Research on Panoramic Sea-sky line Extraction Algorithm

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Abstract. Small targets detection is one of the key technical problems in these fields such as maritime surveillance and disaster rescue. In order to find the target as early as possible, the small target detection algorithm based on sea-sky line extraction is generally adopted, and the accurate extraction of the sea-sky line becomes the basis of the small target detection in the maritime. For the panoramic sea images acquired by the catadioptric panoramic vision system, the sea-sky line extraction algorithm is studied in this paper. The specificity of panoramic vision system creating images makes sea-sky line in a panoramic image an approximate circle. A detection algorithm based on gradient direction is proposed to extract accurately the circular sea-sky line. Experimental results show the efficiency and superiority of the proposed method in this paper.

Introduction.

In maritime surveillance and maritime search and rescue activities, sea targets detection with the aid of image processing and machine vision technology is an effective auxiliary means [1]. Catadioptric panoramic vision system has the following advantages: unified imaging, 360-degree view and rotation invariant, which make it able to monitor full-range and long-distance sea areas, so the system is of great value in maritime surveillance.

Small targets detection generally start with extracting the sea-sky line. The sea-sky line is linear under the conventional visual system (shown in Fig.1 (a)) [2]. But the sea-sky line in a panoramic image shows as an approximate circle due to the specificity of catadioptric panoramic vision system imaging principle; besides, the images of the panoramic acquisition device itself and the ship or buoy carrying the panoramic acquisition system are contained in the panoramic image (as shown in Fig.1(b)). All of these make sea-sky line extraction more complex. According to the derivation of the panoramic imaging model in Refs.[3], sea-sky line extraction in panoramic images can be converted into circle detection under complicated background. At present, common circle detection algorithms are the standard Hough circle transform, the randomized Hough transform (RHT) [4] and the random circle detection algorithm (RCD) [5], etc. However, the above algorithms are usually applicable to the images with “clean” backgrounds, while panoramic sea images contain a lot of interference information due to the influence of complicated sea-sky background and panoramic acquisition device, which seriously affects the determination of the optimal center as well as radius and makes the circular sea-sky line extracted from a panoramic image inaccurate and non-unique. In order to resolve this problem, Refs. [6] extracts the sea-sky line by ellipses fitting on


Figure 1. Visible sea image.
the basis of searching the extreme outer edges, and then locates small ship targets by a method of single window threshold. The algorithm’s real-time performance is good, but it often fails to achieve accurate sea-sky line extraction on condition that abominable sea states lead to a partial loss of the sea-sky line. In this paper, both detection accuracy and real-time performance taken into account, a circular sea-sky line detection algorithm based on gradient direction characteristics is put forward to accurately extract and segment the sea-sky line area.

The remainder of this paper is organized as follows. Section 2 introduces panoramic sea-sky line extraction based on gradient direction. The main steps are described, including the method to rough extraction of sea-sky line and precise extraction of sea-sky line. The results and comparisons of sea-sky line detection in panoramic images in Section 3 and Section 4 concludes this work.

Panoramic Sea-sky Line Extraction Based on Gradient Direction

Inspired by the Refs.[6], a sea-sky line extraction algorithm based on gradient direction characteristics is proposed, whose basic principle is as follows: first, a binary edge image is obtained by edge detection of a panoramic image; then, part of the clutter edges are removed, the center of sea-sky line is approximately estimated, and the rough extraction of sea-sky line is realized through setting two concentric circular rings to block out irrelevant areas according to the radius of sea-sky line; finally, based on the gradient direction the edge points really located on the sea-sky line are screened out from the roughly extracted ones, and thus the precise fitting of the circular sea-sky line is achieved.

Rough Extraction of Sea-sky Line

The panoramic vision system is generally installed on the ship or buoy, the centers of both the fixed camera and the hyperboloid reflector fixture are known and changeless as well as their respective radius, which can be used as priori knowledge. Ideally, point \( O' \) as the center of sea-sky line overlaps with point \( O \) as the center of fixed equipment, and point \( R' \) as its radius can be determined by manual measurement. Actually, point \( R' \) as the center of sea-sky line varies with sea states (not coincident with point \( O \)), and point \( R' \) as its radius also moves between \( r \) and \( R \), whose schematic diagram is shown in Figure 2.

A new algorithm of roughly extracting sea-sky line is designed in the paper: first, the center of sea-sky line is approximately estimated based on gradient direction, and then the concentric circular rings are set based on the estimated center to block out the clutter edge points around sea-sky line and finally the sea-sky line edge is roughly extracted. The details are described below.

1) Eliminating priori interference knowledge

From Fig.2, edges of the fixed camera equipment imaging and the hyperboloid reflector fixture imaging are both circular in panoramic images, which is adverse for the subsequent estimation of the sea-sky line center. As the positions of the above equipments are fixed in the image, the interference can be regarded as priori information and deleted from the edge image. That is to say, detect edges of a panoramic image, and in the edge image, all edge points which the fixed camera equipment (the center point \( O \), the radius value \( r \)) and its inner correspond to are deleted, as well as all edge points which the hyperboloid reflector fixture (the center point \( O \), the radius value \( R \)) and its external correspond to. The result of eliminating the priori interference information is shown in Fig.3, Fig.3 (b) represents the canny edge detection result of the panoramic image in Fig.3 (a), and Fig.3(c) shows the edge image without interference information eliminated according to priori knowledge. As seen in Fig.3(c), the characteristic of sea-sky line in the current edge detection image is the most obvious, a circle in the shape.
(2) Rough extraction of sea-sky line based on an automatic estimation of the center

As is shown in Fig.3 (b), only the sea-sky line in the current edge detection image is approximately circular after eliminating priori interference information, so the gradient directions of points on the sea-sky line are all approximately pointing towards the center. If straight lines are drawn along the gradient direction of each edge point on the sea-sky line, the intersection of these lines will be the sea-sky line center. This means that such a point through which there are most straight lines along the gradient directions is the center of sea-sky line. Thus the above gradient direction characteristic can be used to estimate the center of sea-sky line, and the concrete realization process is as follows: traverse each edge point in the edge detection image, and add 1 to the corresponding accumulator for each point on the straight lines which go across edge points and along gradient directions; theoretically the coordinate of the point corresponding to the biggest accumulator value is the circle center.

Given that the sea-sky line is only approximately circular, Fig.3 (a) is obtained by showing the points corresponding to the top ten of the accumulator values in Fig.3(c), and these points are all close to the center of sea-sky line, so either the coordinate value of the point corresponding to the biggest accumulator value or the average value of the top ten points’ coordinates can be selected for the estimated value of the coordinate of the circle center. The rough detection result of sea-sky line under high sea states is shown in Fig. 4 (b), which is attained by drawing a pair of concentric circular rings (the estimated center coordinate as the center coordinate, the value $R' - \sigma$ and the value $R' + \sigma$ respectively as their radiuses) to block out irrelevant areas, and the estimated center coordinate is from the average coordinate value of the points corresponding to the top ten of the accumulator values. As can be seen in Fig.4, because the sea-sky line center is adaptively determined and that the value $\sigma$ is properly selected, the edge of sea-sky line is roughly extracted while reducing the effective edge point loss, and most of the clutter edge points are successfully blocked out. Therefore, the problems existing in Refs. [6] are solved.
Precise Extraction of Sea-sky Line

(1) Precise estimation of sea-sky line edges

As is demonstrated in Fig. 4 (b), after rough extraction of sea-sky line, part of the clutter edge points still remain around the sea-sky line and are relatively dense in some places, so the essential step is to reduce the influence of the clutter edge points on the sea-sky line fitting. As is mentioned before, the gradient directions of points on the sea-sky line are all approximately pointing towards the center, while the gradient directions of clutter edge points are messy. Thus whether the gradient directions are pointing towards the center can be used as a judgment condition for eliminating clutter edge points. The concrete steps are: first, an angle threshold value $\theta$ is given and a straight line is drawn by connecting certain edge point and the center of sea-sky line; if the angle between the straight line and the gradient vector of the edge point is smaller than the threshold value $\theta$, the gradient direction of the edge point is considered to be pointing towards the center. To put it in another way, the edge point is on the sea-sky line, whereas it belongs to the clutter edge points. For Fig.4(b), traverse all the edge points of the roughly extracted sea-sky line according to the method above, and the edge points which are really on the sea-sky line can be screened out. The result is shown in Fig. 5 (a): the clutter edge points are basically eliminated and effective sea-sky line edges are more completely reserved. Compared with Fig. 4 (b), the sea-sky line edge image in Fig. 5 (a) has the higher Signal-noise ratio.

(2) Circular sea-sky line fitted by the random circle detection algorithm

As is seen in Fig. 5 (a), in the present edge detection image, most of edge information is effective and the information of clutter edges is little. Therefore, the randomized circle detection algorithm is very suitable for detecting the circular sea-sky line. The basic steps are: first, four non-collinear points are randomly selected from Fig. 5 (a), three of which are mapped to a parameter space of circle; then make a judgement on whether the fourth point is on the circle; if it is on the circle and the fitting degree of the circle meets the requirements, the fitting result is the extracted circular sea-sky line. Otherwise, repeat the above steps. The operations will be terminated when the value of repetition times reaches to the specified maximum value $k$ of cycle times, and at this point, the sea-sky line extraction for this frame image is considered to be unsuccessful. The formula for determining the round parameters by the non-common line three-point determination is:

\[
y = \frac{(x_1-x_2)(x_2-x_3)(x_4-x_2)+y_4(y_1-y_2)(x_2-x_3)-y_5(x_1-x_2)(y_2-y_3)}{(y_1-y_2)(x_2-x_3)-(x_1-x_2)(y_2-y_3)} \tag{1}
\]

\[
x = \frac{(y_4-y)(y_1-y_2)}{x_1-x_2} + x_4 \tag{2}
\]

\[
r = \left[(x - x_1)^2 + (y - y_1)^2\right]^{1/2} \tag{3}
\]

where, the coordinates of three non-collinear points are respectively $(x_1, y_1)$, $(x_2, y_2)$ and $(x_3, y_3)$, denoted by point A, B and C; the midpoints of the line segments AB and CD are respectively $(x_4, y_4)$ and $(x_5, y_5)$; the center coordinate is $(x, y)$; the circle radius is $r$. The method of judging whether the fourth point is on the circle is: calculate the distance value $d$ between the fourth point and the center of the circle determined by the first three points; and then compute the difference between the distance value and the radius of the circle determined by the first three points; and if the absolute deviation value $|d - r|$ is less than the given threshold value $D$, the fourth point is considered to be on the circle. When the fourth point is on the circle determined by the first three points, a criterion is needed to judge ultimately whether this circle is qualified, so a judgement standard based on edge gradients is proposed in this paper to judge the fitting degree of the sea-sky line.

The sea-sky line is the common border of the sea and sky area, and the pixel gray values inside and outside the sea-sky line have step changes. If the sea-sky line detection is not accurate, surely part of the sea-sky line is fitted to the sea surface or sky. At the moment, the areas inside and outside the pseudo sea-sky line are relatively smooth, and have really small gradient values. Based
on the characteristic, the following method is adopted in the paper to automatically judge whether
the sea-sky line fitting result is qualified:

A gradient threshold value $M$ is set to judge the continuity on both sides of the sea-sky line; the
number of testing points on the sea-sky line is assumed as value $N$, and the gradient value of each
point that is traversed is calculated. If the value is less than $M$, this point is judged to be continuous
and then add 1 to the value in the accumulator; A ratio coefficient $\alpha$ ($0<\alpha<1$) is set, and the fitting
result is considered to be unqualified when the value of the accumulator is more than $\alpha N$. In short,
the steps above are described as follows: calculate the ratio value, which the fitted sea-sky line parts
distributed on the sea surface or in the sky account for of the whole sea-sky line. If the ratio value
exceeds the set value, the sea-sky line extraction is unqualified.

According to the above method, the fitting result of edge points in Fig. 5 (a) is shown in Fig. 5
(b) which shows that the proposed sea-sky line extraction algorithm based on gradient direction can
precisely extract the sea-sky line in a panoramic image.

**Experiments of Sea-sky Line Detection in Panoramic Images**

The experiments selected three kinds of panoramic sea images, with the characteristic of being
acquired in ideal conditions or partial absence of the sea-sky line or large-scale fracture of the
sea-sky line, as shown in Fig. 6 (a). In the three situations above, the experimental results of the
algorithms in Refs. [6] and our paper are respectively shown in Fig.6(b) and Fig.6(c). One hundred
of images randomly selected are tested respectively under the above three situations and the
statistical detection results of the algorithms in Refs.[6] and our method are shown in Table 1.

![Panoramic images under different situations.](image)

![Direction results of the algorithm in Refs.[6].](image)

![Direction results of our algorithm.](image)

**Figure 6. Direction results of the sea-sky line in different situations.**

**Table 1. Detection accuracy and time of the sea-sky line extraction.**

<table>
<thead>
<tr>
<th>Experimental images</th>
<th>Accuracy of Refs.[6][%]</th>
<th>Time of Refs.[6][s]</th>
<th>Accuracy of ours[%]</th>
<th>Time of Ours[s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal conditions</td>
<td>94</td>
<td>0.278</td>
<td>99</td>
<td>0.235</td>
</tr>
<tr>
<td>Partial absence of the sea-sky line</td>
<td>80</td>
<td>0.335</td>
<td>95</td>
<td>0.301</td>
</tr>
<tr>
<td>Large-scale fracture of the sea-sky line</td>
<td>33</td>
<td>0.390</td>
<td>94</td>
<td>0.374</td>
</tr>
</tbody>
</table>
Based on the data in Table 1, the detection accuracy of the algorithm in Refs.[6] is far below that of our method. The detection time of a single frame image is the shortest when our method is employed, slightly better than that of the algorithm in Refs.[6]. Combining with the statistical results of table 1, we can see that: the proposed method of sea-sky line detection based on gradient direction characteristics has the advantages of high detection accuracy, strong robustness and good real-time performance, etc.

**Summary**

In the paper, research on the algorithm of circular sea-sky line extraction is carried out for the panoramic images with complex background acquired by the panoramic vision system. The algorithm of sea-sky line detection based on the gradient direction is put forward by utilizing the characteristic that the sea-sky line in a panoramic image is appropriately circular. A great number of experimental results indicate that for the panoramic images acquired in different conditions, the proposed algorithm in the paper can achieve the accurate extraction of sea-sky line, and additionally the algorithm has good universality, strong robustness and nice real-time performance.

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**References**


