Research Status and Prospect for Maritime Object Monitoring Technology

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Abstract. With the increase of marine and fishery activities, the observation of maritime object has attracted more and more attention. This paper introduced the common methods of object acquisition and image analysis about the maritime object, and then discussed the development trend of image analysis with the deep learning method.

1. Introduction
The ocean, which covers about three-quarters of the earth surface, has abundant natural resources that attract people to explore and develop. In recent years, marine and fishery activities have increased and marine accidents have occurred frequently. There is a growing attention on the observation and monitoring of marine objects such as marine ships, glaciers, buoys, unknown floating objects and reefs. Therefore, real-time monitoring on maritime objects is urgently needed. As the large-scale maritime targets (such as large ships, drilling platforms, glaciers, etc.) are relatively large in size and most large ships are equipped with navigation aids such as Automatic Identification System (AIS) which can be easily tracked, the focus of monitoring is often on small objects. The purpose of monitoring on small maritime objects is to detect and track small-size objects such as small vessels, floating objects and drowning people.

The monitoring process can be divided into two parts of object acquisition and image analysis. Image analysis is mainly composed of object segmentation, object detection, and object tracking. Depending on the passive or active detection of electromagnetic or sound waves, or the pre-installations of the ship-borne navigation aids, the purpose of the object acquisition is to obtain the image of the target areas and the position information of the target itself. Object segmentation is used to extract the target region of interest through image processing. Object detection is to further extract information on the object so as to distinguish it from the noise and to determine the position and size of the object. Object detection and tracking refer to comparing the characteristics of the object with that in the database to obtain key information such as the object nature or the movement trend. Through the above procedures can the aim of monitoring maritime objects be achieved, providing decision-making references for the follow-up circumstances.

2. Object Acquisition
Object acquisition is achieved through receiving electromagnetic wave signals of various bands emitted, radiated or reflected by the object. For example, in the radar and infrared bands, the object’s position can be determined by transmitting the related electromagnetic waves and receiving echoes. In some infrared and visible light bands, the object and low-temperature water objects can be distinguished via receiving the electromagnetic wave radiation (mainly the heat radiation) emitted by the object. In the visible light band, the position can be identified by directly observing the visible...
light emitted or reflected by the object surface. In addition to the electromagnetic wave signal, sonar systems using acoustic signals and ship-borne navigation aids can also be applied in the process.

2.1. Radar
The radar system mainly emits electromagnetic waves with a wavelength range of 0.001 m to 100 m, and determines the object position according to the its echo. According to the emission wavelength, it can be divided into P, L, S, C, X, Ku, K, Ka band radar, etc. Due to the electromagnetic wave’s diffraction characteristics and the high-frequency electromagnetic wave attenuation caused by substances in the atmosphere (water vapor, oxygen, etc.), in the case of using only a single radar, long-wave from the radar-transmitted wave can probe relatively longer distance while the short-wave can provide a more accurate position. Since the mechanical scanning type of traditional radar has certain congenital defects, a Phased Array Radar (PAR) based on electrical scanning has been developed. At the same aperture and wavelength, it is superior than the traditional radar in the update frequency, the multi-object tracking capabilities, the resolution, and the multi-function performance. At the same time, due to the limitation of the traditional radar in the processing principles, the resolution for the probed object is very poor, and it is easy to lose the contour details of the object. The Synthetic Aperture Radar (SAR), which improves the echo processing method, can effectively penetrate camouflage and partial coverings and obtain the high-resolution images. Although the new radar features excellent performance, its high costs have become an obstacle to large-scale applications. Therefore, in most cases, the traditional radar still possesses high application values. Generally speaking, the performance of radar depends on the ability of the object to reflect the echoes, and the echoes that the radar receiver can receive. Therefore, not only the weak nature of the reflection ability of the electromagnetic wave and the Fiber Reinforced Plastic (FRP) objects are difficult to find, but also the receiver will lose some of the spectral information, losing the objects’ detailed information. In addition, the blind spots that cannot be scanned by the radar, poor absolute accuracy in close range, and the sea clutter reflected by the seawater surrounded by small objects will affect the monitoring effects on the objects.

In view of the above problems, based on the analysis of the fractal features of the high-resolution sea clutter, the literature [1,2] build a model for the sea clutter from the Doppler Power Spectral Density, and study the detection methods of low-speed objects and floating objects in the sea clutter background. However, the researches do not take the environmental factors into the consideration in the range of building models, which result in the reduced accuracy in the models. Because the high-resolution sea clutter is complicated and difficult to analyze, the literature [3] considers the maritime small objects’ detection methods based on the signal-to-noise enhanced preprocessing, and thus improves the detection capabilities of the small objects with low signal-to-noise ratio.

2.2. Infrared and Thermal Imaging
Infrared imaging system can be divided into active infrared imaging and passive thermal imaging. Active infrared imaging is required to emit infrared light to the object and receives the infrared reflected wave. This method has several limitations. It is largely influenced by the climate and the affected distance is very limited. Additionally, it is disturbed by the visible light during the daytime, and compared to the sea surface, the infrared radiation beam at night is too small to be used to search the object. Consequently, this method is usually not used as a means of detecting the maritime objects. Due to the heat dissipation of the engine and the chimney, there is a large temperature difference between the sea surface or the air and the maritime object that moves autonomously in the sea. Thus, the thermal imaging system can be used to detect the maritime objects. The advantages of such system lie in its high sensitivity and spatial resolution. It is suitable for monitoring weak objects and multi-object identification. It has a strong anti-interference ability, can work day and night, has the ability to penetrate the rain and the fog, and is not subject to the climate change. As the nature for the thermal imaging system is to search for a heat source, which is similar to the radar but may in the process lose the details of the appearance, this system is often used to detect the object rather than identify its nature.
The literature [4] considers the problems of removing the periodic stripe noise and extracting the seawater in the infrared images. But this method is not accurate enough when the seawater temperature is close to that of the object or the sea turbulence occurs. The literature [5] proposes a series of testing algorithms on the infrared objects under the complex sea conditions, achieving a processing speed of 25 frames per second, and attaining the real-time monitoring on the objects. However, the insufficiency in the ability to automatically determine the marine environment hinders the intelligent application of the algorithms.

2.3. The Visible Light
Using the visible light to get the information on the objects is done through receiving the reflected light from the object surface. Such method has a long history, simple principles and an easy implementation, which is a relatively basic and effective technology to acquire the objects. The early visible light monitoring mainly relied on the manual operation, which was affected by the personnel qualities and the working time. Instead, to ensure the stability of the monitoring, the computer and the machine vision used to simulate human eye vision are now combined to collect and store the images. The visible light image can retain the details of the external features of the object. The result of the monitoring is easy to identify and keep, and the installation cost is lower than that of the surveillance camera of the radar system. Thus, it can be applied in a large scale and generally considered as a basic means for monitoring the maritime objects. The information by the invisible light system is derived from the electromagnetic waves reflected by the object surface. Obviously, any objects that can reflect, emit, radiate, or block electromagnetic waves in the visible light band will interfere the visible light system, resulting in the object affected by irrelevant clutter and increasing the difficulty of monitoring.

Many scholars currently have done abundant researches on object detection based on the visible light. Under the visible light, the low-speed small objects are small in area, slow in moving speed, and present in a complex and tense sea context. The literature [6] considers the background model representation method of field-related kernel function-Markov Random Field, which improves the detection ability of small objects with low-speed motion while suppressing the wave noise. For the high-speed small objects, the literature [7] considers building a camera linear imaging model to solve the image coordinates of the high-speed objects while measuring the high-speed projectile trajectory images. Such model realizes the measurement of the yaw angle of the objects and analyzes the effect of the parameters of the optical systems on the accuracy of the measurements. In view of the motion of the carrier where the camera is located, the literature [8] proposes an algorithm on searching the moving objects, which combines the plane and the parallax. By compensating the motion error of the detector and filtering out the object’s parallax, the moving object search under the visible light is realized, and the false alarm problem caused by the parallax is eliminated to some extent. In view of the fact that solar glare makes the sensor saturated and unable to detect the object, the literature [9,10] conclude that the sea surface glare has an obvious characteristic of polarization through verified experiments, and thus a polarization adaptive filtering system is designed and constructed to suppress the solar flare to complete the object detection. However, the real-time measurement of the degree of polarization and the polarizing angle still requires further investigation.

The object detection system based on the visible light can retain the appearance characteristics because of its low deployment costs. The effect of the monitoring is in accordance with people’s observation habits so that such system is widely used in islands or ships for monitoring and early warning of maritime objects. At the same time, with the development of artificial intelligence technology, the monitoring process will be automated and intelligent. The binocular stereo vision system is used to measure and locate the object. While in the process of monitoring, the system will output the object distance, determine the object motion, and improve the monitoring effect.

The current problem of the binocular monitoring system mainly includes binocular lens calibration, binocular object matching [11], binocular stereo measurement [12], binocular tracking [13] and so on. In the literature [14], the neural network is used for binocular camera calibration. The neural network can be trained by utilizing the two-dimensional coordinates of the calibration points in the calibration plane to realize the mapping relationship between the two-dimensional and three-dimensional coordinates of the object point. This can effectively correct the distortion factor existing in the system.
and reduce the camera calibration operation. Aiming at the matching problem of two lenses in the binocular system, the literature [15] studies the featureless random matching problem from the perspective of a large field. The centroid judgement method is used to exclude the false objects, and then multiple objects appearing at the same time are sparsely matched based on the limit constraint, improving the rate of object detection and matching under binocular vision. In the literature [16], a ship trajectory tracking method based on binocular stereo vision is proposed. The ship model is tracked by Strong Tracking Kalman Filter (STKF), and the motion state is estimated in real time, but the method is not ideal for long-distance objects.

2.4. The Fusion of Multi-band Electromagnetic Wave
The essence of radar, infrared, visible light or other detection methods is to receive the object’s electromagnetic waves and filter out irrelevant interference. Due to various defects in single sensor and single-frame images in the process of object acquisition, multi-sensors used in multi-platforms across multi-domains have been increasingly used in recent years. The advantages of such technology lie not only in making up for the defects of single source details, and the lack of the dynamic information of single-frame images, but also obtaining the characteristics of the object under different sensors, which is helpful for subsequent analysis and processing.

The literature [17] comprehensively considers radar, infrared, optical and detection methods on maritime objects. It uses real-time data from different researches to extract features of the objects, which can effectively enhance the perception ability of the detection system. In the case of the combination of infrared and visible light, the literature [18] proposes an automatic registration algorithm based on the matching of the object’s motion trajectory, establishing normalized motion direction and motion amplitude descriptor, and using distribution constraints to increase the accuracy of the trajectory line matching. Finally, the optimal global registration matrix is obtained through the iterative update method, which realizes the automatic registration of the heterogeneous video, and combines the object’s features of the infrared with that of the visible light to achieve the information fusion.

2.5. Acoustic Wave
In addition to the electromagnetic waves, the acoustic wave can be used to acquire the objects. Similar to the radar systems, the sonar systems determine the object position by receiving the signal echo emitted by itself or passively receiving the sound wave information from the object. Compared with the electromagnetic waves, acoustic signals are easily subject to the environmental noise in the sea environment, weaker to detect small objects, and require the voiceprint information database support for the object’s recognition. Additionally, the construction costs of the sonar arrays also limit its application range, so the sonar system is generally used for underwater object search in military or scientific research [19].

2.6. The Navigation Aid
The navigation aid system generally consists of navigation lights, signal flags, radio stations, fog clocks, etc. For example, the shipborne AIS system is composed of shore-based base stations and shipborne equipment. As a digital navigation aid, it can provide the ship’s static, dynamic and voyage data to the outside world, which can help the shore-based tower or surrounding ships to detect the objects and facilitate the maritime traffic. The difficulty of the object detection is that the detected object is usually non-cooperative object that cannot provide its own information. But the navigation aids can transform the object itself into a cooperative target and release its own information, thereby increasing the accuracy of the detection. However, on the one hand, such navigation aids require the ship to cooperate to open the information releasing function and provide its own information accurately. On the other hand, for small boats or marine floats lacking such systems, the effect is limited. Consequently, such system is used as an aid to obtain information on small maritime objects.
3. Image Analysis

The object acquisition can be considered as the analog-to-digital conversion process of forming the digital image of the object by different acquisition methods. Image analysis is the process of dealing with the acquired digital image and restoring the object’s features and the states. The image analysis generally consists of the following steps.

3.1. Object Segmentation

Object segmentation is the preprocessing of tasks such as object detection and object recognition. The purpose is to divide the image into several non-overlapping sub-regions. The internal objects in the sub-region have certain similarities, and there are obvious differences among different sub-regions. The process is to mark the pixel blocks in the image, divide and cluster different sub-regions based on the markers, and the interested region can be separately extracted and studied in the object detection, thereby reducing the overall amount of data processing and improving the speed for detection. The commonly used image segmentation methods include threshold-based, edge, region, graph theory, energy functional, wavelet, artificial intelligence neural network, machine learning and other methods.

In the process of object segmentation, the sky and the ocean background can generally be removed, and the areas where ship, the marine float, the reef, and the like are located are extracted for subsequent processing. At present, the research focus of the segmentation methods is mostly the adaptive parameter to select the direction so as to improve the intelligence and enhance the adaptability of the algorithm.

In the literature [20], an infrared object segmentation algorithm based on the adaptive threshold-based region growing and morphological filtering is proposed. Through experimental analysis, the algorithm finally splits the image overlap area ratio to over 98%, which can be used well in the object segmentation in the infrared ship. In the literature [21], the defects of Pixel-Based Adaptive Segment (PBAS) algorithm are improved. Nonlinear threshold adjustment is used to correlate threshold adjustment with background complexity, which is then tested on the ChangeDetection.net 2014 (CDnet2014) data set to achieve higher accuracy on segmentation.

3.2. Object Detection

Digital signal images can be simplified as array elements as pixels, and element values are two-dimensional arrays of gray values. Therefore, object detection based on the digital image processing is also a problem of processing two-dimensional arrays. The purpose is to “induct” the array features of the region of interest, and use the corresponding method to “extract” the array, and the effect reflected on the image means acquiring the detection object from the target area.

The edge of the object usually has a portion with large change in pixels, generally a set of pixels formed by a step change or two step changes. The edge detection method can preserve the object structure, remove the weak correlation area, and reduce the amount of data processing. The traditional method uses the value changes after the step-point differential operation to detect the edge, such as the first-order differential edge Robert operator proposed earlier and its improved Sobel, Prewitt, Kirsch, Canny [22, 23] operators, etc. For the case where the first-order differential rear edge points are not unique, the second-order edge operator Laplacian operator and LoG operator are developed subsequently. With the development of machine vision and image processing, the above-mentioned pixel-level edge operators cannot meet the requirements. In order to improve the accuracy for edge detection, the sub-pixel level edge detection is needed, such as Hessian matrix method and surface fitting method based on pixel interpolation algorithm. In addition to the edges, the corners in the image generally have a higher curvature [24], which is usually composed of multiple edges. The detection methods can be divided into Kitchen-Rosenfeld (KR) method based on edge extraction and a Harris corner detection method based on image gray information. In addition, the method of viewing the image as a pixel array and detecting the morphological edges using mathematical way can be used to detect the Hough transforms [25] of linear or geometric features in images.

The classical detection method mainly focuses on the dramatic changes of the image pixels, and detects differences in color, brightness, texture, etc. on the image. It is usually not effective to distinguish whether these features are the real edges of the object or the texture features of the object.
itself. Considering that people pay more attention to the overall position or size of the object, rather than how many edges, corners or detail texture features the object has, the classic pixel detection method needs to adopt a higher-level or richer edge feature combination. In the classification for the feature combination, the autonomous learning, extraction and classification capabilities of neural networks have gradually become the focus of research in image processing. In the literature [26], the convolutional neural network (CNN) is used to find the patch features, which are substituted into the dictionary for retrieval. The similar feature edge information is collected to obtain the final result, which can achieve better effect after adding the image features. The subsequent literature [27] extends the study of image block features, pre-classifies image blocks, clusters image block corner types in training data, and designs network to determine image block classification corners. The literature [28] proposed a global image-to-image processing method, which treats multiple image blocks as a whole and makes it easier to obtain high-level feature information. In the literature [29], in view of the problem of insufficient information utilized in neural networks, the information of different convolutional layers in the network is complemented and integrated, which improves the information utilization. The results show that multi-scale information fusion on the convolutional neural network can improve detection effect.

3.3. Object Recognition

The function of the object recognition is to detect the object based on its classifications. Different from the clustering process of dividing the region according to the pixel feature set during segmentation, the classification is to classify the detected object into a preset feature set, establish a relationship between the unknown object and the known feature, thereby identifying the object. In the literature [30], the inflection point invariants in local invariants are considered. Three inflection point extraction methods are studied and used in object recognition, which obtain the good results. In the literature [31], the convolutional neural network is used for object recognition. By introducing the L2 norm to improve the anti-noise performance and generalization of the network model, Dropout is used to reduce the network computation in the network connection layer. Simulation experiments show that the improved network increased the recognition rate from 93.76% to 98.10%, confirming the effectiveness of the network.

3.4. Object Tracking

Object tracking is a process of maintaining extracting the object of interest in the video image. Generally, the target model needs to be established in advance. It is generally necessary to establish an object model in advance. The classical tracking algorithms include Meanshift, Particle Filter, Kalman filter, Sliding Window, and Feature-Based Optical Flow.

The Meanshift method [32] searches the object along the rising direction of the probability gradient, calculates the probability distribution of the next frame of the object after modeling, and iteratively obtains the local dense region. Generally, it is suitable for the cases where there is a large difference between the color model and the background. Due to its faster calculation speed, there are now some improved algorithms.

Particle Filter [33] is essentially a method of statistical particle distribution, matching specific particles to the modeling object during object tracking, and defining the degree of similarity measure matching. According to a certain distribution form (uniform distribution, Gaussian distribution, etc.), the particles are “spattered” on the image. The statistical particle similarity determines the possible position of the object, and more particles are added at the corresponding position in the next frame to improve the probability of object tracking.

Kalman Filter is mostly used to describe the motion model to estimate the position of the object in the next frame.

The Slide Window is an exhaustive search sampling strategy based on a certain regular pattern (rectangular or circular, etc.) around the target. Although considering almost all potential positions of the object, there are also problems of excessive calculation that affect tracking efficiency.

The Feature-Based Optical Flow tracking emphasizes the idea of multi-frame object matching. The object model is regarded as a set of feature points. The optical flow feature points of the same object
are searched on different frame images, and the position information of the object is calculated according to the feature point distribution area. At the same time, the feature point changes caused by the change of the object state are updated at any time during the tracking process.

After the emergence of deep learning and related filter methods [34], in dealing with the robustness and accuracy of complex changes, the traditional algorithms are gradually surpassed by leading-edge algorithms, and are currently used as an aid. Around 2010, the methods for object tracking can be roughly divided into production-based models and discriminant models. The traditional algorithms are mostly based on the production model. The discriminant model combines the tracking with the object detection. The online learning or offline training classifier is used to distinguish the foreground object from the background to obtain the foreground object position. The advantage of the discriminant model is that compared with the traditional algorithm which requires manually designing detection features, the detectors trained by neural networks and the models updated online are more adaptable to the complex changes in the tracking process, and thus Tracking by Detection has gradually become the mainstream research direction.

3.5. Deep Learning Synthesis Algorithm
For a large number of training samples for generalized training and simulation verification required to adjust parameters, the computing power of the hardware is unable to support a complex neural network. Therefore, image processing based on neural network has been developing in a slow place until the beginning of this century.

In 2006, the literature [35] made a breakthrough work by demonstrating the training method of multi-layer neural network, which subverted the view that deep network could not be trained at that time and opened the starting point of deep learning. Since deep learning can draw conclusions based on training samples, it is naturally used to imitate human speech recognition and visual processing. The corresponding machine vision research direction has also begun to shift from a single process of segmentation, detection, recognition and tracking to an integrated approach of “image input – neural network processing – outcome output”.

In 2012, Alex Krizhevsky [36] proposed the AlexNet network, which has five convolutional layers and two fully connected layers of convolutional neural networks. Such network is implemented through CUDA and GPU computing, which enables the deep learning algorithm to achieve a 10% improvement in the ImageNet competition, reducing the rates of top 5 error from 25.7% to 15.3%. Since then, almost all the computer vision fields have turned to deep learning. Deep learning combined with GPU training, especially convolutional neural networks, has become a general algorithm for computer vision researches such as image segmentation, object detection and recognition, stereo vision, and object tracking.

4. Summary and Outlook
This paper gives a brief description of the maritime object detection technology. First, it analyzes several object acquisition methods and their effects. Then, based on the acquired digital images, the image analysis process is explained. On the foundation of introducing the existing methods, the characteristics and problems of the deep learning method applied to detection and tracking are summarized. It can be foreseen that with the advancement of computer hardware technology, especially the neural network training based on GPU computing, the efficiency of network learning has increased significantly. Image and video processing technology based on deep learning has gradually become the mainstream research direction of computer vision. The small maritime object detection technology will be frequently used in combination with other popular fields such as deep learning or big data. Such combination will improve the intelligence, automation, and adaptive capabilities of the detection, which will in the end effectively address more complex sea environments and objects.

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