A Survey on Edge Detection based recent Marine Horizon Line Detection Methods and their Applications

Manzoor Ahmed Hashmani
High-Performance Cloud Computing Center (HPC3)
Center for Research in Data Science (CERDAS)
Department of Computer and Information Sciences
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia
manzoor.hashmani@utp.edu.my
mhashmani@ieee.org

Muhammad Umair
High-Performance Cloud Computing Center (HPC3)
Department of Computer and Information Sciences
Universiti Teknologi PETRONAS
Seri Iskandar, Malaysia
muhammad_17008606@utp.edu.my*
m-umair@outlook.com*

Syed Sajjad Hussain Rizvi
Faculty of Engineering Sciences and Technology
Hamdard University
Karachi, Pakistan
sshussainr@gmail.com

Abdul Rehman Gilal
Department of Computer Science
Sukkur IBA University
Sukkur, Pakistan
a-rehman@iba-suk.edu.pk

Abstract*— Sea and sky boundary identification (i.e. marine horizon line detection) from a marine image is a problem of great interest for reasons such as, unmanned surface or aerial vehicle navigation, surveillance by object detection and tracking, and determining the spatial orientation of the ship. Due to the complexity of the marine environment, the problem poses its own unique challenges. In recent years, different methods have been proposed by the researchers to solve the problem. Those methods can be grouped into two categories; (i) edge detection based horizon detection, and (ii) machine learning-based horizon detection. In this paper, we present a survey on edge detection based recent marine horizon line detection methods and their applications. We have selected studies from the previous three years and discussed each study's approach to marine horizon line detection issue, the datasets used for testing purposes and its results. The authors' observations for each study are presented with a recommendation for their suitability for a specific application in the marine environment. Findings of the survey and future research directions for the researchers are also identified and presented. We hope that this survey paper provides a comprehensive overview of edge detection based recent marine horizon line detection methods and help the researchers in exploring new solutions to this challenging problem.

***Keywords*—computer vision, marine horizon line detection, edge detection, Canny operator, Hough transform, Otsu algorithm, marine image dataset;**

I. Introduction

Horizon detection is an important task in marine image processing. By bisecting the image into two regions, i.e. sky and sea, it effectively isolates the two areas and reduces the computational cost involved in surveillance tasks such as object detection, identification and tracking [7]. It can also be used for the unmanned surface vehicle (USV) and unmanned aerial vehicle (UAV) applications such as attitude correction and self-navigation [5] [16]. In a recent study, an image-based horizon detection technique is proposed for determining the ship's spatial orientation [4]. Moreover, its applicability for compensating the movement from a buoy mounted camera is discussed by Fefilatyev et al. [7].

In normal conditions, the horizon line is clearly distinguishable as the most prominent longest linear feature in a marine image. Identification of which can easily be done with little effort. However, the problem becomes challenging when the presence of marine traffic or other foreground objects which occludes the horizon line. The presence of noise in an image, generally induced by haze, wave wakes, water splash and spray adds another dimension to its complexity. Other factors that make this problem even more challenging are color variations across the water body, cloud formations, rough seas and the presence of land or coastal structures in the image.

Different horizon line detection approaches have been suggested in various studies by the researchers. Those studies can be grouped into two major categories; (i) approaches based on image edge detection and (ii) horizon identification by separation of the sea-sky region using machine learning models [17]. The presented survey focuses on the former approach. We have selected studies published in the previous three years and presented each study's approach to the horizon line detection problem, its testing datasets and the final results. Moreover, authors' observations of the study and recommendations of its suitability for a specific marine environment condition is also presented.

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The content of the paper is divided as follows. In Section II, we have presented an argument on the selective use of gray-scale image in edge detection approaches and a summary of the image edge detection process. Section III presents the literature survey on edge detection based recent marine horizon line detection studies and authors' observations. In Table I, we have presented a comparative analysis of these studies and suggested their potential application in real-world scenarios. Section IV describes the important findings of this survey and finally, in Section V, we have presented the concluding remarks and suggested the future research directions.

II. USE OF GRAY-SCALE IMAGE IN EDGE DETECTION AND EDGE DETECTION PROCESS

In recognizing the object, machine vision systems rely on edge detection methods [18]. However, it is a known fact that detecting edges in a color image is a daunting task [18]. In the following subsections, we first present the reason for using a gray-scale image as an ideal candidate for edge detection. Later, a brief on the image edge detection process is presented.

A. Use of Gray-Scale Image in Edge Detection

It has been identified by Novak and Shafer [19] that gray-scale image contains 90 percent of the same edge information as of its color counterpart. Since edge detection in a color image is a challenging and computationally expensive task [6] [18] thus it is preferable to use a gray-scale image as an ideal candidate for the said task. As a result, multiple recent studies such as [1] [2] [8] [10] [11] have successfully used gray-scale images for marine horizon identification.

B. Edge Detection Process

An edge in an image can result from variations in light, shade, color and texture properties. It can be used to identify and extract features from an image. These features can be further used to digitally mark and identify an object [21]. To detect an edge, first, noise form the image is removed without affecting the edge information, then the quality of the edge is enhanced by applying differentiation. In a later stage, the noisy edges are removed by applying an edge magnitude threshold value. Subsequently, the position of the edge and the spacing between pixels, subpixels are estimated. Finally, an edge is identified. There are two categories of edge detection techniques; (i) gradient-based approach and (ii) Laplacian based approach [20]. Sobel, Prewitt and Canny filters are the examples of gradient-based approaches while Marr-Hildreth edge detector is an example of Laplacian-based approach.

III. EDGE DETECTION BASED RECENT MARINE HORIZON LINE DETECTION STUDIES

In this section, we present a survey on edge detection based recent marine horizon line detection studies published in the last three years. Each study is discussed by describing its selected approach, testing datasets, results and observations by authors.

To mitigate the complexity issues associated with Hough transform, Gershikov and Baskin [6] proposed a marine horizon line detection method for color and gray-scale images using seam image operator and two vector edge detection methods, namely, Insensitive Noise Vector Range (INVR) and Minimum Vector Dispersion (MVD). The strength of the edge was calculated using a sliding window method and an edge map of the image was constructed. Linear regression was then applied to the lowest energy path in the edge map to acquire the final horizon line. A total of 20 marine images in color and gray-scale were selected to evaluate the performance of the proposed method. Ground truth for each image was manually identified and marked. A measure of accuracy, independent of an image's vertical resolution was defined. The proposed methods were evaluated against five other horizon detection methods. It was found that methods based on color edge detection or vector edge detection were computationally expense and are not suitable for real-time horizon detection problem. In addition to this, we have observed that limited dataset and absence of curved horizon line images in dataset do not provide enough evidence for the method's effectiveness in curved horizon line detection problem.

Parsad et al. [10] suggested a multi-scale approach to detect the horizon line in marine images. The method first smoothens the image using the median filter then Hough transform, and intensity gradient methods were applied to find the longest candidate line. An affirm score was then calculated and used to identify the best cross-modal pair of a candidate horizon line. However, Hough transform generated candidate line from this pair was selected as a final horizon line. A marine video dataset of 3,100 frames was used to test the efficiency of the proposed method. The frames were manually annotated for ground truth. Eventually, the proposed method was compared with three other solutions. The results showed the robustness of the presented method under conditions such as severe horizon occlusion, wakes and skyline conditions. However, we have noticed that in platform mounted camera scenarios, methods proposed by Ettinger et al. [9] and Fefilatyev et al. [7] produced equally effective results. It was observed that the Multi-modal approach and computations required to select the final horizon line may result into the added computational cost. It was concluded that this approach is suitable for high resolution moving camera images in which high marine traffic and wake noise is present.

Tomasz Praczyk [4] proposed a horizon line detection and tracking method for the marine environment. The method executes a series of iterations to locate the horizon line during which, the source image is transformed into varying sizes. The algorithm starts with a small image and a larger region of interest (ROI) area. It then increases the size of the image and decreases the size of the ROI, ultimately narrowing it down to a few possible locations of lines. The horizon line is then detected by comparing the candidate line's brightness with a parallel line which is one pixel above it. The line with the highest brightness difference is selected as the final horizon line. The study compared the proposed method with four variants of edge detection and Hough transform-based (H-HC) algorithms. To evaluate the performance of the algorithms, the experiment used gray-scale video images, captured on an ocean voyage. A significant difference between proposed and H-HC algorithms was observed in terms of execution speed and angle error with the former method producing better results.

Interestingly, the proposed method with three iterations yielded improved results as compared to its two-iteration variant thus we conclude that ROI minimization plays a significant role in producing better results. It was also established that based on its superior computational efficiency the proposed method can be used in real-time applications. However, the method is not much efficient for low-resolution images.

A horizon detection framework was proposed by Yuan and Fu [5]. The approach used gradient features of an image to detect a pool of candidate lines by applying the problem-specific line segment detection algorithm. To classify the candidate horizon line section, a hybrid feature filtering method was implemented based on morphology and color features. In the final stage, to build the full horizon line, random sample consensus-based (RANSAC) line stitching was applied. Three specific datasets were used for testing purposes, namely the primary dataset of 500 medium-resolution images, the high-resolution Singapore Marine Dataset (SMD) and medium-resolution Marine Obstacle Detection Dataset (MODD). Noise caused by weather was also present in the datasets. The proposed framework was evaluated against three other horizon detection methods. It was found that for mean height deviation and mean angle deviation, the suggested method was slightly better than the previous study conducted by Prasad et al. [10]. In addition to that, the framework requires lesser computational time thus making it a suitable candidate for real-time applications. However, in the case of the blurry horizon and the presence of large land area in the image, the performance of the proposed framework was less efficient as compared to method proposed by Prasad et al. [10].

Yevseiev et al. [11] proposed a horizon line detection method based on texture feature, Otsu algorithm [12] and clustering method. The proposed technique initially calculated the contrast of a gray-scale image. The adapted transformation formula minimized the contrast between the sea and sky regions. A four angle gray-level co-occurrence matrix (GLCM) was computed to extract textural features. The method then identified a candidate region for the horizon line by dividing the image into k equal sub-regions and by calculating each region's feature value. Later by using the Otsu algorithm [12], the candidate point for the horizon line was identified. Finally, linear fitting was applied to construct the horizon line. Manually labeled marine images were used to test the efficiency of the proposed method. It was noticed that the efficiency was sensitive to the presence of clouds and illumination levels in the image. However, the method performed relatively better in a condition where noticeable waves were present in the image. Since no details of the test dataset were presented and only one performance measure was obtained, so we conclude that the generalization ability of this

TABLE I. A COMPARATIVE ANALYSIS OF MARINE HORIZON LINE DETECTION STUDIES

Study	*Proposed Approach*	*Image Channel*		*Image Quality*	*Testing Dataset*	*Authors' Observations*	*Applications*
		Single-Channel	*Multi-Channel*				
[6]	INVR, MVD, Seam operator	X	X	Not mentioned	Primary Dataset	High computational cost, Applicable in limited scenarios	Non-real-time limited scenario
[10]	Median filter, Hough transform, Intensity gradient method	X	-	High	SMD	Highly robust under different environmental conditions	Real-time moving image scenario
[4]	Image manipulation, ROI identification, Pixel level analysis	X	-	High	Primary Dataset	Less effective on low resolution image	Real-time scenario
[5]	Line segment detection, Hybrid feature filtering, RANSAC	X	-	Medium to High	Primary Dataset, SMD, MODD	Less effective when noise and land occlusion is present	Real-time scenario
[11]	Texture feature, Otsu algorithm, Liner fitting	X	-	Not mentioned	Primary Dataset	Sensitive to environmental noise, High computational cost	Close occlusion scenario
[8]	Canny operator, Hough transform, Regional optimal variance	X	-	High	Primary Dataset	Effective under luminous & reflection, Less effective in coastal area	Open sea noisy scenario
[14]	ROI, Multi-scale edge detection , Hough transform, Least square method	-	X	Medium to High	SMD, Buoy Dataset	Computationally efficient, less effective in blur or homogeneous sea-sky region conditions	Real-time scenario
[2]	Probability distribution, Canny operator, Hough transform	X	-	Medium to High	Primary dataset, SMD, Buoy Dataset	Sensitive to motion and occlusion in image, High accuracy in region separation and horizon line detection	Fixed platform and rough sea scenarios
[3]	Saliency gradient feature, Canny operator, Hough transform	X	-	Medium	Primary Dataset	Sensitive to foreground and near horizon line noise	UAV application with limited scope
[1]	Inertial information, Candidate region, Otsu algorithm, Hough transform	X	-	High	Primary Dataset	Superior performance and high accuracy in complex marine scenarios	All general purpose applications

method is questionable. Due to the computational complexity involved in calculating GLCM, we infer that the method is not much suitable for a real-time application.

Xiyao et al. [8] suggested dividing an image into two layers based on water and sky regions. For this purpose, the mean gray-scale values of image pixels were calculated. The sky region was selected by comparing the original gray-scale image pixel value with the mean gray-scale value of the image. The pixel was set to zero if the mean value was greater than actual value otherwise the value of the pixel was set to the result of the original value subtracted from the mean value. In the later stage, the Canny edge detection [13] and Hough transform techniques were applied on the images and two separate candidate horizon lines were identified. Finally, the regional optimal variance was applied to obtain the variance of two lines over the original image. In the case of identical lines, the mean value of them was selected as a horizon line, otherwise, a line with maximum variance was selected as a horizon line. The method was tested on 1000 high-resolution marine images collected by the researchers. The environmental noise and different illumination levels were present in the dataset. The results were compared with other edge-detection based horizon identification techniques and it was found that the proposed method performed better than conventional techniques. The ability to correctly identify horizon line under luminous conditions and reflections stands out as a strength of this algorithm, however, the absence of land and objects in the dataset, limits the scope of this study thus it is a more suitable solution for the open sea applications.

A method based on the region of interest (ROI) and edge detection techniques was proposed by Jeong et al. [14]. The approach first detects ROI on the basis of high color variation present at a horizon line. The original image is resized and divided into N regions with a 50% overlap. A mean vector and covariance matrices were then calculated for color distribution. A Bhattacharyya distance was considered to find the difference in color distributions. The region with the largest distance was considered the ROI. Since multi-scale edge detection is computationally expensive thus ROI based approach was considered to mitigate the issue. Median filters of different sizes were applied to produce multi-scale images. The edges in those images were then detected by using the Canny edge detection method [13]. A weighted edge map was finally produced, and Hough transform and least square method was applied sequentially to identify the candidate horizon line. The method was tested on images from Singapore Marine Dataset and Buoy Dataset. Based on the presented results on processing time, we can infer that the proposed method can be used in real-time applications. However, we suspect that in high marine traffic scene, the applied ROI approach may produce a false ROI region primarily due to the complex gradient color variance.

Liang and Liang [2] proposed a marine horizon detection algorithm by applying probability distribution and physical characteristics. They first segmented the target image into equal size sub-regions (i.e. 30) in a vertical direction. For every region, a gray-level co-occurrence matrix was computed. With the help of weighted textural values, a sub-region was then grouped into either sea or sky region. The approach assumed that the sky has the smallest weighted textural values. A Canny operator [13] was applied to extract edges. Hough transform was used to detect linear features and based on the line equation, a set of largest values of (ρ, β) was selected as candidate horizon lines. For every candidate horizon line, the gray level at position (i, j), an average of gray level, standard deviation and weighted standard deviations were calculated by using a sliding window method. A final horizon-line-selection-criteria was formulated based on the values of standard deviation, weighted standard deviation and Hough transform generated accumulator values. The highest value produced by the criteria was selected as a final horizon line. One primary and two secondary datasets (i.e. Singapore Marine Dataset and Buoy Dataset) were used to evaluate the performance of the proposed method. The results showed that the proposed method was very effective for sea-sky region extraction. It also performed well for horizon detection in an image captured from stable platforms. The efficiency in terms of average angle error and average center location error was significantly better than previously proposed methods, however, it is noticeable that the performance of the proposed algorithm deteriorated in scenarios where the image was captured from a moving object. The algorithm was also found to be sensitive to images with occlusion. In such a case, a horizon line was wrongly detected.

In a study conducted by Lin [3], the saliency gradient feature and Hough transform were proposed to detect the horizon line in complex marine environment. The original image was converted to grayscale and a saliency map was calculated based on region sparsity measure function (RSMF). For each point on the image, a vertical and horizontal gradient was then calculated. Based on acquired information a saliency gradient norm (SGN) map was generated and the Canny operator [13] and Hough transform was applied to generate a horizon line. The position coordinates of the line were then transferred to the original image to finally identify the horizon line. The method was tested on a primary dataset of medium resolution images covering complex scenarios such as rotation, movement, clouds, and small waves. The horizon detection rate of the proposed solution remains almost the same during sunny and cloudy weather which shows the robustness of this method, however, we have noticed that primary dataset used for the testing purposes was very small thus there is a possibility that upon testing on a benchmark dataset, results may change. Moreover, the method was found to be sensitive to the foreground and near horizon line noise.

To detect the horizon line in a maritime scene, an algorithm based on the motion attitude of a camera was proposed by Shan et al. [1]. An inertial sensor captured the motion attitude information based on which a candidate region (CR) for the horizon line was calculated using a geometric relationship. The CR was then turned into a gray-scale image. To remove noise and enhance edge information, the median filter was applied. A binary map was later generated by applying the Otsu algorithm [12] to segmented CR. By analyzing the pixel mutation position in the vertical direction, edges were extracted. Five candidate horizon lines were identified by calculating pixel point clusters having collinear features. A Kernel-based Hough transform was applied in this stage. To select the optimal horizon line, a cost function was designed using predicted, measured and influence facto values of line length and angle. The algorithm was tested on a primary dataset of 2,900 high-resolution images in which glare, occlusion, haze, and ships were visible. Two other horizon detection techniques [7], [15] were compared with the proposed solution and it was found that except for sunny scenes in which all three algorithms performed equally well, the proposed algorithm surpassed the performance of the other two in term of precision and recall values. This superior performance can be attributed to the combination of the camera motion attitude model with improved edge detection and Hough transform algorithms. It was observed that the proposed method showed superior performance across different marine scenario thus it is found to be a fit for all-purpose marine horizon detection problems.

IV. SURVEY FINDINGS

In Section III, we have presented a survey on edge detection based recent marine horizon line detection methods and their comparative analysis. For the reader's benefit, this section highlights the important findings of the survey.

It was found that the majority of the studies used a gray-scale image to identify the horizon line, however, Jeong et al. [14] has proved that color image can efficiently be used for real-time horizon detection problem. Moreover, identification of a region of interest (ROI) or candidate region (CR) can significantly improve the performance of a proposed method while minimizing the computational cost associated with horizon line detection [4] [1]. It was also observed by Liang and Liang [2] that in blurry images, color channels can increase the efficiency of the sea-sky region separation task. The use of supporting data, such as inertial information with computer vision techniques, perform well across complex marine scenarios [1]. In the end, it was found that the Canny operator, Otsu algorithm and Hough transform are dominantly used in marine horizon detection methods.

V. CONCLUSION AND FUTURE WORK

A survey on edge detection based recent marine horizon line detection methods and their applications were presented in this paper. Relevant studies from the past three years were discussed and their proposed methodologies were presented. A comparative analysis of the studies was provided in the tabular form. The observations from the authors were given. Suitability of discussed studies for different real-world applications was also suggested by the authors.

As future work, authors would like to highlight a more complex scenario where the marine horizon line is completely occluded by foreground objects. A hybrid marine horizon line identification approach is recommended in this case. In addition to this, improving the efficiency of the horizon line detection method from a moving ship can be further investigated.

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