

# Computer Vision and Deep Learning in Ship Target Detection

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**Abstract:** With the rapid development of the Marine economy in recent years and the increasing frequency of maritime activities, the criticality of ship target detection in many aspects has become increasingly evident, such as port management, maritime traffic safety, and military defense. By integrating computer vision and deep learning technologies, It provides an efficient and accurate solution for ship target detection. This article will first discuss the significance of ship target detection, and then analyze the technical challenges it faces. These include the interference brought by the complex Marine environment, the difficulties in detecting small targets, the need to handle multi-target occlusion and dense scenes, as well as the need to balance real-time performance and computing power limitations. Next, we will provide a detailed introduction to the key technical paths of deep learning in ship target detection. This includes data-driven methods, the development and changes of convolutional neural network architectures, attention mechanisms and feature fusion strategies, as well as lightweight network design. We will also discuss the application of computer vision and deep learning in some systems and fields. Such as port vessel surveillance systems, maritime traffic management systems, military target identification, and Marine environment monitoring, etc., and it will summarize the future development trends and all its potential.

**Keywords:** Computer Vision; Deep Learning; Ship Target Detection.

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## 1. Introduction

As the process of global economic integration continues to accelerate, the importance of the ocean as a key passage connecting countries around the world is becoming increasingly evident. The ocean not only carries the majority of global trade goods but also plays an irreplaceable role in resource development and military strategy. Ships, as the main force of marine transportation, are of vital importance to promoting economic development and maintaining national security. However, ships face many risks in the complex and changing marine environment [1]. These risks not only threaten the safety of the ships themselves but also pose potential challenges to the marine ecological environment and the global economic order.

Traditional ship detection methods mainly rely on radar and AIS (Automatic Identification System) technologies. Radar technology detects the position and speed of ships by emitting electromagnetic waves and receiving reflected signals, while the AIS system automatically broadcasts information such as the ship's identity, position, and speed through equipment installed on the ship. These traditional technologies have played an important role in ship detection, but they also have some obvious limitations. For example, radar has relatively weak detection capabilities for small ships because their radar cross-sectional area is small and they are easily misjudged or missed. Moreover, neither radar nor AIS systems can provide intuitive visual information, which is insufficient for scenes that require recognition of the appearance of ships (such as ship type identification and abnormal behavior analysis) [2-4].

In recent years, the rapid development of computer vision and deep learning technologies has brought new opportunities and ideas to ship target detection. Computer vision technology perceives and understands the external environment through image or video signals, converting

complex real-world scenes into data forms that can be processed by computers [5]. Deep learning technology provides powerful feature extraction and classification capabilities for computer vision, enabling computers to automatically learn and recognize various patterns and features in images. This combination offers a new solution for ship target detection, which is expected to overcome the limitations of traditional methods and improve the accuracy and efficiency of ship detection [6].

## 2. The Importance of Ship Target Detection

In global trade, ports are key nodes for the transportation of goods. The operational efficiency of ports directly affects the turnover speed of goods and trade costs. Accurate detection of the number, type, and position of ships entering and leaving the port is crucial for optimizing port scheduling. Through efficient ship target detection technology, port management departments can obtain real-time dynamic information of ships in the port, reasonably allocate berth resources, and optimize the order of ship berthing and departure, thereby improving the overall operational efficiency of the port. In addition, reducing the waiting time of ships in the port not only lowers the operating costs of ships but also reduces carbon emissions during their stay in the port, which has a positive significance for environmental protection.

Maritime traffic safety is a global concern. Ships sailing in the ocean face a complex traffic environment, especially in busy shipping lanes and near ports. Real-time monitoring of the navigation status of ships and timely detection of abnormal behavior (such as deviation from the shipping lane and speeding) can effectively prevent collisions. Ship target detection technology provides an important means for maritime traffic management. By deploying detection

equipment in key sea areas, real-time information on the position, speed, and heading of ships can be obtained, providing decision-making support for maritime traffic control departments. This not only helps ensure maritime traffic safety but also improves the smoothness of maritime traffic and reduces congestion.

In the military field, the importance of ship target detection goes without saying. Rapid and accurate identification of enemy ships is crucial for maritime defense and military decision-making. In modern naval warfare, enemy ships may use camouflage and concealment to evade detection, which requires advanced ship target detection technology to improve the accuracy and reliability of identification. Through computer vision and deep learning technology, various types of ships in the ocean can be monitored and identified in real time, potential threats can be detected in a timely manner, and accurate intelligence support can be provided to military command departments, thereby

formulating reasonable countermeasures to ensure national maritime security.

The marine ecological environment is an important part of the Earth's ecosystem, and protecting the marine environment is a common responsibility of all mankind. However, the discharge of pollutants from ships and illegal fishing activities pose a serious threat to the marine ecological environment. Through ship target detection technology, real-time monitoring of the discharge behavior of ships can be carried out, and ships that violate regulations can be detected and punished in a timely manner. At the same time, for illegal fishing activities, ship target detection technology can also play an important role. By monitoring ships in the ocean, illegal fishing vessels can be identified, providing strong support for marine law enforcement departments and strengthening the protection of the marine ecological environment. (Fig.1)

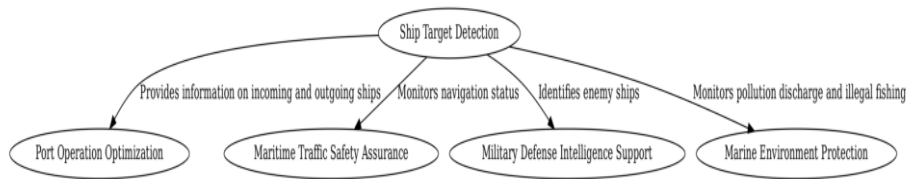


Figure 1. Ship Target Detection Relationship Network Diagram

### 3. Technical Challenges in Ship Target Detection

#### 3.1. Interference from Complex Marine Environments

##### (1) Wave Interference

Waves are one of the most common natural phenomena in the marine environment. The undulations of waves cause the position and orientation of ships in images to change continuously. When ships rise and fall with the waves, their projection shape, size, and position in the image will also change accordingly. This makes the localization of ship targets very difficult, as traditional target detection algorithms typically assume that the shape and position of the target are relatively stable. Moreover, waves can also generate a large amount of noise in the image, which can mask the feature information of the ship, further increasing the difficulty of detection.

##### (2) Fog Interference

Fog is another common interference factor in the marine environment. Fog can reduce the contrast and clarity of images, making it difficult to extract the feature information of ship targets. In foggy conditions, the outline of a ship may become blurred, and its color and texture features may also be obscured. This makes traditional ship detection algorithms based on edge detection and color segmentation difficult to work effectively. In addition, fog can also increase the noise in the image, further interfering with the detection of ship targets.

##### (3) Illumination Variation Interference

Illumination variation is also an important factor that affects ship target detection. The lighting conditions in the marine environment are complex and variable, influenced by factors such as the sun's altitude, cloud cover, and sea surface reflection. Illumination changes can cause uneven brightness and color distribution in the image, altering the feature

information of ship targets. For example, in strong light conditions, some parts of a ship may become overexposed, while in shaded areas, the ship's color may appear darker. These changes in illumination can affect the performance of target detection algorithms, leading to false or missed detections.

#### 3.2. Small Target Detection Challenges

##### (1) Limited Feature Information

Small targets, due to their small size, contain very limited feature information in the image. This makes traditional target detection algorithms based on manual feature extraction difficult to work effectively, as these algorithms typically require sufficient feature information to distinguish between targets and the background. For example, edge detection methods may fail in small target detection because the edge information of small targets may be overwhelmed by noise.

##### (2) Easily Overwhelmed by Background Noise

Small targets in the image are easily overwhelmed by background noise. The marine environment contains a large amount of background noise, such as the ripples of waves and clouds in the sky. These background noises can interfere with the feature information of small targets, making it difficult for detection algorithms to distinguish between targets and noise. For example, in images with many wave ripples, small targets may be mistaken for part of the waves, leading to missed detections.

##### (3) Limitations of Traditional Algorithms

Traditional target detection algorithms often fail to detect small targets accurately, resulting in missed or false detections. These algorithms are usually based on certain assumptions, such as the shape, size, and characteristics of the background of the target. However, for small targets, these assumptions often do not hold. For example, template matching algorithms may fail in small target detection because the shape and size of small targets may change, and template matching algorithms are not adaptable to such changes.

### 3.3. Multi-Target Occlusion and Dense Scene Processing

#### (1) Multi-Target Occlusion

Multi-target occlusion can lead to incomplete feature information of some ship targets. When one ship occludes another, part of the feature information of the occluded ship may be hidden, making it difficult for detection algorithms to accurately identify the ship. For example, in a port, a large ship may occlude a small ship, resulting in incomplete contour and texture features of the small ship. This can affect the accuracy of the detection algorithm, leading to misjudgment or missed detection.

#### (2) Misjudgment in Dense Scenes

In dense scenes, where ships are close to each other, misjudgment is likely to occur. When ships are close together, their feature information may interfere with each other, making it difficult for detection algorithms to distinguish between different ships. For example, in busy shipping lanes where multiple ships are sailing side by side, the detection algorithm may mistakenly identify them as a single ship, affecting the accuracy of the detection results.

### 3.4. Balancing Real-Time Performance and Computational Power Limitations

#### (1) Real-Time Requirements

In practical applications of ship target detection, such as maritime traffic management and port surveillance, it is necessary to obtain real-time information on the position, speed, and heading of ships. This requires detection algorithms to process and analyze images quickly and output detection results in a timely manner. For example, in maritime traffic management, if the detection algorithm cannot output results in real time, it will not be able to detect abnormal ship behavior in time, and thus cannot take effective measures to avoid collisions.

#### (2) Computational Power Limitations

Deep learning algorithms typically require a large amount of computational power to perform complex feature extraction and classification tasks. This is especially true when processing high-resolution images, where the computational burden is even heavier. However, in practical applications, ship target detection systems are often limited by computational power. For example, some small surveillance devices may not be equipped with high-performance computing chips, which restricts the application of deep learning algorithms. Moreover, even on devices with high-performance computing chips, energy consumption and cost issues need to be considered.

## 4. Key Technological Paths of Deep Learning

### 4.1. Data-Driven Methodology

Deep learning is a data-driven approach, and its performance largely depends on the quality and quantity of training data. In ship target detection, the importance of data is particularly prominent. To train high-performance deep learning models, it is necessary to collect a large amount of annotated data, which should cover different types of ships (such as cargo ships, fishing boats, and passenger ships), various marine environmental conditions (such as sunny, rainy, foggy days, and different lighting intensities), and different shooting angles (such as front, side, and top views).

By training on these diverse data, deep learning models can learn the various features and patterns of ship targets, thereby improving detection accuracy and robustness.

Data augmentation is an important part of the data-driven methodology. It artificially transforms the original data to generate more training samples, thereby further enhancing the model's generalization ability. In ship target detection, common data augmentation techniques include rotation, scaling, cropping, flipping, and color adjustment. For example, by randomly rotating and scaling images, the visual effects of ships at different distances and angles can be simulated; color adjustment can enhance the model's adaptability to different lighting conditions. These data augmentation operations not only increase the diversity of training data but also help the model learn a wider range of feature variations, enabling it to better cope with various complex situations in practical applications.

### 4.2. Evolution of Convolutional Neural Network Architectures

Convolutional Neural Networks (CNNs) are one of the most commonly used architectures in deep learning for computer vision, and their powerful feature extraction capabilities make them a core technology for ship target detection. In recent years, CNN architectures have continuously evolved, from early models like AlexNet and VGGNet to more advanced ones like ResNet and DenseNet, with each generation achieving significant improvements in performance and efficiency.

In ship target detection, researchers typically select appropriate CNN architectures based on specific application scenarios and further optimize them. For example, ResNet introduces residual connections to solve the problem of difficult training in deep networks, allowing the network to be designed deeper to learn more complex feature representations. DenseNet further improves feature utilization efficiency through dense connections, reducing the loss of feature information during propagation. These advanced architectures provide stronger technical support for ship target detection.

In addition, to meet the requirements of real-time performance and computational power limitations, lightweight CNN architectures such as MobileNet and ShuffleNet have also been widely applied in ship target detection. MobileNet uses depthwise separable convolution to decompose standard convolution into channel-wise convolution and point-wise convolution, significantly reducing the computational load while maintaining high detection accuracy. ShuffleNet further improves model performance through channel shuffle operations, enabling efficient operation on mobile devices and embedded systems. The emergence of these lightweight architectures has made ship target detection technology widely applicable in resource-constrained environments.

### 4.3. Attention Mechanisms and Feature Fusion Strategies

Attention mechanisms have become an important research direction in the field of deep learning in recent years. By simulating the human visual attention mechanism, the model can focus more on important feature regions in the image, thereby improving detection accuracy and efficiency. In ship target detection, attention mechanisms can be used to highlight the feature information of ship targets and suppress

the interference of background noise. For example, by introducing channel attention mechanisms, the model can automatically learn which channels' features are more important for ship detection, thereby enhancing the expression ability of these features.

Feature fusion strategies involve combining features from different levels to fully utilize both local and global information in the image. In ship target detection, shallow features usually contain rich detail information, such as the edges and textures of ships, while deep features contain higher-level semantic information, such as the overall shape and category of ships. By weighting and fusing shallow and deep features, both the detail and semantic information of the image can be retained, improving the model's adaptability to complex scenes. For example, Feature Pyramid Networks (FPNs) construct a top-down feature pyramid structure to fuse features from different levels, significantly improving the performance of target detection.

#### **4.4. Lightweight Network Design**

To meet the requirements of real-time performance and computational power limitations in ship target detection, lightweight network design has become an important research direction. Lightweight networks reduce the number of model parameters and computational load, thereby improving the speed and efficiency of model operation. For example, MobileNet uses depthwise separable convolution to decompose standard convolution into channel-wise convolution and point-wise convolution, significantly reducing the computational load while maintaining high detection accuracy. ShuffleNet further improves model performance through channel shuffle operations, enabling efficient operation on mobile devices and embedded systems.

In addition, some lightweight techniques based on quantization and pruning have also been applied to ship target detection. Quantization techniques convert the model's weights and activation values from floating-point numbers to lower-bit-width representations (such as 8-bit integers), reducing the model's storage space and computational load. Pruning techniques remove unimportant weights or neurons from the model, further optimizing the model structure and reducing the demand for computational resources. These lightweight techniques not only improve the model's operational efficiency but also minimize the loss of model accuracy, making ship target detection technology widely applicable in resource-constrained environments.

### **5. Application Scenario Analysis**

#### **5.1. Port Ship Surveillance System**

Ports are crucial docking points for ships, and port ship surveillance systems are vital for the safety and efficient operation of ports. Computer vision and deep learning technologies can monitor the number, type, and position of ships in real time, providing accurate information support for port scheduling. By installing high-definition cameras in ports to capture images of ships and using deep learning models for target detection and recognition, automatic monitoring and management of ships can be achieved.

The port ship surveillance system not only optimizes port operational efficiency but also enhances port security. For example, by monitoring the dynamic information of ships in real time, port management authorities can promptly detect abnormal behavior, such as illegal mooring or unauthorized

loading/unloading of cargo. Moreover, combined with other technologies like AIS, the surveillance system can further improve the accuracy and reliability of monitoring. The AIS system provides information on the ship's identity, position, and speed, and when integrated with computer vision technology, it enables comprehensive monitoring of ships.

#### **5.2. Maritime Traffic Management System**

Maritime traffic management is an essential means of ensuring maritime safety. Computer vision and deep learning technologies can be applied to maritime traffic management systems to monitor the navigation status of ships in real time, including speed, heading, and distance. By detecting and tracking ship targets, abnormal behavior such as deviation from shipping lanes and speeding can be identified in a timely manner, thus enabling early warnings to prevent collisions.

The maritime traffic management system can also analyze ship traffic flow and distribution to provide decision-making support for maritime traffic planning and management. For example, by monitoring the traffic flow in busy shipping lanes in real time, traffic management authorities can adjust lane usage rules and optimize ship navigation routes to reduce congestion. Furthermore, combined with satellite remote sensing technology and meteorological data, the maritime traffic management system can enhance its capabilities in monitoring and managing maritime traffic.

#### **5.3. Military Defense Target Recognition**

In the military domain, ship target detection is of great significance for maritime defense and military decision-making. Computer vision and deep learning technologies can quickly and accurately identify enemy vessels, providing real-time intelligence support for military command. By capturing images from cameras installed at military bases, islands, or onboard ships and using deep learning models for target detection and recognition, early warning and tracking of enemy vessels can be achieved.

The military defense target recognition system not only improves the ability to identify enemy vessels but also enhances the flexibility and security of military operations. For example, by monitoring the dynamic information of enemy vessels in real time, military command authorities can adjust defense deployments and formulate appropriate countermeasures in a timely manner. Moreover, combined with other military technologies such as radar and satellites, the defense system can further enhance its capabilities in monitoring and identifying maritime targets.

#### **5.4. Marine Environmental Monitoring**

The protection of the marine environment is a global concern. Computer vision and deep learning technologies can be applied to marine environmental monitoring to detect ship pollution discharges and illegal fishing activities, thereby strengthening the protection of the marine ecosystem. For example, by capturing images from cameras installed on marine monitoring vessels or buoys and using deep learning models to detect features such as ship exhaust outlets and fishing gear, real-time monitoring and management of the marine environment can be achieved.

The marine environmental monitoring system not only monitors the environmental behavior of ships in real time but also provides scientific evidence for the formulation of marine environmental protection policies by analyzing ship navigation trajectories and behavior patterns. For example,

long-term monitoring of ship pollution discharges can assess pollution risks in different sea areas and provide data support for the implementation of marine environmental protection measures. Moreover, combined with marine ecological data and meteorological data, the monitoring system can further enhance its capabilities in monitoring and managing the marine environment.

## 6. Conclusion

Computer vision and deep learning technologies have broad application prospects in ship target detection. Although challenges such as interference from complex marine environments, small target detection difficulties, handling of multi-target occlusion and dense scenes, and balancing real-time performance with computational power limitations still exist, significant progress has been made through research and application of key technological paths such as data-driven methodologies, evolution of convolutional neural network architectures, attention mechanisms and feature fusion strategies, and lightweight network design. In application scenarios such as port ship surveillance systems, maritime traffic management systems, military defense target recognition, and marine environmental monitoring, computer vision and deep learning technologies have played important roles. These technologies have not only improved the accuracy and efficiency of ship target detection but also provided strong technical support for the development of the marine economy and the protection of the marine environment. In the future, with the continuous development and improvement of deep learning technologies, ship target

detection technologies will become more intelligent, efficient, and precise. For example, multimodal data fusion technology will enable ship target detection systems to integrate data from multiple sensors, further enhancing detection accuracy and reliability. Unmanned and intelligent technologies will make ship target detection systems more automated, reducing the need for human intervention. Cloud-edge collaborative computing technology will enable ship target detection systems to operate efficiently in resource-constrained environments, improving system real-time performance and response speed.

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