

# Optimization Strategy for Radar Signal Anti-Jamming in UAV Emergency Delivery

Fan Yang

East China Jiaotong University, Nanchang, Jiangxi, China

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**Abstract:** Drones in emergency delivery operations face complex electromagnetic interference, including active jamming such as suppression and deception types, and passive jamming like chaff, which seriously threatens the reliability of radar detection. Constrained by platform payload and computational power, traditional anti-jamming techniques are difficult to apply directly. This study proposes a set of optimization strategies centered on lightweight design and adaptability, including interference-aware waveform optimization, joint spatiotemporal processing, jamming evasion methods, and lightweight algorithm design. Through theoretical analysis and numerical simulation, the strategy achieves a Signal-to-Interference-plus-Noise Ratio (SINR) improvement of up to 22 dB under compound interference, maintains a stable target detection probability above 90%, and reduces computational complexity to only 30–45% of that of traditional methods. This effectively balances performance with resource constraints, thereby enhancing the reliability of delivery missions.

**Keywords:** Radar signal anti-jamming; Adaptive waveform optimization; Lightweight algorithm; Compound interference; Signal-to-interference-plus-noise ratio

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## 1. Introduction

### 1.1. Research background

The rise of the low-altitude economy and the modernization of emergency rescue systems have propelled unmanned aerial vehicle (UAV) emergency delivery to become a core pillar in scenarios such as disaster relief, medical emergencies, and material replenishment. Leveraging advantages like high mobility, rapid response, and terrain independence, UAVs establish “aerial lifelines” in urgent situations including search and rescue in earthquake rubble, rescuing lost individuals in mountainous areas, and transporting supplies to lockdown zones. They have emerged as a critical force in low-altitude emergency rescue operations. However, the complex characteristics of UAV emergency delivery scenarios pose severe challenges to radar systems. The electromagnetic environment at disaster sites is chaotic, often with damaged communication base stations and severe scattering of electromagnetic signals<sup>[1]</sup>. Some areas face both man-made active jamming (such as suppression and deception types) and passive interference (like chaff and terrain clutter), leading to degraded radar detection accuracy and

target loss. Furthermore, the co-existence of dynamic and compound interference in the low-altitude domain further exacerbates delivery risks.

## **1.2. Research significance**

### **1.2.1. Theoretical significance**

At the academic theoretical level, this research promotes the intersection and integration of knowledge across multiple fields such as adaptive signal processing and intelligent optimization. To address the optimization challenges under stringent platform constraints, the study attempts to combine traditional anti-interference methods with intelligent algorithms, thereby advancing the evolution of anti-interference technology. Furthermore, research on strengthening single-platform anti-interference capability serves as an important foundation for constructing future multi-UAV cooperative perception and distributed anti-interference networks. The scenario models and efficacy evaluation framework established by this research also provide a valuable theoretical reference and technological reserve for subsequent exploration of more complex cooperative intelligent anti-interference problems.

### **1.2.2. Practical significance**

At the engineering level, the anti-interference strategy designed in this research can ensure stable perception of the UAV radar in complex electromagnetic environments, supporting reliable navigation and positioning functions, thereby guaranteeing the safe and timely delivery of rescue supplies, demonstrating significant social value. Simultaneously, through the use of lightweight algorithms and joint optimization strategies, the research overcomes the application bottleneck of advanced anti-interference technologies on lightweight platforms. It achieves a balance between performance and resource consumption, providing a feasible path for the transformation of this technology into large-scale deployable UAV platforms, showcasing important prospects for engineering application.

## **2. UAV emergency delivery radar system and interference analysis**

### **2.1. Radar system architecture for UAV emergency delivery**

The UAV emergency delivery radar system is a dedicated integrated perception-navigation system tailored for complex, low-altitude emergency scenarios. It employs a collaborative four-layer architecture of “Detection-Navigation-Processing-Interaction” to meet core requirements for all-weather operation, high precision, and anti-jamming capability. The system consists of the following four core modules:

- (1) The radar detection module, centered on Frequency-Modulated Continuous Wave (FMCW) radar with phased array radar as a supplement, optimizes RF parameters for “low, slow, and small” targets, enabling real-time scanning of obstacles and landing points within the delivery airspace;
- (2) The navigation and positioning module integrates Beidou multi-constellation positioning and radar terrain-matching technology to guarantee sub-meter level positioning accuracy even in GPS-denied environments;
- (3) The signal processing module, equipped with a high-speed Digital Signal Processor (DSP), performs echo signal analysis, clutter suppression, and target feature extraction;
- (4) The data interaction module utilizes an anti-jamming narrowband communication link to achieve low-latency synchronization of radar data with the UAV flight control system and the ground command center.

This architecture features miniaturization, low power consumption, and modularity, enabling rapid integration onto various types of emergency delivery UAVs, making it adaptable to complex environments such as mountainous areas, urban ruins, and flood disaster zones.

## 2.2. Characteristics of UAV emergency delivery scenarios

The core characteristics of UAV emergency delivery scenarios are environmental complexity, mission urgency, and a harsh electromagnetic environment as follows:

- (1) Geographically, disaster areas feature rugged terrain, collapsed structures, and dense vegetation, where radar beams are prone to blockage and multipath reflection, creating detection blind zones;
- (2) Meteorologically, disaster zones are often accompanied by rain, snow, fog, haze, or sandstorms, causing electromagnetic wave attenuation and reducing echo signal strength;
- (3) Mission-wise, emergency delivery demands rapid system response, requiring completion of route planning, obstacle detection, and landing point confirmation within a short timeframe, imposing extremely high real-time requirements;
- (4) Electromagnetically, the concentration of rescue equipment, communication base stations, and power facilities around disaster areas leads to congested spectrum resources.

Simultaneous operation of multiple rescue UAVs can cause mutual signal interference, further complicating the environment. Furthermore, the system must adapt to high-dynamic operational demands such as low-altitude hovering and rapid penetration, placing stringent requirements on stability and vibration resistance.

## 2.3. Typical jamming types and characteristics faced by radar

Radar systems for UAV emergency delivery face jamming categorized by signal generation method into active jamming and passive jamming, each with distinct characteristics and different mechanisms of impact.

### 2.3.1. Active jamming (suppressive and deceptive)

Active jamming is deliberate interference formed by an interference source actively emitting electromagnetic signals<sup>[2]</sup>. It is highly targeted and poses a significant threat, mainly comprising the following two types:

- (1) Suppressive jamming: This type reduces the signal-to-noise ratio at the receiver by transmitting high-power electromagnetic signals that cover the radar's operating frequency band, preventing the system from identifying target echoes. Common forms include noise blanket jamming, sweep jamming, and pulse jamming. It can render the radar "blind" or significantly reduce its detection range;
- (2) Deceptive jamming: By analyzing the frequency, phase, and modulation characteristics of the radar signal, deceptive jamming simulates and generates false echoes to mislead target identification and positioning. It is mainly divided into range deception, velocity deception, and angle deception. This type easily leads to course deviation and increased landing point errors. Due to its strong concealment, it is difficult to eliminate through traditional filtering techniques.

### 2.3.2. Passive jamming (chaff and terrain clutter)

Passive jamming is interference where the source does not actively emit signals but alters echo characteristics by reflecting or scattering the radar's own electromagnetic waves. It is characterized by strong concealment and wide coverage. The core types are as listed:

(1) Chaff jamming: Composed of passive reflectors like metal strips, it forms an electromagnetic reflecting cloud when dispensed <sup>[3]</sup>. This cloud masks real target echoes and generates a large number of false plots, increasing the signal processing load and reducing system response speed <sup>[4]</sup>;

(2) Terrain clutter: Formed by the reflection and scattering of radar waves from terrain features such as mountains, buildings, ruins, and vegetation. It induces multipath interference, causing distortion in the received signal due to superposition, which leads to errors in judging target range and azimuth. The clutter intensity is related to the beam incidence angle and terrain roughness. This effect is particularly pronounced in mountainous areas and urban ruins, readily increasing the radar's false alarm rate and triggering unnecessary obstacle avoidance maneuvers.

## **2.4. Evaluation of the impact of jamming on radar detection performance**

In the scenario of emergency delivery by unmanned aerial vehicles, the impact of active interference on radar detection performance is significantly greater than that of passive interference. Research indicates that blanket jamming reduces the radar's received signal-to-noise ratio by 30% to 50% through power suppression, shortening the target detection range by over 40%. Deception jamming, by forging target signals, increases angular tracking error by 2–3 times, leading to target misidentification and loss of tracking. Passive chaff interference only raises the radar's false alarm rate by 5% to 8% in low-altitude delivery scenarios. When the frequency point overlap rate between interference and the target signal reaches or exceeds 85%, the radar's identification accuracy for UAVs plummets from 92% to 41%. These quantified data clarify the impact levels of different interference types, providing crucial evidence for the selection of anti-interference technologies and the optimization of subsequent solutions.

## **3. Theoretical basis of key technologies for radar signal anti-jamming**

### **3.1. Adaptive beamforming technology**

Adaptive beamforming is a core method for countering active interference <sup>[5]</sup>. By dynamically adjusting beam weights through array antenna covariance matrix estimation, it achieves target signal enhancement and interference suppression. For the UAV emergency delivery scenario, the Minimum Variance Distortionless Response (MVDR) algorithm can form deep nulls in the direction of interference, with a suppression ratio exceeding 40 dB. This adapts to the characteristic of dynamically changing interference sources during high-speed UAV movement. Simulation verification shows it can improve the radar signal-to-noise ratio by 25–30 dB. The key challenge lies in balancing the computational complexity of real-time covariance matrix updates with the radar's real-time processing requirements.

### **3.2. Pulse compression anti-jamming technology**

Pulse compression is a fundamental time-domain anti-interference technique. Through the synergistic action of linear frequency modulated (LFM) signals and matched filtering, it compresses the signal pulse width and enhances peak power, thereby improving the detection capability for weak long-range signals. This technique features a simple structure and low computational demands, making it suitable for the payload constraints of UAV platforms. It can be deployed without complex hardware upgrades, thereby providing a clear signal characteristic foundation for subsequent interference identification.

### **3.3. Interference recognition and classification algorithms**

Based on the time-frequency domain characteristics of signals after pulse compression, a CNN deep learning recognition model is constructed to achieve precise classification of blanket and deception jamming, with a recognition accuracy exceeding 95%. To address low signal-to-noise ratio scenarios, an attention mechanism is introduced, ensuring that the recognition rate remains above 88% when the SNR is  $\geq 5$  dB. This provides an accurate basis for type judgment in targeted anti-interference solutions.

### **3.4. Anti-jamming performance evaluation metrics**

A three-level evaluation index system of signal-detection-system is constructed, with core thresholds defined as: SNR  $\geq 15$  dB, interference suppression ratio  $\geq 35$  dB, detection probability  $\geq 90\%$ , tracking error  $\leq 0.5^\circ$ , and processing delay  $\leq 50$  ms. This provides a unified and objective standard for performance verification of subsequent anti-interference optimization solutions.

## **4. Design of radar signal anti-jamming optimization strategies for UAV emergency delivery**

### **4.1. Adaptive waveform optimization strategy based on interference awareness**

Designed for scenarios involving single active suppressive jamming and composite “active suppressive + passive chaff” jamming, the core objective is to enhance the target echo SINR <sup>[6]</sup>. An interference awareness module is established, utilizing spectrum detection and signal feature extraction algorithms to capture key parameters of the interference signal in real-time, such as frequency range and power spectral distribution. Targeting the peak interval in the power spectrum of noise-modulated FM blanket jamming, the bandwidth, chirp rate, and carrier frequency of the LFM signal are adaptively adjusted to avoid strong energy regions of the interference, reducing spectral overlap. A waveform matching feedback mechanism is introduced, which corrects parameters in real-time based on the received SINR to ensure optimal detection performance is maintained in dynamic interference environments, achieving an SINR improvement of 8~12 dB. This lays the foundation for synergistic anti-jamming against composite interference.

### **4.2. Joint anti-jamming scheme integrating spatial filtering and temporal processing**

Designed for scenarios involving single active deceptive jamming and composite “active deceptive + active suppressive” jamming, this scheme aims to achieve the dual objectives of suppressing suppressive jamming and distinguishing deceptive jamming. In the spatial filtering stage, adaptive beamforming technology is employed. Based on the direction-of-arrival information of the interference, the weighting coefficients of the array antenna are optimized to form beam nulls towards the interference directions, thereby weakening the intensity of suppressive jamming and achieving over 18 dB of jamming suppression gain. In the temporal processing stage, a target motion trajectory continuity discrimination model is constructed. It extracts motion parameters such as radial velocity and acceleration to differentiate between the stable trajectory of the genuine delivery target and the discrete, false trajectories generated by deceptive jamming. By incorporating radar terrain-matching data, a trajectory credibility assessment is introduced, raising the correct identification rate of deceptive jamming to over 95% and ensuring that radar tracking error is controlled within 12 meters.

### 4.3. Interference evasion strategy for complex emergency delivery scenarios

This strategy primarily addresses single passive chaff jamming and the threat of chaff false targets in composite interference scenarios, utilizing the differences in motion characteristics between the target and the interference to achieve jamming suppression. Based on the difference in Doppler spectral width between the UAV delivery target and chaff interference, a dynamic threshold screening model is constructed: According to the target's radial velocity  $v_r$  and the radar operating wavelength  $\lambda$ , the target's Doppler frequency shift is calculated via  $\Delta f_d = k \cdot \frac{2v_r}{\lambda}$  ( $k$  is an empirical coefficient, typically set to 1.2). By contrasting this with the irregular Doppler spectral characteristics of chaff interference, an adaptive threshold is set to filter out false scattering points. Combined with emergency delivery route planning information, spatial position constraints are introduced to exclude false targets outside the planned flight path, achieving a chaff interference suppression rate of over 90% and improving the target echo SINR by 10 dB, thereby ensuring stable radar tracking of the delivery target.

### 4.4. Design of lightweight anti-jamming algorithms

To adapt to the limited computational resources of the UAV platform and meet the real-time requirements of emergency delivery, the aforementioned strategies are optimized for lightweight implementation. A modular design approach is adopted, decomposing functions such as interference awareness, waveform optimization, spatial filtering, and trajectory discrimination into independent modules. These modules are dynamically scheduled and activated on-demand to reduce unnecessary computations. Core computational processes are optimized by employing efficient algorithms such as Fast Fourier Transform (FFT) and sparse matrix solvers to replace traditional complex computational logic. Furthermore, considering the characteristics of the UAV's embedded processor architecture, data storage and computational parallelism are optimized. Ultimately, the total computational load of the algorithm is controlled within the range of  $2.5 \times 10^6$  to  $3.8 \times 10^6$  FLOPs, which is only 29% to 45% of that required by classical adaptive beamforming techniques. This ensures robust anti-jamming performance while being well-suited to the lightweight computational capabilities of UAVs.

## 5. Theoretical analysis and numerical simulation of anti-jamming strategy performance

### 5.1. Construction of numerical simulation environment and parameter setting

#### 5.1.1. Simulation platform and tool selection

Numerical simulations were conducted on the MATLAB R2023b simulation platform. The simulation model for UAV emergency delivery radar anti-jamming was constructed utilizing the Signal Processing Toolbox and the Radar Toolbox. The simulation process leveraged matrix operation modules for generating interference signals, modeling radar echoes, and performing numerical solutions of anti-jamming algorithms. The data visualization modules were used to complete the statistics and output of performance metrics.

#### 5.1.2. Radar system parameter setting

Considering the lightweight and low-power requirements of UAV emergency delivery scenarios, the core parameters of the radar system were set as follows:

- (1) Operating band: X-band (8~12 GHz), balancing detection accuracy and equipment integration;
- (2) Signal format: LFM pulse signal, with a bandwidth of 50 MHz, a Pulse Repetition Frequency (PRF) of 1 kHz, and a pulse width of 10  $\mu$ s;

- (3) Antenna parameters: Phased array antenna, with 16 elements, a beamwidth of  $15^\circ$ , and a gain of 20 dBi;
- (4) UAV platform parameters: Flight altitude of 500 m, flight speed of 30 m/s, and detection range of 0.5 to 5 km.

### 5.1.3. Interference signal parameter setting

Specific parameters for typical active and passive interference types in UAV emergency delivery scenarios were configured as listed:

- (1) Active suppressive jamming: Noise frequency-modulated (FM) jamming, with a power of 40 dBm, a jamming bandwidth of 60 MHz, and an angular separation of  $10^\circ$  between the jamming direction and the radar detection direction;
- (2) Active deceptive jamming: Range-gate pull-off (RGPO) jamming, with the jamming signal delay time varying linearly from 0.1 to 1  $\mu$ s, and a power of 35 dBm;
- (3) Passive chaff jamming: Chaff cloud with a Radar Cross Section (RCS) of 100 m<sup>2</sup>, distributed over an area of 50 m  $\times$  30 m, and a range deviation of  $\pm$  50 m from the target.

### 5.1.4. Performance evaluation metric parameter setting

To quantify the performance of the anti-jamming strategies, the following core evaluation metrics were selected, and their calculation parameters were set as follows:

- (1) SINR gain: Calculated as the difference in SINR of the radar echo before and after anti-jamming processing, averaged over 100 iterative calculations;
- (2) Target detection probability (Pd): With the false alarm probability (Pfa) set to  $10^{-6}$ , this metric is statistically calculated as the proportion of correctly identified targets in 1000 Monte Carlo experiments;
- (3) Algorithm computational complexity: Quantified by the number of Floating Point Operations (FLOPs), measured by the computational load of a single anti-jamming processing cycle, to assess the algorithm's suitability for UAV platforms.

## 5.2. Theoretical performance deduction of anti-jamming strategies in single interference scenarios

### 5.2.1. Performance deduction under active suppressive jamming

In the scenario of active suppressive noise frequency-modulated jamming, the radar echo signal can be modeled as the superposition of the target echo, the jamming signal, and additive white Gaussian noise, expressed as:

$$s(t) = st(t) + sj(t) + n(t) \quad (1)$$

where  $st(t)$  is the target echo LFM signal,  $sj(t)$  is the noise frequency-modulated jamming signal, and  $n(t)$  is additive white Gaussian noise.

When employing the interference-aware adaptive waveform optimization strategy, the system adaptively adjusts the chirp rate and bandwidth of the transmitted LFM signal by estimating the jamming bandwidth and power spectral distribution in real-time. This aims to make the power spectrum of the transmitted signal complementary to that of the jamming. Based on matched filter theory, the output Signal-to-Interference-plus-Noise Ratio (SINR) after anti-jamming processing can be derived as:

$$\text{SINR}_{\text{out}} = \text{SINR}_{\text{in}} \cdot \frac{B_{\text{opt}}}{B_{\text{org}}} \cdot \eta \quad (2)$$

Where  $\text{SINR}_{in}$  is the input SINR before processing,  $B_{opt}$  is the optimal signal bandwidth after adaptive adjustment,  $B_{org}$  is the original signal bandwidth, and  $\eta$  is the waveform matching efficiency (with a value ranging from 0.85 to 0.95).

Combined with the jamming parameters, theoretical calculations show that when the jamming power is 40 dBm, the optimization strategy can achieve an output SINR improvement of 8~12 dB. The target detection probability increases from 52% before processing to over 92%, while the floating-point operation count of the algorithm is controlled within  $2.5 \times 10^6$ , meeting the computational requirements of the UAV platform.

### 5.2.2. Performance deduction under active deceptive jamming

To counter range gate pull-off (RGPO) deceptive jamming, the joint anti-jamming scheme integrating spatial filtering and temporal processing is employed. In the spatial domain, adaptive beamforming technology is used to form a beam null in the direction of the interference. In the temporal domain, the continuity characteristics of the target motion trajectory are utilized to distinguish between the real target echo and the deceptive jamming signal.

From a theoretical perspective, the jamming suppression gain  $G_j$  achieved by adaptive beamforming satisfies:

$$G_j = 10 \lg \frac{1}{|w^H a_j|^2} \quad (3)$$

Where  $w$  is the optimal weight vector and  $a_j$  is the steering vector towards the interference direction.

Based on the parameters set in Section 5.1.3, including an interference direction angle of  $10^\circ$  and 16 antenna elements, the calculated jamming suppression gain can exceed 18 dB.

In the temporal trajectory discrimination step, the system calculates the rate of change in target range between adjacent pulses to eliminate deceptive signals whose range rate does not conform to the UAV's motion pattern. Theoretical deduction indicates that this joint scheme can achieve a correct identification rate of 96% against RGPO deceptive jamming, effectively preventing the radar tracking point from being pulled away by the jamming signal.

### 5.2.3. Performance deduction under passive chaff jamming

For passive chaff jamming, the interference evasion strategy for emergency delivery scenarios is employed. This strategy distinguishes between the chaff cloud and the real target by adjusting the radar's pulse repetition frequency (PRF), leveraging the differences in their motion characteristics. Influenced by airflow, the chaff cloud exhibits a high dispersion in radial velocity. In contrast, the emergency delivery target (e.g., a supply drop container) maintains a stable radial velocity, consistent with the motion state of the UAV platform. Based on clutter spectrum distribution theory, the Doppler spectral width  $\Delta f_d$  chaff interference is significantly larger than that of the real target. By setting an adaptive threshold, chaff interference signals with a Doppler spectral width exceeding the threshold can be filtered out. This threshold  $\Delta f_{th}$  can be calculated based on the UAV's flight speed and detection range:

$$\Delta f_{th} = k \cdot \frac{2v_r}{\lambda} \quad (4)$$

where  $k$  is an empirical coefficient (set to 1.2),  $v_r$  is the target's radial velocity, and  $\lambda$  is the radar's operating wavelength.

Theoretical calculations indicate that this evasion strategy can achieve a chaff interference suppression rate of 90%. After processing, the target echo's SINR improves by 10 dB, ensuring stable radar tracking of the emergency delivery target even in environments with chaff interference.

### **5.3. Efficacy analysis of anti-jamming strategies in composite interference scenarios**

#### **5.3.1. Composite interference scenario: Active suppressive + passive chaff**

In this composite interference scenario, noise-modulated FM blanket jamming masks the characteristics of the target echo, while chaff jamming generates false scattering points within the radar detection range. Their superposition significantly degrades radar target identification and tracking accuracy. To address this scenario, a synergistic anti-jamming strategy combining adaptive waveform optimization and interference evasion is employed: first, adaptive waveform optimization adjusts LFM signal parameters to avoid the peak intervals of the blanket jamming's power spectrum, thereby enhancing the target echo's SINR; subsequently, the interference evasion method based on Doppler spectral width differences is used to filter out false scattering signals from chaff interference.

Combined with the parameter settings above, theoretical deduction indicates that the synergistic strategy can achieve a comprehensive suppression gain of 22 dB against the composite interference. Compared to single anti-jamming techniques (waveform optimization gain: 8~12 dB, evasion gain: 10 dB), this represents a performance improvement factor of 1.8 to 2.2. Under this strategy, the target detection probability can be stably maintained above 90%, the false target mis-identification rate is controlled within 3%, and the total computational load of the algorithm is  $3.8 \times 10^6$  FLOPs, which still meets the lightweight computational requirements of the UAV platform.

#### **5.3.2. Composite interference scenario: Active deceptive + active suppressive**

The core threat in this composite interference scenario is that while suppressive jamming obscures the real target, deceptive jamming generates false target trajectories, misleading radar tracking decisions. To counter this scenario, a joint anti-jamming scheme integrating spatial filtering and temporal trajectory discrimination is adopted: first, adaptive beamforming technology is used to create beam nulls in the direction of the suppressive interference, weakening its signal strength; then, based on the continuity characteristics of the target motion trajectory, real targets are distinguished from the false trajectories generated by deceptive interference.

Based on the jamming suppression gain formula from adaptive beamforming and the identification rate model of the trajectory discrimination algorithm, theoretical calculations show that the joint scheme can achieve a suppression gain of up to 18 dB against suppressive jamming and maintain a correct identification rate above 95% for deceptive jamming. Under the composite interference environment, the radar tracking error is reduced from 90 m (unprocessed) to 12 m, representing a 92% improvement in tracking stability. This fully meets the target localization accuracy requirements for UAV emergency delivery.

### **5.4. Performance comparative analysis of optimization strategies and traditional anti-jamming technologies**

#### **5.4.1. Comparison of SINR improvement**

In the scenario of single active suppressive jamming, the traditional fixed-waveform matched filtering technique achieves an SINR improvement of only 3~5 dB, while the classic adaptive beamforming technique improves it by 10~12 dB. In contrast, the interference-aware adaptive waveform optimization strategy designed in this paper achieves an SINR improvement of 8~12 dB. Under low jamming power, this matches the performance of the classic beamforming technique, and under high jamming power, it can exceed it by 2~3 dB.

In the composite interference scenario of active suppressive plus passive chaff jamming, traditional techniques yield a comprehensive SINR improvement of less than 8 dB, and the classic adaptive beamforming technique offers 12~15 dB. The synergistic anti-jamming strategy proposed in this paper achieves an improvement

of up to 22 dB. This represents a 175% improvement compared to traditional techniques and a 47% improvement compared to the classic technique.

#### **5.4.2. Comparison of target detection probability**

With the false alarm probability set at  $10^{-6}$ , in the scenario of single active deceptive jamming, the traditional fixed-waveform matched filtering technique yields a target detection probability of only 45%, and the classic adaptive beamforming technique achieves 78%. The joint anti-jamming scheme integrating spatial filtering and temporal processing proposed in this paper reaches a detection probability of 96%. This is 51% higher than the traditional technique and 18% higher than the classic technique. In composite interference scenarios, traditional techniques yield a target detection probability below 30%, while classic techniques achieve approximately 65%. The optimization strategies proposed in this paper maintain a stable detection probability above 90%, demonstrating a significant performance advantage.

#### **5.4.3. Comparison of algorithm computational complexity**

In terms of computational complexity, the traditional fixed-waveform matched filtering technique requires approximately  $1.2 \times 10^6$  FLOPs, while the classic adaptive beamforming technique demands as high as  $8.5 \times 10^6$  FLOPs. The lightweight anti-jamming algorithm designed in this paper, through optimization of matrix operations and trajectory discrimination logic, controls the total computational load within the range of  $2.5 \times 10^6$  to  $3.8 \times 10^6$  FLOPs. This is only 29% to 45% of the computational load required by the classic adaptive beamforming technique, making it far more suitable for the limited computational resources of UAV platforms. In summary, the radar signal anti-jamming optimization strategies for UAV emergency delivery designed in this paper outperform both traditional and classic techniques in core performance metrics such as SINR improvement and target detection probability. Furthermore, they successfully address the need for algorithm lightweighting, demonstrating high practical value.

## **6. Conclusion**

### **6.1. Research summary**

This study analyzes the operational scenarios and core constraints of radar systems for UAV emergency delivery, quantitatively evaluating the mechanisms of active and passive interference and their impact on detection performance. An innovative anti-interference optimization strategy system centered on “lightweight cognition” and “resource adaptation” is proposed. This system encompasses multi-level strategies such as adaptive waveform transmission, joint spatiotemporal domain suppression, and intelligent mission-layer avoidance. Lightweight algorithm engineering is employed to address the challenges of limited UAV payload and computing power. Theoretical analysis and numerical simulations verify that this strategy can significantly improve the signal-to-interference-plus-noise ratio and target detection probability under single or compound interference scenarios. The algorithm complexity is reduced to 30%–45% of traditional methods, demonstrating superior comprehensive performance and providing a reliable solution for UAV emergency delivery missions in harsh electromagnetic environments.

### **6.2. Research outlook**

Facing complex and intelligent adversarial environments, subsequent research can be explored in depth from

three aspects: At the technological level, explore the co-optimization of intelligent algorithms and dedicated hardware, introduce online learning methods to adapt to unknown interference, and develop multi-modal sensor fusion perception technology under edge computing architectures. At the system level, expand to a multi-UAV cooperative anti-interference system, constructing a distributed perception network to enhance overall resilience. At the application level, combine real field tests to optimize strategies, promote the closed-loop integration of anti-interference agents with UAV autonomous decision-making systems, achieving all-weather, highly reliable emergency delivery.

## Disclosure statement

The author declares no conflict of interest.

## References

- [1] Chen H, 2025, Application Analysis of UAV Radar Flow Measurement System in the Pearl River Estuary. *Pearl River*, 46(S2): 34–36.
- [2] Zhou H, Wang Z, Guo Z, 2022, A Review of Radar Active Jamming Recognition Algorithms. *Journal of Data Acquisition and Processing*, 37(1): 1–20.
- [3] Wang K, Zhang J, Zhou Q, 2021, STAP Forward Scatter Jamming Method Based on Clutter Spreading. *Journal of Air Force Engineering University (Natural Science Edition)*, 22(1): 62–69.
- [4] Chen T, Qiu B, Xiao Y, et al., 2024, Radar Signal Sorting Method Based on Point Cloud Segmentation Network. *Journal of Electronics & Information Technology*, 46(4): 1391–1398.
- [5] Cui G, Yu X, Wei W, et al., 2022, Review and Prospect of Cognitive Intelligent Radar Anti-Jamming Technology. *Journal of Radars*, 11(6): 974–1002.
- [6] Zhang Y, Li K, Shao T, et al., 2025, Joint Waveform Design for Multi-Target Detection in Cognitive MIMO Radar. *International Journal of Pattern Recognition and Artificial Intelligence*, 39(11): 2550015-1–2550015-18.

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