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Diagonally-reinforced Lane Detection Scheme for High-performance Advanced Driver Assistance Systems

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Abstract—**In this paper, several optimizations are proposed to enhance the quality of lane detection algorithms in automotive applications. Considering the diagonal directions of lanes, the proposed limited Hough transform newly introduces image-splitting and angle-limiting schemes that relax the number of possible angles at the line voting process. In addition, unnecessary edges along the horizontal and vertical directions are pre-defined and removed during the edge detection procedures, increasing the detecting accuracy remarkably. Simulation results shows that the proposed lane recognition algorithm achieves an accuracy of more than 90% and a computing speed of 92 frame/sec, which are superior to the results from the previous algorithms.**

Index Terms—**Advanced driver assistance systems, image processing, lane recognition, low-complexity digital systems, real-time embedded systems**

I. INTRODUCTION

For the better quality of driving, the recent technologies of advanced driver assistance system (ADAS) are getting more attentions over the past decades. Among the various techniques, the image-based lane recognition algorithm plays an important role to prevent unexpected accidents [1-3]. In general, the edge-based lane detection, which consists of Canny edge detection followed by Hough transform, is widely applied to the commercial vehicles due to its simple but accurate processing steps compared to the color-based [4, 5] and sampling-based algorithms [6]. However, the conventional edge-based algorithm suffers from unnecessary edges from the obstacles in practical road images, resulting the slow realization. If the number of obstacles increases, moreover, the computing complexity of the previous work increases significantly because of the numerous candidates at the voting process.

Considering the characteristics in road images, in this paper, we present several optimization methods that can relax the computing complexity of the lane detection problem while improving the recognition accuracy. The propose algorithm first limits the voting process of Hough transform by setting the tested range of angles. Then, the candidates of lanes are pre-estimated by checking the directions of edges, reducing the computing overheads at the line-voting process. By eliminating the unnecessary computations, the proposed lane detection algorithm enhances the processing time as well as the detection accuracy compared to the conventional method.

This paper is structured as follows: Section II presents the previous image-based lane detection algorithms and Section III details the proposed processing steps. The simulation results are shown and compared to the conventional work in Section IV, and the conclusion remarks are finally made in Section V.

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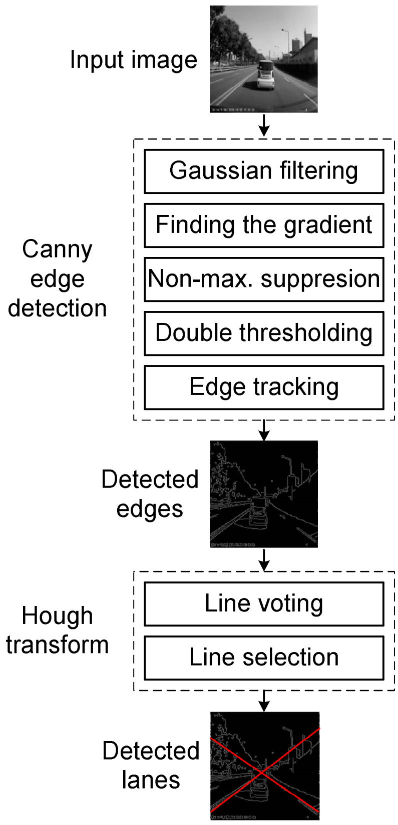

Fig. 1. Conventional lane detection processing.

II. PREVIOUS ALGORITHMS

As illustrated in Fig. 1, the previous edge-based lane detection algorithm conventionally consists of two steps; Canny edge detection [7], and Hough transform [8]. During Canny edge detection, the input gray-scaled image is firstly passed through several filters to reduce the noise level (Gaussian masking) and to find the gradient information. After finding the gradient, the maximum magnitude values are survived by suppressing non-maximum values. Then, two pre-defined thresholds are used for determine the type edges; strong and weak edges. Finally, weak edges are tested by tracking the strong edges as depicted in Fig. 1. After finding the detailed edge information, Hough transform is used to detect the specific lane [8]. More precisely, each edge position generates several pairs of θ and d, which denote all the possible lines including the corresponding point. As shown in Fig. 2, θ represents the angle between the selected line and the x-axis, and d stands for the distance of the line from the origin. If a certain value of θ is selected, the distance d can be directly computed by

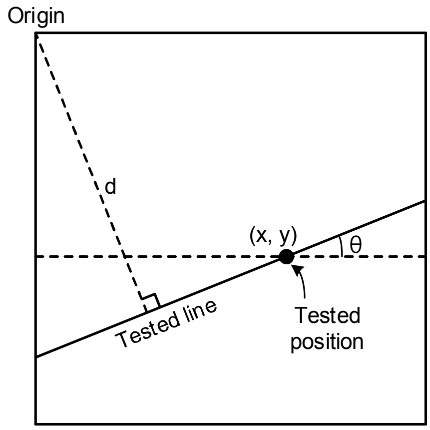

Fig. 2. Coordinate generations during the voting process.

using the following equation; $d = x\sin\theta + y\cos\theta$, where (x,y) denotes the coordinate of the tested edge position. By increasing θ by 1 degree, 180 pairs are voted from each edge, and then the first two lines with the most votes are determined as detected lanes.

Among the numerous recognition steps, in general, the line voting procedure is one of the most complicated parts as it collects all the possible lines defined by the detected edges [9]. Hence, several researches have been introduced for the practical solution by reducing the processing costs of Hough transform. Considering the characteristics of road imagesd, the region of interests (RoI) may be carefully selected to remove unnecessary parts that cannot be the lane positions [8]. In order to relax the complexity of Hough transform, more recent work in [9] divides the image into several regions, reducing the number of competitors during the voting process. However, this divide-and-conquer approach suffers from obstacles especially when there are multiple lines in the received image. In addition, the performance improvements of the previous works are naturally limited as the algorithms are based on the generalized line-detecting methods. To enhance the performances of image-based lane detection enough to be used at the practical applications, in this paper, we present more advanced optimizations by considering the characteristics of real road images.

III. PROPOSED OPTIMIZATIONS

Based on the properties of practical road images, in this section, we propose several optimization algorithms that can reduce the processing complexity without

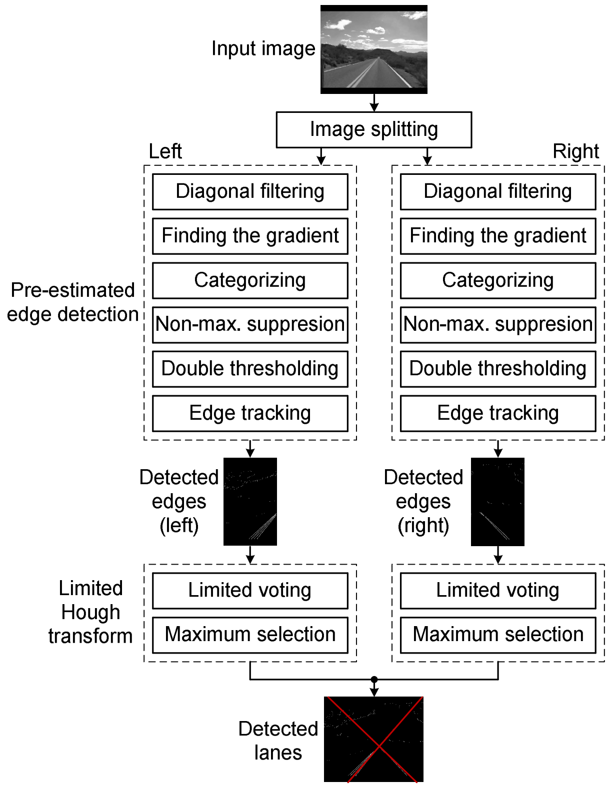

Fig. 3. Conceptual processing steps of the proposed lane detection algorithm.

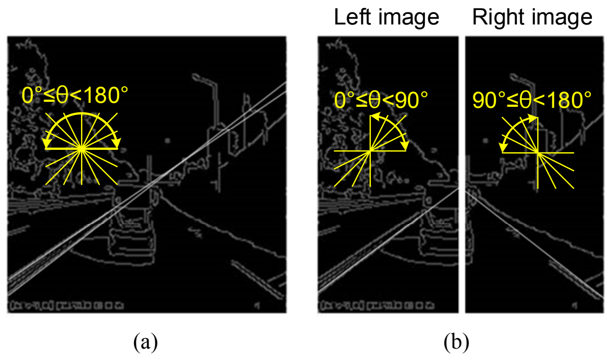

Fig. 4. The voting process based on (a) the conventional algorithm covering the whole image, (b) the proposed image-splitting algorithm.

Table 1. Processing time of the conventional algorithm

Processing step		Processing time	ratio
Canny edge detection	Noise cancelation	6.23 ms	0.45
	Gradient calculation	2.01 ms	0.15
	Others	0.24 ms	0.02
Hough transform	Line voting	5.01 ms	0.36
	Line selection	0.34 ms	0.02
Total		13.83 ms	1.00

Performed by intel® Core i5 CPU at 2.5 GHz, 4 GB RAM

degrading the detecting accuracy. Fig. 3 conceptually illustrates the proposed processing methods, which mainly consist of two steps similar to the conventional methods in Fig. 1. Note all the proposed schemes are based on the fact the lanes in the captured road images have diagonal directions rather than the horizontal and vertical directions.

1. Limited Hough Transform

In the lane-selection process of Hough transform, two lines having the most votes are determined as straight lanes. If one side of lanes is more clear than the other, as illustrated in Fig. 4(a), the previous selection method may cause wrong decisions due to the lack of edges from the obscure lane. Moreover, the conventional voting-and-selection process takes a huge amount of time as the edges are tested in all the directions, i.e. $0° \le \theta < 180°$. For detecting lanes in a 640×480 image, as shown in Table 1, the voting process in Hough transform is one of the most complex steps in the lane detection problem. For realizing the real-time lane detection, hence, it is necessary to develop the limited Hough transform, which removes the unnecessary cases without performing the complicated computing steps. In the proposed scheme, we first split the received road image into two part as shown in Fig. 4(b) and then Hough transform is activated to each side independently. The proposed image-splitting scheme improves the accuracy by nature as it individually selects each lane by only considering the line having the most votes in each side. Simulation results in Section IV shows that the image-splitting scheme enhances the detecting accuracy by more than 20% compared to the conventional method that manages a whole image region. As shown in Fig. 4(b), in addition, the image-splitting relaxes the computing complexity of the voting process by half as it can restrict the range of angles from 180° to 90°. More precisely, the left-side image only considers angles from 0° to 90° as all the lanes in the left-side should have their angles in the restricted region. Similarly, the limited angles satisfying $90° \le \theta < 180°$ are only involved in the voting process of the right-side image as illustrated in Fig. 4(b). The voting range of angles, i.e., the angle of interests, can be reduced aggressively to further relax the computing complexity of Hough transform if we consider the

1/256	4/256	6/256	4/256	1/256
4/159	16/256	24/256	16/256	4/256
6/256	24/256	36/256	24/256	6/256
4/256	16/256	24/256	16/256	4/159
1/256	4/256	6/256	4/256	1/256

(a)

6/256	4/256	1/256	4/256	6/256
4/256	24/256	16/256	24/256	4/256
1/256	16/256	36/256	16/256	1/256
4/256	24/256	16/256	24/256	4/256
6/256	4/256	1/256	4/256	6/256

(b)

Fig. 5. 5×5 masks for noise cancelation at (a) the conventional Canny edge detection, (b) the proposed optimization.

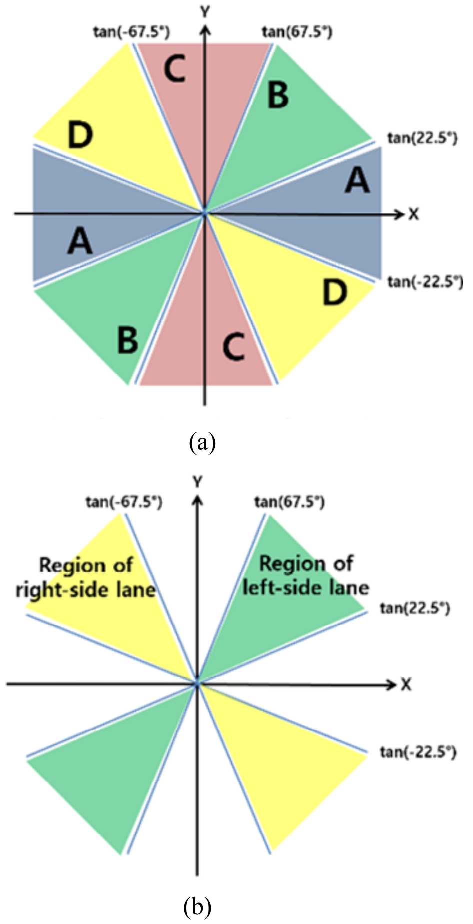

Fig. 6. (a) The categorizing rule of detected edges, (b) the survived edge regions highlighting the diagonal directions.

properties of road images. More precisely, the proposed angle-limiting method covers lanes whose angles range 30° < θ < 60° and 120° < θ < 150° in the left and right sides, respectively. In each detected edge, in other word, the voting range of angles is limited to 30°, reducing the voting complexity remarkably.

2. Pre-estimated Edge Detection

Even we can reduce the voting complexity of Hough transform by limiting the tested angles, the whole process of lane detection still takes a huge amount of time as numerous edges from non-lane obstacles are involved in the voting process. To eliminate these non-lane edges prior to the voting step, we introduce the pre-estimated Canny edge detection based on the two-step filtering approach. We first change the conventional Gaussian filter shown in Fig. 5(a), which is performed at the very beginning as depicted in Fig. 1. The modified filter shown in Fig. 5(b) enhances the diagonal directions than the others so that the horizontal and vertical non-lane edges from obstacles are smoothed out. The second diagonally- reinforcing step is performed after generating the gradient information in Fig. 3. In this step, the edge directions are categorized into four groups as illustrated in Fig. 6(a). By using this categorization, as shown in the figure, group A and C include horizontal and vertical edges, respectively. As depicted in Fig. 6(b), then, we eliminate these edges before activating the voting process as the lines across horizontal and vertical edges cannot be lanes in the practical road images by nature. In other word, the proposed scheme highlights the diagonal edges by selecting the edges in group B and D. Note that the boundary condition of the proposed pre-estimated edge detection is validated by examining various practical road images. Hence, the proposed algorithm effectively reduces the computing complexity by reducing the number of lane candidates involved in Hough transform.

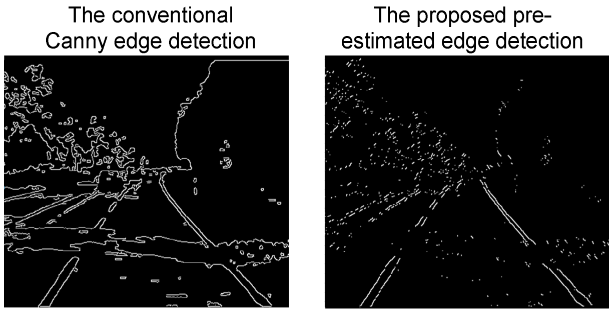

Fig. 7. Detected edges based on the proposed pre-estimated edge detection.

As the non-lane edges are pre-estimated, moreover, the proposed work also enhances the detection accuracy of lanes. Fig. 7 illustrates the effects of the proposed pre-estimated edge detection algorithm. Compared to the image based on the conventional Canny edge detection algorithm, the new image from the proposed method contains much less number of edges while preserving the essential edges associated with target lanes.

IV. SIMULATION RESULTS

In this section, we provide several simulation results and analyze the impact of the proposed diagonally-reinforced algorithm. For fair comparisons, three different lane detection algorithms are implemented for finding the lanes in 640x480 images, i.e., the conventional algorithm, the divide-and-conquer method [9, 10], and the proposed algorithm. All the algorithms are simulated based on the same computing environment associated with 2.4 GHz Intel® Core i5 processor and 4 GB memory. Moreover, all the algorithms use the same RoI for finding the lanes [8].

To test various scenarios, simulations are performed by using three different video samples captured from the ordinary road, the road having the multiple clear lanes, and the road containing the numerous obstacles, which are denoted as S1, S2, and S3, respectively. For example, Fig. 8(a) shows the tested image of S3 set. Note that the conventional algorithm illustrated in Fig. 8(b) and the previous multi-step search in Fig. 8(c) are based on the same edge map as they adopt Canny's algorithm [7]. On the other hand, even three algorithms detect the same lanes, the proposed method in Fig. 8(c) uses more simplified edge map that highlights the diagonal directions. Note that this simplified edge map naturally

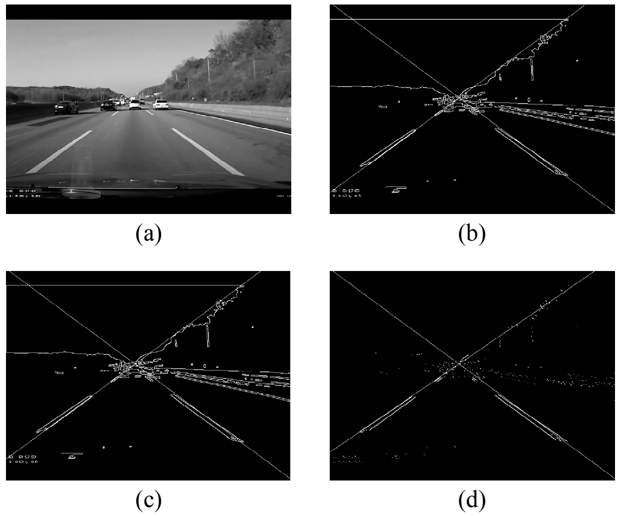

Fig. 8. (a) The tested road image having multiple obstacles, and lane detection results using, (b) the conventional algorithm, (c) the divide-and-conquer method, (d) the proposed work.

Table 2. Number of edges for Hough transform

Sample video	Conventional	[10]	Proposed
S1 (600 frames)	5481	5481	1982
S2 (800 frames)	5279	5279	1458
S3 (200 frames)	6869	6869	2128

Table 3. Requested time for processing a 640×480 image

Detecting step	Conventional	[10]	Proposed
Edge detection	8.48 ms	8.48 ms	8.85 ms
Hough transform	5.35 ms	7.67 ms	1.21 ms
Total	13.83 ms	16.15 ms	10.06 ms

relax the voting overheads at the following Hough transform, and the overall computational complexity is accordingly relaxed, leading to the real-time lane detection.

For the numerical analysis, Table 2 compares the number of edges tested from Hough transform. As the proposed pre-estimated edge detection eliminates the non-lane edges prior to the voting step, on average, the number of edges to be tested in Hough transform is reduced by more than 69%, compared to the original Canny's approach. Hence the overall processing time of lane detection can be greatly shortened as depicted in Table 3. As we added more filtering steps during the edge detection for removing the non-lane edges, the processing time of the proposed edge detection is slightly larger than that of the conventional one. However, the proposed work reduces the processing time of Hough transform by 77% as the number of edges and the range

Table 4. Comparisons of different lane detection algorithms

Algorithm		Conventional	[10]	Proposed
S1 (600 frames)	Accuracy	49.6%	54.8%	94.4%
	Speed	69.7 fps	61.9 fps	92.4 fps
S2 (800 frames)	Accuracy	57.9%	63.3%	99.6%
	Speed	77.5 fps	68.4 fps	94.0 fps
S3 (200 frames)	Accuracy	25.9%	44.4%	70.7%
	Speed	71.5 fps	64.5 fps	90.3 fps

of tested angles are decreased significantly by applying the proposed pre-estimated edge detection and the limited Hough transform, respectively. As a result, the processing time of a whole lane detection is shortened by 27% as depicted in Table 3.

Finally, as shown in Table 4, we simulate different detection algorithms for finding the lanes in three different situations, i.e. S1, S2, and S3. Due to the simplified computing steps, the proposed algorithm maximizes the processing speed of lane detection. For the case of S1, i.e., the typical road situation, more precisely, the proposed algorithm achieves a frame rate of 92.4 fps, which is superior to the other lane detection methods. Moreover, the proposed algorithm also enhances the lane detection accuracy remarkably as it removes non-lane candidates as many as possible before activating the voting process. Compared to the previous ROI technique that may remove the lane image [8], our algorithm always highlights the lane edges, leading to the better detection accuracy. As shown in the table, as a result, the proposed algorithm always achieves the detection accuracy of more than 70%, even in the case of S3, where the previous works suffer from the unwanted obstacles. Therefore, the proposed diagonally-reinforced detection scheme provides an accurate and fast solution, which is suitable for the practical embedded systems in automobiles.

VI. CONCLUSIONS

In this paper, we have presented several optimizations to enhance the performance of lane detection problem. In order to reduce the computing complexity without losing the recognition accuracy, the proposed detection algorithm emphasizes the diagonal directions in practical images by modifying the edge detection procedures and limiting the computations of voting step. Simulation results show that the proposed diagonally-reinforced technique improves the detecting performance remarkably, compared to the previous state-of-the-arts.

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