The research of ship yaw detection method based on virtual navigation channel

Juanjuan Shao, Shu Zhou*, Xin He, Xinzeng Zhang and Xindong Liu

School of Electrical and Information Engineering, Jinan University, Zhuhai 519070, China

*Corresponding author’s e-mail: 14104910@qq.com

Abstract. The ship may deviate from the proposed route at any time because it will be influenced by the wind current and other factors during the navigation. Especially near the bridge river area, the river terrain is complex, such as straight and curved navigation channels. If the ship yaws without regulation immediately, this may cause unpredictable consequences such as hitting the bridges. To address the problems above, this paper proposed a ship yaw detection method based on virtual navigation channel. By building the virtual navigation channel from the video stream, the detected distance between the ship and the virtual navigation channel is used to determine whether the ship has the risk of hitting the bridge. The proposed method has been examined in the practical environment. The results show that the method can effectively detect the yawing ship and provide a technical support for the safe driving of the ship in the complex environment.

1. Introduction

With the rapid development of transportation, a large number of cross-river bridges are built. There are many ships passing under these bridges every day. Those ships often carry many heavy cargoes. If ships yaw, they will hit bridges and that will be dangerous for the ships, bridges and people. To address this problem, it is necessary to find a method to avoid this accident. There are two main methods of bridge collision prevention: active collision prevention and passive collision prevention \[1\]. Active collision prevention is a kind of method to avoid ship collision accidents by intervening in ship navigation management and navigation track \[2\]. Passive collision prevention is a method to resist ship collision through reinforcing bridge piers or auxiliary anti-collision facilities \[3\]. To our best knowledge, most researchers focused on passive collision prevention method. In this paper, we proposed an active ship yaw detection method based on virtual navigation channel to avoid the accidents of collision. The method first constructed virtual navigation channel, and then measured the distance between ship and virtual navigation channel \[4\]. When the distance is larger than the predefined threshold value, the proposed method can send a warning message via alarm and light signals to the people in the ship so that they can control ship to navigate safely. We examined our proposed method in the practical environments. The results show that the ship yaw detection method based on virtual navigation channel can guide the ships to navigate in the river safely and provide a promising strategy for navigation business.

2. Ship yaw detection method based on virtual navigation channel

2.1. Construction of virtual navigation channel
The first step of our proposed method is to construct the virtual navigation channel. Since the terrains of the river are different, the shapes of the virtual navigation channels are different. However, the general processes of virtual navigation channel construction are same and listed in figure 1.

2.1.1. Determination of virtual navigation channel endpoints. Before constructing the virtual navigation channel, the coordinates of the virtual navigation channel’s endpoints should be determined so that we can draw the shape of virtual navigation channels with endpoints. The Zhengyou Zhang checkerboard calibration method is used to calibrate the camera [5]. The virtual navigation channel’s four endpoints are converted and determined from the world coordinate system to the image coordinate system [6]. As is shown in figure 2, firstly we install the ultrasonic sensor at the same height of the reference plate, and measure the distance $\Delta H$ between the reference plate and the water surface. The distance from the camera to the water surface is $H_2 = H_1 + \Delta H$. The navigation width of bridge is $L_2$ and the distance which can be detected by our method is $D_2$. Assuming that $Z=0$ and the upper left corner of the zero plane is the origin of the coordinate system, the world coordinates of the four endpoints of the virtual navigation channel on water surface are $A (L_2, D_2, 0)$, $B (L_2, 0, 0)$, $C (0, 0, 0)$, $D (0, D_2, 0)$. According to the similarity theorem of triangle $(\frac{L_2}{L_1}, \frac{D_2}{D_1})$, the length of $L_2$ and $D_2$ on the reference plane can be obtained, and the coordinates of A, B, C, D on the reference plane are: $a (L_1, D_1, 0)$, $b (L_1, 0, 0)$, $c (0, 0, 0)$, $d (0, D_1, 0)$. By using the camera calibration parameters and coordinates of a, b, c, d, we calculate the pixel coordinates of the virtual navigation channel endpoints in the image plane, then the virtual navigation channel can be drawn in the image.

2.1.2. Linear virtual navigation channel construction. After calibrating the endpoints of the virtual navigation channel, the moving ship can be detected in the image through using three-frame difference method and mixed Gaussian background difference method [7, 8]. We draw virtual navigation channel in the image by using the straight lines which defined as straight channels $l_a$ and $l_b$ between the four endpoints A, B, C and D, which are shown in figure 3.

2.1.3. Curved virtual navigation channel construction. Due to the navigation environment is complex, sometimes the navigation channel is curved. To address this case, we use lines to construct the straight virtual navigation channel between A and B, which called $g$, and use Bezier curve [9] to construct the curved virtual navigation channel between C and D, which called $h$, which is shown in figure 4. As shown in figure 4, to avoid obstacles, we use the second order Bezier curve, which is composed of two
endpoints C and D, and one control point. The mathematical formula is as follows:

\[ B(t) = (1-t)^2 P_0 + 2t(1-t) P_1 + t^2 P_2, t \in [0,1] \]  

(1)

Where \( P_0 \) and \( P_1 \) are endpoints, and \( P_2 \) is control point. The shapes of curved virtual navigation channel can be constructed by the second-order Bezier curve, which is shown in figure 5. It is worth noting that the red dot on the left in the figure 5 is the control point, and the blue dash line between the control point and the endpoint is the control line. There are one control point, two endpoints and two control lines in the (a), (b), (c) and (d). The two endpoints have the same coordinates. The concept of the control line is used to help us describe and understand the method easily, it does not exist practically. We can see the y-coordinate of control point in the figure (a) is the same as the figure (b), but the difference of the x-coordinate of control point causes the different curvature of the curve. In contrast, the x-coordinate of control points are the same in the figure (b), (c) and (d), the difference of their y-coordinate cause the bending position of the curves are different. Therefore, if the endpoints are known, we can regulate the shape of the curve by adjusting the coordinate of the control point.
2.2. Ship yaw detection based on virtual navigation channel

On the basis of constructing the virtual navigation channel, we can detect whether the ship yaws by calculating the distance from the ship to the virtual navigation channel. We marked the moving ship by the rectangular frame in the image, and the distance from the rectangular frame vertex to the virtual navigation channel can be regarded as the distance from the ship to the virtual navigation channel.

2.2.1. Ship yaw detection based on linear virtual navigation channel. For the linear virtual navigation channel, since we had known the moving ship’s coordinates, the distance from the ship to the linear virtual navigation channel can be obtained by using the formula of the distance between point and line.

As shown in figure 6. The coordinate of vertex A is \((x, y)\), and the coordinate of vertex B is \((x + \text{width}, y)\), the width is the width of the rectangular frame. If the four endpoints of the virtual waterway are \(P_1(x_1, y_1), P_2(x_2, y_2), P_3(x_3, y_3), P_4(x_4, y_4)\), then the expression of line segment \(P_1P_2\) is:

\[
\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}
\]

The distance from point \(A(x, y)\) to line segment \(P_1P_2\):

\[
d_1 = \frac{|(y_2 - y_1)x + (x_1 - x_2)y + (x_2y_1 - x_1y_2)|}{\sqrt{(y_2 - y_1)^2 + (x_1 - x_2)^2}}
\]

Similarly, the distance from point \(B(x + \text{width}, y)\) to line segment \(P_3P_4\):

\[
d_2 = \frac{|(y_4 - y_3)(x + \text{width}) + (x_3 - x_4)y + (x_4y_3 - x_3y_4)|}{\sqrt{(y_4 - y_3)^2 + (x_3 - x_4)^2}}
\]

Finally we set a threshold value for the distance from the ship to the virtual navigation channel, when the distance between ship and virtual navigation channel is less than this threshold value, the yaw direction will be indicated.

2.2.2. Ship yaw detection based on curved and virtual navigation channel. For curved virtual navigation channel, the coordinates of rectangular frame vertex which marks the moving ship had been known. We extract the coordinate of pixel point on curve, and the distance from the vertex of rectangular frame to the pixel point of curve will be calculated to get the distance from ship to curved virtual navigation channel. As is shown in figure 7, the coordinate of vertex A is \((x, y)\), and the coordinate of vertex B is \((x + \text{width}, y)\). In this study, all of curved virtual navigation channels are yellow; their RGB values are \((230, 255, 0)\). All pixel coordinates \(B_i(x_i, y_i)\) are extracted from the video frame and then the distance between point \(A(x, y)\) and point \(B_i(x_i, y_i)\) is calculated. We can detect the ship yaws through the minimal distance which is taken as the reference value. The formula is as follows:
If $d$ is less than the minimal distance, we state that the ship has the risk of yawing.

$$d = \min \left\{ \sqrt{(x - x_i)^2 + (y - y_i)^2} \right\}$$  \hspace{1cm} (5)

If $d$ is less than the minimal distance, we state that the ship has the risk of yawing.

3. Experimental Results

3.1. Case 1: Linear virtual navigation channel

We examined the proposed method based on linear virtual navigation channel in Sun-Moon Lake of Jinan University, Zhuhai. The figure 8 shows the results. We can see from the figure 8 (a) that the ship doesn’t yaw, the white rectangular frame is used to mark the moving ship. Two red linear lines are the virtual navigation channels that we constructed. The ship in the figure 8 (b) yaws and the red rectangular frame is used to mark it. And we use the red arrow to display yaw direction. We further tested our method at the site of Hengqin Bridge of Zhuhai City. The result is shown in figure 9. We can see from the figure 9 that the ship doesn’t yaw. There exists a certain distance between the ship and virtual navigation channel. The ship went through the bridge safely, and there was no risk of hitting the bridge.

![Figure 8](image1.png)  \hspace{1cm} ![Figure 9](image2.png)

Figure 8. The simulation effects of ship yaw detection method of linear virtual navigation channel.

3.2. Case 2: Curved virtual navigation channel

We test the ship yaw detection method based on curved virtual navigation channel at the site of Hengqin Bridge of Zhuhai City. The result is shown in figure 10. In the figure 10, the yellow lines are the virtual navigation channels which we constructed. The moving ship is marked by white rectangular frame, which shows the moving ship doesn’t yaw. If the ship yaws, the white rectangular frame will become red and there will be a red arrow to shows the yaw direction of moving ship.

![Figure 10](image3.png)

Figure 10. The ship yaw detection of curved virtual navigation channel.
3.3. Analysis
In this section, we will make a detailed analysis of the test results above. From these results, we can see that no matter the ship yaw detection based on the linear or the curved virtual navigation channel, the yaw detection only depends on the distance from the moving ship to the virtual navigation channel. When the distance does not reach the threshold value we set, the ship is marked by the white rectangular frame and safely navigates in the river. Once the ship deviates from the channel, its white rectangular will turn red and a red arrow appears to indicate the direction of its yaw. And we can control the ship's navigation direction depends on the red arrow’s direction. Therefore, the key of the method is to construct the correct virtual navigation channel and set the appropriate distance threshold. The above results also indicate that this method has a good practical applicability, for different river environments. We can flexibly use the linear or curved virtual navigation channel to match the actual environment. In the complex bridge river environment, this method can play a good role in early warning.

4. Conclusion
In this paper, we studied the technology of ship yaw detection based on virtual navigation channel. Through constructing the virtual navigation channel and calculating the distance from the ship to virtual navigation channel, we implemented the detection of the ship yaws. The experimental results show that the performance of our proposed method. There are still some points which need to be improved and supplemented in the future work. For example, since where exists strong wind around bridge area, the camera will shake. This is a great impact on the detection of moving ships which affects the calculation of the distance between the ship and the virtual navigation channel. However, considering the methods of ship yaw detection that have exited, this detection method still is a great innovation in past detection method. Compared to other ship yaw detection methods, this ship yaw detection method based on virtual navigation channel can detect the ship’s yaw navigation problem in real-time and effectively, and it is a promising method in ship yaw detection research field.

Acknowledgements
This work is supported by Science and Technology Planning Project of Guangdong Province, China under grant number 2017B20218002.

References
[1] Guoyu Chen, Zhengquan Zhang. Two types of Installations and Three Missions for Defending Ships Hitting Bridge [J]. Urban Road, Bridge and Flood Control, 2008, (6): 179-179.
[2] Qingwen Deng, Zhongyi Sun, Duan Wang, et al. Design of active collision alarm system for Bridge [J]. Instruments and Apparatus.
[3] Bo Geng. Safety Assessment of Bridge ship collision [D]. Tongji University, 2007.
[4] Ting An. Research on ship Detection and tracking method based on feature Information extraction [D]. North China University of Electric Power, 2015.
[5] Ying Lu, Huiqing Wang, Wei Tong, et al. Camera Calibration algorithm based on Harris-Zhang Z. plane Calibration method [J]. Journal of Xi'an University of Architecture and Technology (Natural Science), 2014, 46 (6): 860-864.
[6] Zhang Z. Camera calibration [J]. 2014, 28(1-2): 76-77.
[7] Bo-Xuan L I, Shen Y L, Yue H U. New algorithm based on Gaussian mixture model and three frame difference method [J]. Journal of Engineering of Heilongjiang University, 2016.
[8] Wang H L, Wang J Q, Ding H F, et al. Moving target detection based on the improved Gaussian mixture model background difference method [J]. Advanced Materials Research, 2012, 482-484: 569-574.
[9] Wei Yang, Yihong Li. A preliminary study of Bezier Curve based on VC [J]. Science, Technology and Economics, 2015, (8).