

# Design of Unmanned Aerial Vehicle Frequency Hopping Communication System

Tianchen Long \*, Yanwen Wang, Hongqing Ma, Chang Cai, Feng Liu

School of Electronic Information, Xijing University, xian, Shaanxi, China

\* Corresponding author: Tianchen Long

**Abstract:** The development of drone technology has led to the widespread application of its communication system in multiple fields. This article first introduces the composition and principles of unmanned aerial vehicle communication systems, with a focus on analyzing the principles and parameters of frequency hopping communication technology, which enhances anti-interference and security through pseudo-random frequency switching. Next, we will explore time-frequency analysis methods, including linear and nonlinear methods, and explain their applications and advantages in processing complex signals. Finally, we will combine the two to improve the accuracy and reliability of signal processing.

**Keywords:** UAV; Communication System; Frequency Hopping Communication; Time Frequency Analysis; Mixed Time-frequency Analysis.

## 1. Introduction

Drones are widely used in military reconnaissance, environmental monitoring, and agricultural production, and their communication system stability and reliability affect performance and mission execution. Traditional wireless communication is limited by spectrum resources and interference, and frequency hopping technology has become an effective solution. At the same time, the complex and diverse communication signals of unmanned aerial vehicles have promoted the development of time-frequency analysis methods. This article will delve into the principles of unmanned aerial vehicle communication systems, elaborate on frequency hopping communication technology, and explore time-frequency analysis methods and their application prospects in depth.

## 2. Composition of UAV Communication System

The multi rotor drone communication system consists of the drone body and remote control or ground terminal. There are four main modules inside [1] (as shown in Figure 1):

1. The power module supplies energy to various parts of the system.
2. The detection module monitors the flight status, including inertial measurement units, barometers, and electronic compasses.
3. The control module optimizes parameters based on detection data and generates control instructions to adjust flight.
4. The driver module responds to instructions and adjusts the flight situation in real time.

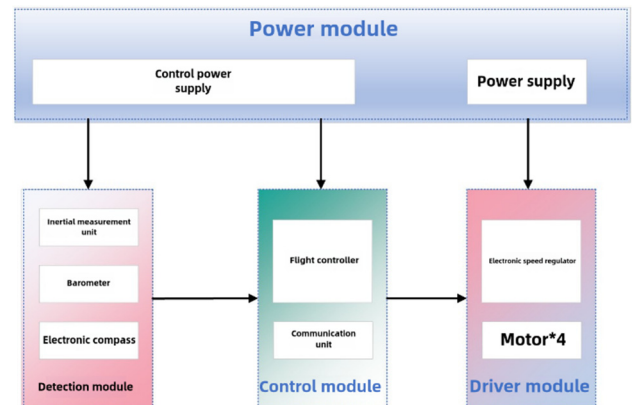


Figure 1. Hardware System Composition of Unmanned Aerial Vehicle

## 3. Principles of UAV Communication and Frequency Hopping Communication

The principle of drone communication involves signal transmission, reception, and execution to ensure accurate response to ground commands. The ground remote control station or main control terminal sends control instructions, which are converted and transmitted to the remote control receiving equipment through the radio wave uplink channel. The device decodes and converts signals into commands that the drone can recognize, and sends them to the autopilot to control flight, such as lifting, advancing, retreating, and turning [2] (as shown in Figure 2).

## 4. Basic Principles of Frequency Hopping Communication

Frequency hopping communication has evolved from traditional radio communication and relies on code controlled frequency hoppers for communication. Using carrier modulation to transmit information, dynamically switching frequencies according to a preset pseudo-random sequence to achieve hopping [3]. The receiver captures the demodulated signal according to the set mode and maintains

synchronization with the transmitter to recover the original information (as shown in Figure 3). Drone frequency hopping communication has anti-interference and security advantages, but it is difficult to detect due to its transmission and reception

being controlled by pseudo-random codes, frequency change algorithms, and high synchronization requirements. Algorithm updates affect the frequency hopping mode and detection.

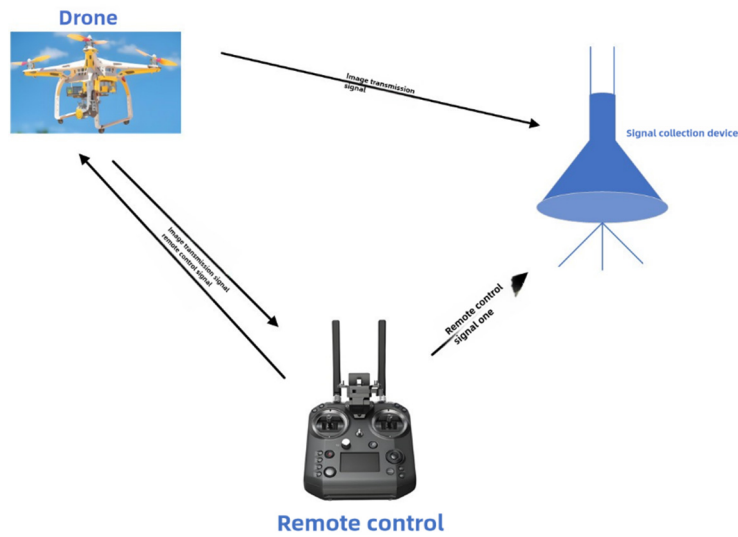


Figure 2. Schematic diagram of drone communication

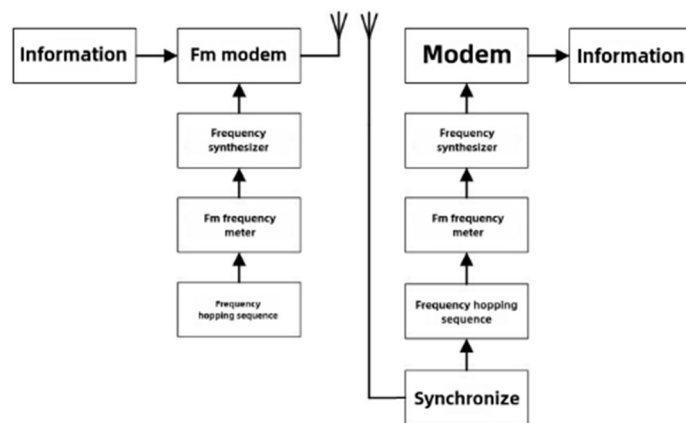


Figure 3. Schematic diagram of frequency hopping communication

## 5. Main Parameters of Frequency Hopping Communication

The frequency hopping system has multiple key indicators, each of which has a significant impact on system performance [4]:

1. The number of hopping frequencies reflects the number of carrier frequency changes and is positively correlated with anti-interference performance. Increasing the frequency can enhance anti-interference.

2. The frequency hopping channel width covers the frequency range, affecting anti-interference and detection probability. Widening can enhance anti-interference and concealment.

3. Frequency hopping processing adjusts the signal bandwidth to generate gain, broadens frequency coverage, and improves anti-interference performance.

4. The frequency hopping pattern reflects the frequency switching process, and the complexity affects the anti-interference ability. The more complex, the higher the reliability.

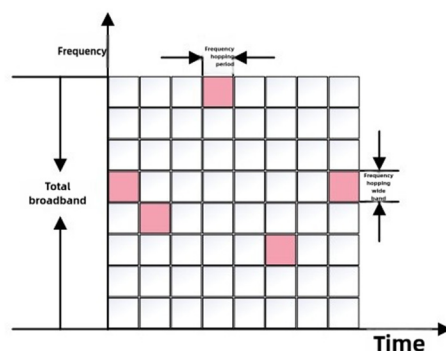


Figure 4. Schematic diagram of frequency hopping

5. Frequency hopping speed is important for dealing with follower interference, and improving it in military applications can enhance security, but it is limited by equipment.

6. The frequency hopping duration is inversely proportional to the hopping rate, and the rate change affects the length of the cycle.

## 6. Time-frequency Analysis

Random signals are divided into stationary and non-stationary signals (as shown in Figure 5). The characteristics of a stationary signal are constant, and Fourier transform can

analyze its time-domain or frequency-domain features. The characteristics of non-stationary signals vary over time and require joint time-frequency analysis, commonly using local Fourier transform [4]. Time frequency analysis is divided into linear and nonlinear methods, such as short-time Fourier transform (STFT) and Gabor transform, which are suitable for linear correlation of signal components [5]; Nonlinear distributions such as Wigner distribution (WVD) and its derivatives are used for signals that do not satisfy linear correlation conditions, with high time-frequency resolution. However, WVD analysis of multi-component signals is affected by cross terms and can be improved through Hilbert transform.

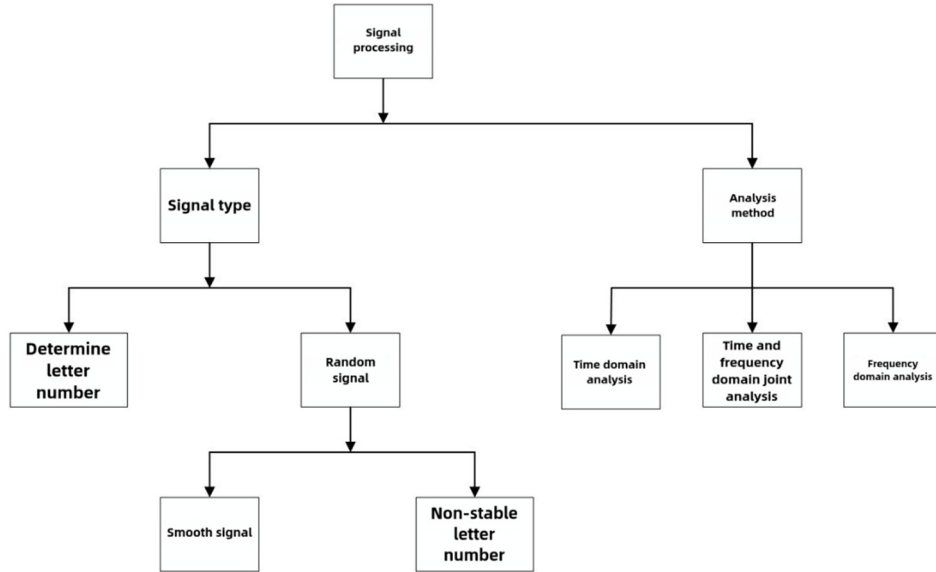


Figure 5. Classification diagram of signal processing

## 7. Linear Time-Frequency Analysis

### 7.1. Short Time Fourier Transform

The Short Time Fourier Transform (STFT) was proposed by Dennis Gabor in 1946. It uses window functions of different shapes such as rectangles, Hanning windows, or Hamming windows to perform local analysis on signals, and reveals the time-frequency characteristics of signals by performing Fourier transform for each time window, which traditional Fourier transform cannot achieve [6].

The expression for STFT is shown in equation (1):

$$\text{STFT}_s(t, \omega) = \int_{-\infty}^{+\infty} s(\tau)h(\tau - t)e^{-i\omega\tau}d\tau \quad (1)$$

Among them,  $h(t)$  is the window function, and  $s(t)$  is the signal. The window function  $h(t)$  divides the signal  $s(t)$  into several segments through its translation parameter  $t$ . The specific window function extracts the signal  $s(t)$  within the time period  $\tau$  near time  $t$ , obtaining  $s_t(\tau) = s(\tau)h(\tau - t)$ . Afterwards, performing Fourier transform on the segmented signal  $s_t(\tau)$  can display the frequency distribution of the original signal within a specific time period.

### 7.2. Gabor Transform

Gabor transform is an STFT that relies on Gaussian windows. It has good time-frequency domain localization effect and can comprehensively capture signal information. It is suitable for signal analysis in multiple fields such as communication, image processing, and sound processing (formula (2) is the expression of Gabor transform).

$$Gf(\omega, b) = \int_{\mathbb{R}} e^{-i\omega t} \overline{g(t - b)} f(t) dt \quad (2)$$

## 8. Nonlinear Time-frequency Analysis

### 8.1. Wigner Distribution

The Wigner Ville distribution (WVD) is a Cohen class bilinear time-frequency representation that is fundamentally different from STFT in that it can accurately distribute the energy of a signal on the time-frequency plane [7].

The expression for WVD transformation is shown in equation (3):

$$WV_s(t, f) = \int_{-\infty}^{\infty} s\left(t + \frac{\tau}{2}\right) s^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi f\tau} d\tau \quad (3)$$

Where  $s(t)$  is the signal function,  $\tau$  is the integral variable, and  $t$  is the time shift.

When analyzing multi-component signals, WVD may be affected by cross terms, resulting in a decrease in time-frequency resolution and an increase in the complexity of information extraction. To reduce interference, Hilbert transform was introduced to improve WVD by converting the signal into analytical form and reducing the influence of cross terms.

The improved WVD expression is shown in equation (4):

$$W_z(t, f) = \int_{-\infty}^{+\infty} z\left(t + \frac{\tau}{2}\right) z^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi f\tau} d\tau \quad (4)$$

The definition of the analytical signal  $z(t)$  is shown in equation (5):

$$z(t) = s(t) + jH[s(t)] \quad (5)$$

The definition of Hilbert transform is shown in equation (6):

The definition of Hilbert transform  $H[x(t)]$  is shown in equation (6):

$$H[x(t)] = \lim_{\delta \rightarrow 0} \left[ \int_{-\infty}^{-\delta} \frac{s(t-u)}{u} du + \int_{\delta}^{+\infty} \frac{s(t-u)}{u} du \right] \quad (6)$$

The analysis signal  $z(t)$  is the original signal plus its Hilbert transform  $H[x(t)]$ , which can reduce cross term interference when processing complex signals and make WVD more effective in practical applications.

## 8.2. Pseudo Wigner Ville Distribution, PWVD

In practical applications, finite length data is usually processed, so an improved strategy called Pseudo Wigner Ville Distribution (PWVD) is adopted [8], which introduces a window function  $h(\tau)$  on the basis of the original WVD for time local smoothing processing. The expression for PWVD is shown in equation (7):

$$\text{PWVD}_z(t, f) = \int_{-\infty}^{+\infty} z\left(t + \frac{\tau}{2}\right) z^*\left(t - \frac{\tau}{2}\right) h(\tau) e^{-j2\pi f \tau} d\tau = W(t, f)_f^* H(f) \quad (7)$$

## 8.3. Choi Williams Distribution

In 1989, Hyung Il Choi and William J. Williams jointly proposed the Choi Williams distribution [9], Provide new analytical methods for the field of signal processing. The expression of CWD distribution is shown in equation (8):

$$C_x(t, f) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} A_x(\eta, \tau) \Phi(\eta, \tau) e^{j2\pi(\eta t - \tau f)} d\eta d\tau \quad (8)$$

In equation 2.12,  $A_x(\eta, \tau)$  is defined as the autocorrelation function of signal  $x(t)$ , as shown in equation (9):

$$A_x(\eta, \tau) = \int_{-\infty}^{+\infty} x\left(t + \frac{\tau}{2}\right) x^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi \eta t} dt \quad (9)$$

The core function  $\Phi(\eta, t)$  is shown in equation (10):

$$\Phi(\eta, \tau) = e^{-\alpha(\eta\tau)^2} \quad (10)$$

Among them,  $\alpha$  is the regulating parameter that controls the degree of suppression of cross terms in the signal.

## 9. Conclusion

In this research, we have comprehensively investigated the design of unmanned aerial vehicle frequency hopping communication systems. The unmanned aerial vehicle communication system, which is crucial for the operation of drones in various fields such as military reconnaissance, environmental monitoring, and agricultural production, has been dissected in terms of its composition and principles. The frequency hopping communication technology, a key aspect of enhancing the system's anti-interference and security capabilities, was elaborated upon. Its basic principles, involving code-controlled frequency hoppers and pseudo-random frequency switching, along with its main parameters like the number of hopping frequencies, channel width, processing gain, hopping pattern, speed, and duration, were all analyzed in detail. These parameters were found to have significant impacts on the overall performance and characteristics of the frequency hopping system.

Furthermore, the time-frequency analysis methods, both linear and nonlinear, were explored. Linear methods such as the Short Time Fourier Transform and Gabor transform, which use window functions to analyze signals in the time-frequency domain, and nonlinear methods including the Wigner Ville Distribution and its derivatives like the Pseudo

Wigner Ville Distribution and Choi Williams distribution, which are designed to handle different types of signals and overcome issues such as cross-term interference in multi-component signals, were studied. The combination of frequency hopping communication and time-frequency analysis techniques holds great potential for improving the accuracy and reliability of signal processing in unmanned aerial vehicle communication systems.

However, it should be noted that there are still some challenges and areas for further improvement. For example, the complexity of frequency hopping algorithms and the high synchronization requirements may pose difficulties in practical implementation. Additionally, while the time-frequency analysis methods have been developed to handle various signal characteristics, there is still room for optimization in terms of computational efficiency and real-time processing capabilities, especially when dealing with large amounts of data. Future research could focus on refining these aspects to make the unmanned aerial vehicle frequency hopping communication system more efficient, reliable, and adaptable to the ever-evolving demands of the application scenarios. Overall, this study has laid a solid foundation for the continued development and enhancement of unmanned aerial vehicle communication technologies.

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