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Inland waterway vessels tracking using closed circuit television

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Abstract

The aim of this paper is to use closed-circuit television (CCTV) to search and track moving objects in inland waterways. The area of the analysis is the part of the West Odra river between the Długi and Kolejowy bridges in Szczecin. The points of interest are chosen intentionally due to the risk of vessel collision with bridges. The results of the research into the implemented methods of tracking objects could be utilized in the future to extend inland navigation services, which could be used by the captains of the ships and River Information Services operational personnel as well.

Introduction

Each year the number of transport and recreational vessels grows in the inland waterways. We are dealing with an increasing trend, thus ensuring the safety of navigation is becoming more challenging. Economic development forecasts indicate that by increasing the demand for goods exchange related to the European Union borders enhancement, transport requirements will increase by about one third. The main direction of the European Union's transport policy is to reduce the negative impact of road transport on the environment, supporting environment-friendly transport branches and technology such as inland waterway transport. Achieving this goal requires overcoming current problems and extending support to the development of inland waterways. One of the ways to intensify activities in this direction is represented by the European Commission for Transport on 17 January 2006 Integrated European Action Programme for Inland Waterway Transport (NAIADES) (GUS, 2014).

Inland waterways in Poland are not exploited as much as in other European countries. Despite numerous economic and environmental advantages, as a country we are at the bottom of the list of countries benefiting from this mode of transport. The number of kilometres of waterways constitutes only a few percent of the total number of kilometres of rivers that flow through our country. The natural conditions favourable for the development of inland waterways require a relatively high rate of network density. The density of the inland waterway network is the ratio of the length of inland waterways to the surface of the study area per 1000 km^2. In Poland the rate of inland waterway density is 11.7 km per 1000 km^2. Accordingly the highest density is in the Netherlands with over 147 km per 1000 km^2.

As far as inland waterway transport is concerned, the sensitive areas from a navigational point of view are primarily the intersection of waterways with road and rail infrastructure. When a vessel collides with a bridge this limits not only waterway transport, but also other modes of transportation such as vehicular, rail and even pedestrian. In the area of the Regional Water Management Board in Szczecin the average number of collisions is one per year. One of these major collisions was in 2001. A transport vessel collided with the railway bridge in Szczecin, which caused the destruction of the bridge rails and as a result it needed to be rebuilt. To increase navigational safety near the bridges the Office of Inland Navigation in Szczecin uses closed-circuit television (CCTV) video cameras to observe the actual view of the navigational situation.

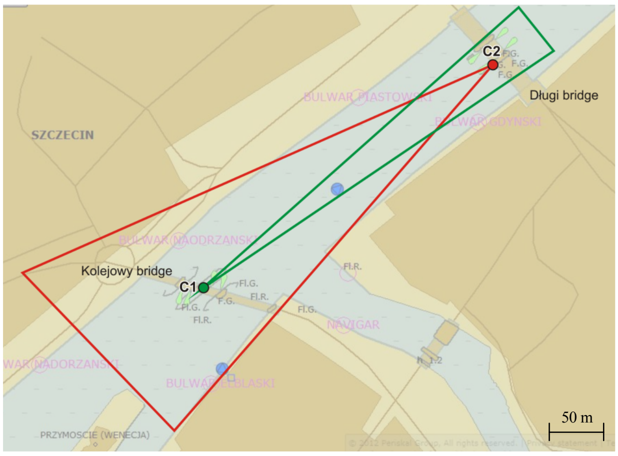

Figure 1. Chosen cameras fields of view. C1 – Kolejowy bridge camera, C2 – Długi bridge camera

The research problem

At present the CCTV cameras on European rivers are used for passive observation of the current situation. Cameras are used to record incidents around bridges, overpasses, intersections locks and waterways. There is no automated usage of the cameras. Additionally, taking into account the fact that about 50% of transport vessels do not have AIS transponders, the extra information from video cameras and the automatic identification of the navigational situation could be helpful in reducing the risk of vessel collisions with bridges. It is reasonable to use the cameras mounted on the bridges in a more active way. We can achieve this using image processing and image analysis methods. Recognition and tracking objects in video sequences could be used to detect the motion of moving objects and determine the path of these objects as well. It could be used mainly to automate processes that could happen autonomously without human interference. A wide range of algorithms are used in road transport, and others are used in aviation or medicine. To make an appropriate choice we need to define, not only the initial conditions, but also what needs to be obtained, and the problem that is to be solved. The main goal of image analysis in road transport is to measure the number of passing vehicles and detect traffic jams or collisions. Its function is also to recognise number plates. The uniqueness of road traffic, the construction of vehicles and their speed, determines the choice of algorithm for image analysis. These algorithms must satisfy equally the criteria of reliability and speed of action in real time (Kujawski, 2014a).

The research in (Breitsprecher, Kujawski & Trojanowski, 2009; Kujawski, 2014a; 2014b) shows that not all algorithms that are used in road transport can be implemented into water transport, especially in respect to vessels of inland navigation. The objects moving on water are much bigger than road vehicles. What is more there is also a greater difference in the dimensions of the units. The length of yachts, boats and motor-boats can range from a few to tens of meters, while pusher tugs, motor-barges and whole pushed sets could measure from several to over one hundred meters. Such differences in the size and movement speed of each vessel determine the choice of algorithm for image processing. Water, on which the vessels are moving, generates much greater reflection than the black surface of a road. The feature that makes the image analysis on inland water more difficult, is the fact that water can have various shades depending on lighting conditions and it will often be similar to the colour of the sky.

In the paper (Kujawski, 2014a) the results of efficiency and the speed of the chosen algorithms were presented. One of the criteria was to find an algorithm that could be used in real time according to the maximum of the processed frames per second. Four different tracking algorithms were tested in (Kujawski, 2014a):

- optical flow, based on Lucas-Kanade and Farneback methods, that fall into groups for image features analyses;
- Continuously Adaptive Mean Shift (CAMShift) method that is able to handle dynamic distribution by matching the size of pixel search window for each following picture frame and is based on colour distribution;
- Mixture of Gaussians (MoG) method, based on the extraction of pixels' features of the object. For objects in motion the values will be different than for the background or objects at rest;
- Speeded up robust features (SURF) method is improved Scale-invariant feature transform (SIFT) algorithm which extracts from an object features resistant to the transformation of individual pixels and does not depend on scale or orientation.

During the tests using the videos of moving inland vessels the discrepancy problem occurred. The slowest methods were more robust for disturbances in the videos. I decided to find out what can be done to decrease the discrepancy during object tracking, choosing the fastest algorithm called "Camshift" (François, 2004; Salhi & Jammoussi, 2012; Góral, 2014). Properly determining a track of moving objects could be used to designate a 2D representation of the path of an inland vessel. The main problem after determining the track is the appropriate geographic representation of this path.

Determining the track of moving objects

First of all we can distinguish the five points of the Camshift algorithm from (Intel, 2000).

1. Set the calculation region of the probability distribution to the whole image.
2. Choose the initial location of the 2D mean shift search window.
3. Calculate the colour probability distribution in the 2D region cantered at the search window location in an ROI (region of interest) slightly larger than the mean shift window size.
4. Run Mean Shift algorithm to find the search window centre. Store the zeroth moment and centre location.
5. For the next video frame, centre the search window at the mean location stored in Step 4 and set the window size to a function of the zeroth moment found there. Go to Step 3.

The algorithm was implemented in the Visual Studio 2012 using the OpenCV library (Bradski & Kaehler, 2008). Ten different video files were tested. The video sequences were accumulated from two cameras installed on the Długi and Kolejowy bridges in Szczecin. The files were provided by the Office of Inland Navigation in Szczecin. Video sequences have the parameters presented in Table 1.

Table 1. Video sequence main parameters

Files from Kolejowy bridge. (Camera C1)	Files from Długi bridge. (Camera C2)
Format: AVI	Format: AVI
Overall bit rate: 2 375 Kbps	Overall bit rate: 1 052 Kbps
Format/Info: Advanced Video Codec	Format/Info: Advanced Video Codec
Codec ID: h264	Codec ID: h264
Width: 1 280 pixels	Width: 1 280 pixels
Height: 720 pixels	Height: 720 pixels
Display aspect ratio : 16:9	Display aspect ratio: 16:9
Frame rate: 2.000 fps (frame per second)	Frame rate: 4.000 fps (frame per second)
Colour space: RBG (Red, Green, Blue)	Colour space: RGB (Red, Green, Blue)
Bit depth: 8 bits	Bit depth: 8 bits

The Camshift algorithm could be used to track the defined colour range on the image as a probability distribution. During the research, a specified video file containing a unique colour part was chosen. The aim of analysis was to find the best colour range from Hue, Saturation, Value (HSV) representation of points in a Red, Green, Blue (RGB) colour model, which enable the tracking of

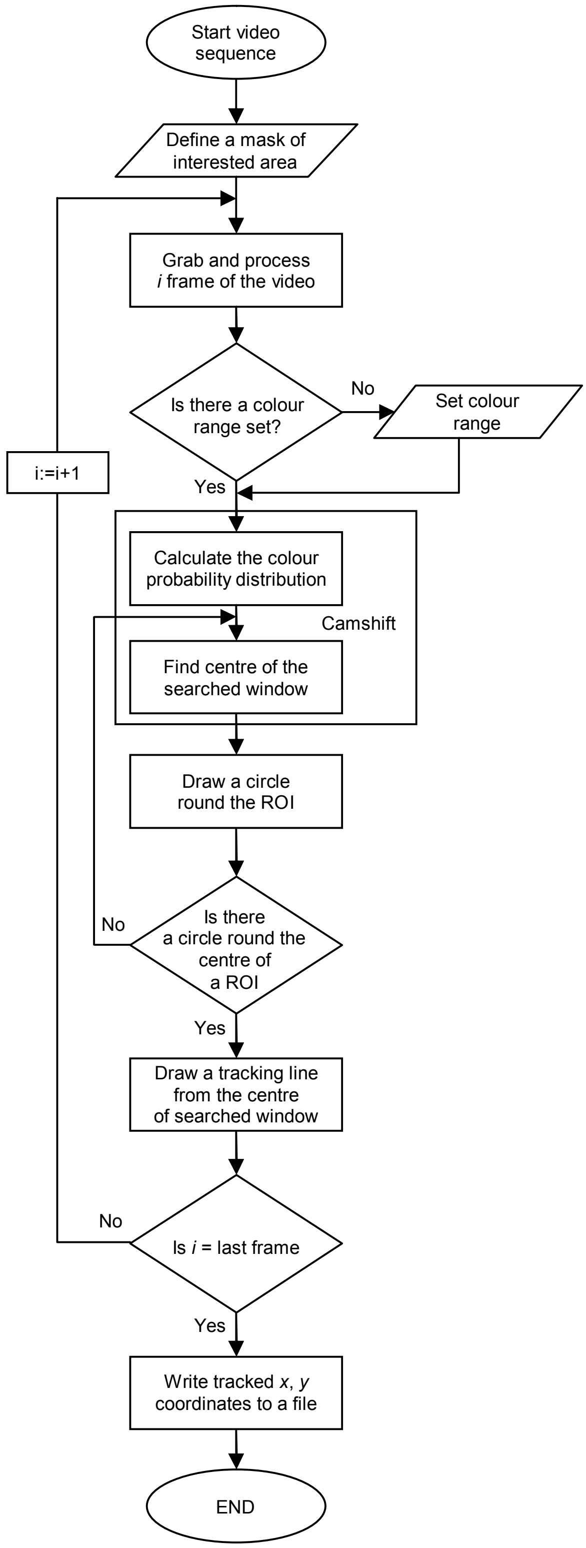

Figure 2. Simplified algorithm of image processing sequence

objects with the best robustness. The discrepancy was measured as a ratio between correctly and incorrectly identified pixels. The track of the moving vessel was automatically established and recorded using the Camshift algorithm. The identified track was compared to the reference track which was established by the coordinates of expected points during the vessel's passage.

The algorithm for determining the path of a moving object was presented on Figure 2. At the beginning it is necessary to define the mask, which is an area where the vessel is expected due to the elimination of the unwanted parts of an image. This is so that the other parts of the video containing moving objects other than inland vessels, such as cars, trams, trains or pedestrians, can be rejected. The second step is to define the searched colour range. We could do this by manually specifying or can simply click the colour we are searching for on the video image. From this, image processing starts. For discrete image probability distributions, the mean location of the centroid is found as follows:

Find the zero[th] moment:

$$M_{00} = \sum_x \sum_y I(x, y) \tag{1}$$

Find the first moment for x and y:

$$M_{10} = \sum_x \sum_y x\, I(x, y)$$
$$M_{01} = \sum_x \sum_y y\, I(x, y) \tag{2}$$

Mean search window location (the centroid) is found as:

$$x_c = \frac{M_{10}}{M_{00}}; \quad y_c = \frac{M_{01}}{M_{00}} \tag{3}$$

where:

M_{00} – zero[th] moment;
M_{10} – first moment for x;
M_{01} – first moment for y;
$I(x, y)$ – pixel probability value in the position (x, y) in the image, and x and y range over the search window;
x_c, y_c – the centroid coordinates x, y of searched window (Intel, 2000).

Experiment results

The cameras in the tests are mounted on the Długi and Kolejowy bridges. This location was chosen due to the highest number of accidents occurring in this area. The test contains 10 video files of different situations. Mainly it was the passage of vessels from one bridge to another. Five of the video files were acquired from the camera mounted on the Długi bridge (C2) and the other five files were acquired from the camera mounted on the Kolejowy bridge (C1). Figure 3a and 3b presents two examples of the tested video images. The difference between the expected and measured points was gathered in Table 2. The four example graphs showing the results from cameras C1 and C2 are provided in Figures 4 and 5.

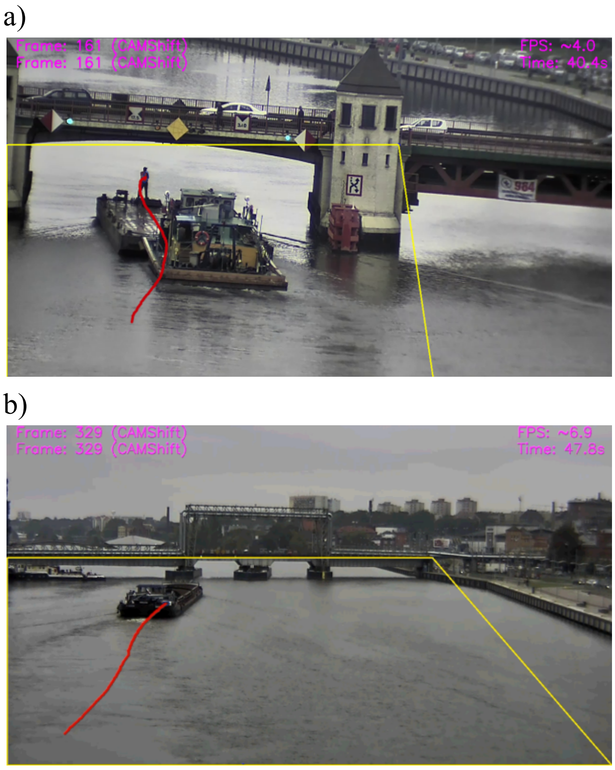

Figure 3. Example of recorded material: a) The view form C1 camera from Kolejowy bridge; b) The view from C2 camera from Długi bridge

During the procedure some dependences were noticed. The original file, or in other words the video file which was not filtered, gives fairly good results. The error level is between 7.48 and 10.82 percent of all recorded points. Nonetheless, despite these results the files were filtered to examine the accuracy of the tracking. Thus, the rest of the video sequences were blurred, sharpened and the saturation was increased to make the searched colour more visible. There is no doubt that the blurred files give extremely poor results, with over 60% incorrect points, and the sharpened files results depend upon the input material (Table 2).

These two cameras give different output material. The camera C1 from Figure 1 is mounted at the Kolejowy bridge and gives a closer point of view than the camera C2. Both cameras are equipped with the same lens and the same sensor, but have different fields of view because the zoom lens was

Table 2. All tested videos and the results of accuracy measurement during object tracking. FN –Number of all frames in video file; DTR – Number of points established in track; LPR – Number of correct tracked points; PBR – Percent of incorrect searched points in track

No.	Vessel name	Vessel type	Camera	Duration time [s]	FN	DTR [pt]	Original File LPR [pt]	Original File PBR [%]	Blurred File LPR [pt]	Blurred File PBR [%]	Sharpened File LPR [pt]	Sharpened File PBR [%]	Saturated File LPR [pt]	Saturated File PBR [%]
1	Navigare	Motor Barge	C2	185	740	607	548	9.7199	300	50.5766	335	44.8105	550	9.3904
2	Odra Lloyd 12	Pusher tug	C2	219	876	712	644	9.5506	309	56.6011	359	49.5787	649	8.8483
3	Odra Lloyd 12	Pusher tug	C2	291	1164	969	877	9.4943	552	43.0341	579	40.2477	878	9.3911
4	Vota	Motor Barge	C2	692	2768	2477	2209	10.8195	1269	48.7687	1335	46.1042	2231	9.9314
5	Bizon-0-114	Pusher tug	C2	267	1068	936	866	7.4786	536	42.7350	561	40.0641	869	7.1581
6	n/n	Pusher tug	C1	148	296	139	128	7.9137	45	67.6259	121	12.9496	129	7.1942
7	Odra Lloyd 12	Pusher tug	C1	129	258	204	191	6.3725	94	53.9216	181	11.2745	192	5.8824
8	Bizon-0-140	Pusher tug	C1	126	252	186	172	7.5269	91	51.0753	164	11.8280	173	6.9892
9	Navigare	Motor Barge	C1	148	296	231	211	8.6580	108	53.2468	203	12.1212	214	7.3593
10	Vota	Motor Barge	C1	434	868	791	731	7.5853	402	49.1783	698	11.7573	739	6.5740

set up at different focal lengths. The view angle of the C1 camera is about 7° and the view angle of the C2 camera is about 32°. Due to this fact, the results should be considered separately. The other difference is the frame rate. To avoid large video files the Office of Inland Navigation in Szczecin decided to decrease this to 2 frames per second (fps) for the camera C1 and 4 frames per second for the camera C2. This does not appear to impact on the results. The algorithm is robust enough to track the objects even when they are changing position or shape. Slightly better results are given by files filtered by the saturation filter. This is because the searched colour range has the strongest values. The intensity of each colour is visible longer during the vessel's passage.

According to the different fields of each camera's view, another observation has arisen. The view from the C2 camera gives a longer visible area of the vessel's passage and generates the highest number of error tracking points overall. This is because the examined area of the video image, close to the upper edges, is less visible. At the beginning, the tracked object has at least 20 px width and 20 px height, and at the end the resolution drops to less than 2×2 px. Greater accuracy of tracking objects occurs for images which contain the hue colour range from 0 to 50 degrees and from 320 to 360 degrees in the HSV representation model. This is equivalent to colours such as oranges, reds, deep yellows, pinks and purples.

In Figures 4 and 5 we can see the dashed lines which represent the reference tracks and the green lines representing the measured tracks. As we can see, the difference is hardly visible when we consider the original and saturated file. The values of measured errors show the difference of incorrect pixels when they were offset more than 2 pixels from the centroid. Even when the measured error reached 9% incorrect points, the tracked feature was shifted more than 2 pixels, but in practice this was not higher than 6 pixels in each direction (width and height).

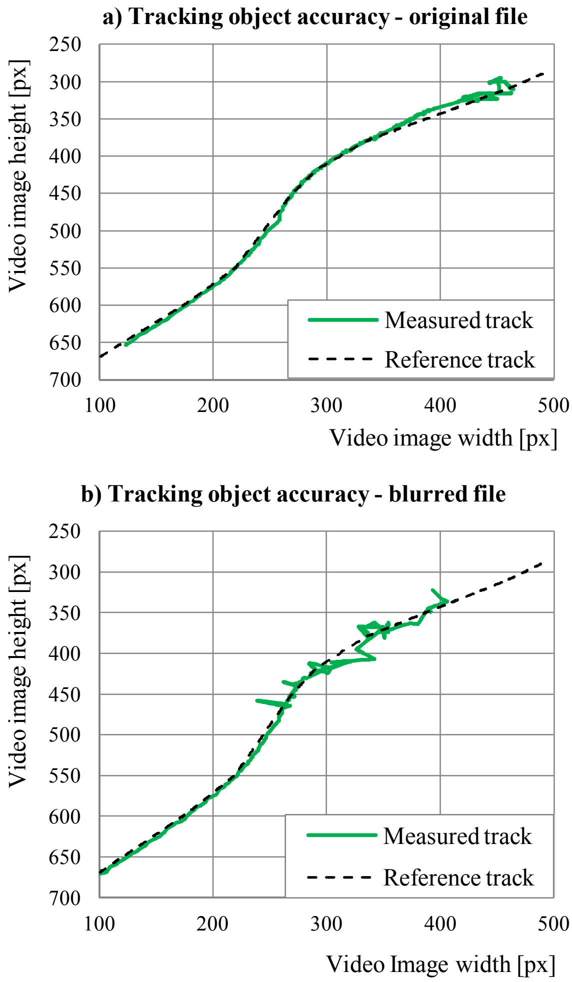

Figure 4. Tracking object accuracy comparison. Video acquired from camera on Długi bridge (C2); a) original file, b) blurred file

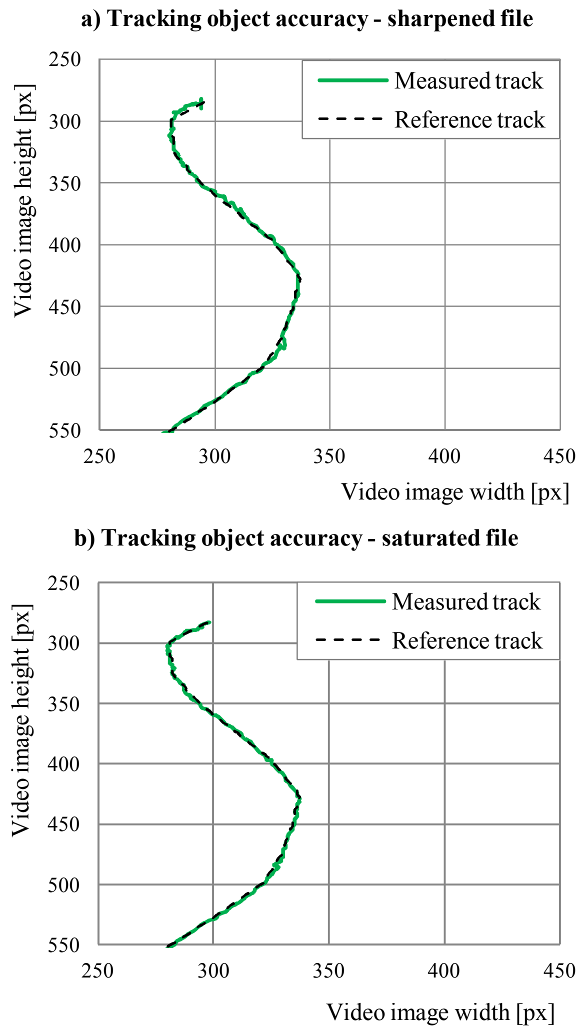

Figure 5. Tracking object accuracy comparison. Video acquired from camera on Kolejowy bridge (C1); a) sharpened file, b) saturated file

Conclusions

In this paper I used the videos from CCTV cameras mounted on the Długi and Kolejowy bridges on the Odra River to establish a track of vessels' passage. The videos were provided courtesy of the Office of Inland Navigation in Szczecin. Taking into account the former results of my analysis in (Kujawski, 2014a) I used the fastest algorithm known as Camshift. When the specified feature appeared in the video, my algorithm was able to detect, track and draw the path of the passing vessel. The searched feature was a specified colour range, picked in real time from the video. The errors of incorrect tracked points were measured with reference to the expected track. The tolerance was set up to 2 pixels offset in each direction. Every point that shifted more than 2 px was treated as an incorrect one. The results show that the algorithm is robust for fast changes of the tracked objects, even if the change concerned the shape or size. Former assumptions that the filtered video files could increase accuracy concerned only the files for which colour saturation was set at a higher level than the original file. The other image transformations like sharpening or blurring the video image are not suitable for colour feature detection and tracking. The best features to track are colours with a hue range from 0 to 50 degrees and from 320 to 360 degrees in the HSV representation model. This is equivalent to colours such as oranges, reds, deep yellows, pinks and purples.

Established tracks can be used to further the work in determining the position of inland vessels in the CCTV coverage area. The next step of my work will be a comparison of inland vessels' tracking using CCTV cameras with other methods of determining the vessels' position. The results of this future research will be used to automatically identify a navigational situation. This extra information could be used by ships' captains and River Information Services operational personnel to improve the safety of inland navigation in areas in which there is an increased risk of vessel collisions with bridges.

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