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Algorithms for Detection of Ships Under Visual Surveilance

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Abstract : Visual surveillance in the maritime domain has been explored for more than a decade. Although it has produced a number of working systems and resulted in a mature technology, surveillance has been restricted to the port facilities or areas close to the coastline assuming a fixed-camera scenario. This paper presents several contributions in the domain of maritime surveillance. First, a novel algorithm for open-sea visual maritime surveillance is proposed. The paper explores a challenging situation with a camera mounted on a floating platform. The developed algorithm detects, localizes, and tracks ships in the field of view of the camera.
Keyword : detection, artifact, surround

1. INTRODUCTION

In this application the camera is installed approximately parallel to the ocean surface, which is of floating platform based visual maritime surveillance. The acquired data comes from the visible part of the spectrum and is represented by the RGB-color model. The focus of the camera is set to infinity, and, thus, allows detection only of far away objects located just above the horizon line. Because the camera is firmly attached to its non-stationary floating platform the scenery it observes is directly dependent on the uncontrolled motion of the buoy.

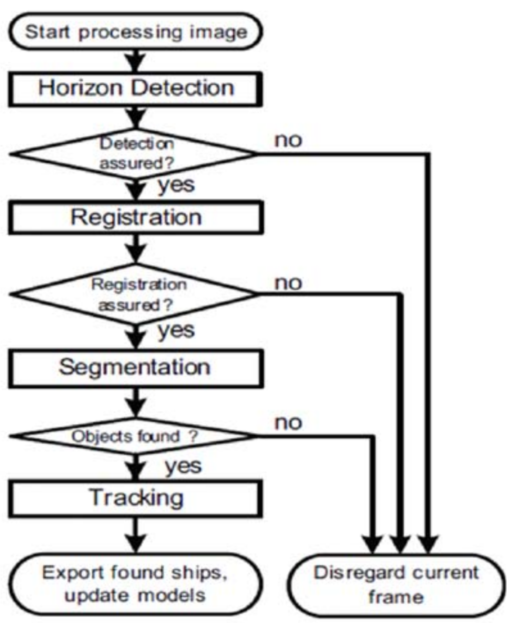

Fig. 1. Outline of the detection and tracking algorithm.

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Algorithm consists of four main modules: horizon detection, image registration, segmentation, and tracking. Depending on the confidence of horizon detection or registration the current frame can be dropped from consideration.

Thus, the images extracted from the floating platform based camera has motion pattern with the three categories of images.

2. OVERVIEW OF ALGORITHMS

The algorithm for the detection and localization of ships uses a four-step strategy to find possible targets. Each of those components may either produce output for the consecutive step or take away the current image frame from the processing pipeline. It is important to rule out the inappropriate frame early in the process, if it is found that model assumptions are not satisfied because no correct detection is possible. In that case the frame is labeled as ’intractable’ and the algorithm moves onto the next frame in the image sequence. Figure 1.1 shows the basic structure of our approach and the order of how the components of the algorithm are used.

Horizon detection is the base step in the algorithm for several reasons. The found horizon line is used to determine if the current frame satisfies the model assumptions about water and sky regions. The horizon line is also used in the following image registration step as a reference line for image alignment. Finally, the horizon line is used in the segmentation step to reduce the search space of all possible targets as objects of interest are expected to be above the horizon line and also adjacent to it.

The purpose of the image registration module is to register all frames of the video sequence in the common coordinate system [8]. High confidence in the correct alignment of horizon images is another verification that the observed scenery satisfies model assumptions. Low confidence in the correct alignment indicates that the horizon detector failed and a new detection of the horizon is required. However, the most important role of the registration step is the ability of subsequently track the detected targets. As described before, the camera is a subject to a rapid random motion associated with the buoy’s floatation. This results in large inter-frame motion in the field of view that lends to ambiguity in the correspondence of targets between frames in the video sequence. Correctly registered frames of the video sequence allow tracking of the targets on the horizon with a linear Kalman filter [4]. The segmentation step of the algorithm localizes the regions of the image above the horizon that potentially contain ships. The most important factor affecting localization is the appearance of ships, which depends on the illumination, orientation, and weather condition. Low - contrast profiles of ships are also subject to compression artifacts of the video encoder of the camera. Output of the segmentation step is important for subsequent tracking, because segmented targets are used as an input into the tracking algorithm.

The tracking step is used to increase the accuracy of ship detection and reduce false alarms. Due to limited inter frame motion of the camera an assumption is made that the object present in the current frame will be present in the next frame in the vicinity of the current location. The size and appearance of the detected objects must also show consistency between frames. The tracking module accepts as its input the output from the segmentation algorithm and rules out targets that do not have consistent history of location, size, and appearance. The tracking algorithm provides the final output of detected and localized targets in the obtained image.

The modules in Figure 1.1 provide confidence for their output. This allows streamlining the processing of the data by stopping further processing of the frames which have been found to be a poor fit for the assumed model. For example if the horizon detection step shows low confidence in the horizon, or high confidence in the absence of horizon, further processing of the frame is halted. For such frames it is impossible to detect ships with other steps of the algorithm because they assume the correct horizon line. Similarly, low confidence in the correct registration of the frame in the global coordinate system is a reason for the frame to be disregarded from further processing because the segmentation and tracking results depend on it.

2.1. Horizon Detection

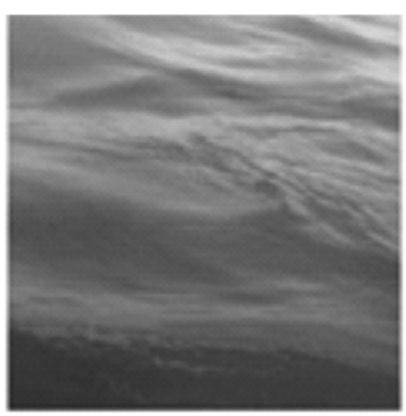
The two most relevant horizon detection algorithms [2], [3] were tested in [5]. It was found that in case of presence of the horizon line in the field of view, all of the approaches worked well for the localization of the horizon line. The approach to horizon detection described in this work combines features from [1],[2],[3].

The situation when the optical axis of the moving camera lies close to parallel to the ocean surface will result in horizon images, *i.e.* images where the horizon line separates the two most significant regions of the image-sky and water (Figure (*a*)). The other two categories of images are obtained when only sky region is visible (camera points off the water surface, see Figure (*b*)) or only water region are visible (see Figure (*c*)).

An important constraint in our model is that possible objects of interest, i.e. ships, comprise only a small fraction of the field of view, and thus, most of the scenery is represented by a water and sky regions. An exception occurs when such a constraint is not held (see Figure (*d*)-(*e*)), such condition is detected, and the results are not affected. Figure Categories of horizon images. Camera that is attached to the untethered buoy will provide images of several possible categories:

(*a*) Images with horizon clearly discernable

(*b*) Camera point to the sky is the only scenery visible in the image



(*c*) Water surface images

(*d*) Object such as ships when they take a big fraction of the field of view may seriously affect horizon detection

(*e*) Blur that comes from water splashes is another factor affecting horizon detection.

Fig. 2.

The approach can be summarized as the following :

- Images with high confidence in the location of the horizon line are considered for further analysis.
- High confidence in the absence of the horizon line in an image is an indication that the camera is pointing to the sky or water region only, and thus, no further search of the ships is possible and such image is disregarded.
- Low confidence in the location of the horizon line addresses the situation when an exceptional situation occurs: field of view is blocked or quality of imagery is corrupted by a water splash. Images with such conditions are detected and taken away from the processing pipeline.

2.2. Image Registration

The image registration step serves two purposes. First, image registration can help detect a situation when no horizon is present in the image, *i.e*. when the horizon detection fails. Second, if the horizon line is present in the image, then registration of such an image in the coordinate system common for all frames allows simplified tracking of the targets.

The first situation can be exemplified by the following. If the horizon line is not present in the image (for example, the previous horizon detection step failed and only water regions are present), registration of such an image will not be possible because of the dynamic nature of the water surface. Ship detection will not be possible in the image either, since ships may be located on the horizon line only. In the case of only sky regions present, registration is possible. However, correct registration will point to the absence of horizon line, and thus, absence of ships in the image.

The approach to simplified tracking is shown in Figure 2 Original video, obtained from a camera installed on a buoy, contains high-magnitude random motion of the field of view (Figures 2 (*a*),(*b*),(*c*)).

Such motion is erratic in nature and has a big inter-frame distance between the same features in neighboring frames of the video sequence. By registering those frames (see Figure 2 (*d*)) it is possible to use a simple linear Kalman-based tracker to track each target in the global coordinate system. Use of the horizon line allows us to simplify the registration significantly. Using the horizon line as the axis in the coordinate system common for all frames reduces the search for alignment into one dimension, along the horizon line. Also, since the horizon line is found prior to the registration step, no additional computations are required.

Even consecutive frames of a video sequence exhibit a high magnitude non-linear intra-frame motion in Figure 2. (*a*),(*b*),(*c*) which is the result of rapid camera motion. By registering frames in a single coordinate system it is possible to track ships with a simple Kalman-based linear tracker. Figure 2. (*d*) shows registration of Figure 2. (*a*)-(*c*) in such a coordinate system. The horizon line simplifies area-based registration of frames by constraining the number of degrees of freedom to one. Figure 2. (*e*) shows the values of one-dimensional normalized cross-correlation scaled in the range [0..1] during registration of frames Figure 2. (*a*) and (*b*) along the horizon line. The peak corresponds to the optimal alignment along the horizon line.

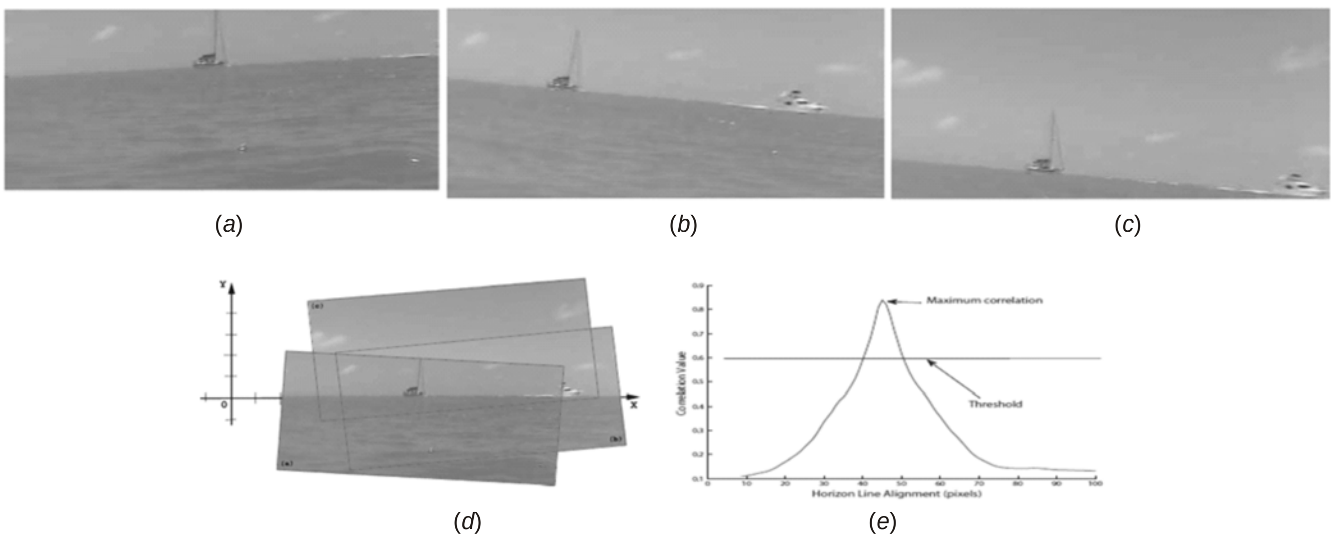


Fig. 3. Registration of frames in global coordinate system.

The methods for image registration, are divided into two major categories: area-based and feature based. In our approach, we assume that all the frames are related to each other through affine transformation due to the motion of camera. Thus, the area based method is sufficient. Moreover, having constrained the search for alignment to one dimension, the area-based method is significantly faster. One-dimensional normalized cross correlation is used as a similarity measure between the registered images. The peak in its value corresponds to the best alignment of the images along the horizon. Only rectangular patches of the edge images which overlay sky regions adjacent to the horizon are used for registration. The height of the rectangular patches is parameterized. For correlation purposes the images are converted into real-valued gradient images where the intensity of the channel is computed using the magnitude of the color gradient [6].

In the aforementioned quantities, R is the intensity of the red channel, G - green, and B - blue. The magnitude of the color gradient was selected as a method to emphasize the edges of ships' silhouettes in a low-contrast maritime environment.

However, to reduce computation, the Laplacian filter applied to the grayscale image can also be used. Before taking the gradient, the image strip is processed through the Gaussian filter to smooth effects of compression artifacts. The size of the filter and parameters of the gaussian function are chosen manually to compensate for effects of compression artifacts and to preserve most important features. For our dataset the size of the filter was 9 pixels and the sigma parameter of the gaussian function was chosen to be 0.5.

The first two frames of the video that passed through the previous blocks of the algorithm initialize the global coordinate system and create the base image. Later frames are used to grow the base image and to update its pixel values.

Those frames of the video sequence, where the maximum cross-correlation is below the threshold, are not considered further. For example if the horizon line is found incorrectly, the maximum of cross-correlation will not show significant values, and thus the frame will not be further processed. Figure 2(*e*) shows an example where the maximum of the similarity measure between Figure 2 (*a*) and (*b*) is above the threshold, confirming the correct horizon detection. The value for T2 is learned experimentally on a small dataset of maritime images.

Another important use of the threshold T2 is for those images where the sky regions above the horizon are completely uniform in appearance. Use of the area- based methods is limited only to the regions of the image above the horizon line which provides some non-uniform texture (for example, cloud formations or floating objects). The cross-correlation metric will not show significance for images with uniform sky and without floating objects (including ships) on the horizon, thus, halting further processing of those images.

3. CONCLUSION

This work presents novel algorithms for open-sea visual maritime surveillance using a highly non-stationary camera. The camera installed on a buoy is a subject to rapid erratic motion. The proposed algorithm detects, localizes, and tracks ships in the field of view of the camera and outputs images of the found targets. The experiments, conducted on a large dataset of video data obtained from a prototype of a buoy-based surveillance system, show good results.

Specifically, the algorithm detects and tracks correctly of up to 88% of ships. In the context of ship detection, a new horizon detection scheme was developed for a complex maritime domain that provides accuracy of horizon localization of 98%, and detection of horizon images with the rate of 99%. To the best of our knowledge this is the first work that focuses on low-quality image data from highly non-stationary camera. The developed algorithms are fast and are well suited for low-powered autonomous systems deployed for long periods of time.

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