397 times in 2013, and 306 times in 2012.[2] Obviously, the frequency of civil aviation radio interference is increasing. Among them, the proportion of air interference has always been high, accounting for 55%, and it is on the rise. Because air interference cannot be received on the ground, and the object of interference is the air flight crew, which brings great difficulties to the detection of interference sources. UAVs are used as flight platforms, equipped with radio monitoring equipment for interference source detection. Aerial monitoring can avoid multipath fading.[3] Compared with existing ground-based fixed stations, monitoring vehicles and handheld devices, the aerial monitoring mode can get higher efficiency in detection and a larger coverage area. Radio monitoring with UAVs generally requires two operators at least, one for the drone controlling and the other for the radio monitoring system. In this article, the Mission-Planner is redeveloped, bringing radio monitoring system into the ground station software, constructing a ground terminal system for aerial radio monitoring based on drone cooperated with antennas, radio receivers and other equipment to reduce the workload of interference source detection, streamline staff and improve efficiency.

2. Direction Finding and Positioning Principle

The principle of direction finding and positioning is to obtain the azimuth information of the target signal source at different locations according to the mobile monitoring system. The positions of the two observation points and the target signal source constitute a position triangle, and the position coordinates
of target signal source can be detected according to the geometric knowledge of the triangle\cite{4}. As shown in Figure 1, at Q1, the coordinate of the monitoring system at point M is \((x_m, y_m, z_m)\), and the azimuth of the target signal source P is \(\alpha_m\), measured at this time, and the angle of pitch is \(\beta_m\). The monitoring system moves from M to N, at this time the coordinate of monitoring system is \((x_n, y_n, z_n)\), the azimuth angle of the target signal source P at this time is \(\alpha_n\), and the angle of pitch is \(\beta_n\)\cite{5}.

![Cross-locating diagram](image)

**Figure 1.** Cross-locating diagram

In the triangle PMN, if the specific positions of the M and N points are known, and the azimuth and angle of pitch of the observation stations can be obtained at the two points of observation, the triangle formula of the angle of pitch \(\beta_m\) is derived according to the trigonometric function theorem\cite{6}:

\[
\tan \beta_m = \frac{z - z_m}{y - y_m} \cdot \sin \alpha_m
\]  

(1)

Similarly, the triangle formula for azimuth \(\alpha_m\) is:

\[
\tan \alpha_m = \frac{y - y_m}{x - x_m}
\]  

(2)

In the same way, the triangle formula from the azimuth angle \(\alpha_n\) is:

\[
\tan \alpha_n = \frac{y - y_n}{x - x_n}
\]  

(3)

Convert into matrix form is:

\[
\begin{bmatrix}
-\tan \alpha_m & 1 & 0 \\
0 & \tan \beta_m & -\sin \alpha_m \\
-\tan \alpha_n & 1 & 0
\end{bmatrix}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix}
= \begin{bmatrix}
y_m - x_m \cdot \tan \alpha_m \\
y_m \cdot \tan \beta_m - z_m \cdot \sin \alpha_m \\
y_n - x_n \cdot \tan \alpha_n
\end{bmatrix}
\]

(4)

Suppose \(A=\begin{bmatrix}
-\tan \alpha_m & 1 & 0 \\
0 & \tan \beta_m & -\sin \alpha_m \\
-\tan \alpha_n & 1 & 0
\end{bmatrix}\), \(X=\begin{bmatrix}
x \\
y \\
z
\end{bmatrix}\), \(B=\begin{bmatrix}
y_m - x_m \cdot \tan \alpha_m \\
y_m \cdot \tan \beta_m - z_m \cdot \sin \alpha_m \\
y_n - x_n \cdot \tan \alpha_n
\end{bmatrix}\)

If \(AX=B\), then \(X=A^{-1}B\), so that the location of the target signal source is determined.

3. Ground Terminal System Design

This system is redeveloped based on the Mission-Planner open source ground station platform\cite{7}. It retains the functions needed such as electronic maps, meter display, simple operation and so on, and reduces complex redundant functions in the ground station software. The software is streamlined and easy to operate. System structure diagram is shown in Figure 2, and the system interface is shown in Figure 3.
In the ground terminal system, the radio direction finding function is designed according to the direction finding method. The functional structure diagram is shown in Figure 4, and the solution flow chart is shown in Figure 5.

4. Cross Positioning Test

In this paper, we use the way of rotating antenna to detect radio and directional cosine intersection positioning method to locating the radio resource. According to the way of radio detection[8], the directional antenna is installed on the body of the multi-rotor drone. The rotation of the drone is used to drive the antenna to rotate, so that the direction finding antenna can rotate at a uniform speed in the air. The multirotor drone is controlled to rise to a proper height through the ground terminal system, and
two-point direction-finding and cross-positioning are performed on a set target signal source. The pitch and azimuth angle of the drone platform are recorded as well as the location information. The position information of the target signal source is calculated based on the direction finding and positioning principle. Then compare it with the actual position information of the target signal source to verify the function of the ground terminal system.

Set the target signal source at the point P (104.309423, 30.953547, 421.92), fly the drone up to the height higher than the obstacles around the test site, so that the target radio signal propagates close to the line of sight. Two locations, point A1 and point A2, were selected as the monitoring sites for the aerial convergence test of the air radio monitoring system. The air radio monitoring system successively flew to point A1 (104.30337, 30.94918, 441.72) and point A2 (104.30234, 30.9492, 441.63) to detect signal source. Using the ground terminal solution to calculate the location coordinates of the interference source.

The experimental results show that the ground terminal system can be used for the actual radio interference source detection. The location information of the interference source calculated by the positioning algorithm is shown in Figure 6. In Figure 7, the red points are the actual positions of the interference sources, and the blue points are the positions of the settlement results. The distance between the position calculated and the actual target source position is about 103.76m. The source of the error is mainly because of the accuracy of the monitoring system. However, this method can basically achieve direction finding and positioning, and has certain application value in real life.

5. Conclusion

In recent years, the electromagnetic environment on which our civil aviation industry depends for safe operation has become increasingly complex and even worsened. Radio interference incidents have frequently occurred in various places. But at present there is no effective means of aerial monitoring for relative departments. According to the functional requirements of the aerial radio monitoring system based on UAV, this paper designed a software system with the function of positioning radio interference through the redevelopment of Mission Planner, an open source ground control station. It can be used in aerial radio monitoring with devices. In two-point cross-position test, the result of the tests demonstrates that the system works well in interference detection. There is only one operator needed to finish the drone controlling and radio monitoring, and in this way, the cost can be cut and the efficiency can be promoted. The aerial monitoring system can improve the work efficiency and bring much convenience into the detection, and has certain practical guiding significance to some extent.

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