DOI: 10.54254/2755-2721/116/20251725

Research on the Technology and Application of Remote Wireless Transmission of Digital Image Signal

Yuchuan Chen

College of Physics and Opto-Electronic Engineering, Taiyuan University of Technology, Taiyuan City, Shanxi Province, China

13753574456@163.com

Abstract. With the increasing demand for remote real-time high-quality video transmission, especially in the context of large area applications of unmanned aerial vehicle (UAV) and remote location instant live broadcast, traditional wired transmission methods have been surpassed by digital transmission methods due to their superior performance in image quality, transmission distance and delay. Therefore, this study focuses on the application of digital image wireless transmission in remote scenarios such as UAVs, including key digital transmission technologies such as Orthogonal Frequency Division Multiplexing (OFDM) and Coded Orthogonal Frequency Division Multiplexing (COFDM), as well as public network link communication technologies such as 4G and 5G, by means of a literature study and a case study. It also analyzes the development of WiFi, Lightbridge and OcuSync graphics transmission systems using DJI brand products as case studies. The analysis shows that digital image wireless transmission, especially COFDM and advanced proprietary systems such as DJI's OcuSync, has significant advantages in terms of transmission distance, interference immunity, encryption techniques, and reusability. However, factors such as building obstruction, frequency interference, and weather conditions can affect the transmission quality. To mitigate these challenges, solutions are proposed, such as auxiliary signal enhancement systems, adaptive frequency hopping and software-defined radio technologies.

Keyword: UAV, wireless graph transfer, digital image processing, DJI, COFDM, OFDM.

1. Introduction

With the rapid development of science and technology, the remote wireless transmission technology of digital image signals has shown broad application prospects in various fields, especially in the unmanned aerial vehicle (UAV), remote real-time broadcast, and other scenes. The demand for high-quality, long-distance, low-delay image transmission is growing. Due to its limitations, the traditional wired transmission method has been gradually replaced by digital wireless transmission technology, which stands out for its excellent image quality, long transmission distance, and low delay.

This paper focuses on wireless image transmission technology, especially the key technologies in remote application scenarios such as unmanned aerial vehicles. By using the methods of literature research and case analysis, we deeply analyze the key digital transmission technologies such as orthogonal frequency division multiplexing (OFDM) and coded orthogonal frequency division

DOI: 10.54254/2755-2721/116/20251725

multiplexing (COFDM), as well as the application of public network link communication technologies such as 4G and 5G. By analyzing specific product cases from industry leaders such as DJI, this paper reveals the practical application and advantages of these technologies in drone image transmission.

These technologies are chosen as the research direction because they can not only solve many problems in traditional image transmission, such as limited transmission distance, easy interference, and high delay, but also meet the growing demand for remote high-definition real-time transmission. The development of these technologies is of great significance to the drone industry, and has promoted the wide application of drones in many fields, such as aerial photography, inspection, and rescue. At the same time, they also bring new research directions and technical challenges to professional fields such as image processing and communication engineering. For users, these technologies improve the reliability and efficiency of image transmission, reduce the cost of use, and improve the user experience. In addition, as a model of interdisciplinary development, these technologies promote the integration of computer science, communication engineering, image processing, and other disciplines and are of great significance for promoting scientific and technological progress and industrial upgrading.

2. Uav image transmission method

The existing UAV image transmission is mainly divided into digital image transmission and analog image transmission. Analog graph transmission mainly relies on analog signal processing technology. After the analog image signal is captured by the image sensor, it is processed by appropriate amplification, modulation, etc., and then sent through the transmission medium. After receiving the signal, the receiver restores the analog image signal through demodulation, amplification and other processing. The principle of digital image transmission mainly includes three steps: analog-to-digital conversion (ADC), digital signal processing and transmission, digital-to-analog conversion (DAC). Analog-to-digital conversion (ADC) is an image sensor that captures an analog image signal and converts it into a digital signal through the ADC. Digital signal processing and transmission is to compress, encode and encrypt the digital signal, and then send it through the transmission medium. Digital-to-analog conversion (DAC) is when the receiver receives a digital signal and converts it back to an analog signal through DAC for display or further processing.[1]

Compared with analog image transmission, digital image transmission has obvious advantages in anti-interference ability, transmission distance, encryption technology and reusability. The anti-interference ability of digital image transmission is strong, which will ensure that the digital signal is not easily disturbed by noise, and thus ensure the image quality. In terms of transmission distance, the transmission distance of digital image transmission is longer, because it can extend the transmission distance through the relay station.Therefore, in order to meet the requirements of the industry, the pursuit of digital image transmission with lower latency rate has become the mainstream while ensuring high definition pictures and long-distance transmission[2].

3. Applied technologies

3.1. Orthogonal frequency division multiplexing (OFDM)

Orthogonal Frequency division multiplexing (OFDM) is an important digital modulation technology, which effectively improves the speed and efficiency of data transmission by distributing a single data stream to multiple independent channels or subcarriers [3]. In the UAV image transmission system, the application of OFDM technology can significantly improve the quality and stability of video transmission, especially in complex electromagnetic environment [4]. However, OFDM also has disadvantages, such as carrier frequency offset, very sensitive to phase noise and carrier frequency offset, and high peak-to-average ratio, making it more complex and power consuming than other modulation techniques. And OFDM requires fast Fourier transform (FFT) and fast inverse Fourier transform (IFFT) to convert signals between the time domain and the frequency domain. These involve complex mathematical operations that require more processing power and energy.

DOI: 10.54254/2755-2721/116/20251725

3.2. Coded orthogonal frequency division multiplexing (COFDM)

Coded orthogonal Frequency division multiplexing (COFDM) is a communication technology that is particularly suitable for UAV video transmission, because of its unique signal processing and transmission capabilities, which can provide stable and high-quality video transmission in multi-path and high-interference environments. COFDM encodes data into multiple subcarriers, and uses orthogonality to reduce the interference between subcarriers, which effectively improves the signal anti-interference and transmission efficiency [5]. However, COFDM is sensitive to phase noise and carrier frequency offset. Phase noise can lead to orthogonality destruction between subcarriers and ICI, which can degrade the performance of the system. Carrier frequency offset will lead to frequency offset between subcarriers, increase the difficulty of demodulation and reduce transmission efficiency.

3.3. Multiple-input multiple-output (MIMO)

Multiple-input multiple-output (MIMO) technology refers to the use of Multiple transmitting antennas and receiving antennas at the transmitting end and receiving end respectively, so that the signal is transmitted and received through Multiple antennas at the transmitting end and the receiving end, so as to improve the communication quality [6]. It can make full use of space resources, realize multiple and multiple collection through multiple antennas, and can double the channel capacity of the system without increasing spectrum resources and antenna transmission power, showing obvious advantages. Due to the multi-path transmission, the signals received by the receiving system are different in time delay, phase, size, etc., which are calculated by the system matrix and processed according to the internal algorithm. The difference between different signals is compared, the best selection is made, and then handed over to the later stage for processing [7].

3.4. Public network link communication

Public network link communication, including but not limited to 4G, 5G, 6G, etc [8, 9]. Through the mobile communication transmitting module carried on the UAV body, the encoded digital signal is uploaded to the public domain network through the mobile base station for decoding and downloading, so as to realize the real-time display of the image. Due to the continuous development of the new generation of mobile communication technology, the delay rate of wireless data transmission is also greatly reduced. UAVs based on mobile communication technology have realized ultra-long distance transportation of goods, and there is a demand for drone delivery. In addition, mobile communication technology and private network communication links based on software radio complement each other to achieve maximum transmission of information.

4. Case analysis

According to DJI UAV's own publicity, the company's self-developed map transmission system has three major systems: WIFI map transmission, Lightbridge map transmission, and OcuSync map transmission, which are updated and developed year by year, of which OcuSync map transmission has launched the third generation [10].

4.1. WiFi graph transfer

WiFi has a high bandwidth, in a certain range can achieve high-definition video transmission, but its effective control distance is relatively close, in the open area of its transmission distance is about 1 km, in the urban buildings between the effective transmission distance is only 300 m.

The UAV signal based on Wi-Fi communication is aperiodic in time domain, without fixed pulse repetition interval and pulse width. The bandwidth is about 16.5 MHz in the frequency domain, and there are fixed communication channels to choose from.There are five channels in the 5.8GHz band, and the center frequency points of each channel are distributed at 5 745 MHz to 5 825 MHz, and the interval between adjacent channels is 20 MHz.[11]Each time data is transferred, a four-handshake mechanism is usually required to establish a link. In order to ensure that both parties receive the information completely, a packet loss retransmission mechanism is adopted. The transmission time may be greatly increased due to the loss of a data packet.[12]Due to the poor real-time monitoring ability, weak signal anti-interference ability and short transmission distance, WiFi image transmission technology is not suitable for the over-the-horizon communication needs of UAV lead rate, so it is only applied to DJI's early low-end UAV products, including spark, mavic Air, and some scenes with no high requirements for distance.

4.2. Lightbridge graph transfer

Lightbridge is a dedicated communication link technology independently developed by DJI, which broadcasts data in a one-way way, similar to broadcast television and satellite radio. The image signal transmitted by Lightbridge diagram is transmitted from the sky end to the ground end as a one-way downlink signal, which can achieve almost "zero delay" 720p high-definition transmission and display, and the distance is usually more than 2 km, or even more than 5 km in the case of open without interference [13]. When the limit distance is reached, the WIFI image transmission screen appears stuck, and the reconnection handshake mechanism lasts for 30-60 seconds. In the case of weak signal, Lightbridge can achieve reconnection within 10s, although there will be a fringe weak signal warning. This also means that the risk of completely losing control when using ightbridge graphics is greatly reduced [14].

4.3. OcuSync graph transfer

OcuSync has a higher level of reliability and stability than Lightbridge, taking DJI Mavic 3 Pro as an example. Compared with traditional WiFi communication, Mavic 3 Pro adopts the latest self-developed OcuSync third-generation communication technology (O3+) and dual-frequency communication (2.4GHz and 5.8GHz). Under the FCC system, the maximum effective distance of the signal without blocking interference reaches 15km, the transmission power is less than 33 dBm, and the maximum download rate of the remote control reaches 15MB/s under the condition that the real-time image transmission quality is 1080p/60fps [15]. However, in the presence of dense woods and in the building environment of buildings and high-density steel structures, the OcuSync graph transmission system based on the traditional frequency band began to show signal carbonton, or even signal loss.

5. Factors affecting the the effectiveness of digital image wireless transmission

5.1. Factors affecting

5.1.1. Architecture. The building and other structural obstacles make the electromagnetic wave signal dependent on linear propagation greatly weakened, and the signal is lost and so on. In addition, under the interference of strong magnetic field signal, when flying near the steel structure building, due to the strong electrical conductivity of the steel structure, it will produce a certain signal reflection and attenuation of the electromagnetic wave, thus affecting the image transmission.

5.1.2. Frequency band. At present, the mainstream graph transmission is mainly 5.8 and 2.4GHz, of which 5.8GHz band, although the data transmission rate is faster, but the penetration is relatively weak. The 2.4GHz band, though more penetrating, is susceptible to interference from other wireless devices. In addition, the same frequency signal interference will also affect the digital image wireless transmission effect[16]. When two or more wireless devices communicate using the same frequency, their signals can interfere with each other, resulting in signal attenuation, distortion, or loss. This interference reduces the signal-to-noise ratio at the receiving end, making it difficult to separate the useful signal from the noise.

5.1.3. Transmission media. In rain, snow and haze weather, the moisture in the air will change the conductivity and dielectric constant of the medium, and then affect the transmission characteristics of

DOI: 10.54254/2755-2721/116/20251725

electromagnetic waves[17]. This change will cause electromagnetic wave refraction, reflection and other phenomena in the transmission process, and further reduce the intensity and coverage of the signal. On the other hand, the electromagnetic wave may pass through multiple paths to the receiving end, including the direct path, the ground reflection path and the rain scattering path. These electromagnetic waves of different paths are superimposed on each other at the receiving end, which will produce a multipath effect, resulting in signal distortion and interference.

5.2. Solutions

5.2.1. Use auxiliary signal enhancement system. Taking DJI's launch of a new image enhancement system as an example, DJI Celluar can implement a 4G signal assisted image transmission system by carrying a traditional mobile phone SIM card. Under normal circumstances, with the help of the public network link communication technology, only O3+ image transmission is used for transmission when the connection of 4G signal is maintained and the distance is not far. When there is occlusion and the original signal is weakened, the 4G signal begins to take over the picture transmission work of the UAV [18].

5.2.2. Signal processing and demodulation algorithms at the receiving end. Zhang proposes key technologies that can improve the reliability of microwave communication through forward error correction (FEC) technology and adaptive adjustment, and selects and optimizes demodulation algorithms by utilizing phase synchronization algorithm, frequency synchronization algorithm, constellation recognition and recovery algorithm [17]. Regarding adaptive adjustment, taking DJI's latest DJI SDR graph transmission system as an example, it supports 2.4GHz, 5.8GHz, DFS non-inductive automatic frequency hopping, which automatically realizes the most efficient transmission of signals.

5.2.3. Development of software radio technology. The development of software radio technology can effectively improve the transmission effect. Taking DJI SDR graph transmission system as an example, which adopts dual system technology of SDR and Wi-Fi. Compared with the requirements of ultra-long-distance transmission from drones, this product is defined as a multi-camera real-time monitoring solution in the field of photography sets. As compared to Wi-Fi mapping, SDR achieved a 650% increase in transmission distance, a 67% increase in transmission bit rate, and a 30% reduction in transmission latency. Transmission distance up to 3 km, support 1080p 60fps transmission specifications, bit rate up to 20Mbps, latency as low as 35ms, and no limit on the number of receivers[19]. This fully realizes the greater communication efficiency.

6. Conclusion

This paper explores in depth the key technologies that wireless image transmission systems rely on, including OFDM, COFDM, MIMO and public network link communication, and analyzes in detail the three generations of image transmission systems used by the market leader DJI: WiFi image transmission, Lightbridge image transmission and OcuSync image transmission. Through the analysis of these systems, this paper reveals their advantages in transmission distance, anti-interference ability, encryption technology and reusability, and also points out their limitations in complex environments, such as building block, frequency band interference and bad weather. Further, this paper proposes a variety of solutions, such as the use of auxiliary signal enhancement system, the optimization of signal processing and demodulation algorithms at the receiving end, and the development of software radio technology to address the above challenges. These schemes not only improve the reliability and stability of image transmission, but also provide a useful reference for the development of wireless image transmission technology in the future.

However, the content of this paper mainly focuses on transmission technology, and there is no in-depth discussion on the conversion process from image signal to digital signal. In the future, the author will focus on the encoding and decoding technology of wireless image transmission system, and further improve the efficiency of image transmission from the direction of image processing and decoding and decoding, and plan to contribute new theories and technical support for the development of wireless image transmission technology through more extensive literature research and experimental verification.

References

[1] The Latest Study Club. [Digital and analog graph transmission].https://mp.weixin.qq.com/s/DLJEh30vrPiaVbmi59pF3w.
[2] Wen Kailin Implementation of low latency high-definition digital image transmission [D] Shaanxi: Xi'an University of Electronic Science and Technology, 2018 DOI:10.7666/d.D01664525..
[3] Liu B., Ding D,, Yang L., Xue N., & Liu Z. (2022). OFDM transmission technology of UAV data based on DNN. Systems Engineering and Electronic Technology..
[4] Jiang L., Zhang Q., Han S., et al. System Engineering and Electronics, 2019,41(3): 651-658. A Space-Frequency Coding Diversity Method for Dual-Polarized Antennas Based on Mini UAV [J]. (3).
[5] Farhan, M. (2023). COFDM System: An Overview. Journal of Siberian Federal University. Technology and Technology, 16 (8), 1026-1034..
[6] Shi X L. (2019). FPGA implementation of MIMO-OFDM modulator and Turbo decoding for wireless graph transmission system (Master's thesis, Xidian University).[D]..
[7] HollyView. [technology introduction]. Retrieved from http://hollyview.cn/info/detail-2365.html
[8] S. Homayouni et al., "On the Feasibility of Cellular-Connected Drones in Existing 4G/5G Networks: Field Trials," 2021 IEEE 4th 5G World Forum (5GWF), Montreal, QC, Canada, 2021, pp. 287-292, doi: 10.1109/5GWF52925.2021.00057..
[9] Chen Xinying, et al., Overview of Communication for 6G Uavs. Journal of Electronics and Information Technology, 2022.44 (3): 781-789..
[10] PangBo(2020). Research on Signal Analysis and Recognition of Unmanned Aerial Vehicle Image Transmission (Master's thesis, Beijing University of Posts and Telecommunications).
[11] Min FAN, Siyuan SHAO, Chao HE, Xiang WANG, Haiming WANG. Next-generation mmWave WLAN: vision and key enabling technologies[J]. Chinese Journal on Internet of Things, 2023, 7(3): 1-14..
[12] Feng Xiaochen et al. developed an ultra-low power wireless sensing system using Wi Fi channels Journal of Instrumentation, 2021 41 (9): Pages 131-140.
[13] Xuan H. et al., Design and Evaluation of Highly reliable Multimode Wireless Communication for Uavs. Reliability and Environmental Testing of Electronic Products, 2023.41 (6): 58-62..
[14] Tang, M. (2023). Drone Detection and Classification with Machine Learning..
[15] DJI. (2023). Mavic 3 Pro specifications. Retrieved from https://www.dji.com/cn/mavic-3-pro/specs.
[16] Jia Xu-zhong, Discussion on the Interference Problem of Wireless Graph transmission. Television Technology, 2023.47 (7): 91-93.
[17] Lu, H. H. (2021). Study on the transmission characteristics of electromagnetic waves in Charged particle Flows (Master's thesis, University of Electronic Science and Technology of China).
[18] DJI Support. DJI Cellular. Retrieved from https://support.dji.com/help/content?customId=zh-cn03400007101&spaceId=34&re=CN&lang=zh-CN.
[19] DJI. (2024). SDR Transmission. Retrieved from https://www.dji.com/cn/sdr-transmission?site=brandsite&from=insite_search