Ship Detection and Tracking in Nighttime Video Images Based on the Method of LSDT

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Abstract: Ship detection and tracking has been recognized as a challenging task in the maritime administration. The method of LSDT (Light Spot Detection and Tracking) has been applied to achieve ship detection and tracking based on the nighttime surveillance video. Firstly, the light spots in the video images are detected through LOG and invalid spots are filtered by the gray threshold. Multiple targets are subsequently tracked by Kalman filtering and light spots are marked to determine properties in order to add and delete spots. A case study has been performed in the middle reach (Wuhan) of the Yangtze River. Nighttime surveillance video has been obtained and further utilized for method verification. The results show that the ship can be detected and tracked by LSDT effectively. The present study provides an alternative for ship detection at night, thus improving the maritime surveillance efficiency.

1. Introduction

Ship detection and tracking technologies are of significance for ensuring safe navigation and reducing maritime accidents. It could be achieved by a number of different ways, such as radar, AIS and video surveillance. However, shortage have been noted by using aforementioned methods in practical circumstances. For example, visibility is low and the scene is blurred at night. Although the radar can help navigation, the radar targets are not clear enough to determine what targets are [1]. The AIS signal is easily lost and affected by shipborne equipment [2]. Maritime accidents happen frequently at night. To improve ship navigation safety, it is essential to explore robust ship detection and tracking method at night.

The traditional ship detection at night can be divided into three categories. First of all, the infrared camera is utilized to perform ship detection because of its adaption to the light at night and severe weather, such as the foggy day. Liu et al [3] built a platform on the pier and set up an infrared camera to construct a system which can detect ship during day and night to avoid collisions. Liu et al [4] used the infrared camera for ship monitoring to realize abnormal behaviour detection in port and reduce the possibility of theft of ships, but the infrared camera is more expensive. Secondly, synthetic aperture radar SAR is chosen for ship detection. Tello et al [5] and Marino [6] used wavelet transform and notch filter for ship detection by SAR image respectively, but the energy consumption of SAR is higher so that it is difficult to ensure continuous monitoring. And this method is mainly used for fishery monitoring and oil spill management. Finally, satellite imagery is used for fishing vessel detection,
mainly detecting ship by boat lighting. The earliest operation system is a linear scanning system and then developed into visible infrared imaging radiation system VIIRS to collects DNB data [7]. D. Elvidge et al. designed the DNB data ship detection system. Yamaguchi et al. [8] proposed the ship traffic flow density assessment algorithm based on DNB data and BT3.7. However, this type of method is more suitable for fishing vessel detection while less applied in other scenarios.

In summary, there are limited researches on ship detection at night by an ordinary camera. Considering real-time traffic signal detection method [9], when ship sails at night, ship lights would be turned on. Given the ship lights can be detected and tracked, it is thus possible to realize ship detection and tracking by this way. On the basis of this, the ship detection and tracking method LSDT was studied by collecting ship navigation video at night in Wuhan Section of the Yangtze River. Specifically, it mainly consists of two steps: the first step is ship light spots detection by LOG [10]; then the Kalman filtering is utilized to perform light spots tracking [11]. Through the LSDT proposed in this paper, ship detection and tracking at night by an ordinary camera can be accomplished. The content of this paper is organized as follow: the current ship detection and tracking methods at night are introduced firstly; ship light spots detection based on LOG and multiple targets tracking based on the Kalman filtering are thus illustrated; the effectiveness verification of LSDT is further demonstrated through a case study; some preliminary conclusions are drawn at the end.

2. Methodology

It is always difficult to identify ship directly at night, especially in the inland river environment. Due to the background in the video, features of the ship image cannot be extracted effectively. The navigation scenery at night near the Wuhan Tianxingzhou Bridge in Wuhan Section is shown in figure 1. The ship could be hardly detected in the nighttime video images. However, while the ship is sailing, ship lights are turned on. Thus ship detection and tracking could be accomplished through the method of light spot detection and tracking (LSDT).

![Figure 1. Nighttime video image of ship navigation at Wuhan reach, Yangtze River](image)

The ship light spot detection and tracking method mainly includes the following steps, as shown in figure 2.

![Figure 2. Flowchart of ship detection and tracking](image)

In the first step, all visible light spots are detected in the grayscale image of night surveillance video based on LOG. The image collected in the inland river at night has other light sources. As shown in figure 1, the visible light spots include the bridge and building lights in addition to ship lights. Therefore, considering the influence of other lights, after spot detection is implemented, the spots should be filtered according to the gray value of spots and the ship light spots should be kept as much as possible.
In the second step, light spots are tracked. Since one ship has multiple ship lights, multiple target tracking is required. In this paper, the Kalman filtering tracking method is adopted to track multiple moving objects.

Finally, the method is verified by the surveillance video at night near Wuhan Tianxingzhou Bridge.

3. Light spot detection
The ship detection is actually light spot detection which means to find the bright area surrounded by the low gray pixel in the gray image. Therefore, the spot detection can be converted into blob detection. In this paper, the LOG is used for blob detection [12].

3.1. LOG
Marr and Hildreth combined Gaussian filtering and Laplacian to form the LOG (Laplacian of Gaussian) blob detection [7]. The basic thought of LOG is to filter the image through a Gaussian filter firstly and then perform a Laplacian operator on the filtered image to obtain the edge. This filter makes full use of the Gaussian function to reduce the noise influence, and the probability of detecting the false edge is reduced by Laplacian template.

The two-dimensional Gaussian kernel function is written as:

$$G_\sigma(x, y) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$  \hspace{1cm} (1)

The Laplacian operator is expressed as follows:

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$  \hspace{1cm} (2)

Apply a Laplacian operator to a two-dimensional Gaussian function:

$$\nabla^2 G = \frac{\partial^2 G}{\partial x^2} + \frac{\partial^2 G}{\partial y^2} = \frac{-2\sigma^2 + x^2 + y^2}{2\pi\sigma^6} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$  \hspace{1cm} (3)

Thus, LOG is obtained:

$$LOG = \sigma^2 \nabla^2 G$$  \hspace{1cm} (4)

In fact, when LOG operator is for image processing, Gaussian convolution can be used for smoothing firstly, and then the Laplacian operator is used for Laplacian convolution.

3.2. Algorithm flow of spot detection
The main process of spot detection includes image gray processing and blob detection through LOG, then maximum value filtering and background detection to detect image peaks in order to get the center position and radius of spots, and finally spot overlap determination according to the proportion of overlap area occupied itself area. The algorithm processing flow of light spot detection is shown in figure 3.
3.2.1. Image input and scale transformation. The original image captured by the camera is the RGB image and it needs to be converted to the grayscale image. Since the spot size is not definite, the image is performed by multiple-scale LOG kernel to ensure detection effect. Therefore, the equal interval vector is constructed for the generation of different scale filters which depend on the convolution kernel parameter $\sigma$.

3.2.2. Detection through LOG. In order to simplify the calculation, Gaussian convolution and LOG convolution are performed in the horizontal direction and the vertical direction respectively and then the results in the two directions are summed. Taking spot detection with $\sigma=1$ as an example, the specific flow is as follow: firstly, LOG operator is performed on the vertical direction and Gaussian convolution is performed on the horizontal direction, the result is shown in figure 4(a); secondly, Gaussian convolution is performed on the vertical direction and LOG operator is performed on the horizontal direction, the result is shown in figure 4(b); finally, summation operation is performed and the result is shown in figure 4(c).

3.2.3. Spot determination by threshold. Since the nighttime inland video image contains background lights such as architectural lights, it is necessary to filter the detected non-ship spots. The gray threshold is set to make it. If the threshold is too low, the detected spots contain other light spots. And as the amount of spots increases, the tracking difficulty increases. On the other hand, if the threshold is too high, ship detection and tracking cannot be realized because the lights of ship cannot be detected. In this paper, the threshold is determined by the experiment.
3.2.4. Peak detection. Peak detection consists of three steps: maximum filtering, background detection and image erosion. Since the size of detected spots is small, the maximum filtering is utilized to increase it. Then according to the comparison of the image before and after maximum filtering, the background of the image is determined and eroded. Finally, the result of the maximum value filtering is compared with the background image after erosion and the peak is obtained which means the center point of the spot in the image are obtained.

3.2.5. Spot overlap determination. The flow of spot overlap determination is as follow: first of all, calculate the sum \( r_{\text{sum}} \) and the difference absolute value \( r_{\text{diff}} \) of the two spots’ radius, calculate the distance \( d \) between the center points of the two spots. If \( d \leq r_{\text{diff}} \), it is indicated that the smaller spot is located in the larger spot so that the smaller spot can be disregarded; if \( r_{\text{sum}} \leq d \), it means there is no overlap. Otherwise, the overlapping area between the two spots need be calculated. The calculation of the overlapping area is shown in figure 5, where \( r_1 \), \( r_2 \) and \( d \) indicate the radius of two spots and the distance between the center points respectively. Based on this, the ratio of the overlapping area occupied each spot is calculated separately. If the ratio is greater than the threshold (0.1 is taken here), the spot is considered to overlap. The pseudo code of the overlapping area calculation is written as follows.

```
input: x_1, y_1, r_1, x_2, y_2, r_2, supposed r_1 \geq r_2
1: d=\sqrt{(x_1-x_2)^2 + (y_1-y_2)^2}, r_{\text{sum}} = r_1 + r_2, r_{\text{diff}} = r_1 - r_2
2: if d \leq r_{\text{diff}}, then
3: area=\pi * r_1 * r_2
4: else if d \geq r_{\text{sum}}
5: area=0
6: else
7: \theta_1 = \cos((d^2 + r_1^2 - r_2^2) / 2 * r_1 * d)
8: \theta_2 = \cos((d^2 + r_2^2 - r_1^2) / 2 * r_2 * d)
9: area=2*(0.5*r_1*2*\theta_1 + 0.5*r_2*2*\theta_2 - 0.25*sqrt((d + r_1 + r_2)* (r_1 + r_2 - d)* (r_1 + d - r_2)* (r_2 + d - r_1)))
10: end if
return area
```

Figure 5. Schematic diagram of spot overlapping area calculation

4. Light spot tracking
After the light spot detection is implemented, the Kalman filtering is used to track light spots. Since the number of light spots detected in the image is more than one, it is necessary to accomplish multiple target tracking [13]. For the spots detected in a single frame image, Kalman filtering single target tracking is sequentially cycled, and then Kalman filtering multiple target tracking can be realized.
4.1. Kalman filtering

Taking a single spot tracking as an example, assuming \( x_k \) and \( y_k \) represent the position of the center of the spot respectively, \( v_x \) and \( v_y \) represent the speed in the direction \( x \) and \( y \) respectively, \( a_x \) and \( a_y \) represent the acceleration in the direction \( x \) and \( y \). The vector \( X_k \) defined to describe the state of moving spot is as follow:

\[
X_k = [x_k, y_k, v_x, v_y]^T
\]

The observation vector \( Z_k \) is:

\[
Z_k = [x_k, y_k]^T
\]

On the basis of this, the state transition matrix, the controlling input matrix, the control value at the time \( K \) and the system measurement matrix are determined as follow:

\[
A = \begin{bmatrix}
1 & 0 & dt & 0 \\
0 & 1 & 0 & dt \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix},
B = \begin{bmatrix}
dt^2 / 2 & 0 \\
0 & dt^2 / 2 \\
dt / 2 & 0 \\
0 & dt
\end{bmatrix},
U_k = \begin{bmatrix}
a_x \\
a_y
\end{bmatrix},
H = \begin{bmatrix}
1 & 0 & 0 \\
0 & 1 & 0
\end{bmatrix}
\]

After Kalman filtering parameters are obtained, the process of target tracking by Kalman filtering is to predict the state of the next moment and calculate the covariance matrix firstly, as shown in equation (8).

\[
X_{k+1}' = AX_k + BU_k \\
P_{k+1} = AP_k A^T + Q
\]

The state variable value matrix and the covariance matrix are obtained after the correction value is added by the update step, as shown in equation (9).

\[
X_{k+1} = X_{k+1}' + K_{k+1} (Z_{k+1} - HX_{k+1}') \\
P_{k+1} = P_{k+1}' - K_{k+1} HP_{k+1} \]

The Kalman gain coefficient calculation is shown in equation (10).

\[
K_{k+1} = P_{k+1}' H^T (HP_{k+1}' H^T + R)^{-1}
\]

After predicting and updating, as shown in equations (8) and (9), the correction value at the next moment is obtained. And the target tracking through Kalman filtering is implemented by cycling the two above steps continuously.

4.2. Multiple target tracking process based on Kalman filtering

Some major issues have to be resolved for multiple target tracking of the ship at night. Firstly, because the number of light spots detected is more than one, it is necessary to match them in each frame image. Secondly, due to the problem of flashing of lights, the spot detection is unstable, for example, the same spot may not be detected all the time in the adjacent frame images. At last, when the ship leaves the video surveillance area, the corresponding spots need to be deleted. For the first problem, the Hungarian algorithm [14] is adopted to match spots. For the second problem, Kalman filtering is performed on the tracking spots of the previous frame image, and then the observation result is matched with the measurement result through the Hungarian algorithm. According to the matching results, whether the spots are retained is determined. For the last problem, the new detected spots unmatched is recognized as new spots and the spots whose number of unmatched time reaches the threshold is set as spots that have left the video monitoring area and have to be deleted. The tracking process is illustrated in figure 6.
4.2.1. Prediction by Kalman filtering. The spot detected in the image of the previous frame are sequentially predicted according to the parameters of the Kalman filtering described above, and the covariance matrix and the Kalman gain coefficient are calculated.

4.2.2. Data match. The corresponding Euclidean distance between the measurement points and observation points is calculated, the Hungarian algorithm is used to match the two point sets according to the distance matrix. The distance threshold is set and the distance between the matching points is compared with the threshold to determine whether it is a valid match. If the measurement point is far from the observation point, the pairing is considered invalid.

4.2.3. Update by Kalman filtering. The effective matching points of observation based on the measurement points and the covariance matrix are updated.

4.2.4. Spot addition and deletion. Considering the possibility that new ships enter the video surveillance area, new spots need to be tracked. In the data matching process, in addition to the invalid match, the measurement points that are not matched are included and added to the current spot tracking data as new spots. At the same time, the unmatched points in the observation points are marked. If the time number of marking reaches the threshold, the spots may have left the video monitoring area and the observation points are deleted.

Spots tracking is achieved by iterating the above steps until the ship tracking is accomplished.

5. Case study and discussions
The VS2015 and OpenCV programming environment are chosen to realize ship detection and tracking in the nighttime surveillance video. Taking the ship surveillance video around 19 o’clock on March 22, 2018, as a case study of LSDT method verification, the image is 1920*1080, as shown in figure 1. The current time and camera label are marked on the upper left and lower right of the video screen due to the equipment, so the image is cropped before ship detection and tracking. The cropped image is shown in figure 7.
5.1. Light spot detection

5.1.1. Spot detection results. According to the method flow, the spots are detected firstly. In order to make the ship tracking effect obvious, the images are taken every 30 frames in the video for light spot detection and tracking. The images are taken every 30 frames from the first frame to the 991st frame in the video, and the number of spot detections is as shown in table 1.

| Frame  | Number of detected spots |
|--------|--------------------------|
| 1      | 31                       |
| 31     | 8                        |
| 61     | 9                        |
| 91     | 8                        |
| 121    | 8                        |
| 151    | 8                        |
| 181    | 8                        |
| 211    | 8                        |
| 241    | 8                        |

The results of spot detection in 1st, 181st, 361st, 541st, 721st, and 901st frame are shown in figure 8. It can be seen that the number of detected spots is relatively stable. The number of ship light spots is 3 to 4 and other spots are coastal architectural light spots. It can be concluded that the stability of spot detection by this way is satisfactory.

5.1.2. Gray threshold setting. When ships sail in the inland river, the influence of coastal lights and reflected lights from the river surface increase the difficulties of ship light spot detection. In order to
filter other spots, after the LOG convolution, the spots are filtered by the gray threshold. As shown in figure 9, when the threshold is set 60/70/80/90/100/110, the number of detected spots is 32/24/13/9/5/2. It is found through experiments that when the threshold is between 80 and 100, the spot detection result is more satisfactory; when the threshold is set to 100, the ship spots in some images are not detected. Therefore, 90 is taken as the gray threshold.

![Figure 9. Spots detection results under the different gray threshold](image)

5.2. Light spot tracking

5.2.1. Spot tracking results. According to the algorithm flow of multiple target tracking by Kalman filtering, the spots are tracked and the tracking results corresponding to figure 9 are shown in figure 10 (the distance threshold 10). The same spots in the adjacent frame images are connected by colored polylines.

![Figure 10. Spots tracking results](image)

It can be seen that the method based on LSDT can realize the goal of ship detection and tracking. The image tracking visual effect has been affected to some extent due to the fact that the number of spots detected on the same ship is not unique and the lights are flickering. However, it is feasible to determine ships and its running state at night through an ordinary camera by detecting the spots and tracking them.
5.2.2. Distance threshold setting. After matching the observation points with the tracking points by Hungarian algorithm, it is necessary to determine the results of match. If the distance between the matching points is greater than the distance threshold, it is considered to be an invalid match. In this paper, the distance threshold is obtained experimentally. The tracking result in 421st frame with distance threshold 5 is shown in figure 11(a) and the corresponding result in 871st frame with distance threshold 15 is shown in figure 11(b). It can be seen that when the distance threshold is 5, the same spots in adjacent frames is disconnected which affects the tracking result; when the distance threshold is 15, some unrelated spots are connected. Therefore, the distance threshold in this paper is set 10 and the corresponding tracking result is shown in figure 10.

![Distance threshold experiment results](image)

6. Conclusions
In this paper, a method of LSDT for nighttime ship detection and tracking is proposed, and the experiment based on the actual monitoring video verifies the effectiveness of the method. So far, the previous researches in ship detection at night are mostly based on infrared camera and SAR. By using LSDT, we are capable of detecting and tracking light spots of inland ship with an ordinary camera. Further researches are still necessary for improving the proposed method, such as: how to filter the lights of background and how to convert multiple target tracking into single target tracking for multiple spots of the same ship to improve the tracking effect.

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