Research on Key Technologies of Unmanned Combat Vehicle Early Warning Radar

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Abstract Aiming at the operational requirements of unmanned combat vehicles, this paper first introduces the operational advantages of unmanned aerial vehicles, and then analyzes the key technologies combined with the characteristics of unmanned aerial vehicles and gives solutions; Finally, the development of follow-up equipment is prospected, which can provide a good reference and help for the design of unmanned combat vehicle early warning radar.

Keywords Unmanned combat vehicle · Early warning radar · Array Integration · Classification identification

1 Introduction

Unmanned combat vehicles can be divided into various types according to their combat tasks. Unmanned combat vehicles with forward assault missions mainly carry machine guns, artillery, anti-tank missiles, etc.; Unmanned combat vehicles tasked with jamming and confrontation mainly carry microwave weapons, lasers, jamming equipment, etc.; Unmanned combat vehicles with the mission of reconnaissance and obstacle clearance are mainly equipped with photoelectric/infrared sensors, acoustic sensors, mechanical arms, etc.; Unmanned combat vehicles tasked with air defense must carry early warning radars, air defense antiaircraft guns, and air defense missiles [1].

As the military gap between major powers gradually narrows, wars will continue to be dominated by local wars, making it difficult to engage in direct military rivalries between major powers. Major power conflicts have evolved into confrontations between small countries that they support. In these local conflicts, the first round of strikes by one side of the war will be non-contact, precision guided weapon air strikes, and air defense operations are essential, just as unmanned combat vehicles are used

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in other combat modes, The unmanned air defense vehicle will replace the currently manned air defense weapons with its unique advantages. Its main advantages are:

(1) The combat effectiveness of individual weapons and equipment is limited, and future operations will mainly focus on cluster operations. The regional joint defense, multi-layer interception, and multi-vehicle cooperative operations of unmanned air defense vehicles can achieve real-time information interaction and air intelligence information sharing, maximizing operational effectiveness.
(2) Unmanned air defense combat vehicles are suitable for 24/7 duty, without personnel involvement, and there will be no situations such as misoperation or delaying the aircraft. Moreover, equipment supply and energy supply can be managed in a data-based manner, enabling orderly operations and support.
(3) For autonomous unmanned air defense combat vehicles, the rapidity of battlefield deployment and deployment, complex battlefield situational awareness capabilities, multi target layered fire distribution, and rapid response capabilities to emergent targets are unmatched by personnel [2–4].

2 Key Technology Analysis

Unmanned air defense combat vehicles are mainly equipped with unmanned support and support teams to intercept and strike close range low altitude targets that appear and penetrate in the face of aircraft, supporting ground assault forces. As the focus of air defense weapons and equipment, early warning radar will also usher in the trend of unmanned development. Of course, due to the constraints of unmanned combat vehicle platforms, there is also a high demand for unmanned combat vehicle radar design, which requires lightweight, miniaturization, integrated design, and the ability to real-time target classification and recognition, and target detection in complex electromagnetic environments.

2.1 Integrated Technology of Active Phased Array Antenna

2.1.1 Technical Difficulties

Unmanned combat vehicle early warning radar is limited by the severe limitations of unmanned air defense vehicles on the volume and weight of radar loads, and generally uses X and above bands. During the design process of high band active phased array antenna arrays, there are many problems such as high antenna specification requirements, high integration, and difficult implementation. In addition to the current development of radar systems towards multi-function integration, conventional phased array antennas cannot meet the system requirements in terms of weight, volume, efficiency, reliability, and other aspects. Therefore, it is necessary to carry out research on low-cost and highly integrated phased array antenna array design technology. Active phased array antenna arrays implemented using new technologies must have the following characteristics [5, 6]:

(1) High integration and lightweight. Limited by the vehicle platform, phased array antennas must occupy as little volume and weight as possible. Therefore, the antenna array needs to be designed and processed in an integrated antenna and feeder manner to reduce the number of interconnecting cables and connectors, as well as reduce volume and weight. At the same time, advanced heterogeneous integration technology, vertical interconnection technology, and advanced packaging technology are used to develop advanced highly integrated and efficient component integration modules, thereby further realizing array integration and lightweight.
(2) Low cost. Traditional discrete modular devices not only increase the volume and weight of radar, but also increase the cost of radar. The antenna array can use customized and highly integrated silicon based multifunctional chips in components, power supplies, and control systems on a large scale, effectively reducing the amount of module equipment and significantly reducing chip costs; At the same time, using advanced three-dimensional packaging technology to reduce dependence on packaging substrates can also significantly reduce chip packaging and integration costs.
(3) Scalability. Active phased array antenna integration can abandon the architectural idea of interconnecting functional modules in conventional arrays through cable components, and introduce the concept of microsystems for system level integration at a micro scale. It is possible to integrate a single functional circuit into a single chip, multiple functional circuits into a single heterogeneous chip, and components into SIP or SOC. Finally, advanced three-dimensional packaging technology and three-dimensional interconnection technology are used to replace conventional mechanical assembly and cable connection. The phased array integration technology based on microsystems can greatly improve the array integration degree, integrate more T/R channels and achieve more functions in limited space, and meet the requirements of multi-functional integrated radar systems for phased array antenna arrays.

2.1.2 Solutions

(1) Integrated design of components and antenna units
    (a) Using electromagnetic and circuit joint simulation to comprehensively consider the impact of cavity effects; Improve the stability coefficient of the entire link through reasonable gain allocation and cavity isolation;
    (b) By reasonably selecting the implementation form of the antenna unit, it can meet the requirements of the LTCC process, have good repeatability, stability, and sufficient mechanical strength, and meet the conditions for structural assembly and installation connection;

   (c) Screening for amplitude and phase inconsistencies in microwave components and establishing semi-automatic assembly lines for the production and assembly of T/R components.

(2) Integrated Network Design

   (a) Using ultra-thin LTCC multilayer hybrid digital analog wiring, the module uses LTCC boards as the circuit carrier, including passive circuits such as power splitters, microwave transmission lines, microstrip stripline conversion, and digital analog hybrid circuits such as power supplies, digital circuits, and drive circuits;
   (b) Using a groove dug in the LTCC board, the microwave chip is installed in a shallow groove, coupled with an LTCC cover plate, and the integration between the two layers of LTCC is improved through ultrasonic hot pressing welding;
   (c) LTCC multilayer boards and MCM technology are used to achieve highly integrated components. Precision assembly technologies are used, including the bonding and welding of various materials, chips, components, and LTCC boards, ultrasonic hot pressing welding between LTCC boards, welding and ball planting on the surface of LTCC boards, control of different welding temperatures, and gold wire bonding.

(3) Electromagnetic compatibility design of components

   (a) Adjust the operating mode of the transceiver circuit, turn off the transmitter circuit during reception, provide maximum device isolation, and avoid the impact of the transmitter circuit on the receiver circuit;
   (b) Using simulation software to guide wiring design;
   (c) The microwave transmission line adopts a stripline system to isolate microwave circuits from digital circuits and low-frequency circuits;
   (d) Simulate and calculate the cavity, and take measures such as adding partitions to reduce the cavity effect and mutual coupling;
   (e) Reasonably distribute the gain links of the transmission circuit in the physical space, and conduct stability simulation analysis to ensure the stability and reliability of the transmission circuit;
   (f) All vertical interconnections adopt coaxial like structures to reduce electromagnetic leakage at the interconnections.

2.2 Real Time Target Classification and Recognition Technology

2.2.1 Technical Difficulties

Due to the attitude sensitivity of the target, the RCS fluctuates greatly, affecting recognition performance. The classification of aerial targets depends on the modulation characteristics of the targets. However, the modulation characteristics of the targets have problems of instability and attitude angle sensitivity, and the modulation spectrum cannot be observed at some attitude angles. After obtaining target features, how to distinguish different targets to the maximum extent and improve the recognition rate is a problem to be solved in the design of the recognizer. When designing a recognizer for radar aerial target recognition, factors such as recognition performance, generalization ability, and recognition computational complexity should be considered.

2.2.2 Solutions

In order to utilize system resources as reasonably as possible, the system can use intelligent classification and recognition technology for real-time and rapid target classification, providing a basis for adaptive resource scheduling [7].

(1) Using hierarchical, multi feature, multi algorithm parallel, and sequential recognition, targets are classified and clustered against a type template library based on perceived motion characteristics and RCS characteristics, and key targets are subjected to fine feature perception and feature extraction.
(2) Build a deep recognition network with transfer learning capabilities to improve the ability to identify small sample targets. According to the results of target classification and threat assessment, decisions are adjusted based on the assessment results to achieve sequential fusion recognition of inter frame decisions and improve recognition robustness. The real-time target classification and recognition architecture is shown in Fig. 1.

A certain type of radar has achieved classification verification of fixed wing aircraft, propeller aircraft, and helicopters using RCS and JEM characteristics, with a recognition rate greater than 85%, as shown in Fig. 2.

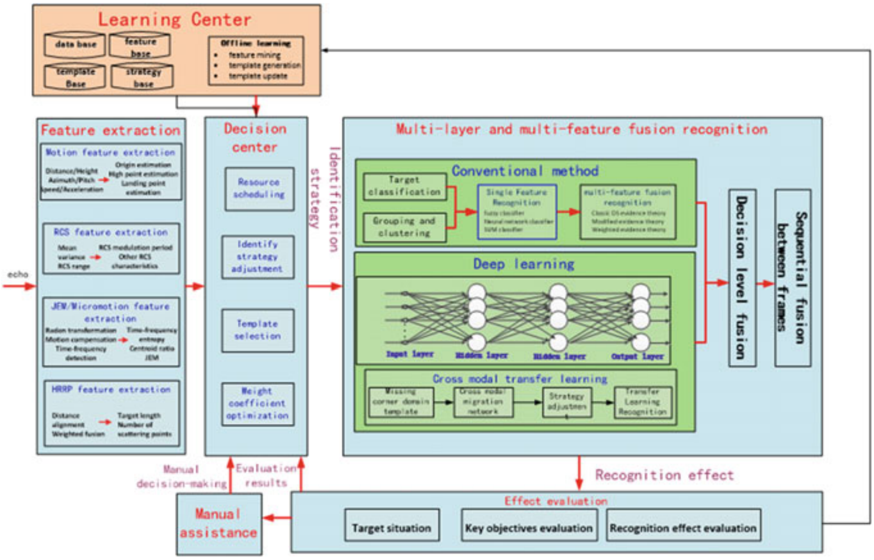


Fig. 1 Real time target classification and recognition architecture

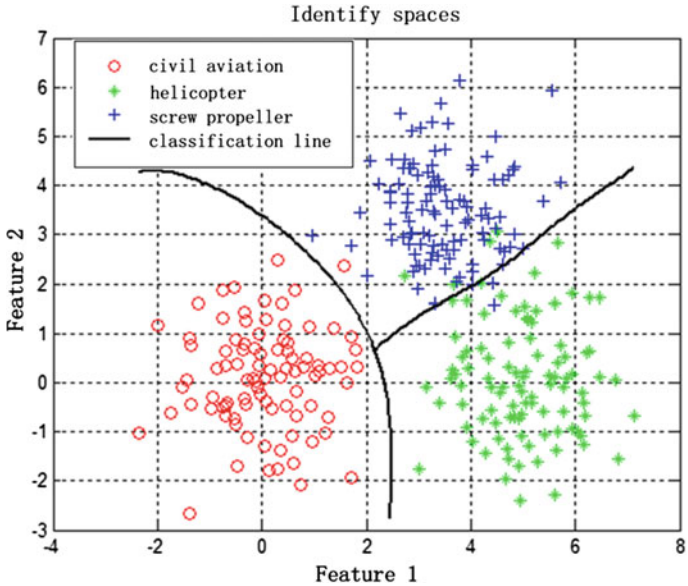


Fig. 2 Target classification and recognition features

2.3 *Integrated Anti-interference Technology*

2.3.1 Technical Difficulties

With the development of electronic countermeasures technology, the means of active jamming are becoming increasingly diverse and complex. Various electromagnetic radiation crisscross in the airspace, dynamically change in the time domain, densely overlap in the frequency domain, and fluctuate in the energy domain, seriously affecting the detection performance of radar systems. "Radar operators cannot simultaneously identify various types of interference for multiple simultaneous interferences, and therefore cannot implement corresponding targeted anti jamming measures. It is difficult to achieve satisfactory results by taking only a single type of anti jamming measures [8, 9]

2.3.2 Solutions

Comprehensive use of multiple spatial, temporal, and frequency domain means to refine anti-interference methods, using ultra-low sidelobe, adaptive nulling, and sidelobe blanking anti-interference techniques in the spatial domain, using large time bandwidth, low peak power, pulse compression, narrow pulse rejection, and interference suppression techniques based on waveform entropy in the time domain, and using frequency regulation, multiple complex signal modulation, and adaptive frequency agility anti-interference techniques in the frequency domain, It is possible to achieve the comprehensive anti-interference function of the radar as much as possible based on a limited amount of equipment [10].

Use the jamming environment to conduct comprehensive interception, identify multiple jamming types, use the expert intelligent anti-jamming decision-making system, call corresponding anti-jamming measures from the anti-jamming measures library to counter multiple jamming (Fig. 3)

Figure 4 shows the effect pictures before and after the comprehensive application of anti-interference measures. Compared with the display and control interfaces before and after the interference suppression measures take effect, the number of echoes decreases by 94.5%, the number of dots decreases by 92.5%, and the number of false tracks decreases by 100%. Through comprehensive interference suppression processing in space, time, and frequency domains, the number of jamming echoes, dots, and false tracks on the radar display and control interface are significantly reduced, and the comprehensive anti-interference measures have significant effects.

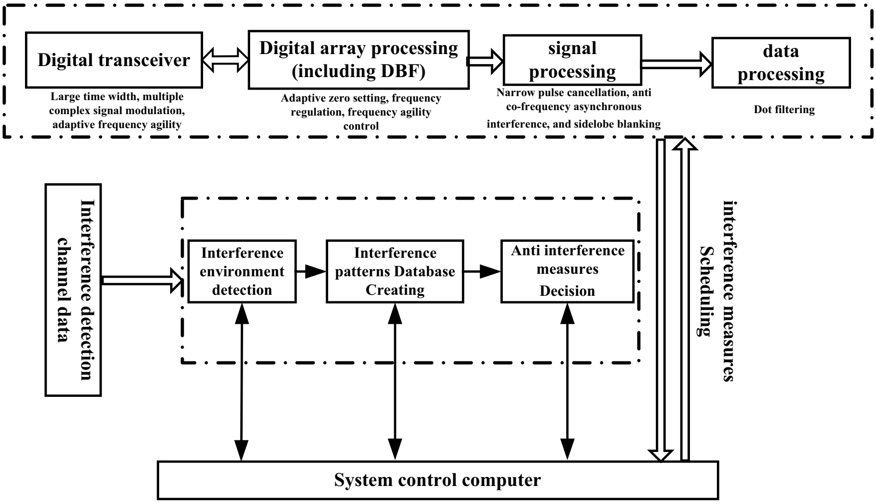
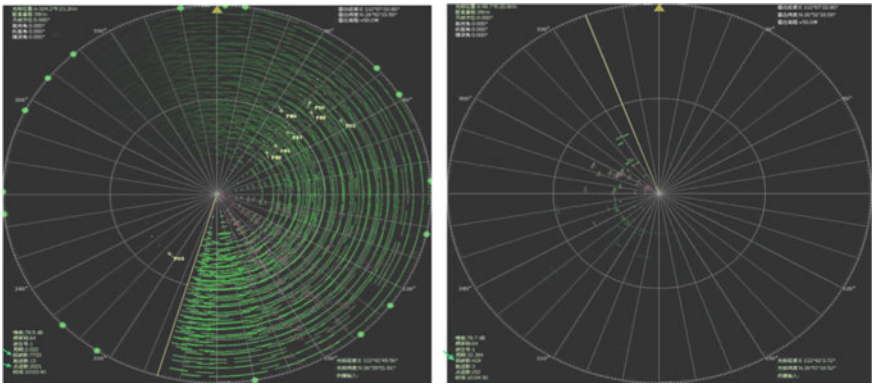


Fig. 3 Radar integrated anti-jamming process



(a) Before interference suppression (b) After interference suppression

Fig. 4 Effect diagram before and after interference suppression

3 Conclusion

In summary, unmanned air defense vehicles are an important component of ground unmanned combat forces, and early warning radar, as an important load of unmanned air defense vehicles, its performance will affect the operational effectiveness of the entire vehicle. With the further development of weapon technology, the future unmanned combat vehicle early warning radar will have the capabilities of automatic situational awareness, automatic optimization of operating parameters, intelligent target detection and recognition, and conformal to combat vehicle platforms, which will also promote the further development of unmanned system technology.

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