Research on Collision Avoidance Method Based on Image Recognition Technology

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ABSTRACT: This paper describes the development of unmanned surface vessel (USV) collision avoidance technology, introduces the basic principles and key technologies of image recognition technology, analyzes the shortcomings of traditional collision avoidance technology, and explains the research status of the image recognition technology in the collision avoidance of unmanned surface vessel. The design ideas of the existing research and development results are summarized. Advantages and disadvantages are analyzed and compared. This paper focuses on the techniques of stereo vision, deep learning, multi-sensor fusion, and the method of unmanned surface vessel collision avoidance based on image recognition technology. The future development trend of this field is also discussed.

CCS Concepts:

• Computing methodologies → Computer graphics → Image manipulation → Image processing

1. INTRODUCTION

With the vigorous development of shipping industry, the water transportation routes are becoming denser and denser, and the total number of ships has risen sharply. By the end of 2017, the total number of domestic registered ships has reached 145,200, and the number and capacity of ships have increased year by year. The total amount is also constantly increasing. The water safety situation in China is becoming more and more complicated, and various types of ship accidents have occurred. How to optimize water transportation and ensure the safety of ship navigation is an important research direction in the field of ship navigation.
As an autonomous small-scale water surface platform, the unmanned surface boat (USV) can realize self-planned routes, autonomous navigation, and autonomous obstacle avoidance, and can complete military and scientific research tasks such as maritime cruise, environmental reconnaissance, and target detection. It can also be competent for civilian tasks such as carrying goods. With the rapid development of unmanned technology and the continuous expansion of application fields, unmanned surface vessels are developing towards commercialization and large-scale development. The development of unmanned ocean-going cargo ships with larger scale, complexity and safety requirements is more and more possible [1]. The marine environment is complex and changeable. Other vessels, reefs, surface floats and moving objects on the water surface will pose a threat to the navigation of unmanned surface vessel. The key direction of unmanned surface vessel research is how to keep safe and effective in complex sea environment. The key to the unmanned surface vessel's autonomous navigation on the water is its fast and efficient autonomous path planning capability and autonomous obstacle avoidance capability, which benefits from the accurate and rapid autonomous perception of the unmanned surface vessel to the surrounding environment. There are many types of shipboard equipment, such as laser radar, millimeter wave radar, ship self-identification equipment and video sensing device. Unmanned surface vessel’s sensing environment and avoiding obstacles autonomously are complicated process, which including obtaining navigation environment information, autonomous analysis of obstacles and correcting command decision. Autonomous obstacle avoidance ability is important for judging the intelligent degree of unmanned surface vessel. Indicators are also important guarantees for maintaining safe and orderly water transportation.

In summary, it is very necessary to vigorously develop an autonomous identification and collision avoidance technology suitable for the navigation environment of unmanned surface vessel. In order to solve the existing problems, the application of image recognition technology of the collision of unmanned surface vessel has become a research hotspot in the field of unmanned surface vessel and computers in recent years, and it is also an important theoretical basis and technical guarantee for the future of automated shipping. This paper summarizes the current application of image recognition technology in the unmanned collision avoidance of unmanned surface vessel, analyzes the problems encountered in practical applications, and predicts and discusses its future development trends.

2. UNMANNED SURFACE VESSEL COLLISION AVOIDANCE KEY TECHNOLOGY

Starting from the practical application of collision avoidance of unmanned surface vessel at sea, environmental perception is the basis of unmanned surface vessel collision avoidance technology. Environmental perception refers to collecting the environmental parameters of surrounding environment and surrounding objects by means of sensor acquisition as unmanned intelligent devices. Information such as relative distance, angle and motion state is obtained [2]. The environmental information of the unmanned surface vessel’s navigational waters is obtained through environmental perception, and then the information is analyzed and identified by the processing system, and then the collision avoidance instruction is made [3]. There are five main types of existing strategies:

1. Hydrowoustic sensing equipment: Equipment including underwater acoustic sensors, hydroacoustic sonar, etc., use the characteristics of sound waves propagating in water, convert sound information into electrical signal processing, to accomplish tasks such as underwater object detection, navigation environment perception, etc. This type of perceptual equipment is currently one of the unmanned surface vessel infrastructure [4].

2. State-aware devices: Equipment including GPS, magnetic sensors, inertial navigation systems, etc., can directly obtain information such as the position, navigational attitude, and steady state of the ship. This kind of equipment is mainly used for positioning the ship itself and maintaining a stable navigation state. Determining the state of unmanned surface vessel motion is an important condition for collision avoidance decision-making.

3. Radar: The existing shipborne radar is divided into various categories: ultrasonic radar, laser radar, millimeter wave radar, etc. The radar device transmits a specific signal to the surrounding environment, and then identifies the location of the object according to the received echo signal [5].
The radar can effectively detect targets within a certain distance, and its performance is stable and accurate. But the shortcoming is that there is a blind zone, and the target information acquired is not accurate enough [6]. The ME70 mapping unmanned surface vessel launched by China Yunzhou Science and Technology Company mainly uses laser radar to detect obstacles.

(4) Image recognition sensor: The image recognition sensor can directly receive environmental information, and after preliminary digital processing, the information is directly submitted to the system for further processing. Suitable types of targets for imaging at sea include visible light, infrared, low light, laser fog, etc. Visible light image recording is mainly used in the case of good light. Infrared night vision, laser and fog recording are for night and special weather conditions such as fog. Its advantages are large amount of information acquisition, low cost, high efficiency, and real-time [7].

(5) Fusion sensor: This type of sensor combines radar and machine vision sensors to obtain more accurate and diversified detection information. The C-Taegut unmanned surface vessel developed in the United Kingdom, can detect the navigation environment under complex conditions and complete autonomous navigation through the combination of radar, vision sensors and infrared sensors. Converged sensors that take into account the advantages of multiple types of sensors are also trends in the development of environmentally aware devices [8].

At present, the most widely-used obstacle avoidance sensing scheme is the application of radar as the main detecting device, and the state sensor as an auxiliary, limited by the development of the technology, the practical application of the image recognition sensor is not widely. Compared with other sensing technologies, optical image-based sensing technology is more likely to effectively distinguish surface targets because optical images contain more detailed information on target regions. and has been designed and developed by more and more researchers. Thus this technology has an important position in the field of autonomous navigation and collision avoidance [9].

3. IMAGE RECOGNITION SYSTEM PRINCIPLE

The navigation environment image information acquired by the shipborne equipment need to be processed and analyzed in advance, and then identified and classified. Finally the identification conclusion is obtained based on these work. The image recognition system flow is as follows:

3.1 Image Preprocessing

In the image acquisition process, random noise generated by various factors will affect the later recognition. Therefore, the original image should be processed in advance. The preprocessing includes geometric transformation, brightness transformation, filtering, image restoration, etc., in order to improve the image data, suppress unwanted deformations, and enhance important image features for later classification and identification [10].

3.2 Image Segmentation

Image segmentation is a key step in image recognition. After segmentation, the unrelated image background is removed, leaving important parts of the original image that need to be identified. This step can make the extraction of later features more accurate and efficient. Commonly used segmentation methods are based on threshold, edge-based, region-based, cluster-based analysis, wavelet-based transformation, mathematical morphology, artificial neural network-based, genetic algorithm-based segmentation methods, etc. [11].
3.3 **Feature Extraction**

Feature extraction is to further analyze and understand the image data, extract the information related to the classification in the data, and select effective and identifiable features from a large number of features to achieve the purpose of reducing the recognition difficulty and improving the recognition speed. The common identification features of the recognition targets involved in the actual navigation environment of the unmanned surface vessel include geometric features, moment features, transformation features and SIFT features.

3.4 **Classification and Identification**

In the feature space, the features that have been processed are subjected to regular contrast recognition. This step can be performed by using a variety of classifiers, such as KNN classifiers, Bayesian classifiers, and neural network classifiers\[^{[12]}\].

4. **RESEARCH STATUS**

4.1 **Infrared Image Recognition**

As an image acquisition device with strong anti-interference ability and good day-to-day work continuity, infrared imaging equipment is becoming more and more mature. Low-cost uncooled infrared focal plane array imaging equipment has been widely used and loaded on unmanned surface vessel. People's ships play an active role in the autonomous navigation and collision avoidance. The algorithms for identifying moving targets of infrared images mainly include mathematical morphology based methods, multi-resolution attention mechanism based methods, wavelet analysis based methods, and sequence Monte Carlo based methods\[^{[13]}\]. Jun Liu\[^{[14]}\] proposed a multi-scale fractal feature MFFK for underwater infrared motion ship target detection and tracking. By detecting the infrared image skyline, the ROI region of interest is determined and its multi-scale fractal feature MFFK is calculated. In this way, the water target is identified and detected. When the target is determined as an obstacle, the improved Mean-Shift algorithm is used to track the target, and when the motion vector is determined to affect the own ship route, the corresponding obstacle avoidance plan is started. The method flow is shown in Figure 2. The algorithm has strong adaptability and high precision, but when multiple targets overlap in a complex environment, the reliability is reduced.

![Figure 2. Infrared image recognition process based on multi-scale fractal features](image)

4.2 **Dynamic Identification**

For the problem of mutual occlusion of moving targets and targets collected during navigation, a more anti-interference identification scheme is needed to solve the problem. Zinger\[^{[15]}\] proposed a background-based mobile ship detection method, which first performs segmentation to divide SVM (Support Vector Machine), distinguishes different ships by motion characteristics, and measures motion saliency of different regions to detect moving ship targets. The accuracy of this algorithm is...
better than the traditional SVM algorithm. Kaido [16] designed the marine environment image automatic detection and tracking method, using morphological processing of the navigation environment image divided into multiple rectangular regions, and then use the SVM classifier to judge each region to detect dynamic targets. The experimental results show that in the complex dynamic environment, the above two methods have better accuracy and adaptability, and further optimize the recognition level under dynamic conditions.

4.3 Stereo Vision
Stereoscopic vision is an important form of machine vision. It can restore two-dimensional information to three-dimensional shape. Based on the principle of parallax, the imaging device is used to acquire multiple images of the calibration object from different positions, and calculate the positional deviation between the corresponding points of the image to get the 3D geometric information of the object. It has the advantages of high efficiency, simple system structure and low cost [17]. Huntsberger [18] proposed a stereo vision-based maritime environment autonomous recognition collision avoidance method (Hammerhead Vision Collision Avoidance System), which can detect geometric hazards in the navigation environment (i.e., objects above the waterline that may affect navigation), and generate a grid map representing hazard warnings to avoid decision making. The system hardware consists of four cameras at different angles on the same baseline, as shown in Figure 3, which provides a combined field of view of 100 degrees and a high angular resolution. After the original image is acquired, the image is first pre-processed by rectification, noise reduction, etc., the parallax image is cut, the unrelated area is removed, and then the multi-scale filter is used to enhance the image feature of the picture. Finally, the classifier algorithm is used for identification and risk analysis. The target determined to be dangerous will be handed over to the system for collision avoidance processing. The system flow is shown in Figure 4. The unmanned surface vessel equipped with the Hammerhead vision system conducted several sailing experiments in Virginia, demonstrating good performance. The system is the first stereoscopic obstacle recognition system designed for high-speed, autonomous offshore operations on small vessels.
the image acquisition and preprocessing difficult, and the overall efficiency of the system still needs to be improved, so as to better adapt to the unmanned surface vessel obstacle avoidance system with extremely high reaction speed.

4.4 Deep learning

Deep learning is a new research direction in the field of machine learning. It combines low-level features to form more abstract high-level representations, attribute categories or features, and gives hierarchical representation of data. Deep learning has become a research hotspot in the image field with its strong self-learning ability and adaptability. It is also widely used in automation machinery, autonomous vehicles, and unidentified ship self-identification to avoid obstacles [20]. Guihuai Wang [21] proposed a method based on deep learning for image recognition of ships in front of surface unmanned surface vessel, and established a water surface unmanned surface vessel sensing platform based on image recognition system. The image was collected by a camera mounted on the platform of the middle part of the hull. Equipment such as radar, inertial navigation and GPS assisted sensing. The deep learning framework is produced by the SSD model. Compared with other target detection models, SSD achieves high-precision accuracy and achieves quasi-real-time monitoring in time. After fully training the SSD-assisted classification network, the water test with the ship in different scene categories is used for the test. The experimental results show that the precision is higher than 90% in the case of good illumination, but for some special shapes. The identification of ships (cargo ships, special ships) is prone to misjudgment when training the deep learning model, multiple parameters need to be adjusted to improve its recognition ability. In the absence of sufficient training, it is easy to cause poor efficiency and high error rate. In order to solve the above problems, Khellal et al. [22] introduced an learning algorithm based on Extreme Learning Machine (ELM) for training deep learning models and using ELM-based sets for classification. The algorithm is shown in Figure 5. The results of the algorithm verification by using the VAIS data set proved that the deep learning model is trained by this method, and the training efficiency is greatly improved without affecting the training effect.

![Figure 5. Schematic representation of an ELM-based algorithm](image)

4.5 Multi-Sensor Fusion

The fusion sensing device integrates many different types of sensors into the same device, so that it has high-precision and diversified information sources, and the short plates of various sensors complement each other to avoid the degradation of recognition sensitivity caused by external factors. In this regard, Weidong Chen [23] proposed a maritime target recognition method that combines radar and visual data, using monocular cameras, laser radar, inertial sensors and other equipment loaded on unmanned surface vessel to work collaboratively, through image processing, segmentation, SVM classification. When the maritime target is identified, the laser radar and other sensors are used to detect the azimuth synchronization to cross-validate whether the image recognition result is correct. The system structure is shown in Fig. 6. The effectiveness of the proposed architecture is confirmed by experiments.

![Figure 6. Multi-sensor fusion obstacle recognition system](image)
Shengnan Zhang [8] designed an unmanned surface vessel front obstacle sensing method that combines millimeter wave radar and vision sensor. The original image is processed by the mean value drift filtering fuzzy C-means algorithm. The value is divided, the segmentation is completed, and finally the target contour is selected for recognition by morphological processing and threshold setting. On the basis of image recognition, the spatial coordinates of the millimeter wave radar operation are merged with the visual information, and the obstacle information acquired by the image recognition is matched with the data obtained by the radar to determine the target position and coverage. Both of the above methods can effectively reduce the false positive rate of maritime target recognition, so that image recognition can be used for unmanned surface vessel collision avoidance with higher accuracy and better reliability.

5. DEVELOPMENT TRENDS
With the continuous development of sensing technology, information technology and automatic planning technology, and the increasing emphasis on water transportation safety, countries have invested a lot of manpower and material resources to develop image recognition technology for unmanned surface vessel collision avoidance. Delay, high recognition rate, high recognition domain and high reliability will become the trend of image recognition technology in the collision avoidance of unmanned surface vessel [24].

(1) Low latency
The speed of modern small ships is constantly increasing, and the requirements for self-identification are also improved. The identification technology must respond in time to effectively warn dangerous information and set aside sufficient time for operation and risk avoidance. The lower the response delay, the better the actual use effect, so reducing the delay has always been the focus of image recognition technology development and optimization.

(2) High recognition rate
The water transportation environment is complex and the climate is changeable. In some special extreme weather conditions (such as storms, low-altitude fog, etc.), the visibility is low, and it is easy to produce overlapping images of ships in the distance, water reflection on the surface of the water, and bumps in the ship. In the case of shadows, the image acquisition equipment can obtain poor image quality, the recognition difficulty is increased, and the speed and accuracy are reduced. To solve this problem, researchers are constantly optimizing algorithms and analysis mechanisms (such as low Resolution image enhancement, foggy environment image classification processing technology [25], etc.), in order to maximize the recognition accuracy and recognition rate in poor environments, and enhance the environmental adaptability and stability of ship image recognition technology [26].

(3) High recognition domain
In reality, the number of ships entering the estuary and tributary gathering places is large, and it is easy to generate route conflicts, which is a high-level section where collision accidents occur. Image recognition technology needs to identify multiple ship targets, and it must ensure accuracy under the premise of rapid identification. Therefore, the wider identification domain is very important and has a great effect on dealing with complex navigation conditions.

(4) High reliability
Ship collision avoidance systems need not only accurate predictability and high degree of intelligence, but also adapt to the harsh environment of maritime change, in some extreme environments (such as strong natural electromagnetic interference, thunderstorms, severe weather, etc.) [27]. The stability and reliability of image recognition technology itself have been improved. Therefore, the development trend of ship image recognition technology is to improve the ability of identification and enhance the stability of analysis and reliability to adapt to complex navigation environments.
6. CONCLUSION
With the improvement of electrification level, the advantages of intelligent, low-cost and real-time video surveillance, it can be applied to the unmanned surface vessel's autonomous navigation and collision avoidance. The image processing algorithm can detect the water surface target and provide a certain way and valid information to avoid collision and identification. Intelligentization and high speed have always been the development direction of modern ships. The improvement of ship speed has put forward higher requirements for ship intelligence. Image recognition technology applied to unmanned surface vessel autonomous navigation and collision avoidance is important for improving the autonomy of unmanned surface vessel. Significance is also an important direction for the intelligent development of unmanned surface vessel in the future.

Acknowledgment
This research was supported by Wuhan University of Technology Independent Innovation Fund Undergraduate Program (Item Number:2018-ND-B1-18).
This research was supported by National College Students Innovation and Entrepreneurship Training Program (Item Number: 201810497170)

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