Research on Target Detection Technology for Maritime Rescue Based on Waterborne Unmanned Aerial Vehicles

Du Wen

School of Ocean Engineering and Technology, Sun Yat-sen University, Zhuhai, Guangdong, 519000, China

wend26@mail2.sysu.edu.cn

Abstract. The rapidly emerging waterborne unmanned aerial vehicles (UAVs) have been widely used in maritime rescue missions in recent years. The purpose of this study is to review the target detection technology for its application in maritime rescue. Starting from the current application status of waterborne drones in maritime rescue, this paper introduces various unmanned aircraft models, such as Helper, and their application scenarios. Subsequently, the research status of target detection and the current algorithm models for camera applications were analyzed, and the advantages of the improved YOLOv8 model in accuracy and the shortcomings in computational efficiency were identified. Foggy weather at sea has a significant impact on the results of object detection. Therefore, through the study of foggy scene simulation and image defogging, the improved dark channel defogging algorithm model is found to be highly efficient and practical. However, in terms of hardware, the interference of environmental adaptability and battery life to target detection still needs to be addressed. This paper proposes some specific solutions, such as deep learning algorithm optimization and wireless charging methods. Target detection technology for waterborne drones has far-reaching implications for the informatization of maritime rescue, not only for the optimization of rescue methods, but also for the improvement of rescue efficiency.

INTRODUCTION

Drone technology is gradually becoming an indispensable tool in maritime search and rescue missions. Compared with traditional water rescue, drones have the advantages of low energy consumption and high efficiency, and do not produce large amounts of Marine waste, meeting the current demand for green and environmentally friendly Marine ecological development. As a result, the application and development of waterborne drones have received attention from the scientific community. Among them, the application of sea rescue target detection technology by waterborne drones has received extensive attention.

The complexity of the maritime environment is the main cause of difficulties in maritime rescue, and the location and identification of targets are greatly affected. Su suggested that equipping drones with good target detection capabilities would not only be very effective in accurately locating people or ships in need of rescue under complex marine conditions, avoiding a large number of blind spots that are overlooked by relying solely on ships or manual monitoring, but also enable rapid and efficient task fulfillment in specific beach rescue scenarios such as material delivery and maritime fire rescue [1]. Dou believes there are still many technical bottlenecks in target detection, such as the difficulty in detecting small targets. As a result, improvements were made to the Convolutional Block Attention Module (CBAM) self-attention module, and the Efficient Channel Attention Module (ECAM)-based You Only Look Once version 4 Tiny (YOLOv4-Tiny) object detection algorithm was studied to achieve precise detection of small objects. The algorithm's accuracy mean Average Precision (mAP) can reach 43.5%, and the detection speed is 65 frames per second [2].

Based on the former model, Zhang studied the Dual Hierarchical Siamese Region Proposal Network (DH-Siam RPN) algorithm for ocean target tracking in fog, achieving defogging for unmanned aerial vehicle (UAV) target detection [3]. Under the condition that defogging was achieved, Zhao conducted a comparative test of different algorithms and found that the improved You Only Look Once version 8 (YOLOv8) model had an accuracy rate of up to 83.5% and a recall rate of 67.4%, which was much higher than other models and had the best detection performance [4]. Subsequently, Lu developed an innovative Detection Transformer for Maritime target detection (DETRMaritime) model based on the YOLO model, which reduced the number of references and computational complexity by approximately 70%, representing a significant improvement in target detection processing speed [5]. With the combination of algorithms and various technologies, the target detection capabilities of UAVs will play a significant role in future maritime rescue operations.

This paper first reviews the current situation of unmanned aerial vehicles (UAVs) in maritime rescue and the current situation of single-target detection, the specific application scenarios and model algorithms of waterborne UAVs, and the research on target detection in foggy weather, and presents some discussions and analyses. The objective of this paper is to study the application and development of target detection technology for maritime rescue by waterborne drones, and to propose methods for improving the accuracy and efficiency of target detection by combining existing hardware technology and developed algorithm models.

CURRENT STATUS OF INTERNATIONAL RESEARCH

Research Status of Unmanned Aerial Vehicle (UAV) Maritime Rescue

As an important tool for developing the Marine economy, waterborne drones can play a significant role in the ocean, and there are countless application scenarios. At present, great progress has been made in the academic research of sea surface rescue, and a unified command system for maritime rescue has been established in response to the special environment of the sea. Drones can shine at sea. Many countries and organizations around the world have collaborated in the field of unmanned aerial vehicle (UAV) maritime rescue, sharing technical resources and rescue experience to jointly deal with maritime emergencies on a global scale. Water drones have been widely used in maritime rescue operations since 2016. The first was the Helper drone developed by the French Helper company, which enabled high-speed flights to drowning people and real-time transmission of full-quality high-definition images, marking a new stage in maritime rescue [6]. The strong maneuverability and straightforward operation of waterborne drones have made them highly promising in maritime rescue operations.

By taking advantage of their unique flight altitude and the use of high-definition cameras, waterborne drones can effectively lock onto objects in the water and precisely locate ships and floating objects to provide information to search and rescue teams. Due to the battery life problem of small drones (lasting about 30 minutes), they are often used in nearshore beach rescue operations. At nearshore beaches, if Marine creatures such as sharks approach, they will be detected and identified by the shark-repelled water drone, along with the use of warning devices such as speakers to ensure the safe evacuation of beach visitors. International drones commonly used for sea rescue include Schiebel's CAMCOPTERS-100 and Martek Aviation's ViDAR [6]. These waterborne drones can deliver some small supplies, but their main function is to locate the target and then carry out the main rescue mission with large vehicles such as helicopters and ships, but they are equipped with meteorological monitoring equipment on the basis of target detection to collect data such as wind speed, temperature, humidity and wave height in real time, and to conduct preliminary detection of complex sea conditions and weather. It helps the crew assess the risks and make a reasonable navigation plan [1].

Algorithm Models for Unmanned Aerial Vehicle (UAV) Target

Detection Technology in Maritime Rescue

Research Status of Object Detection

Object detection is an important task in the field of unmanned aerial vehicle vision. Object tracking algorithms are used to track the positional changes of the target, and the initial position of the target is initialized with the first frame image of the video as the target template. The main approach to object detection is deep learning, especially convolutional neural networks, which have made significant progress in object detection. Traditional object detection methods, such as SIFT based on manual features, are gradually being replaced by deep learning methods [3]. At present, small object detection is one of the biggest technical challenges because traditional detection uses methods that are beneficial to large object detection, which leads to the need for more scale algorithm improvements for the implementation of small object detection. Zhao embedded the feature pyramid structure (FPN) into SDD, and some others proposed the SANA network structure based on the self-attention mechanism. Both have achieved effective progress, with the latter increasing the success rate by 2.44 percent and the accuracy by 2.36 percent [3, 4]. In addition, multi-object detection technology is also advancing.

Application of Camera Algorithm Models

For unmanned aerial vehicles to achieve target detection, the application of camera algorithms is required first. The cameras used are not essentially different from those used in mobile phones or cameras, but they usually need to be equipped with different types of sensors and analytical tools in combination, along with the application of algorithms to achieve higher precision and smarter functions, ensuring they can function in more complex environments.

The data sent by the camera for target positioning includes both horizontal and vertical rotation angles, and the placement distance has a direct impact on the precise positioning of target detection. When the target moves a certain distance, an Angle α is formed, which varies with the distance of movement. When the cameras are placed far apart, the discontinuity of information acquisition may cause α to remain constant, which results in an error in target positioning [7]. Therefore, minimizing the distance between cameras can effectively improve the accuracy of target detection. The current mainstream Scaneagle drone in the world, is equipped with a high-definition camera array, which not only has the ability to rotate 180 degrees, but also expands the single scan range to 80 times, and many targets that cannot be seen with the naked eye can be presented in the transmitted image with extremely high clarity [8].

In the process of object detection, especially small object detection, algorithms need to be input into the camera to cooperate in order to achieve various detection functions. There are various types of algorithms, including first-order SSD and YOLO for real-time performance, as well as second-order R-CNN for high accuracy. The YOLO algorithm, which offers superior speed and high accuracy in detection, has been widely used and is being developed and improved. The improved YOLOv8 model, for example, uses a weighted bidirectional feature pyramid network to extract feature images, a structure that processes multi-scale image features by fusing features of different scales through top-down paths (from high-level features to low-level features) and bottom-up paths (from low-level features to high-level features). This is a new attempt that has never been applied to any model before. Based on the aggregated local and global feature representations of the feature map, this improved network structure enables the model to perform efficient inference with lower computing resources (though the computing speed needs to be improved) while maintaining high accuracy [1].

TARGET LOCALIZATION IN EXTREME CONDITIONS OF FOG ON THE SEA SURFACE

Simulation of Foggy Scenarios at Sea

The environment at sea is very complex. Due to the temperature difference between the ocean surface and the air, a large amount of fog can easily form over the sea, which also increases the difficulty of target detection. Therefore, simulating foggy scenarios at sea is a necessary process to solve the problem.

For researchers, the most important approach is to first select the appropriate dataset, such as the RTTS dataset used by Zhao, or the Tiny Person and COCO datasets from the Internet, which can serve as the basis for suitable sea surface images [1, 3]. Then, the researchers can process the existing data using an image-fogging algorithm model to simulate the foggy scene. For example, the model proposed by Narasimhan worked efficiently in 2002.

Image Defogging Algorithm

With the successful simulation of foggy scenarios, researchers can start to improve target detection in foggy sea conditions. Since the main problem is the blurriness of the target, the research is mainly focused on image defogging algorithms.

The principle of image defogging is straightforward. Its underlying logic is to clear the image transmitted by the camera and feed it back to the camera to achieve precise positioning of the target. In 2009, a group of researchers proposed the dark channel prior defogging algorithm, which calculates the gray level and the clarity of the image based on the different dark channels of the image in both foggy and non-foggy conditions [5]. Based on his previous research, Zhang compared the results of the dark channel defogging algorithm and the DehazeNet defogging algorithm when processing 3000 images simultaneously. He found that the former took an average of 100 milliseconds while the latter took 500 milliseconds, and after modifying the correction coefficient to 0.95 and taking the initial transmittance to 0.1. The average time of the improved dark channel prior defogging algorithm was reduced to 15 milliseconds, although there were occasional local exposure issues, it was obvious that the dark channel was more efficient in use [3]. There are also algorithms that are directly based on the YOLOv8 model, introducing the ECA attention mechanism to effectively reduce the interference of irrelevant features, with an 8.9% increase in accuracy and a 5.6% increase in map [1].

PROBLEMS AND IMPROVEMENT

Environmental Adaptability Issues

The sea environment is complex and changeable, often causing disruptions to the work of water drones. First, high salt and high humidity can affect the stability of electronic components during target detection and reduce the lifespan of the drone. At the same time, strong winds at sea pose a great challenge to the stability of the drone's fuselage. Therefore, even though drones have the ability to fly autonomously, flight control in harsh conditions is a major challenge [9]. At present, interventions in the sea environment are rather difficult to achieve, so the only way is to improve the manufacturing process of waterborne drones. In addition, deep learning algorithms need to be further refined and more advanced technologies combined to achieve better flight control and target recognition [6].

Battery Life Issues

Drone endurance is undoubtedly a key concern as well. Not only the lack of power of the waterborne drones themselves, but also the final target detection results will be greatly affected. Maritime rescue missions often require long periods of continuous operation, and currently, drones are mostly powered by lithium batteries, which makes it difficult to meet the actual needs. Moreover, with the addition of target detection algorithm capabilities, some cameras may need to be powered independently, and the power consumption has increased significantly, making the impact of endurance problems more prominent [6].

The issue of battery life in object detection is also a research area that needs to be improved, and attempts can be made to extend battery life by dynamically adjusting flight modes. When carrying out maritime rescue missions, cruise in low energy mode first, and switch to high energy mode when a fast response from target detection is needed to achieve the expected goal. Fast charging technology could also be introduced. Since it consumes a lot of power, it would be more efficient if the camera's battery could be charged quickly. However, frequent back-and-forth charging would still be a waste of time. To address this issue, consider setting up low-energy mobile charging stations in the sea or developing wireless charging technology based on renewable energy sources such as solar power. Such solutions will not only help to extend working hours, but also effectively reduce human intervention and enable efficient, environmentally friendly, and continuous maritime rescue [10].

CONCLUSION

This paper mainly reviews the application of target detection technology for unmanned aerial vehicles (UAVs) on water, analyzes the current research status and application scenarios as well as some algorithm models, and then organizes the scene simulation and defogging algorithms of target detection in the most severe foggy weather. The limitations of existing technologies in adapting to the Marine environment and the problem of battery life of unmanned aerial vehicles are discussed and analyzed, and suggestions for improvement, such as manufacturing process improvement, flight mode adjustment, and fast charging technology, are proposed. Target detection technology for waterborne drones in maritime rescue is a very important development direction in Marine science and technology. Judging from the current development momentum, more innovative achievements and scientific research developments will soon emerge in this field.

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