Automatic UAV Relay Communication System Based on Microwave Directional Antenna

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Abstract. To tackle the communication problem of unmanned aerial vehicle (UAV) complex aerial operations, we propose an automatic UAV relay communication system based on microwave directional antenna. Our system is organized by the design scheme, overall structure and working process. The system has the ability to transmit information at a distance, which solves the problem of limited communication distance caused by the transmission power limitation of UAV communication system. The system can automatically switch into different communication mode according to communication network environments to improve the communication quality. In addition, it increases the mobility and enhances endurance in severe environment to meet the emergency communication covered on demand.

1. Introduction

Due to the characteristics of low cost, small size, and high maneuverability, UAVs are widely used in power line inspection, meteorological observation, agricultural farming, public security monitoring, military reconnaissance, and personnel rescue [1, 2, 3, 4]. However, a single UAV communication system cannot carry out long-distance UAV communication in signal-free areas. Among various non-line-of-sight transmission methods, aerial platform relay communication is an ideal communication method for solving wireless communication in harsh terrains such as mountain areas [5, 6]. Directional antennas are generally employed to ensure accurate and reliable data reception, and improve the reception gain and anti-interference ability. Traditional research on directional antenna alignment is mainly focused on the case that both sides of communication are relatively static with low real-time requirement. As a result, the alignment method of antenna attitude angle is relatively simple. In the UAV relay communication system, static alignment is difficult to determine the position of the UAV with high accuracy in real time. It is of great significance to study the alignment method of directional antenna in UAV relay platform to improve the communication reliability of relay platform system [7, 8].

In this paper, we design a fully automatic UAV relay communication system based on microwave directional antennas. The system can be applied to different communication environments encountered
in UAV emergency operations. We solve the limit of UAV communication distance caused by the transmission power limitation by setting the signal strength threshold. It can improve the communication quality in harsh signal environments. Meanwhile, it improves the maneuverability and endurance of drones in complex operating environments, and realizes emergency communication covered on demand.

2. UAV directional antenna position calculation

This section will explain the tracking position calculation of the UAV and the ground-end PTZ. The relay UAV is equipped with GPS during flight, which can obtain the absolute position information of the UAV in real time. When the UAV flies above the target position, the relative position information of the UAV and the ground target station is calculated. The onboard microprocessor controls the operation of the gimbal motor to achieve real-time directional alignment of the transmitting and receiving antennas quasi.

Directional antenna alignment calculates the antenna's azimuth and pitch based on the GPS positioning coordinates of two points. As can be seen from Fig. 1, \( A \) is the location of the antenna, that is, the observation point; \( P \) is the target point, and the projection of \( P \) on the ground is \( B \); \( A \) and \( P \) are located in the northern hemisphere (0-90° n) and the eastern hemisphere (0-180° e). The direction of vector \( AN \) is the true north direction considered by point \( A \), surface \( QAN \) is the reference horizontal plane of point \( A \), and arc \( AB \) is the spherical distance between points \( A \) and \( B \). \( \angle PAQ \) represents the elevation angle \( \gamma \) of the antenna, \( \angle QAN \) is the azimuth angle \( \theta \), and \( \angle AOP \) is set to \( \phi \). Suppose the positioning coordinates of the antenna location \( A \) are \((X_0, Y_0, H_0)\) (longitude, latitude, altitude), the target positioning coordinates are \((X_1, Y_1, H_1)\), and the distance from the sea level to the center of the sphere is \( R_0 \) (about 6378 kilometers). Due to the irregular ellipsoid shape of the earth, according to the projection theorem [9] Eq. (1) can be obtained:

\[
\cos \phi = \cos (X_1 - X_0) \cos Y_1 \cos Y_0 + \sin Y_1 \sin Y_0
\]  

(1)

The azimuth \( \theta \) derived from the geometric relationship can be shown by Eq. (2):

\[
\theta = \arccos \left( \frac{\cos Y_1 \sin (X_1 - X_0)}{\sin \phi} \right)
\]  

(2)

The elevation angle \( \gamma \) is shown by Eq. (3):

\[
\gamma = \arctan \left( \frac{H_0 + R_0}{H_1 + R_0} \right) / \sin \phi
\]  

(3)

The \( \theta \) and \( \gamma \) can be calculated by the airborne system and the ground end, and the multi-axis gimbal is used to make the directional antenna perform real-time alignment, so that the drone can communicate with the ground end.
3. Design of relay communication

This section will introduce the design of the communication hardware on the airborne side and the ground side. The UAV relay system has the functions of microwave directional antenna communication, relay communication, and long-distance communication. The overall system includes the relay UAV system and the receiving end of the ground station. The relay UAV system includes an onboard UAV microprocessor (including GPS positioning module, 4G module), directional antenna (receiving antenna, forwarding antenna) automatic control PTZ system and airborne relay forwarding module. The receiving end of the ground station includes a ground receiving module and a ground-air directional antenna alignment module.

3.1. Airborne relay communication

The airborne relay forwarding module will receive the signal to be forwarded in the VHF or UHF band by the receiving antenna, and can up-convert this signal to the S band. Relay forwarding module is the key to realize the relay function of UAV. It can be summarized as four modules: low noise amplifier, intermediate frequency processing, frequency conversion and RF power amplification. As can be seen from Fig. 2, the low-noise pre-amplifier unit pre-amplifies the received VHF or UHF signal. This link is the first stage of the input of the relay and forwarding equipment, and uses a low-noise coefficient amplifier chip. The signal can be further amplified by the intermediate frequency amplifying unit. It mainly filters out-of-band clutter through a filter, reduces the burden of frequency and power consumption for the subsequent circuit and appropriately amplifying the signal, and adjusts the input signal to the range required by the frequency conversion module. The unit added a multi-channel ESC filter to realize the working mode of parallel transmission of multiple narrow channels, which can avoid the power suppression of the entire frequency band by strong interference signals. The frequency conversion unit converts the VHF or UHF signal to the S-band. The unit employs an integrated mixing module to ensure that the mixing gain is high and the bandwidth of the selected chip meets the 200MHz bandwidth requirement. The power amplification unit amplifies the S-band signal power. The unit has two stages of amplification circuits to increase the gain of the mixed and filtered RF signal, so that the output power meets the conditions. The principle of the repeater antenna pan-tilt control system is the same as that of the transmit antenna pan-tilt control system described above. In turn, the forwarding signal can be aligned with the receiving directional antenna of the next hop UAV through the forwarding antenna to extend the communication distance in a "relay" manner.
Figure 2. Airborne relay communication.

3.2. Ground receiver

The receiving module on the ground receiving end is shown in Fig. 3, which can receive the forwarded S-band signal, and then down-convert it to a useful signal in the VHF / UHF band, and output the signal through the power divider for back-end demodulation processing. The ground receiving module mainly includes front-end low-noise amplifier, frequency converter, intermediate frequency processing, local oscillator unit and power supply module. We choose a broadband amplifier and attenuator since the forward relay forwarding module forwards the signal to a broadband signal of not less than 200 MHz. Due to the peak value of the output power of the airborne forwarding equipment is 3W, and there is a certain distance from the ground receiving end to the UAV and the carrier of this signal transmission is the S-band high-frequency signal. As a result, the attenuation is rapid. At the ground receiver, the performance of low noise emission and the overall gain of the receiving subsystem are selected. After calculation, the noise factor of the ground sub-system should be less than or equal to 2 dB, and the system gain requirement should not be less than 60 dB. Corresponding to the relaying and forwarding module, a multi-channel ESC filter is used to transmit multiple narrow-band signals in parallel, then a wide-band signal output is synthesized. Finally, a multi-channel signal output at the end of the ground receiving device with a power divider to satisfy the multi-channel signal Processing needs. The ground-air directional antenna alignment module can adjust the attitude angle of the ground station directional antenna in real time, so that it can maintain high-precision real-time alignment with the high-altitude relay communication UAV. The GPS module on the UAV's onboard microprocessor is employed to collect the latitude, longitude, altitude and other position information of the airborne directional antenna and the GPS information of the target station's directional antenna (transmitting source). The operation of the gimbal motor is controlled by the onboard microprocessor of the UAV. Then, the antenna is oriented and aligned to ensure that high-quality signals are received. The UAV's airborne relay forwarding module can receive, amplify, and convert the signals in the VHF or UHF frequency band and wide band. The forwarded signal can be continued by aligning the next hop UAV directional receiving antenna transmission. Through the increase in the number of drones and the way of relay transmission, the communication distance can be effectively extended. Finally, the signal can be received and processed at the closer ground receiving end.

Figure 3. Ground receiver.
3.3. Software design
Due to the low bandwidth of the current UAV’s communication system, the mainstream 4G TDD bandwidth can reach 100Mbps, and FDD can reach 150Mbps, which is much higher than the current UAV’s point-to-point communication mode, providing sufficient bandwidth protection for UAV applications. Convenient for integration, it is a two-way high-bandwidth communication method, which can realize the functions of data transmission and image transmission at the same time. Therefore, the system will preferentially use the 4G network for communication when the 4G signal is fine. The system work algorithm is shown in Fig. 4.

Figure 4. Software algorithm flow diagram.

4. Experimental results
We send the signal source 3 km away from the ground terminal and specific audio single-frequency FM signals at multiple frequency points in the frequency band, with a transmission power of 10W. When the UAV is on the ground, the ground receiving terminal is useful for observation with a spectrum analyzer which signal is up to 0-1 dB. Then the UAV lifted off, forwarded the transmitter, received the signal on the ground and sent it to the spectrum analyzer for testing. The test results are shown in Fig. 5. It can be seen that the system can complete the task of relay communication in high altitude.

Figure 5. Signal-to-noise ratio of UAV relay system.

5. Conclusion
In this paper, we propose a UAV relay communication system based on microwave directional antenna. Due to the system has the ability to transmit information at a distance, it can solve the problem of short communication distance caused by the limited launch power of UAV. Experimental results show that the proposed method can ensure that the UAV can still complete the task of relay communication at relative high altitude. Meanwhile, the system can switch the communication mode autonomously to meet the needs of different actual communication environments.
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