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A Review of Low Altitude Aircraft Detection

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Abstract. Low altitude flying objects have been widely used in many fields, bringing a lot of convenience to society, and have important strategic significance in both military and civilian fields. However, low altitude flying objects often pose a significant threat to the safety of low altitude areas in low altitude environments. In recent years, the number of accidents caused by drones has been increasing. In recent years, low altitude target detection technology has received increasing attention from researchers and has made significant progress in various research methods. It is urgent to conduct a systematic review of effective detection technologies for low altitude targets. This article provides a comprehensive overview and analysis of the latest progress in low altitude target detection. Initially, it outlined the contemporary research landscape, including various detection technologies such as radar, radio, and vision. Subsequently, a thorough review and analysis of these methods were conducted, and the main challenges in this field were explored. Finally, the discussion integrates key insights and insights drawn from the discussion.

Keywords. Low-altitude, target detection, radar, radio, vision

1. Introduction

Low-altitude targets typically denote aircraft flying below 3000m altitude, categorized into civilian and military sectors based on their potential applications. Continuous monitoring of low-altitude targets is essential across both domains.

In civilian contexts, low-altitude targets find utility in unmanned aerial vehicle (UAV) management and air traffic control. Radar and infrared sensors enable real-time monitoring and identification of such aircraft, ensuring air safety and efficient traffic management. In military realms, advanced surveillance equipment and radar technology facilitate the monitoring and identification of enemy aircraft and drones, preemptively detecting potential threats to support military operations and national defense.

In order to further promote the development of low altitude aircraft target detection technology, researchers have conducted extensive research on this topic. Radar equipment is used to detect the angle, speed, and distance of low altitude aircraft to determine their flight trajectory [1]. With the rapid development of 5G ad hoc networks, wireless detection has gradually become the focus of low altitude target detection. For example, This article detects the Angle of Arrival (AoA) and Direction of Arrival

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(DoA) information of an object to obtain its spatial position [2]. In recent years, computer vision has developed rapidly, and detecting low altitude targets with computer vision has the characteristic of low cost. Use cameras to capture images of low altitude target information, and use neural networks to recognize and classify the collected target information [3]. The above three technologies have different characteristics. In terms of monitoring distance, radar and radio have comparable monitoring distances, while computer vision has the shortest monitoring distance. Although some progress has been made, they also have certain limitations. Radar technology and computer vision technology are more sensitive to weather changes, and the accuracy of monitoring in adverse weather conditions will decrease. Radio technology is susceptible to interference from other signals in the air, resulting in significantly increased losses during signal propagation and lower monitoring accuracy.

In recent years, there have been many articles that have been summarized in a way that differs from the structure of other articles [4]. Focusing on recent technological evolution, the article analyzes the current landscape in detail while forecasting future trends. Through this review, readers gain comprehensive insights into the latest technologies and the pivotal role of low-altitude target detection, facilitating a deeper understanding of its trajectory and future directions.

This study offers an overview of the significance of low-altitude target detection and the advancements in various research methodologies. This article provides a detailed introduction to the current development status of radar, radio, and computer vision detection technologies in the second section. In the third section, specific progress has been made in current technology and the limitations of each technology have been introduced. The fourth section introduces the future development trends of the three technologies mentioned above. In the fifth section, we will introduce the future applications of the three technologies mentioned above. The conclusion was drawn in the last section. A comparison of radar, radio, and image detection technologies is shown in Table 1:

Table 1. Comparison of Technologies for Radar, Radio, and Image Detection

Detection category	Detection distance	disadvantage
Radar detection	Far	Affected by weather
Wireless detection	Far	Affected by other signals
image detection	Near	Affected by weather

2. Research Overview

The detection methods for low-altitude targets are primarily categorized into three groups based on signal form: radar detection, radio detection, and visual detection. Despite the significant advancements in deep learning, traditional methods like radar and radio retain certain advantages, intensifying competition in this field.

Radar detection boasts long operating ranges and minimal susceptibility to weather conditions. However, it struggles to identify hovering low-altitude targets and differentiate slow-moving ones from surrounding objects like trees. Radio detection, on the other hand, identifies low-altitude targets by analyzing their communication signals with controllers, enabling precise identification of detailed target features. Yet, it fails to identify targets absent from the spectrum library or those in electromagnetic silence.

Visual detection involves classifying low-altitude target features, offering cost-effective image acquisition but demanding substantial computational resources. It's noteworthy that current detection methods endeavor to overcome these limitations through various fusion techniques.

3. Research Status

3.1. Radar Detection

3.1.1. The current state of radar detection research

Radar technology is mainly used for object detection, distance measurement, and tracking. The radar system detects the presence and position of target objects by emitting radio waves and receiving their reflected signals. Radar technology is widely used in low altitude target detection. The principle of radar detection is shown in Figure 1.

In traditional radar based detection schemes, manual feature extraction is usually required, and deep learning models have excellent learning ability, which can significantly reduce labor costs. This article Combining radar and neural network classifiers to achieve real-time detection and classification [5]. Micro Doppler features contain the micro motion and vibration information of the target, and these features are used as a dataset for convolutional neural network(CNN) training and testing.

Traditional radar recognition systems perform well in single target detection, but their performance significantly decreases when detecting multiple targets. A multi drone monitoring system based on intelligent radar signals has been designed, and its effectiveness in single target and multi target situations, as well as super-resolution Direction Of Arrival(DoA) estimation, has been demonstrated [6]. A method for estimating micro moving targets and micro Doppler parameters has been proposed [7] . By utilizing Doppler information, the radar system's detection and recognition capabilities for low slow small targets have been enhanced.

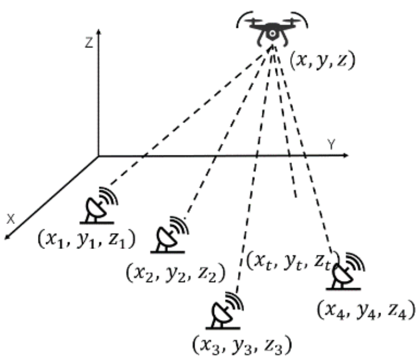

Figure 1. Principles of radar detection

In addition, a multi-resolution spatiotemporal adaptive processing (STAP) method is proposed for ultra-low altitude target detection based on radar [8]. The author proposes a consistent clutch covariance matrix (CCM) estimation scheme to reduce computational complexity and apply coherent accumulation between sub coherent processing intervals(CPIs), further improving the performance of Subtractive Chromatic Noise Reduction(SCNR).

3.1.2. Drawback of radar detection

(1) The Interference of Stealth Technology:

The combination of modern military technology and stealth technology helps to reduce the possibility of targets being detected by radar. Stealth aircraft effectively reduces the probability of being detected by radar by reducing the radar reflection area.

(2) Limitations of Radar Beam Characteristics:

The width of the radar beam score can affect the detection range and target resolution. A wider beam can increase coverage, but may sacrifice detection resolution, and vice versa.

(3) Influence of Weather Factors:

Natural factors such as weather can also affect the detection accuracy of radar. For example, adverse weather conditions may weaken the transmission and reception of radar information, thereby affecting the detection performance of radar.

3.2. Wireless Detection

3.2.1. The current state of wireless detection research

Traditional radar detection methods have limitations in identifying hovering small low altitude targets. With the rapid development of 5G technology, the dense networking of 5G base stations provides abundant electromagnetic resources for space. Using 5G signals for low altitude target detection not only saves costs, but also reduces the impact on urban electromagnetic environments such as radar. Wireless signal target detection usually relies on aircraft broadcasting ADS-B signals and decoding to obtain information such as position, speed, and altitude [9]. Once the target position is determined, the target tracking algorithm can be used to continuously track its position. The principle of wireless detection is shown in Figure 2.

In base station detection, it is necessary to send and receive 5G signals. Especially when the target has anti reconnaissance capabilities, it is necessary to conceal the transmitted information to avoid low altitude targets detecting detection actions. This article proposes a new low altitude target detection system based on 5G base stations [10].

In addition, this article fully utilizes the advantages of Automatic Dependent Surveillance - Broadcast (ADS-B) technology and optoelectronic target tracking and detection, and designs a monitoring system that combines ADS-B and optoelectronic turntable to improve the efficiency of target monitoring [11].

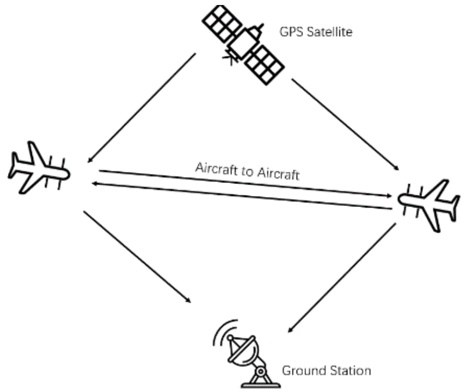

Figure 2. Principles of wireless detection

Traditional LTE (long term evolution) downlink signals are mostly used for communication data transmission. Therefore, An LTE downlink signal is designed suitable for object detection, called target localization reference signals(TLRS) [12]. TLRS only accounts for 0.266% of the traditional LTE downlink time-frequency resources. At the same time, a passive radar system with duplex long-term evolution was proposed for unmanned aerial vehicle detection.

3.2.2. Drawback of wireless detection

Radio signals are influenced by various factors including geographical features, architectural structures, and weather conditions within their coverage areas. Moreover, they are vulnerable to interference from other signals, resulting in diminished signal quality. The transmission of ADS-B signals may inadvertently disclose sensitive information regarding aircraft position, altitude, and velocity, potentially giving rise to privacy concerns.

3.3. Image Detection

3.3.1. The current state of image detection research

Low altitude targets have fast flight speeds and require long-range or real-time detection. The YOLO series is a one-stage detection model with high detection speed, which can achieve real-time monitoring based on YOLO [13]. Due to its low cost and easy scalability, image detection has been widely studied [14]. The traditional YOLOv5S model performs poorly in detecting small unmanned aerial vehicles due to limitations in network structure. For this purpose, the author added Convolutional Block Attention Module (CBAM) to the backbone network to improve the model's ability to extract image features and enhance the features of a small object detection layer [15]. And in the loss function section, Efficient Intersection over Union (EIOU) replaces Generalized Intersection over Union (GIOU) [16]. In order to effectively interfere with and attack drone targets and achieve lightweight network. Detection was performed on yolov4 [17,18]. Such as, Perform channel pruning and layer pruning on the YOLOv4 network to reduce the depth and width of the network[19]. Implement the deployment of object detection algorithms through inference quantification on embedded platforms. The principle of image detection is shown in Figure 3.

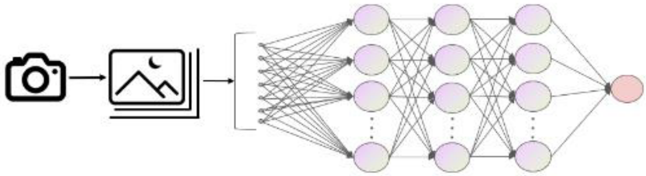

Figure 3. Principles of image detection.

With the rapid development of Transformers, they have also achieved a lot of results in the field of object detection. The article proposes a low altitude convolutional network called Convolution Transformer Network (CT Net) [20]. The Photovoltaic Panel Fault Detection and Location System Based on Series Depth Mode structure of this network can improve the detection performance of small targets while saving processing time and storage space, and achieve a performance of 0.996mAP on self-made datasets.

In addition to high-speed low altitude targets, there are also some slower low altitude targets. These slowly moving targets often face interference from background noise in image detection, making it difficult to effectively distinguish them from the surrounding background. The slow movement of these targets results in a high similarity between them and the visual features of the surrounding environment, which increases the difficulty of detection algorithm recognition and may lead to a decrease in detection accuracy. To address this issue, a spatial temporal features measurement method (STFM) was proposed, which combines short-term energy aggregation (SEA) and long-term trajectory continuity (LTC) mechanisms to explore the temporal characteristics of slowly moving targets [21]. In addition, a new passive monitoring method is proposed for infrared targets in the article [22]. This method is passive and therefore cannot be detected by the target, and it has been verified that combining a Kalman filter with two infrared cameras can alleviate errors.

3.3.2. Drawback of image detection

In deep learning methods, large-scale labeled data is usually required to train models, which makes image detection challenging in situations with limited computing resources. In addition, image detection is very sensitive to the quality of the input image, and complex scenes and the presence of occlusion can also increase the difficulty of detection.

4. Trends in Development

4.1. Further Research Investigations

Although the positioning methods mentioned above, such as radar, radio, and vision, have varying degrees of maturity, they will still be research hotspots in the coming years. The performance of radar in detecting slowly moving targets is poor, but the technology is already quite comprehensive. Radio technology has broad applicability and potential efficiency in the field of low altitude target detection. Its technical characteristics and application potential will drive its in-depth research in this field. Especially the latest developments in technology such as machine learning in vision. In the coming years, it will be further developed and promoted. The rapid development of neural networks has provided enormous development space for vision. However, visual inspection requires high image quality, which also brings some limitations.

In addition to the aforementioned technologies, infrared detection, acoustic detection, and sonar detection can also be used for low altitude target detection. Infrared detection utilizes the radiation characteristics of targets in the infrared band for detection. Infrared detection has a good response to the thermal characteristics, heat distribution, and infrared radiation of low altitude targets. Sound wave detection detects targets through the propagation of sound waves, especially for the sound or vibration generated by aircraft. This method can identify targets through features such as sound frequency, direction, amplitude, etc. Sonar technology utilizes the propagation of sound waves in water or solids for target detection, which can be used to detect underwater and airborne targets.

Although there are many techniques for low altitude target detection, slow moving small targets and infrared small targets still have detection difficulties. How to use multiple detection techniques to cooperate with the system and achieve high-precision low altitude target detection is of practical significance.

4.2. A Novel Approach and Theory

With the rapid development of low altitude target detection technology and computer resources, attention mechanisms and transfer learning have sparked a frenzy in the field of computer science. The core idea of transfer learning is to apply the knowledge and model parameters learned in one task to another related task, thereby improving the performance of the latter. Transfer learning can solve the problem that the dataset in a task is difficult to cover all targets. In addition, attention mechanism algorithms have also shown superior performance in the field of computer science, and models based on attention mechanisms have shown stronger intelligence and adaptability. Multimodal learning, ensemble learning, and others are also worth further exploration in the future.

5. Applications of Low Altitude Target Detection

Low altitude target detection technology has been widely applied in the military and national defense fields, but due to its high detection cost, it has not yet been widely applied in civilian applications. There is still a lack of corresponding research in the field of people's livelihood, and there is still great development space and broad application prospects.

5.1. Low Altitude Target Monitoring

Due to the typical characteristics of low altitude targets, detecting low altitude targets with conventional radar has its inherent weaknesses. Moreover, even if low altitude targets are detected by the enemy's radar, it is already too late, and the flight time from the exposure point to the attack point is generally only a few tens of seconds. A short time window poses extremely high requirements for detecting low altitude targets.

5.2. Bird Strike Detection

The collision between birds and aircraft is a serious aviation safety issue that may cause damage to the aircraft's fuselage, engines, or other components, and even endanger the lives of crew members and passengers. Therefore, aerial bird detection is a crucial task aimed at reducing the risk of bird strike accidents. There are many difficulties in bird detection, such as the small radar reflection area of small birds, which is difficult to be detected by the system; The accuracy of detection systems such as radar, infrared sensors, and cameras for detecting birds still needs to be improved.

5.3. Low Altitude Safety Assurance

Low altitude target detection has important applications in low altitude safety assurance. It helps to monitor and identify flying targets such as low altitude aircraft and drones to ensure the safety of low altitude airspace. This technology can be used to prevent air collisions, monitor unauthorized flying objects, and enhance safety monitoring of critical areas.

6. Conclusion

This article divides low altitude target detection methods into three aspects and comprehensively summarizes and analyzes various methods. Current researchers have conducted sufficient research on all three methods mentioned above, but there are still many challenges in low altitude target detection, such as the inability of radar to detect hovering targets, susceptibility of radio to interference from other signals, and the need for a large amount of computing resources and susceptibility to occlusion in images. Addressing the above challenges and deepening research on low altitude targets, effectively integrating the above three methods, will be a key focus of future research.

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