Journal of Electrical Engineering 6 (2018) 107-115
doi: 10.17265/2328-2223/2018.02.007

A Study on Fast and Robust Vanishing Point Detection System Using Fast M-Estimation Method and Regional Division for In-vehicle Camera

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Abstract: The vanishing point detection technology helps automatic driving. In this paper, the straight lines on the road associated with the vanishing point are extracted efficiently by using the regional division and angle limitation. And, the vanishing point is detected robustly by using the fast M-estimation method. Proposed method could detect straight-line features associated with vanishing point detection efficient on the road. And the vanishing point was detected exactly by the effect of the fast M-estimation method when the straight-line features not associated with vanishing point detection were detected. The processing time of the proposed method was faster than the camera frame rate (30 fps). Thus, the proposed method is capable of real-time processing.

Key words: Automatic driving, Hough transform, fast M-estimation method, line detection, vanishing point.

1. Introduction

The automatic driving of cars is currently being actively studied. The study of the automatic driving of cars includes specialized situations such as the avoidance of obstacles [1] and parking [2-5] etc. [6-9]. However, this research detects the vanishing point from the in-vehicle camera images. This vanishing point is an important point, a car should go toward this point [10].

There are several methods of detecting a vanishing point. This study uses the Hough transform [11, 12] to detect a vanishing point. The road has features that aid in the detection of the vanishing point, such as the center line marked on of the road. These features are straight-lines. The straight-line feature is detected by Hough transform. Then, the vanishing point is estimated by the point of intersection of the detected straight-line group.

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However, straight-line features which are not associated with the vanishing point (such as utility poles and grade separations) exist on the road. The method devised by Tokuda et al. [13] made it easy to detect a straight-line associated with the vanishing point by narrowing down an area, and detecting a straight-line progressively.

In this study, the above method is expanded. A straight-line feature on the road not associated with the vanishing point is removed by limitation of the detect area and straight-line angle. And a straight-line feature associated with the vanishing point is quickly detected. And the vanishing point is detected robustly by the fast M-estimation method [14-17] without being affected by the false detection more.

2. Detection Method of Straight-Line Associated with the Vanishing Point

Various straight-line features exist on a road. As a car proceeds straight ahead, a camera set behind the rear-view mirror takes images. The main straight-line features associated with vanishing point detection are road surface indications such as the centerline and traffic lane boundary lines. In addition, the guardrail bars, the step of the height difference between the road and the sidewalk, and low walls are also straight-line features associated with the vanishing point detection. However, the straight-line features not associated with vanishing point also exist on or near the road, such as stop lines, telephone poles, the pillars of road signs, and pedestrian bridges. Although electric wires extending parallel to a road converge at the vanishing point, they are not straight-line features in many cases because they are slack.

The straight-line features associated with vanishing point detection have a common property. The main straight-line features exist on the right and left rectangular domains of the lower half of the in-vehicle camera image. In many cases, few effective straight-line features exist in the domain of the upper half of the in-vehicle camera image. In addition, in the neighborhood of the center in the domain of the lower half, the straight-line features associated with vanishing point are less likely to exist. Instead, straight-line features not associated with the vanishing point, such as arrows and diamonds indicating the approach of a pedestrian crossing, are more likely to exist. Thus, a narrow central region in the lower half is excluded, such as shown in Fig. 1a. And, the angles of the straight-line features associated with vanishing point detection are 100 degrees to 170 degrees in the right area, and 10 degrees to 80 degrees in the left area. Most are straight-line features perpendicular or horizontal even if the straight-lines features not associated with vanishing point detection on the road could be included in this domain. Thus, it is thought that most of the straight-line features not associated with vanishing point detection can be removed by reducing the range of angles of the straight-lines used in the detection as shown in Fig. 1b.

The detection of straight-line features not associated with vanishing point detection is thought that largely reduced by an effect of the area division and angle limitation. Thus, a dashed traffic lane boundary line is difficult to detect by Hough transform in comparison with a solid line, but the straight-line degree relatively becomes higher by using proposed method, and it is thought that it becomes easy to detect.

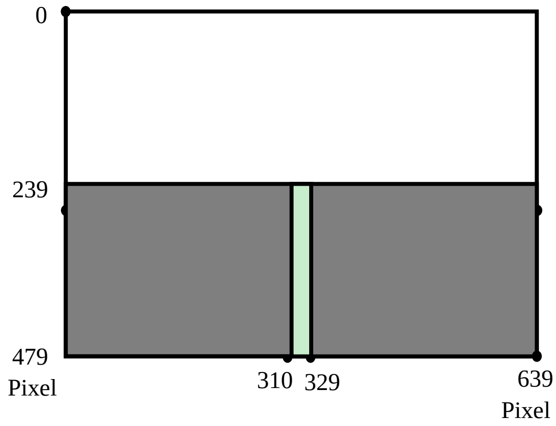
Then, Hough plane is created by Eq. (1) using only Fig.1 area data.

$$\rho = x \cos \theta + y \sin \theta \tag{1}$$

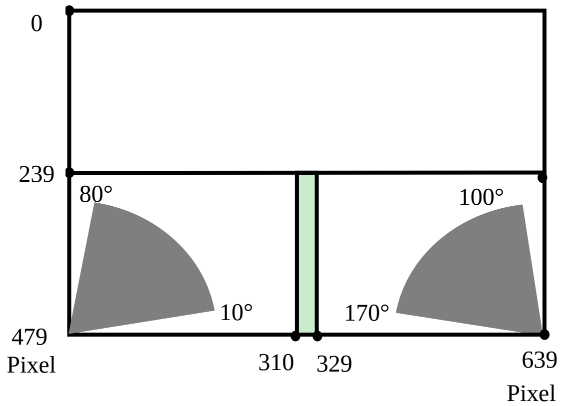
Next, the number of straight-lines to be detected is considered. The method of Tokuda et al. [13] detected 21 straight-lines in total. As for the proposed method, the detection of straight-line features not associated with vanishing point detection is expected to be greatly reduced. The straight-line detection area becomes less than half after area division. And the target angles also become less than half owing to the angle limitation. Thus, the number of straight-lines detected in the Hough transform step of the proposed method is about 1/4 of that in the method of Tokuda et al. In other words, the proposed method detects ten lines (each five straight-lines are detected in the right and left areas).

It is assumed that other cars may hide straight-line features associated with vanishing point detection. However, the traffic lane boundary lines on both sides, which are the most influential candidates, are not covered except during lane-changing if the distance from the car in front is not extremely small.

Edge detection is carried out in preparation for detecting a straight-line by Hough transform. However, after analysing the result of edge detection using the in-vehicle camera image, it was found that when a truck was in the neighboring traffic lane, the design of the carrier of the truck was detected as edges (Fig. 2). Horizontal features of the carrier of the truck are straight-line features associated with vanishing point. However, the straight-line features associated with vanishing point cannot be accurately detected in this situation. Therefore, a regional division plan is incorporated. If the domain of the right-angle trapezoid, as shown in Fig. 3 is used, the carrier of the truck in the neighboring traffic lane domain is removed. Because



(a) Regional division



(b) Angle limitation

Fig. 1 Regional division and angle limitation.

Fig. 2 Result of the edge detection of the track.

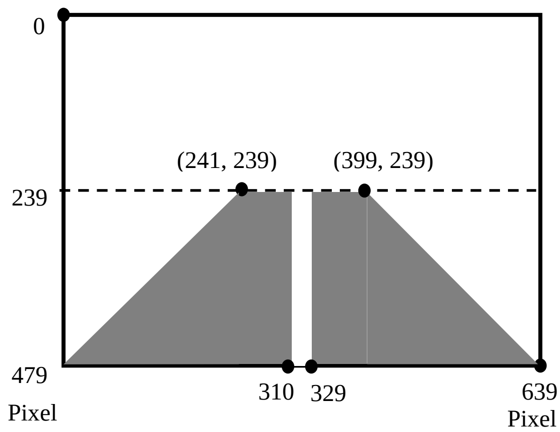


Fig. 3 Regional division 2 (Trapezoid).

targeted ranges in the Hough transform are less than rectangular ranges, an increase in the detection speed can be expected. However, the far side traffic lane line of the neighboring traffic lane is removed from the detection domain. Thus, the risk of reducing the number of straight-line features associated with the vanishing point arises. Which range is better is determined in a later experiment.

3. Vanishing Point Detection by the Fast M-Estimation Method

Even if domain division and angle restrictions are used, straight-line features associated with the vanishing point, such as shadows, may be detected. When using the least-squares method, a general method, when even one false detection line is included, the output result becomes strange, as shown in Fig. 4. Thus, the vanishing point cannot be detected exactly. As a solution, the vanishing point is detected by the fast M-estimation method [14-17], instead of the least-squares method, for determining the point of intersection of the group of detected straight-lines. The vanishing point can be detected rapidly and robustly without being affected by the false detected lines, as is Fig. 4, by the fast M-estimation method. The value of the estimation function of the central region in the fast M-estimation method agrees with that of the quadratic estimation function of the least-squares method. And the value of other than neighborhood of the center converges to 0 (Fig. 5). Thus, the output result of the fast M-estimation method is in accord with the result of the least-squares method without false detected point. And the fast M-estimation method shows robustness characteristics only for false detected points.

The details of the processing procedure of the proposed method for detecting the vanishing point are shown. First, for noise reduction, the Gaussian filter is applied to the input image. Next, edge detection is carried out by the Canny edge detector method. Then, the straight-line features associated with the vanishing point are detected by Hough transform with division and angle limitation (as explained in Section 2). The coordinates of the point of intersection of all straight-line combinations are detected. Then a weight is voted to the coordinates of intersection. And the fast M-estimation method is applied for each weight. The second B-spline basis function which is the error estimate function of the fast M-estimation method, can be realized quickly by applying three times of box filters. Thus, the coordinate where weight reaches maximum is output as the vanishing point after three times of box filters were applied like Fig. 6. Here, the filter size was assumed to be 9 × 9 pixels. In addition, the vanishing point of the in-vehicle camera image exists in the neighborhood of the central part of image when right and left turns are excluded. Thus, the outer periphery area removes the range applying the fast

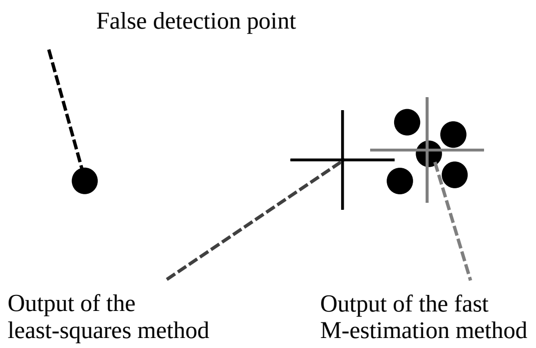


Fig. 4 Least-squares and fast M-estimation method.

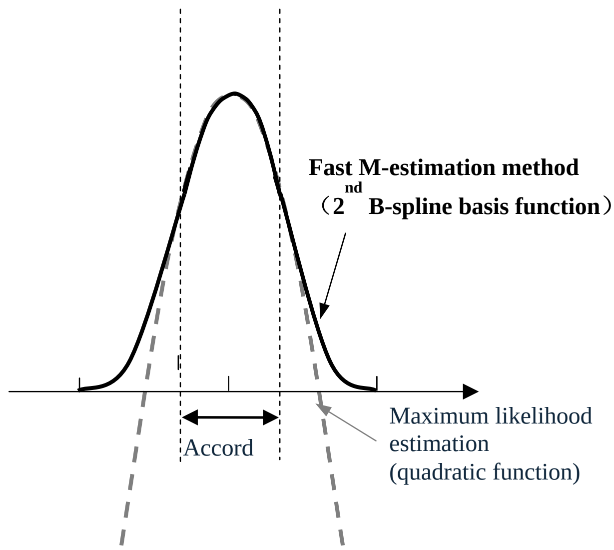


Fig. 5 The estimation functions.

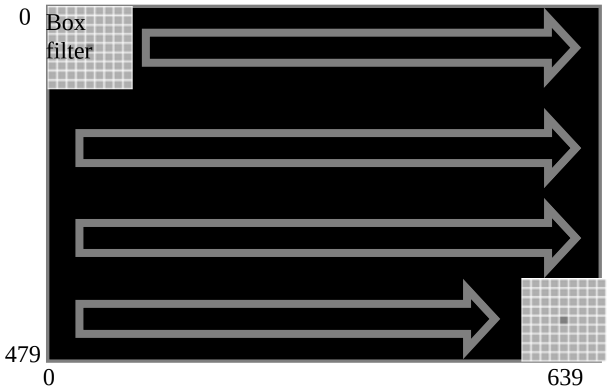


Fig. 6 Filtering process of the fast M-estimation method.

M-estimation method. Fig. 7 shows the flowchart of the proposed method.

In addition, by inspecting in-vehicle camera images, the range in which the vanishing point could exist is determined. As a result, the range determined by the fast M-estimation method was narrowed down to that shown in Fig. 8. This method can increase the detection speed without loss of robustness.

4. Experiments

4.1 Experiments of Vanishing Point Detection

By the proposed method, the vanishing point is detected from the image of the in-vehicle camera (Fig. 9). The specifications of the in-vehicle camera are shown in Table 1. The in-vehicle camera is an inexpensive model with a market price of approximately \$70. Thus, its performance of this in-vehicle camera is poor. With this in-vehicle camera, the images of the Tomei expressway were recorded.

Fig. 10 shows examples of the result of straight-line detection by the proposed method and the method of Tokuda et al., using an image with the specifications mentioned above. By the method of Tokuda et al. (Fig. 10a), many straight-line features not associated with the vanishing point, such as a telephone pole or electric wire, were detected. Part of the traffic lane boundary line was not detected because other straight-lines had higher straightness. However, the proposed method (Fig. 10b) succeeded in greatly reducing the detection of straight-line features (a telephone pole or electric wire) not associated with the vanishing point.

Fig. 11 shows results of vanishing point detection by the least-squares method and the fast M-estimation

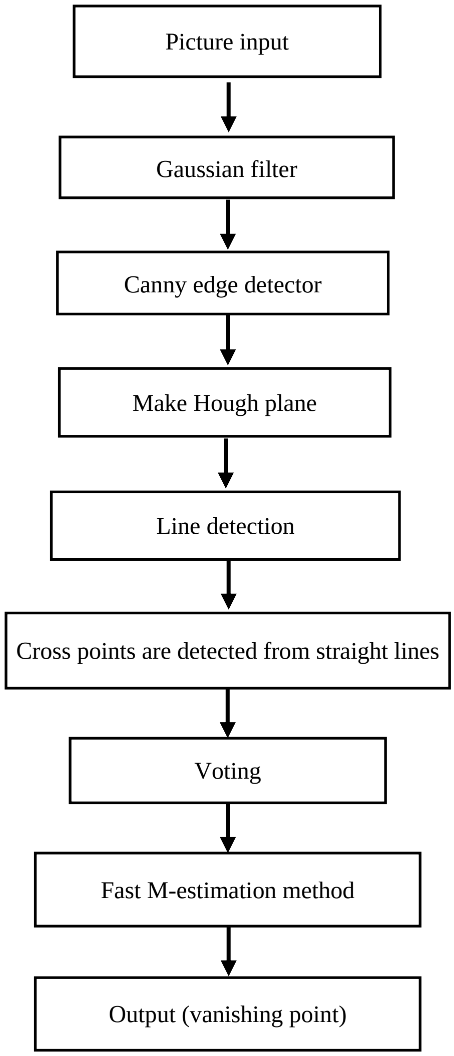


Fig. 7 Flowchart of the proposed method.

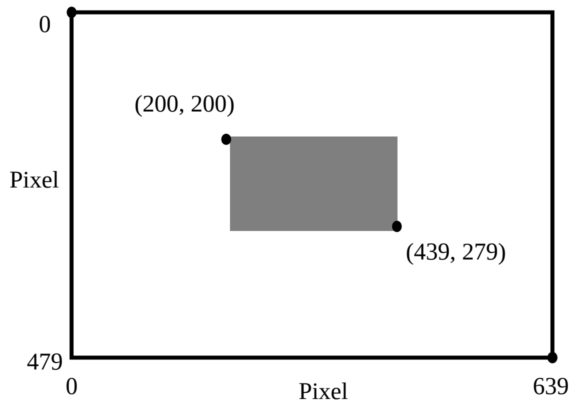


Fig. 8 Applied limited area of the fast M-estimation method.

Fig. 9 In-vehicle camera.

Table 1 Specifications of the in-vehicle camera.

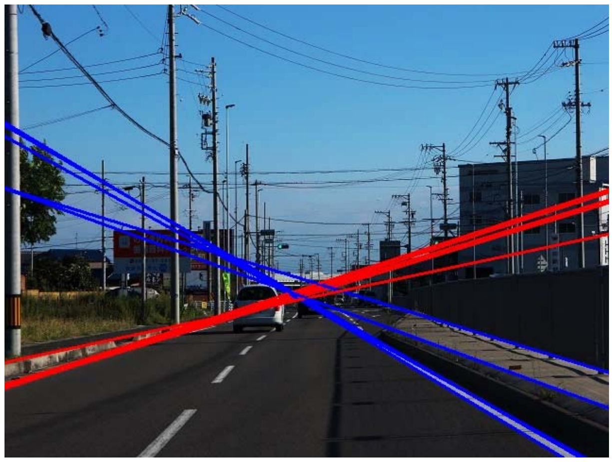
Model name	Yupiteru DRY-mini1X
Picture element	1,300,000 pixel color CMOS
Image size	VGA (640 × 480 pixel)
Frame rate	30 fps
Lens angle of view	135 degrees
The biggest record angle of view	Diagonal 118 degrees (horizontally 100 degrees, vertical 53 degrees)

method using the point of intersection of a group of straight-lines detected by the proposed method. The diagonal part of the safety zone, which is not associated with the vanishing point, was detected as a straight-line. The circle on the left is a result of vanishing point detection by the least-squares method. On the other hand, the circle on the right is a result of vanishing point detection by the fast M-estimation method. When the least-squares method is used, the vanishing point is affected by the false detected line. However, the vanishing point is correctly detected when fast M-estimation method is used, and is not affected by the false detected line.

In the experiment, 100 images each for every situation or time (daytime, evening, night, in a tunnel), as shown in Fig. 12 were used. In addition, the judgment of true or false detection was carried out as follows. If the vanishing point detected by observation was included inside the detection circle of a radius of ten pixels, the detection was deemed successful (Fig. 13). Fig. 14 is result of each classification image detection sample (daytime, evening, night, in a tunnel).

Table 2 shows the results of the vanishing point detection rate. As a result of the experiment, the following was proven. The combination of domain division and angle limitation and the fast M-estimation method resulted in an approximately 10% improvement

(a) Tokuda et al. method



(b) Proposed method

Fig. 10 Result of the line detection.

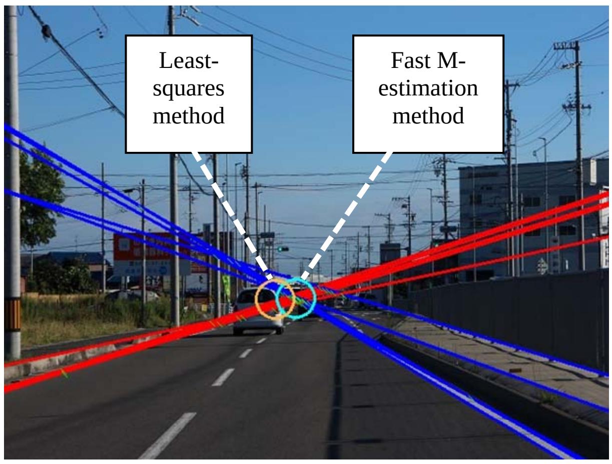
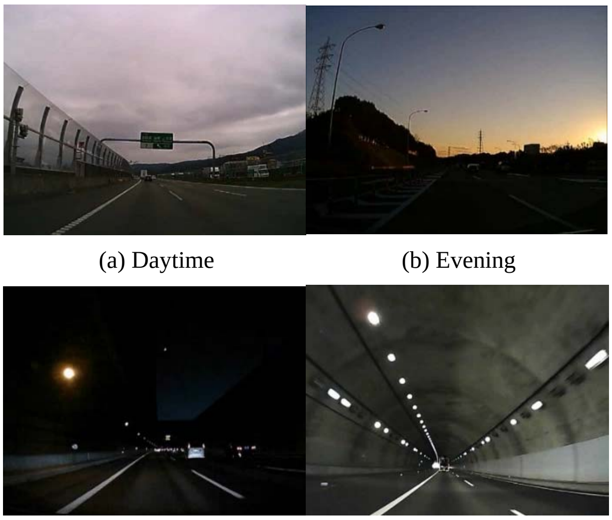


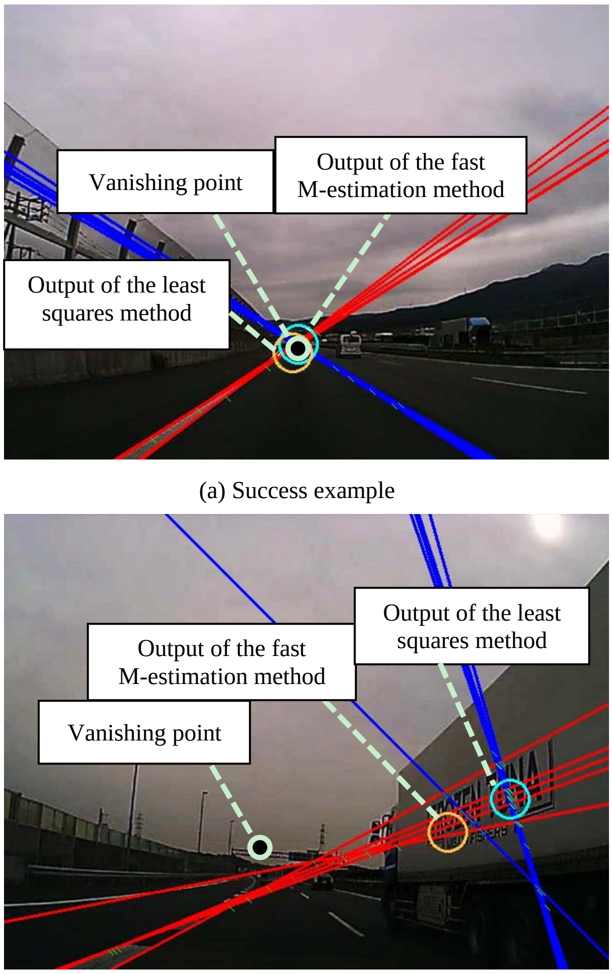
Fig. 11 Result of the vanishing point detection.



(a) Daytime (b) Evening

(c) Night (d) Tunnel

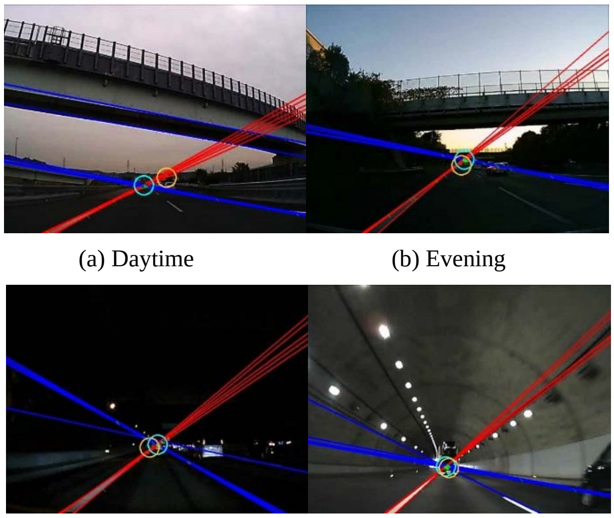
Fig. 12 Classification image example according to the situations.



(a) Success example

(b) Failure example

Fig. 13 Success example and failure example.



(a) Daytime (b) Evening

(c) Night (d) Tunnel

Fig. 14 Result of the each classification image detection.

in the rate of detection each. Therefore, rate of detection of the proposed method improved approximately 22.1% compared with the traditional method. And the rate of detection of the proposed method became 73.8%. At the rate of detection according to the situation, the rate of detection in the evening was low remarkably. The reason for this is considered. The contrast of the straight-line features associated with vanishing point was approximately reduced by strong backlight. Thus, the straight-line features associated with the vanishing point disappeared at a step of the edge detection.

In addition, the rate of detection of the right angle trapezoid domain was slightly superior to that of a rectangular domain, as found by comparing the results of the two kinds of proposed methods.

The results of the two methods (rectangle and right-angle trapezoid) were different only when a truck was in the neighboring traffic lane. There was no problem of the far side traffic lane line of the neighboring traffic lane being removed from the detection domain. However, as a result of the experiment, the lens distortion of the peripheral region was found to be large in the cheap in-vehicle camera. Thus, the far traffic lane boundary line was not detected very much without being reflected as a straight-line.

Table 2 Rate of detection by the situations (%).

Line detection method		Tokuda et al.		Proposed method (Rectangle)		Proposed method (Trapezoid)	
Vanishing point detection method		Least-squares	Fast M-estimation	Least-squares	Fast M-estimation	Least-squares	Fast M-estimation
Situation	Daytime	59	63	63	82	69	88
	Evening	34	24	24	28	28	28
	Night	53	68	79	91	79	91
	Tunnel	61	87	85	94	86	95
Average		51.7	60.5	62.8	73.8	65.5	75.5
Average (Except the evening)		57.7	72.7	75.7	89.0	78.0	91.3

Table 3 Specification of the PC.

CPU	Intel® Celeron ® CPU887 @ 1.50 GHz
Main memory	4 GB
OS	Windows 7 Professional 32bit
Software	Visual Studio 2013 Ultimate (C++)

Table 4 Processing time of the vanishing point detection.

Method	Processing time [ms]
Tokuda et al. and least squares method	334.1
Proposed method 1 (Rectangle and normal Fast M-estimation method)	149.0
Proposed method 2 (Trapezoid and limited area Fast M-estimation method)	32.4

The rate of detection in the evening was low remarkably. The contrast of a straight-line feature associated with vanishing point was reduced by the strong low-angle sun backlight. And the straight-line feature associated with the vanishing point was disappeared at the stage of edge detection. In this problem, the hardware improvement of the camera, not image processing, is necessary. In the right-angle trapezoid domain, the rate of detection that removes the case of evening, was 91.3% (over the 90%).

Other newly gained knowledge is as follows. The Hough transform was able to detect a large-radius curve of the expressway degree without a problem.

4.2 Experiments of the Processing Time

Next, the processing time is considered. Table 3 lists the specifications of the PC used in the experiment. It is a low performance PC. Table 4 shows the average processing times of each methods. The right-angle trapezoid domain method was faster than the rectangle domain method, and was also superior in the processing time. The right-angle trapezoid domain decreased to less processing time than one-tenth processing time of the proposed right-angle trapezoid domain method (32.4 ms) was faster than the camera frame rate (30 fps = 33.3 ms). Thus, the proposed method is capable of real-time processing.

5. Conclusions

The proposed method could detect straight-line features associated with the vanishing point effectively from in-vehicle camera images by adopting suitable domain division and angle limitation. And, the vanishing point was detected accurately by the effect of the fast M-estimation method even when a straight-line feature not associated with vanishing point detection was detected. The processing time of the proposed method was faster than the camera frame rate (30 fps). Thus, the proposed method is capable of real-time processing.

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