Research Progress of Anti-jamming Technology of Unmanned Aerial Vehicle (UAV) Data Link

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Abstract. An high-speed stealth UAV will be developed by an aviation research institute. Data link is an important part of UAV system. In order to have a deeper understanding of data link system, this paper was made through studying many recent academia papers. The basic composition and working principle of UAV data link system was introduced in this paper, the current UAV data link interference and anti-interference technology was expounded, the key problems faced by the development of UAV data link anti-interference technology were summarized, and the future development trend of UAV data link anti-interference technology was pointed out.

1. Overview of UAV data link system
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1.1. basic composition
UAV data link system is usually composed of ground system and airborne system. Among them, the ground system commands, controls, tracks and positions the UAV in the air through wireless transmission [3], and its framework is shown in Figure 1. UAV data link system is divided into uplink and downlink. The uplink transmits the command of the ground system to the UAV; the downlink transmits the telemetry data and infrared or television images of the UAV to the ground system [4,5].

Figure 1. Basic composition of UAV data link system

1.2. Working principle
At the transmitting end, the ground system generates the remote control command, which is sent to the ground data terminal for coding, encryption and spread spectrum to form the remote baseband signal; then through the transmitter for phase modulation, it generates the remote intermediate frequency signal, which is converted up to form the remote radio frequency signal; then after power amplification, it is output to the remote transmission antenna, and then transmitted to the UAV.
through the ground air link. At the receiving end, the UAV receives the remote control RF signals through the antenna and the receiver respectively, and sends the remote control instructions to the UAV flight control system after amplification, despreading, demodulation and other processing [6].

2. Data link interference and anti-interference technology
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2.1. Data link interference
Data link interference refers to the interference of electromagnetic wave emitted by radio interference equipment on data link receiving function of UAV. Typical UAV data link interference includes monophonic interference, modulation interference, broadband noise interference, sweep interference and other interference. Single tone interference and modulation interference belong to narrow-band interference; modulation interference is to modulate narrow-band noise to DS-SS working frequency point, including noise AM interference and noise FM interference; wide-band noise interference and sweep interference belong to wide-band interference, whose essence is to increase the background noise of the system; sweep interference is linear frequency modulation(LFM) signal, sweeping in the working frequency band of the system [7].

From the perspective of implementation, data link interference can be divided into suppressive interference and deceptive interference. Oppressive jamming is to shield the spectrum signal of enemy data link by transmitting some jamming signal, so that the received signal of enemy data link is blurred or completely covered. According to the width of jamming channel, the jamming can be divided into aiming jamming, semi aiming jamming and blocking jamming. Deceptive jamming is to make enemy drones execute our instructions by imitating enemy data link signals. There are two ways to implement deceptive jamming: one is to intercept and analyze the enemy data link signal, and then implement jamming; the other is to detect and acquire the enemy data link frequency band, copy its data link signal, and then send it to the enemy data link equipment to implement jamming [8].

2.2. Data link anti-jamming technology
At present, the anti-jamming technology of UAV data link mainly includes channel coding technology, spread spectrum technology, multiple input and multiple output technology, orthogonal frequency division multiplexing technology, adaptive antenna technology and perception radio technology [9,10].

2.2.1 CHANNEL CODING TECHNOLOGY. When the data link of UAV is disturbed, there will be error code in the transmission data, so the remote control command, telemetry parameter or image received by the receiver will be wrong. According to Shannon's channel coding theory, as long as the transmission rate of information is lower than the channel capacity, a channel coding method can be found to reduce the error probability arbitrarily. Therefore, the anti-interference ability of data link can be improved by processing data through channel coding [11]

2.2.2 SPREAD SPECTRUM TECHNOLOGY. Spread spectrum technology is to modulate the transmitted signal to a wide frequency band, and recover the signal to the information bandwidth through correlation reception at the receiving end [12]. According to the different ways of spread spectrum, spread spectrum technology can be divided into direct sequence spread spectrum technology, frequency hopping technology and time hopping technology.

The direct sequence spread spectrum technology uses the spread spectrum code sequence with high code rate to expand the spectrum at the transmitting end, reduce the power spectrum density of the data link signal, make it difficult for the enemy to detect, so as to improve the anti-interference ability; the same spread spectrum code sequence is used at the receiving end to despread, and then after the spread spectrum code sequence modulation, the signal spectrum is widened, the power spectrum density is reduced, and the spread spectrum signal changes after demodulation For narrow-band signal, the power spectral density is increased and the system gain is increased several times, so the anti-interference ability is improved.
Frequency hopping technology uses the spread spectrum code sequence signal in the transmitter for frequency shift keying modulation, which makes the carrier frequency constantly jump, and uses the spread spectrum code sequence in the receiver to recover the signal. In the time domain, FH signal is a multi frequency FSK signal. In the frequency domain, FH signal will jump at unequal intervals in a wide frequency band. Compared with fixed frequency signal, as long as the enemy does not know the law of carrier frequency hopping, it is difficult to intercept our communication content. Even if some frequency points are interfered by the enemy, normal communication can still be carried out on other frequency points that have not been interfered, so it has good anti-interference ability.

The time hopping technology stores the input data in the transmitter first, and then the on-off switch is controlled by the spread spectrum code sequence of the spread spectrum code generator. After two-phase or four-phase modulation, it is transmitted after RF modulation. At the receiving end, the IF signal output by the RF receiver is controlled by the same spreading code sequence generated locally as the transmitting end, and then sent to the data memory by the two-phase or four phase demodulator. After timing, the output data can be recovered correctly as long as the two ends of the receiving and transmitting are in strict synchronization in time.

2.2.3. *Multiple input and multiple output technology*. Multiple input and multiple output technology refers to the wireless communication technology that transmits signals through multiple antennas at the transmitting end and receives signals through multiple antennas at the receiving end. Multi input and multi output technology, combined with orthogonal frequency division multiplexing technology and space-time coding, can realize space diversity, time diversity and frequency diversity, and can realize anti-interference in the space, time and frequency domain [13]. At present, how to apply multi input and multi output technology to data link anti-jamming technology still needs to be studied on antenna configuration, power distribution, signal detection and other issues.

2.2.4. *Orthogonal frequency division multiplexing technology*. Orthogonal frequency division multiplexing technology divides the channel into several orthogonal subchannels, transforms the high-speed data signals into parallel low-speed data streams, and then modulates them to the subchannels for transmission. Orthogonal signals can be separated in the receiver by using correlation technology to reduce the interference between sub channels. If the signal bandwidth on each subchannel is less than the correlation bandwidth of the signal, then each subchannel can be seen as flat fading, thus eliminating intersymbol interference [14].

2.2.5. *Adaptive antenna technology*. At present, the data link of UAV mostly adopts the directional antenna technology for anti-jamming. The directional antenna means that the electromagnetic wave transmitted and received in one or several specific directions is very strong, while the electromagnetic wave received by the transmitter in other directions is 0 or very small. The purpose of anti-jamming is achieved by suppressing the received interference signal. The narrower the beam, the stronger the concealment and the stronger the anti-jamming ability.

Adaptive antenna technology uses the principle of phased array antenna to carry out spatial filtering for beams from all directions. It adjusts the excitation of antenna elements, optimizes the antenna array pattern, processes and identifies interference signals by using digital signal processing technology, forms the zero point of beam in the direction of dry interference source, suppresses the signals beyond the receiving direction, and reduces interference. Reduce electromagnetic environmental pollution [15]. The disadvantage of adaptive antenna is to form a blind area in the direction of zero point, which affects the normal use of users in this area.

2.2.6. *Cognitive radio technology*. Cognitive radio is an intelligent wireless communication system. Through cognitive and active learning of the surrounding radio environment, the working parameters of the communication system, such as coding mode, modulation mode, working frequency and transmission power, are changed in real time. The idle spectrum is dynamically detected and utilized to adapt to the changes of the external radio environment [8].
The UAV data link can use cognitive radio technology to monitor the interference in the communication frequency band. According to the characteristics of the interference source signal, it can change the channel coding mode, spread spectrum code sequence, frequency hopping pattern, time hopping mode, power configuration, antenna mode and other parameters of the data link in real time, reasonably use the radio spectrum resources, and improve the information transmission ability and anti-interference ability [16].

3. Key technical problems
At present, the challenges faced by UAV data link anti-jamming technology are as follows:

3.1. Long distance transmission loss
Long distance transmission loss is the most serious challenge faced by UAV data link system. It includes the reduction of power attenuation and spectrum efficiency, transmission delay, increase of system error rate and packet loss rate, and decrease of receiver SNR.

3.2. Doppler shift of high speed motion
The high-speed motion of UAV will bring Doppler shift to the receiver, and the magnitude of Doppler shift is proportional to the speed of motion and inversely proportional to the wavelength. Because the frequency of electromagnetic wave is inversely proportional to the wavelength, the lower the working frequency band is, the smaller the Doppler frequency shift is for the UAV in high-speed motion state; however, the spectrum resource in the low-frequency band is very tight, and the Doppler frequency shift is a great challenge for the UAV data link.

3.3. Signal fading caused by roadblocks
The main frequency band of UAV data link application is microwave (300MHz~3000ghz). The microwave link has higher available bandwidth, but the microwave frequency is high, the wavelength is very short, there is no diffraction function, the communication will cause shadow fading and multi-path fading.

3.4. Artificial non malicious interference and malicious interference
Non malicious interference refers to the interference of the radio signals of other devices in the spectrum environment to the data link of UAV, while malicious interference mainly exists in the military field, mainly including partial pressure interference and deceptive interference.

3.5. Spectrum environment congestion
Due to the shortage of spectrum resources, it is bound to be threatened by external interference signals. The traditional UAV data link frequency band includes HF, VHF and Satcom. Satcom frequency band can not guarantee that every data transmission phase can be used, but HF and VHF become more and more crowded. In China, the available frequency bands of UAV issued by the Ministry of industry and information technology only include 840.5mhz ~ 845mhz, 1430mhz ~ 1444mhz and 2408mhz ~ 2440mhz.

4. Future development trend
The future development trend of anti-jamming technology of UAV data link system is as follows:
(1) have a wide range of spectrum management and distribution capabilities, such as high throughput, high reliability physical layer and MAC layer protocols and strategies.
(2) the ability to solve the power attenuation of long-distance information transmission, such as low-power MIMO system integration.
(3) improve the ability of anti malicious interference and non malicious interference, such as spread spectrum, frequency hopping, multi-source cooperative communication, asynchronous cooperative information transmission, cognitive radio and other technologies.
5. Conclusion
With the application of UAV in various fields more and more widely, its data link system is facing the challenges of spectrum resource shortage, complex environment, vulnerable to environmental interference and human interference. Traditional spread spectrum communication technology can not meet the reliability requirements of UAV data link. Therefore, more flexible and Adaptive Anti-jamming Technology, such as intelligent sensing spectrum environment and system reconstruction, is needed to improve the anti-jamming ability of UAV and ensure the quality of communication link.

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