TRAFFIC LIGHT RECOGNITION USING CIRCULAR SEPARABILITY FILTER

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Abstract: This paper proposes the camera-based approach to recognize the traffic light for driver assistance. The circular separability filter applied to RGB images extracts the area of the traffic light. The separability has large value in the boundary where the intensity between two areas changes like the step and it doesn't depend on the intensity difference (height of the step). Scanning the circular mask in each RGB image, the separability is calculated. The separability becomes large in an area where a color is homogeneous and a shape is similar to the circle. Therefore, the pixel with large separability is selected as the candidate of the traffic light. Unlike the conventional method which calculates the circularity from the binarized region, the proposed method can identify the traffic light whose outline is indistinct and whose radius is small. At first, the proposed method removes the region where the saturation is low and the brightness is extremely low or high because there is few possibility that the traffic light is included in these regions. Next, the circular mask is scanned in each RGB image captured from the on-vehicle color camera and the separability between the inside circle and the outside ring is calculated. The maximum value of separability calculated in RGB images is selected as the separability of each pixel. Pixels with large separability are detected as the candidate region of the traffic light. Finally, the candidate region around which inactive traffic lamps exist is identified as the traffic light. Experiments recognizing various traffic lights under various weathers and time show the effectiveness of the proposed method.

1 INTRODUCTION

More than 700,000 traffic accidents a year still occur in Japan though the number of traffic accidents tend to decrease recently. Because older drivers will also increase, it is expected that the risk of the traffic accident will rise in the future. To deal with this situation, many driving support technologies have been developed as part of Intelligent Transport Systems (ITS). It is important to decrease the traffic accident in the intersection because more than half of traffic accidents occur in intersections. In the intersection, overlooking or misidentifying a traffic light caused the serious accident. Therefore, the driving support system which rouses the attention or avoids danger by showing an aspect of the traffic light to the driver is very useful.

It requires large cost and large time to construct the road-to-vehicle communication system transmitting an aspect of the traffic light to vehicles by the telecommunication facility. Therefore, a lot of methods to recognize the color of the active traffic light in images captured from the on-vehicle camera have been proposed. Because an active traffic light is usually a red, yellow or green bright region, most of conventional methods first convert the RGB color space to some color spaces so as to detect candidate regions with specific colors of traffic lights. Then, candidate regions are detected in the converted image by the binarization and the morphological operation. Finally, traffic lights are identified by verifying information around candidate regions, e.g., their contours. M. R. Yelal et al. (M. R. Yelal, 2006) proposed the method using the La*b* color space. This method detects only traffic lights with simple background, e.g., clear sky because traffic lights are identified by verifying edge information around candidate regions. L. Tsinas et al. (L. Tsinas, 1996) proposed the method using the HSI color space. This method causes a lot of false detection because candidate regions of traffic lights are verified by only the size of the region. Several methods identifying the traffic light from the circularity of the candidate region were proposed because the outline

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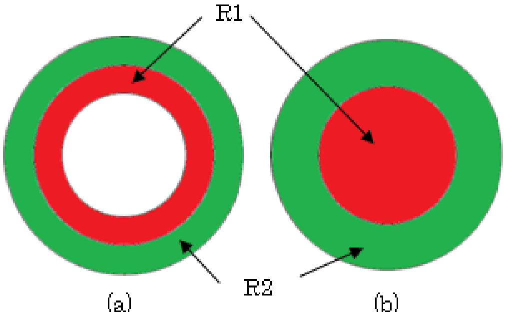
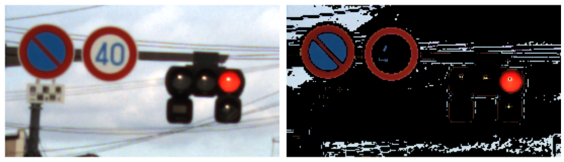


Figure 1: Circular separability fileter. (a) Conventional filter. (b) Proposed filter.

of the traffic light is a circle. K. Lu et al. (K. Lu, 2005) evaluated the circularity of the traffic light by the difference between the maximum distance and the minimum distance from the center of the candidate region to the contour point. M. Omach et al. (M. Omachi, 2009) evaluated the circularity of the candidate region by the Hough Transform. J. Park et al. (J. Park, 2009) distinguished whether or not the candidate region is the traffic light by the Haralick's circularity and intensities in right and left neighbor regions. D. Nienhuser et al. (D. Nienhuser, 2010) use a morphological operator to extract circular regions. These methods estimate the circularity of the candidate region obtained by binarizing the color conversion image. Therefore, they are very sensitive to the threshold for the binarization. Moreover, it is difficult to identify the traffic light whose shape is distorted in an image because of the brightness saturation or whose view is small because of the distance. Though some methods (A. Nakano, 2010) recognize the traffic light by learning a variety of traffic light images, it is difficult to detect the traffic light in the complicated background under various brightness.

This paper proposes the method to recognize the traffic light by applying the circular separability filter (K. Fukui, 1988), (K. Fukui, 1995) to RGB images. The circular separability filter outputs large value in a round area where color is homogeneous. The separability is calculated by scanning the circular mask in each RGB image and the pixel with high separability is detected as the candidate of the traffic light. Unlike the conventional method which calculates the circularity from the binarized region, the proposed method can identify the traffic light with indistinct outline and small radius.

At first, the proposed method converts the RGB color space to the HLS color space and the region where the saturation is low and the brightness is extremely low or high is removed from the image.



(a) (b)

Figure 2: Preprocessing. (a) Input image. (b) Preprocessing image.

Next, the circular mask shown in Fig.1(b) is scanned in each RGB image while changing its radius. The pixel with large separability is detected as the candidate of the traffic light. The circular separability filter has been used the pupil detection (K. Fukui, 1988). This method used the double ring mask shown in Fig.1(a) because the purpose is to find the round contour regardless of its internal pattern. This mask tends to detect the traffic sign or the signboard as the traffic light wrongly. Finally, it is examined whether the inactive traffic lights exist around the candidate region. If inactive traffic lights are detected in the right and left or top and bottom of the candidate region, it is identified as a traffic light.

2 TRAFFIC LIGHT DETECTION

2.1 Preprocessing

The saturation of the active traffic light is usually high. Moreover, the black region or the white region can be excluded from the candidate of the traffic light. Therefore, the region where the saturation is low and the brightness is extremely low or high is removed from the image.

The RGB color space is converted to the HLS color space. In the HLS color space, the hue H_i is represented as the value between 0 and 360 degrees. The saturation S_i and the brightness B_i are represented as the value between 0 and 1. The pixel P_i satisfying the condition (1) is excluded from the candidate of the traffic light.

$$P_i: S_i < THs \text{ or } B_i < THb \text{ or } B_i > 1 - THb \quad (1)$$

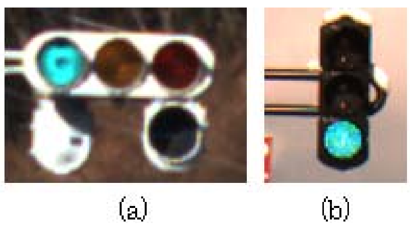


Figure 3: Typical traffic lights in Japan.

THs and THb are thresholding parameters decided experimentally. In the experiment, THs was set to 0.33 and THb was set to 0.12. Fig.2(b) shows the image after preprocessing. White or black areas, e.g., clouds in the sky are removed from the input image shown in Fig.2(a).

2.2 Circular Separability Filter

As shown in Fig.3, the frame of the traffic light is white or black typically in Japan. Our method detects the circular oundary between the traffic lamp and the surrounding white or black region by the circular separability filter. The circular mask shown in Fig. 1 (b) consists of the inside round area R_1 and the outside ring area R_2. The separability η is given by

$$\eta = \frac{\sigma_b^2}{\sigma_r^2}$$

$$\sigma_b^2 = n_1\left(\overline{P_1} - \overline{P_m}\right)^2 + n_2\left(\overline{P_2} - \overline{P_m}\right)^2 \quad (2)$$

$$\sigma_T^2 = \sum_{i=1}^{N}\left(P_i - \overline{P_m}\right)^2,$$

where n_1 is the number of pixels in R_1, n_2 is the number of pixels in R_2, N is the total number of n_1 and n_2, P_i is the intensity of the pixel i, P_1 is the average intensity in R_1, P_2 is the average intensity in R_2 and P_m is the average intensity in the total region of R_1 and R_2. The separability η has a value within a range from 0.0 to 1.0. It approaches 1.0 when the intensity between two areas changes like the step and it approaches 0.0 when the intensity between two areas changes gradually.

The separabirity η between R_1 and R_2 becomes large when the intensity of the pixel in R_1 is similar, the intensity of the pixel in R_2 is also similar and the intensity in R_1 is different from the intensity in R_2. Therefore, the separability η becomes large when the circular boundary between R_1 and R_2 corresponds to the contour of the traffic lamp. Traffic signs or signboards often have some textures in the inside. The circular separability filter (Fig. 1 (b)) proposed in this paper can suppress to detect round contours of traffic signs or signboards wrongly.

The separability is unstable in the hue image because hue in a white or black region is not decided correctly. Therefore, our method calculates the separability in each RGB image.

Figure 4: Search area.

2.3 The Candidate Region of the Traffic Light

As shown in Fig.4, the image above the vanishing line is divided equally into n search areas S_i (i=1~n) because traffic lights usually exist above the vanishing line in an image. To search for the candidate of the traffic light, the circular mask is scanned in each area S_i while changing the radius. Far traffic lights exist in a lower area S_i than near ones. The radius of the traffic lamp is smaller in a lower area S_i. Therefore, the variable range of the radius in a lower area is set smaller than a upper area. In experiments, we divided the image above the vanishing line into twenty search areas S_i (i=1~20) as shown in Fig.4. S_1 is the top area and S_{20} is the bottom area. The radius in S_1 is changed within the range from 15 pixels to 20 pixels. On the other hand, the radius in S_{20} is changed within the range from 4 pixels to 9 pixels. In each area S_i, twenty positions or less with the large separability η are selected as the candidate region C_i of the traffic light. The radius of the circular mask whose separability is the maximum is chosen as the radius of C_i. In Fig.5(a), candidate regions whose separability are high are shown in purple round regions. Some mis-detection regions appear in candidate regions.

Figure 5: Verification. (a) Candidate regions whose separability are high. (b) Candidate regions after color verification. (c) Candidate regions after evaluating E_S.

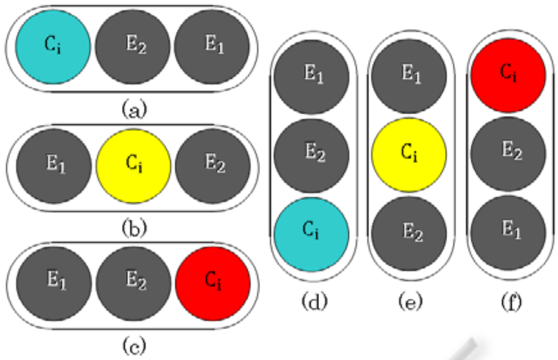


Figure 6: The position of the candidate region and inactive areas. (a) Blue in horizontal type is active. (b) Yellow in horizontal type is active. (c) Red in horizontal type is active. (d) Blue in vertical type is active. (e) Yellow in vertical type is active. (f) Red in vertical type is active.

2.4 The Verification of the Candidate Region

Each candidate region Ci is verified by color and the existence of inactive traffic lamps.

2.4.1 Verification of color

The RGB image is converted to the HSV color space and the average hue value H_m is calculated in the candidate region C_i. The candidate region Ci not satisfying the condition (2) is deleted from candidate regions because the color of the traffic light is near red, yellow, or green. It is difficult to distinguish red or yellow by using only hue value because yellow hue is close to red hue. Then, our method discriminates red or yellow by using the average blue value Rm and the average green value Gm, in addition to Hm.

$$\begin{aligned} &\text{Green} &&: 140 < H_m < 200 \\ &\text{Yellow} &&: 10 < H_m < 60 \text{ and } |B_m - G_m| > 120 \\ &\text{Red} &&: 0 < H_m < 10 \\ & && \quad 10 < H_m < 60 \text{ and } |B_m - G_m| < 120 \end{aligned} \qquad (3)$$

2.4.2 Verification of Two Neighboring Region

If the candidate region is the true traffic light, two inactive traffic lamps are sure to exist around the candidate region. The arrangement of them can be expected because the color of the active traffic lamp has been decided by color verification. As shown in Fig.3, there are two types of traffic lights in Japan. One is the vertical type and the other is the horizontal type. When the color of the candidate region C_i is green, inactive two lamps E_1 and E_2

exist in the right side or the upper part of C_i as shown in Fig.6 (a) and (d). When the color of the candidate region C_i is yellow, one inactive lamp E_1 exists in the left side or the lower part and another inactive lamp E_2 exists in the right side or the upper part, as shown in Fig.6 (b) and (e). When the color of the candidate region C_i is red, two inactive lamps E_1 and E_2 exist in the left side or the lower part, as shown in Fig.6 (c) and (f).

The location and the radius of E_1 and E_2 are estimated from those of C_i. In E_1 and E_2, the circular separability and the average brightness in the HSV color space are examined because an inactive traffic lamp is a round region where with low intensity. The evaluation value K_i given by the equation (4) is estimated to verify the existence of the inactive traffic lamp.

$$K_i = B\eta_i + (1 - AVb_i) \qquad (4)$$

In equation (4), $B\eta_i$ is the circular separability in E_i (i= 1 or 2) and AVb_i is the average brightness in E_i (i= 1 or 2).

If E_i is an inactive traffic lamp, K_i is large because $B\eta_i$ of the inactive traffic lamp is large and AVb_i of it is small. If either K_1 or K_2 is low, this region is excluded from the candidate regions. In remaining candidate region, the evaluation value E_s given by the equation (5) is estimated. The candidate region whose E_S is large is identified as the traffic light.

$$E_s = \eta + kAV_s + K_1 + K_2 \qquad (5)$$

In equation (5), η is the circular separability of the candidate region, k is the constant parameter larger than 1.0, AV_s is the average of the saturation in the candidate region. In experiments, k was adjusted to 2.0.

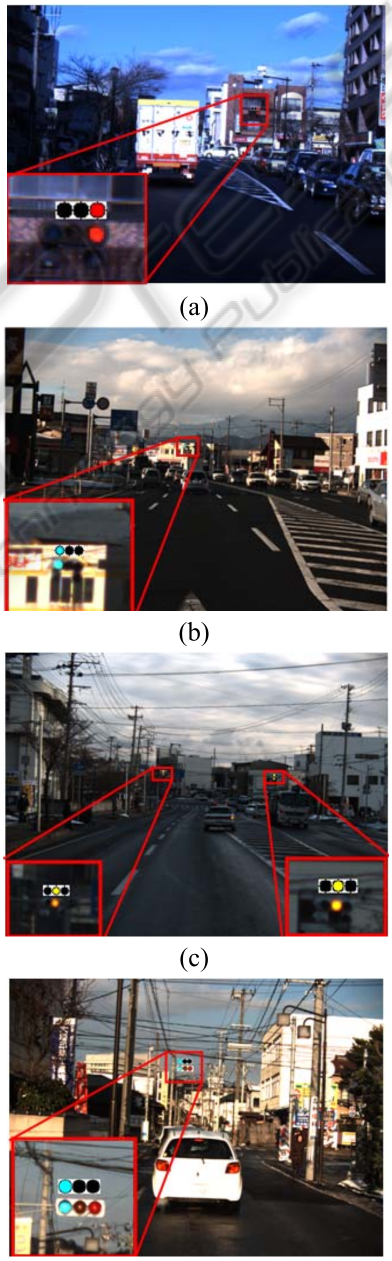
Figure 5(c) shows the candidate region whose E_s is large. Only traffic light is detected exactly.

3 EXPERIMENTS

Experiments have been conducted to recognize various traffic lights in images captured from the on-vehicle camera. The focal length is 16 millimeters and the image size is 1600 × 1200 pixels. Figures 7 and 8 show some recognition results. Traffic lights in complicated backgrounds are recognized correctly in Fig.7 (a), (b), (c) and (d). Traffic lights at the backlight are recognized in Fig.8 (a). It is difficult to recognize traffic lights in Fig.8 (b), (c) and (d) because the brightness of active lamps is very low.

Table 1: Evaluation result.

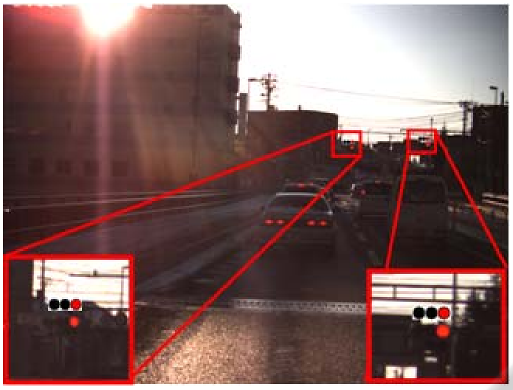
	10 pixels or more	4 pixels or more
Detected traffic lights	47	301
The number of true positive	46	275
True positive rate(%)	97.8	91.4
The number of false positive	0	16
False positive rate(%)	0	5.3
The number of false negative	1	10
False negativerate(%)	2.2	3.3



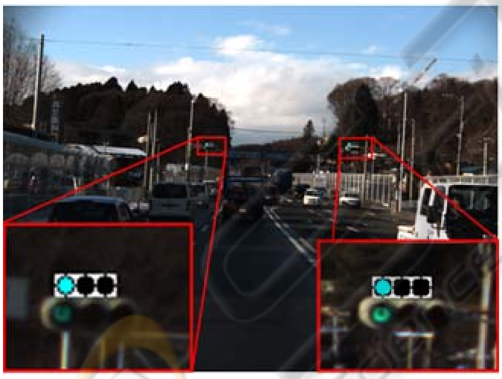
(a) (b) (c) (d)

Figure 7: Some experimental results (1).

However, the proposed method can recognize them correctly because the circular sparability catches slight contrast between a traffic lamp and a frame around it. In fig.8 (e), a part of the traffic light is lacked because of the reflection caused by direct sunshine. However, the active red light is detected correctly. In experiments conducted under a variety of weathers and time, active traffic lamps whose radius are four pixels or more in images have been recognized. Table 1 shows the evaluation result of the proposed method. For the traffic light whose radius is ten pixels or more, the recognition rate is 97.8%. For four pixels in a radius, it is 91.4%.

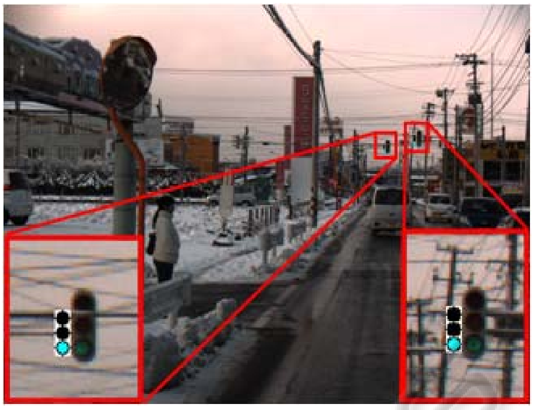


(a)



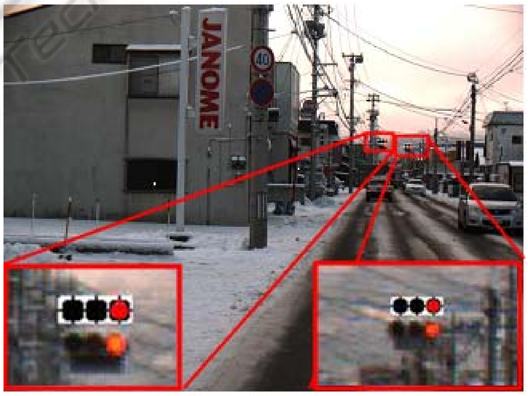
(b)

(c)



(d)

(e)



(f)

Figure 8: Some experimental results (2).

4 CONCLUSIONS

This paper proposed the method for the traffic light recognition using the on-vehicle camera. The candidate of the traffic light is detected by the circular separability filter applied in each RGB image. Unlike the conventional method using the circularity calculated from the binarized candidate region, the proposed method can identify the traffic light whose outline is indistinct and whose radius is small because the separability doesn't depend on the intensity difference. The candidate region around which inactive traffic lamps exist is identified as the traffic light. In experements,we comfirmed that traffic lights whose radius is four pixels or more were recognized by the accuracy of 91.4 %. In the future, we will improve the performance and the processing time by tracking detected regions. Moreover, the proposed method will be evaluated by comparison with several different approaches.

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