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UAV Data Link System: A Survey

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Abstract

In recent years, drones have developed rapidly and have been gradually applied to various industries. The data link in the UAV is a critical system connecting the UAV and the ground control terminal, which can ensure the safety and stability of the UAV flight—the application requirements of multiple scenarios put forward higher requirements on the UAV data link. However, the data link system is becoming more and more complex, which is the focus of current research in the UAV industry. This article summarizes the basic structure of the data link communication system and the development status of related technologies and gives the future research direction.

Keywords

UAV; data link; image transmission; anti-jamming; cluster.

1. Introduction

With the advancement of information technology, the application scenarios of unmanned aerial vehicles have become more and more extensive, starting from the military field to the civilian field, playing a huge role inline inspections, pesticide spraying, disaster area search and rescue, aerial photography, engineering construction, and other fields. Facilitate people's work and life. The UAV system mainly includes the aircraft body, flight control system, data link system, ground control station, power system, etc. Only when the various systems coordinate with each other can the UAV complete the task efficiently and accurately.

As one of the critical development technologies, the UAV data link communication system is a sufficient guarantee for the safe flight of the UAV and the accurate execution of the mission. In the actual flight process, the UAV faces multipath fading, inter-symbol interference, and other signal interference. If the information is not processed in time or inaccurately, it is likely to cause safety accidents in complex situations such as unmanned aerial vehicles. Therefore, how to improve the reliability and real-time performance of UAV data link information transmission is a hot research direction at the moment.

2. Overview and structure of UAV communication link

The UAV system is divided into five parts: ground control station, flight controller, communication link, and aircraft body and power system. We mainly study the communication link. The communication link is also called the data link, and the communication is in accordance with the agreement. The protocol and information transmission method connects the ground control station, the drone, or the mission aircraft, and the relay platform for information transmission and instruction interaction. The data link is called the neural network of the drone. In the drone system Internally and between the UAV system and other systems, a network platform with real-time, flexible, and reliable information interaction and joint operation is built, and the UAV can be interconnected with the ground control center. Therefore, the UAV or UAV clusters can better complete the task [1].

2.1. Data links are classified according to the direction of transmission

2.1.1. Uplink

It mainly completes the sending and receiving remote control commands from the ground control station to the drone. The uplink adopts direct expansion technology to ensure the safe transmission of information. When the control station sends data through the uplink, the drone captures and executes it and controls it. The station establishes a communication link and maintains synchronization [2] to realize the control station's control of the UAV's attitude and parameters.

2.1.2. Downlink

Complete the flight data and image transmission mission from the UAV to the ground. The downlink needs to transmit a large amount of data, so it has a higher bandwidth, and the transmission rate is much higher than that of the uplink.

2.1.3. Relay link

At present, most UAVs use customized line-of-sight data links. When UAVs are beyond the range of the wireless TV range, they need to use a repeater or an over-the-horizon satellite communication data link [3], that is, a relay link.

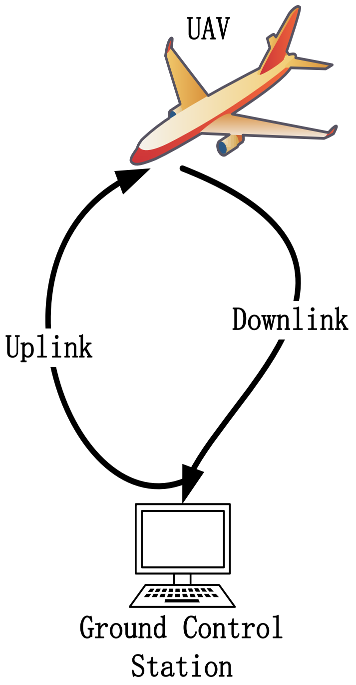

Figure 1 Uplink and Downlink Diagram

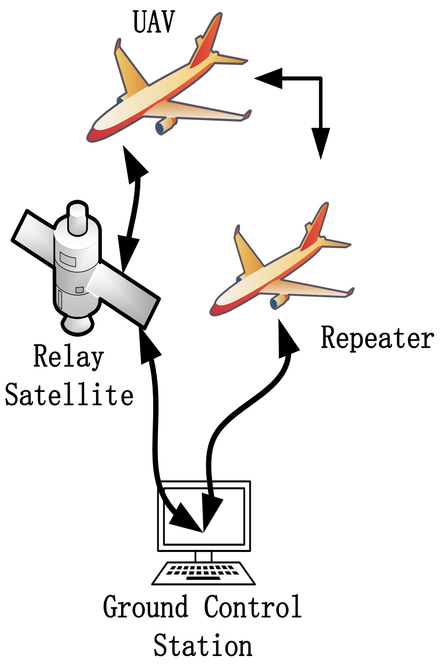

Figure 2 Relay Link Diagram

2.2. Datalink is classified according to equipment

2.2.1. Onboard part

The airborne part includes the airborne data terminal (Aerial Data Terminal, ADT) and antenna. The airborne data terminal consists of an RF receiver, a transmitter (data transmission station), and a modem connecting the receiver transmitter to other system parts [4]. Sometimes it also includes a data processor, which is used to compress the data to meet the bandwidth constraints of the downlink.

2.2.2. Ground part

The ground data terminal (Ground Data Terminal, GDT) includes antennas, a radio frequency receiver and transmitter (data transmission station), and a modem. If the UAV sensor data is compressed before transmission, the ground data terminal must use a processor to decompress the data [5].

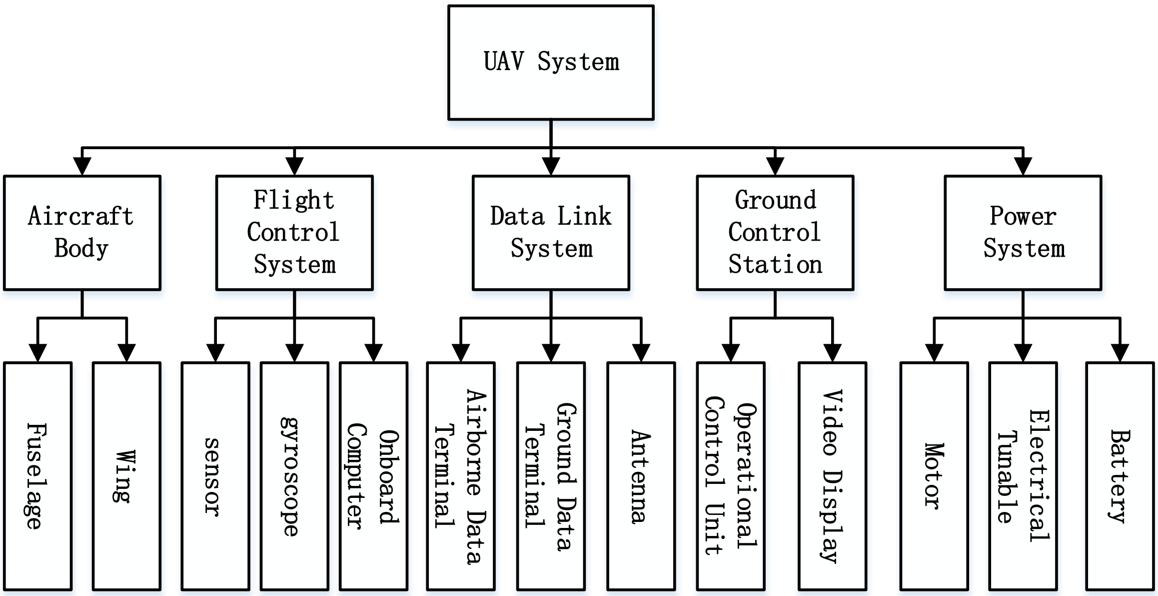

Figure 3 Composition of UAV system

3. Data link data transmission process

The purpose of the data link is to allow the UAV and the ground control terminal to communicate with each other. Both the UAV and the ground terminal can be used as a signal source or as a sink. After the signal source sends a signal, the sending device processes the signal and sends it into Channel, the signal is easily interfered by noise and other signals in the process of channel transmission, and the receiving end may receive wrong information. Therefore, it is particularly important to improve the reliability and anti-interference of the channel. The receiving end uses the receiving device to respond to the signal. After processing, it is sent to the sink and converted into the original message [6], and the drone or the ground end can make the corresponding instructions. This process can be summarized by the model in Figure 4 [7].

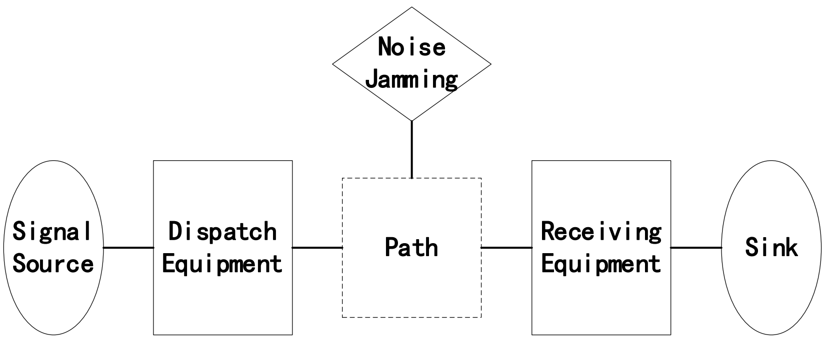

Figure 4 General model of signal transmission process

3.1.1. Signal encoding and decoding method

PCM (Pulse Code Modulation) is pulse code modulation, which transmits information in binary form. PCM belongs to digital modulation and requires analog/digital and digital/analog conversion technology [8]. PPM (Pulse Position Modulation) is pulse position modulation,

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which can be used at different times. The position of the pulse that appears to convey information belongs to analog modulation and requires an integrator and filter. Both are coding methods for signal pulses. The control terminal sends the signal to the coding circuit, converting it into a set of pulse coding signals (PPM or PCM). After this group of pulse code signals is modulated by a high-frequency modulation circuit, they are sent out through a high-frequency amplifier circuit [9]. Because PPM is easy to be distorted, the mainstream encoding method is PCM waveform encoding.

3.1.2. Signal modulation and demodulation method

Modulation is the process of converting a signal into a suitable transmission channel. Modulation is divided into baseband modulation and carrier modulation. Modulated signals have three primary purposes: first, to obtain higher transmission efficiency and distance in wireless transmission; second, to move multiple baseband signals to different carrier frequencies. Channel multiplexing improves channel utilization; third, it spreads the signal bandwidth, enhances system reliability, and reduces other signal interference [6]. Modulation is mainly for modulating analog signals and digital signals.

3.1.2.1 Analog signal modulation

Analog modulation refers to modulating specific parameters of the carrier waveform with an analog baseband signal, such as amplitude, phase, and frequency. These parameters change with the change of the baseband signal, so there are amplitude modulation (AM) and frequency modulation (Frequency Modulation). FM) and phase modulation (Phase Modulation, PM) are three modulation methods [10].

3.1.2.2 Digital signal modulation

UAVs and ground control terminals, and other systems use digital signals. Digital signal modulation methods mainly include Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying. Control (Phase Shift Keying, PSK) and relative differential phase shift frequency control (Differential Phase Shift Keying, DPSK) [11], corresponding to the amplitude, frequency, phase of the carrier, and the relative carrier phase value of the symbol before and after. Pass digital baseband signals. The DS-BPSK modulation method is used in the UAV uplink, and the 2CPFSK modulation method is used in the downlink [12]. This modulation method has good anti-interference and high-frequency band utilization, which can meet the requirements of downlink transmission. A large amount of data is required.

3.1.2.3 Signal demodulation

Demodulation is the inverse process of modulation, recovering the original signal from the modulated signal. There are two ways of coherent demodulation and non-coherent demodulation. Coherent demodulation needs to recover the readable carrier, and the initial baseband signal is obtained using the modulated signal and the cohesive page. This coherent carrier is the same frequency and phase as the original carrier signal modulating the baseband signal at the transmitting end; non-coherent demodulation There is no need to recover the coherent carrier, so it is simpler than the coherent demodulation method [12].

3.2. Channel

The channel is a physical medium used to transmit the signal emitted by the sending device to the receiving end. In the UAV signal transmission process, the propagation of electromagnetic waves in space is mainly used. The inherent properties of the channel and the introduced noise and interference directly affect The quality of communication [6].

3.3. Receiving equipment

The function of the receiving equipment is to amplify and inversely transform the signal (such as decoding, demodulation, etc.), restore the signal lost in the long-distance transmission in the

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channel, and minimize the impact of noise and interference on the original signal. For multiplexing Signal, but also demultiplex [6].

4. Datalink information transmission method

4.1. Data transmission

The data is used for the information interaction between the drone and the ground control terminal through the data transmission link. It is divided into airborne data transmission radio and ground data transmission radio. Signal Processing, DSP) technology and software wireless technology to transmit UAV flight data and other information data transmission station, has now developed to all use digital processing technology, the control accuracy of the digital radio station is higher, the airborne digital radio station is the ground Send instructions to decode to change the flight parameters and collect and sort the various parameters of the drone flight to the ground. The ground data transmission station contains flight parameters and sends instructions to the drone, which is conducive to the control end to grasp the drone flight State [13] accurately.

4.2. Image transmission

The UAV image transmission system is an integral part of the UAV system. The image transmission requires the highest communication capabilities. It uses the camera mounted on the UAV to obtain images through wireless means and transmits it stably to the receiver on the ground in real-time. Professional aerospace vehicles do not have independent video image transmission equipment. The image transmission only exists in the field of consumer drones. The image transmission is divided into the following categories:

4.2.1. WiFi image transmission

WiFi image transmission is a digital technology based on the TCP/IP protocol to establish a communication handshake mechanism. Each time a data packet with a size of 512 bytes is transmitted, it must be ensured that it is complete and that it is necessary to lose a byte. Resend this data packet, and the sender will send the next one after the receiving end confirms that it has received this data packet. Real-time performance is significant for drones. This two-way handshake mechanism can easily cause image delays, and drones are prone to occur. There are substantial hidden dangers in-flight accidents such as plane crashes [14].

The transmission distance of WiFi image transmission is about 600 meters to 800 meters. It can use 2.4GHz and 5.8GHz frequency bands. The penetration of 5.8GHz is poor. 2.4GHz has good penetration and image stability. WiFi technology is now very mature and cost-effective. It is relatively low and can easily transmit video through wireless WiFi. Many drones on the market use WiFi image transmission, but the disadvantage is that the transmission distance is short and the delay is high.

4.2.2. Lightbridge and OcuSync image transmission

Lightbridge is a high-definition long-distance digital image transmission technology developed by DJI itself. Like WiFi, it has two frequency bands of 2.4GHz and 5.8GHz, and the communication distance can reach up to 7KM. Lightbridge technology uses one-way image data transmission, similar to the data transmission method of a TV broadcast tower. The ground control terminal is only responsible for transmitting flight instructions to the drone. The drone is only responsible for transmitting image signals and various flight data to the control terminal. The anti-interference ability is strong. Unlike WiFi image transmission, a handshake mechanism needs to be established first, and data is sent and received on this basis. Therefore, Lightbridge's real-time performance is far better than WiFi, and WiFi is easily disconnected by interference. Once the connection is disconnected, it needs to be Lightbridge took longer to recover.

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Table 1 Comparison of image transmission methods

GRAPHIC TRANSMISSION METHOD	ADVANTAGE	FAULT
WIFI image transmission	Convenient connection and low cost	High delay and short transmission distance
LIGHTBRIDGE image transmission and OCUSYNC image transmission	One-way image tran- smission, small delay	Difficult to carry out secondary application development, can only be used for aerial photog- raphy
4G/5G image transmission	Image and vidio transmi- ssion quality is high, with low latency	Insufficient local signal strength, signal tower is needed
OFDM/COFDMimage transmission	Strong anti-fading ability and anti-interference ability,with high frequen- ce band utilization	High construction cost and technic- al requirements, often used in large-scale projects

OcuSync is an improved image transmission technology on LightBridge. OcuSync utilizes high-efficiency digital compression technology and channel transmission technology, with automatic frequency hopping technology [13] and up to 19 fixed channels, with a delay of up to 50ms and no obstruction. The transmission distance is up to 7 kilometers without interference. OcuSync design adopts many of the most advanced channel coding technology, multi-antenna technology, diversity technology, channel estimation and equalization technology in the current communication field, and a complete upper layer protocol stack, so the wireless image transmission distance is relatively long, and the delay is low [15].

4.2.3. 4G/5G image transmission technology

WiFi image transmission distance is too short and the defects of delay, it is difficult for drones to complete power inspections, sea rescue, and other long-distance complex tasks [17], due to the extensive coverage of 4G base stations in my country, 4G image transmission It has also been widely used in UAVs, mainly based on multipath multi-layer architecture technology. 4G image transmission has a slight delay and high image quality, but where the base station coverage is low, it will affect the speed and quality of image transmission [18]. The development and application of 5G communication technology have accordingly promoted the development of UAV image transmission. 5G has applied MIMO (Multiple Input Multiple Output) and beamforming technology [19] to make its signal more stable and less susceptible to interference. Features such as low bandwidth and low latency, but my country's 5G base station coverage is not as high as 4G, so now it is not possible to simply use 5G image transmission, 4G and 5G compatibility can be used, the system automatically switches, and at the same time meets the high coverage of 4G and 5G The security and high-speed data transmission [17].

4.2.4. OFDM/COFDM image transmission technology

Orthogonal Frequency Division Multiplexing (OFDM) is a kind of multi-carrier modulation. It is currently the most widely used transmission technology for drones. It is suitable for high-speed data transmission and can also be used in narrowband bandwidth. Sending a large amount of

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data can fight against multipath fading or narrowband interference. Still, it is susceptible to frequency offset and phase noise generated by the channel. A significant signal peak power to average power ratio will reduce the efficiency of the RF power amplifier. COFDM is coded OFDM, called coded orthogonal frequency division multiplexing, adding channel coding and interleaving technology before OFDM modulation to reduce the bit error rate [20], making signal transmission safer and more reliable.

5. Key Technologies of UAV Data Link

5.1. Anti-interference technology

UAVs will face complex electromagnetic environment and other human interference during the flight. UAV data confidentiality and security have great hidden dangers. At present, channel coding and spread spectrum technology are adopted at home and abroad to improve UAVs. The anti-jamming performance of the data link, the emergence of technologies such as multiple-input multiple-output (MIMO), orthogonal frequency division multiplexing (OFDM), and adaptive antenna technology has provided technical support for improving the anti-jamming performance of UAVs[21].

5.2. Data image compression coding technology

The ground control terminal needs to accurately grasp the drone's nearby images and drone flight parameters in real-time so that the operator can make correct decisions. Therefore, the downlink requires high bandwidth to transmit data and pictures. As the demand for drones increases, Sometimes a large amount of data cannot be transferred to the ground in time, which requires digital image compression technology to compress the information based on retaining all the original data information and decompress it after reaching the ground. The operator can get complete real-time information. The video image captured during high-speed motion has low pixels. To achieve high-quality image compression and transmission, the steps shown in Figure 5 can be taken to complete the information of video images.

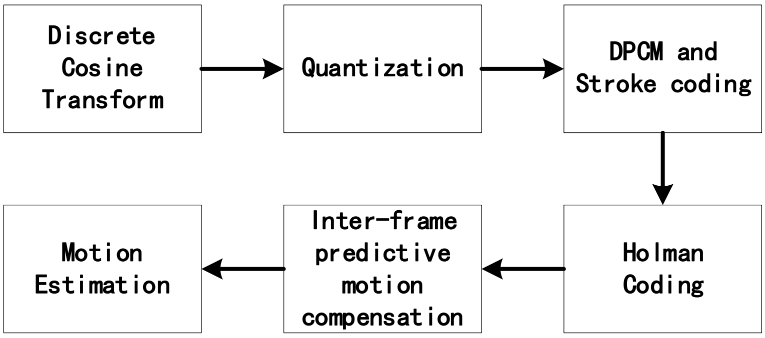

Figure 5 UAV video image compression coding process

5.3. Relay transmission technology

The communication method adopted by the UAV and the ground control terminal is wireless communication. When the flying distance of the UAV exceeds the range, relay communication is used. At present, there are mainly three types of relay communication methods: ground relay and UAV. Jihe Satellite Relay [22]. The drone relay operation is more straightforward than the ground relay, and the relay distance is longer. The data link technology requirements are relatively high because it has easily interfered in the air, and the drone relay communication system has a small channel capacity. To meet the needs of big data and image transmission [23], satellite relay has a large coverage area and is mainly used for military drones. The United States Global Hawk [1] and other long-haul drones use satellite relays.

6. UAV cluster communication technology

As the application scenarios of UAVs become more and more abundant, due to the limited load capacity and communication distance of a single UAV, complicated situations put forward higher requirements on the performance of UAVs. Still, UAVs with complex functions require a very high cost; stability and reliability are also greatly affected. Multiple UAVs cooperate in the form of "task assignment," which can achieve complex tasks that a single UAV cannot complete [24]. Human-machine clusters have the characteristics of complementary functions, high efficiency, robustness, and scalability. At present, there are three collaborative control methods for UAV clusters: centralized control, decentralized control, and distributed control [25].

6.1. Centralized control

The centralized control technology is also called swarm technology. There are leaders and other follower drones. It is mainly used in small rotor drones. Once other drones are disconnected from the leader, they will lose control and are more robust. Poor [24], the UAV cluster uses a narrowband connection for information interaction and command transmission, completes formation transformation, task assignment, etc., transmits each UAV status data to the control terminal in real-time, and transmits video images through the broadband connection. Extensive data services are converged to the cluster head node [25].

6.2. Distributed control

Distributed control has no central controller. Each UAV has its control terminal. The system algorithm is more straightforward and has the characteristics of scalability. There will be no communication between the UAV units in the formation. The control terminal can only Master part of the information of the cluster. Its flight safety is not good, and it is prone to the collision of drones between formations.

6.3. Distributed control

Distributed control does not require a central node. Formation individuals only need to communicate with other drones in their field. There are fewer communication data packets and communication links. When the communication conditions are relatively poor, the system is somewhat more stable. In addition, when an individual fails or is missing, it has little impact on the overall design. Other UAVs can be supplemented in real-time to restore working status quickly, but their flight flexibility and safety are not as good as centralized control [25].

7. Future Development Direction of UAV Data Link Technology

7.1. Laser communication technology

Modern UAVs use radio communication, which has poor confidentiality and is easily interfered with by external signals. Laser communication makes up for these shortcomings. It has high confidentiality performance and is not easy to be intercepted. It is suitable for long-distance extensive data transmission. The reason why laser communication has these characteristics is that infrared rays transmit along a straight line, and the beam spread angle is slight, and it is not easy to be found. However, this technology has many problems now, and it needs to increase investment to speed up the technical breakthrough [25].

7.2. Channel synthesis technology

The shortage of spectrum resources has become a complex problem that needs to be broken through today's UAV communication. Therefore, it is necessary to improve the utilization and effectiveness of the spectrum continuously. Technologies such as power control and frequency band selection can be used, and the system should send as little data as possible. UAVs generally use a wired or bus structure inside, and the external communication system mainly uses a "three-in-one" or "four-in-one" integrated channel system. The internal and external systems cooperate in developing channels.

7.3. Development of "One Station, Multiple Machines" Technology

"One station, multiple aircraft" technology refers to a control station on the ground that can control multiple drones to fly and perform tasks. This technology has not been widely used. Now it is mainly "one station, one aircraft." The expansion of the application range of the machine, "one station, one machine," will accelerate the development of "one station, multiple machines" [27]. In addition, the "one station, multiple aircraft" technology will significantly improve the efficiency of UAV missions, mainly to improve UAVs' dynamic random access capability and the ability to perform tasks cooperatively.

7.4. In-depth development of drone cluster collaborative control technology

With the diversification of drone missions and the system's complexity, drones will inevitably fail when performing tasks. This requires other drones to supplement their positions in time to improve the system's fault tolerance; when the task environment is complex and changeable, UAVs with different structures and functions are required to cooperate to complete the task; in addition, at the same time, the information fusion between UAVs is improved, the stability and convergence of the system are improved, and the optimal control of the cluster is realized [25].

8. Conclusion

UAV data link technology is a non-ignorable part of the development process of UAV technology. The complex and changeable environment has put forward higher requirements on the UAV data link in recent years. Starting from the UAV data link system structure, this article discusses the key technologies and future development directions of the data link system. As drones become more and more widely used in all aspects, they will affect future life and the military. As the "neural network" of the UAV, the data link communication system is essential for the UAV to perform tasks efficiently, comprehensively, and accurately [27]. Whether it is the security and real-time performance of information transmission, or the development of drone cluster technology, it is the critical research direction of the drone data chain in the future.

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