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# Robust Lane Detection Algorithm Based on Triangular Lane Model

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**Abstract.** Recently, various technologies and sciences are developed for fourth industrial revolution which includes artificial intelligence, robotics, internet of things, 3-D printing, and autonomous transportation. The autonomous transportation is one of the fourth industrial technology, and has been studying for safety driving. Accurate lane detection and lane departure warning system is very important for autonomous transportation. However, conventional methods have some problems of applying real-driving such as extracting miss lanes under cloudy weather and vehicle disturbance situations. In order to solve the real driving problems, we propose a new lane detection technique for lane departure and forward collision warning system using a single in-vehicle camera. The proposed method consists of triangular lane model, feature points extraction method. In the near field, a triangular lane model is used to approximate a pair of lane boundaries. Subsequently, feature points extraction method based on hyperbola curve model is applied to obtain lane curvature in the far field. Mathematical B-spline applied to feature points for curved lane fitting. Simulation results show that the proposed lane detection and tracking method has good performance.

## 1. Introduction

As a fundamental part of intelligent transportation systems (ITS), the method of obtaining and identifying in-formation about the road by intelligent vehicles plays a very important role in ITS, and lane

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detection is a pre-requisite for realizing lane departure warning(LDW), which are also the key technologies for achieving intelligent vehicle vision aided. Vision-based lane detection and tracking system becomes an important mechanism in vehicular autonomous technology to alert a driver about road physical geometry, the position of the vehicle on the road, and the direction in which the vehicles heading.

Many studies have progressing for realizing ITS. In general, robust lane detection algorithm proposed by Yoo et al. [1] shows that the angle between the vanishing line and the segment which is extracted from the Line Segment Detector(LSD) [2] can be used. In addition, Ozgunalp et al. [3] proposed the lane detection algorithm based on vanishing point estimation using stereo camera, but the method needs stereo camera for acquisition of load images. In addition, much computation and hardware power are needed due to the cameras. And Cheng et al. [4-7] proposed the road centerline extraction technique from remotely sensed imagery, the method is high accurate and high performance. However, the method is not suitable under LDW. Chen and Wang [8] proposed the hyperbola-pair road model, which corresponds with the road model of parallel parabolas in ground lane. Lim et al. [9] proposed a search method based on river flow, which can search for feature points on curve lane in the far field. Furthermore, Tan et al. [10] proposed the improved river flow(IRF) for searching the feature points and used random sample consensus(RANSAC) for fitting the curve lane. Although the method improves the accuracy of detection lane, the method requires high computational complexity due to the calculation of the parameter of hyperbolic lane. The parameters of the mathematical model are solved according to the feature points of lane markings from a road image. However, the difficulty in this kind of method is the extraction of feature points of lane markings from a road image, especially under some challenging conditions, such as the dashed lane markings and vehicle occlusion. However; these conventional methods have some problems of autonomous driving system such as much operation power and slow operation speed owing to many extractions of feature points.

In this paper, in order to solve the problems of conventional method and improve the LDW, we propose a new method consisting of a triangle model for straight lane detection and feature point extraction for curved lane detection using single in-vehicle camera. A straight lane detection technique using triangular lane model and feature points extraction method is used to estimate driving lane. In the near field, a triangular lane model is used to approximate a pair of lane boundaries. Subsequently, a feature points extraction method based on hyperbola curve model is applied to obtain lane curvature in the far field. In order to confirm efficiency of proposed method, we compared the conventional and proposed method in various images. The experimental results show that the proposed method can accurately detect lane under challenging conditions. Consequently, accurate lane can be detected by the proposed method under tough environment and vanishing lane due to other cars.

## 2. Method

### *2.1. Proposed lane detection algorithm*

To apply the curved lane detection algorithm, the region of image on the front of vehicle is divided into near and far fields. However, in the proposed method, the region is divided into three parts to detect a driving lane in highway image. As shown in Figure 1, one is near field, another is intermediate field, and the other is far field.

In this paper, we proposed the method that is modeling straight lane in near field into triangle. Triangular model based lane detection consists of two stages. First, the lane is detected in the near field by straight-line detection algorithm. Second, to detect the curve lane, approximated straight lane is detected after resetting Region of interest(ROI) of intermediate field by straight lane information of near field to intermediate field region from far field region. Figure 2 shows the triangular lane model. The Figure 2(a) shows near field that is usual method in lane detection, (b) is the intermediate area based on near field. Lastly, the feature points of curve lane are estimated using the information of Figure 2(a) and (b), and whole driving lane is extracted by B-spline.

The Figure 3 shows flow chart of proposed algorithm, and Table 1 shows various parameters used for the lane detection.

Table 1: Variables used for the lane detection

| Variable | Meaning |
|---|---|
| $u_l$, $u_r$ | Left and right lane boundaries |
| $b_l$, $b_r$ | The slopes of straight lane marking in the near field |
| $vp$ | The vanishing point $(u_{vp}, v_{vp})$ |
| $h_l$, $h_r$, $r$ | The length variables on the hyperbola |
| $P_0$, $P_1$, $Q_0$, $Q_1$ | The feature points for the curve lane |

*2.2. Straight lane detection in near field using triangular lane model*

In Figure 4, all the straight lanes meet at the vanishing point and are separated into left lane and right lane based on perpendicular line $\overline{S_0}$ passing through the vanishing point. The angle $\theta_d$ of the driving lane calculated as the angle between line segment $\overline{S_1}$ and $\overline{S_2}$ is defined as $\theta_d = \theta_{L,1} + \theta_{R,1}$ where $\theta_{L,1}$ is the angle between $\overline{S_0}$ and $\overline{S_1}$ and $\theta_{R,1}$ is the angle between $\overline{S_0}$ and $\overline{S_2}$. The $\theta_d$ depends on the characteristics of the camera and road conditions, but remains constant within a certain road section when using a single camera. Therefore, the driving lane can be extracted by selecting the optimal line segment using the angle calculated by the left and right line segments.

In this paper, the straight lane in the near field can be approximated by the proposed algorithm, and the approximated straight lane consists of line segments toward the vanishing point. In addition, optimized driving lane is detected using angles between line segments and perpendicular line passing through the vanishing point.

In order to perform the proposed algorithm, we first obtain the binary image by the edge detection filter and then detect the line segments by applying the Hough line transform. Then, the line segment that does not pass the vanishing point is removed from the detected line segments and the angles between the remaining line segments and $\overline{S_0}$ are calculated. Next, we divide the left lane and the right lane by the sign of the angle to obtain the set $L_\theta = \{\theta_{L,i} \mid i = 1, 2, \cdots, s\}$ and the set $R_\theta = \{\theta_{R,j} \mid j = 1, 2, \cdots, t\}$ where s is the number of left lanes and t is the number of right lanes.

By scanning a horizontal line moving in a point unit along the perpendicular line $\overline{S_0}$, we detect both the left and right line segments that are encountered for the first time. Further, the angle included in the set $L_\theta$ and $R_\theta$ corresponding to the detected line segment is selected, and the appearance-frequency of the angle is increased by one. Left weight $W_L(\theta)$ and right weight $W_R(\theta)$ are made by appearance-frequency of angles. Therefore, decision weight $D(i, j)$ is given by

$$D(i, j) = W_L(\theta_{L,i}) \times W_R(\theta_{R,j}) \tag{1}$$

and angle of candidate driving lane $\theta_d(i, j)$ is given by

$$\theta_d(i, j) = \theta_{L,i} + \theta_{R,j} \tag{2}$$

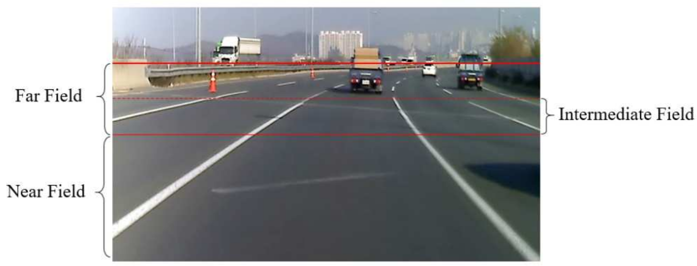
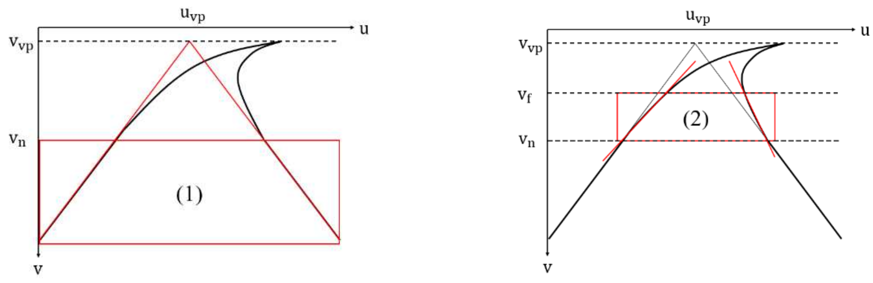



Figure 1: Each area for the applied method.




(a) (b)

Figure 2: Triangular lane model, (a) ROI in the near field, (b) ROI in the intermediate field.

where $1 \leq i \leq s$ and $1 \leq j \leq t$.

Last, the left and right lane are detected by $\theta_{L,i}$ and $\theta_{R,j}$ as maximum value $D(i, j)$ which correspond range of $\theta_d(i, j)$ according to feature of camera and the gradient $b_l$, $b_r$ and vanishing point $vp$ which cross the two lanes are calculated from detected left and right lanes.

Algorithm 1 shows the pseudocode for optimal lane selection. ROI in near field selected to sub-image, and then driving lane is detected according to algorithm 1.

**Algorithm 1** Optimal Lane Selection from line segments

Line segments $S_n, n = 1, \cdots, N$
Calculate the angles $\theta_n, n = 1, \cdots, N$
Classify $\theta_n$ into $L_\theta = \left\{\theta_{L,i} \mid i = 1,\ 2,\ \cdots,\ s\right\}$ and $R_\theta = \left\{\theta_{R,j} \mid j = 1,\ 2,\ \cdots,\ t\right\}$
$h \leftarrow$ height of ROI
for $y = 0$ to $h - 1$ do
  $I \leftarrow$ find the nearest left segment on y
  $W_L(\theta_{L,I}) \leftarrow W_L(\theta_{L,I}) + 1$
  $J \leftarrow$ find the nearest right segment on y
  $W_R(\theta_{R,J}) \leftarrow W_R(\theta_{R,J}) + 1$
end for
for $i = 0$ to $s$ do
  for $j = 0$ to $t$ do
    $D(i, j) \leftarrow W_L(\theta_{L,i}) \times W_R(\theta_{R,j})$
  end for
end for
$D_{max}(S, T) \leftarrow max\left\{D(i, j)\right\},\ i = 1, \cdots, s;\ j = 1, \cdots, t$
Select $\theta_{L,S}$ and $\theta_{R,T}$

### 2.3. *Curve lane detection in far field*

Hyperbola model is used for the curve lane to extract the feature of hyperbolic lane. The Figure 5 shows the hyperbolic curve graph of $y = k/x$ at $x > 0$ to explain feature of hyperbolic curve.

First, the equation of tangent line passing through point $P_1(x_1, y_1)$ is defined by

$$y = -\frac{k}{x_1^2}x + \frac{2k}{x_1} \tag{3}$$

To calculate the coordinate of the point $P_0(x_0, 0)$ where the tangent meets the $x$-axis, zero is substituted to $y$ and $x_0$ is substituted to $x$ in Eq. (3). Then, $x_0$ becomes twice as large as $x_1$ with $x_0 = 2x_1$. In addition,

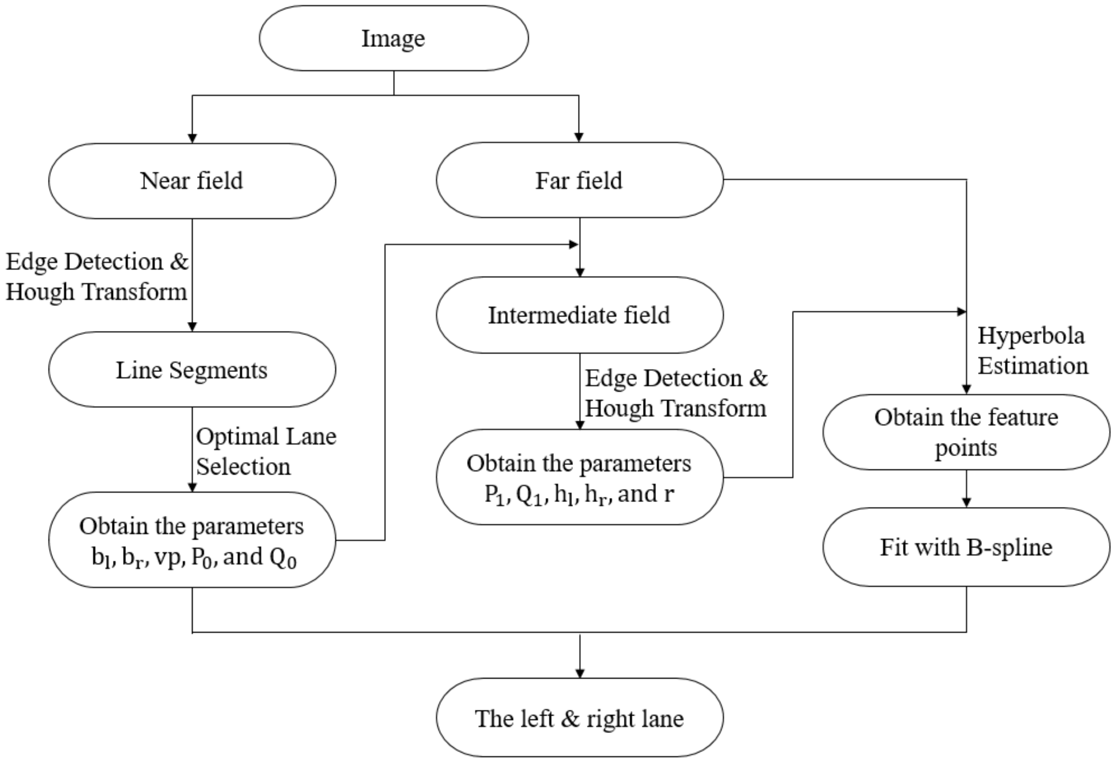



Figure 3: Flow chart of proposed algorithm.

hyperbolic curve passing through foot of perpendicular at point $P_1(x_1, y_1)$ to $x$-axis of tangent equation of contact point $P_2(x_2, y_2)$ can be calculated and can be known $x_2 = x_1/2$, $y_2 = 2y_1$, and $\tan\theta_2 = 4\tan\theta_1$ by relation of $x_1y_1 = x_2y_2$. And $k = x_1y_1$ is expressed by substituting the coordinate $P_1(x_1, y_1)$ into the hyperbolic equation. In Figure 5, we can obtain $x_1 = r$ and $y_1 = d\sin\theta_1$. Then, hyperbola curvature k is given by

$$k = r \cdot d \cdot \sin\theta_1 \tag{4}$$

Assuming that $P_{i+1}(x_{i+1}, y_{i+1})$ is the contact point of the tangent line of the hyperbola passing through the foot of perpendicular from $P_i(x_i, y_i)$ to the x-axis, the coordinate of $P_{i+1}(x_{i+1}, y_{i+1})$ is calculated from the relationship of $x_2 = x_1/2$, $y_2 = 2y_1$, and Eq. (3) as follows:

$$\begin{cases} x_{i+1} = x_i/2 \\ y_{i+1} = 2y_i \end{cases} \tag{5}$$

Therefore, Eq. (5) shows that if a point on hyperbolic curve is known, the shape of the hyperbolic curve can be estimated.

In many papers, hyperbola is used to model curved lanes. The hyperbolic pair model is given by

$$\begin{cases} u_l = \frac{k_l}{v-v_{vp}} + b_l \times (v - v_{vp}) + u_{vp} \\ u_r = \frac{k_r}{v-v_{vp}} + b_r \times (v - v_{vp}) + u_{vp} \end{cases} \tag{6}$$

for left and right hyperbola where the $k_l$ is left hyperbola curvature and $k_r$ is right hyperbola curvature. In this paper, the hyperbolic pair model such as Eq. (6) is applied for lane feature extraction. In Eq. (6), the

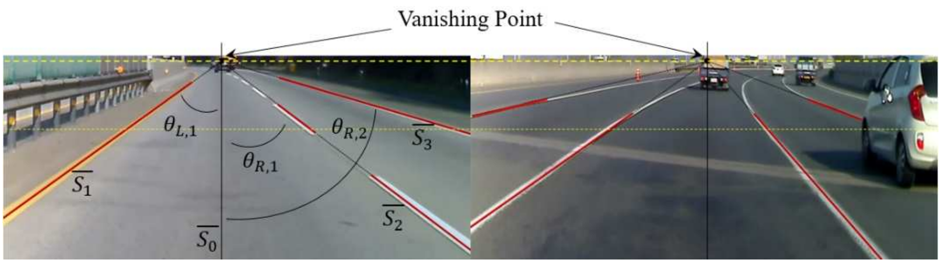



Figure 4: Characteristic of driving lanes from camera.

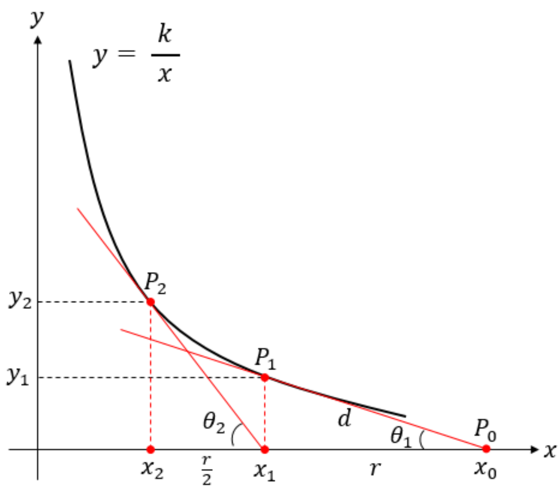



Figure 5: Feature of hyperbola.

straight lane pair in the near field is given by

$$\begin{cases} u_l = b_l \times (v - v_{vp}) + u_{vp} \\ u_r = b_r \times (v - v_{vp}) + u_{vp} \end{cases} \tag{7}$$

where $b_l$ is the slope of the left lane, $b_r$ is the slop of the right lane, and $vp(u_{vp}, v_{vp})$ is the coordinate of vanishing point. The slopes $b_l$ and $b_r$ are computed by the straight lanes detected in the near field, as shown in Section 1.2. And by calculating the intersection of two straight lanes, $vp(u_{vp}, v_{vp})$ is also obtained.

Furthermore, the coordinates of the feature points $P_0$ and $P_1$ on the left lane and the feature points $Q_0$ and $Q_1$ on the right lane are obtained by straight lane detection at the intermediate field. The $h_l$ and $h_r$ are calculated by

$$\begin{cases} h_l = u_{l,1} - \left\{ b_l \times (v_{l,1} - v_{vp}) + u_{vp} \right\} \\ h_r = u_{r,1} - \left\{ b_r \times (v_{r,1} - v_{vp}) + u_{vp} \right\} \end{cases} \tag{8}$$

where feature points $P_1(u_{l,1}, v_{l,1})$, $Q_1(u_{r,1}, v_{r,1})$. And coordinates of set $L = \left\{ P_i(u_{l,i}, v_{l,i}) \mid i = 2, 3, \cdots, m \right\}$ and set $R = \left\{ Q_i(u_{r,i}, v_{r,i}) \mid i = 2, 3, \cdots, n \right\}$ are estimated by

$$\begin{cases} v_{l,i} = v_{l,i-1} - \frac{r}{2^{i-1}} \\ u_{l,i} = \left\{ b_l \times (v_{l,i} - v_{vp}) + u_{vp} \right\} + 2^{i-1} \times h_l \end{cases} \tag{9}$$

and

$$\begin{cases} v_{r,i} = v_{r,i-1} - \frac{r}{2^{i-1}} \\ u_{r,i} = \left\{ b_r \times (v_{r,i} - v_{vp}) + u_{vp} \right\} + 2^{i-1} \times h_r \end{cases} \quad (10)$$

where $r = (v_n - v_{vp})/2$.

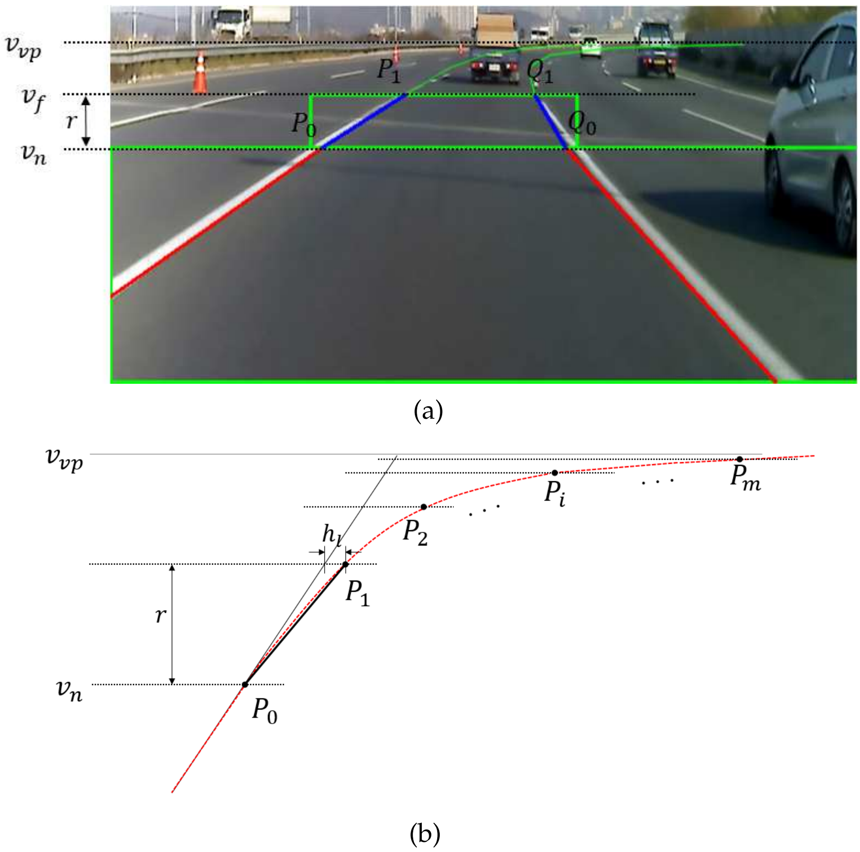



Figure 6: Feature points of the curve lane: (a) initial points of $P_0$, $P_1$, $Q_0$, and $Q_1$ from straight lane detection and (b) complete points of left side lane.

Whole curve lane can be detected by dynamic programming algorithm from starting points which are feature points $L = \left\{ P_i \mid i = 0, 1, 2, \cdots, m \right\}$. Finally, the curve lane is detected by B-spline which use estimated feature set $L = \left\{ P_i \mid i = 0, 1, 2, \cdots, m \right\}$ by feature points. The Figure 6 shows result of extracted feature points and method. And then, the right curve lane is detected by same method.

## 3. Results

To verify the proposed algorithm, experiments were conducted in the road environment. The vehicle used in the experiment was a car with a car height of 0.6m and a camera with HD resolution and 60fps was used for image capture. The running road was set as a straight section and a curved section, and the vehicle traveled at a constant speed of 80 km / h.

From the results, it is found that the proposed method can robustly and accurately detect both straight line and curved line under various conditions. The results of our experiment indicate the good performance of our algorithm for lane detection, especially under some challenging scenarios such as the dashed lane and

Table 2: Comparison with conventional and proposed methods.

| | **Conventional method** | **Proposed method** |
|---|---|---|
| Normal situation |  |  |
| Cloudy weather situation |  |  |
| Disturbed situation by other cars |  |  |

vehicle occlusion. The Table 2 shows result of comparison with conventional and proposed method. The proposed method based on straight lane in near field can be detected the lanes on normal state efficiently. Therefore, vanishing lane of far field is detected more than the conventional method by proposed method because of proposed method using near field information. In addition, the lanes can be detected using proposed method on cloudy weather and existing other cars in driving lane or opposite lane.

The Figure 7 shows the result at various cases. The Figure 7(a) is driving images at normal situation. the straight and curve lanes are detected like conventional method. And Figure 7(b) shows the result of cloudy weather. Finally, Figure 7(c) shows the result when other cars are existing in driving lane or opposite lane. The proposed method processed curve lane detection based on straight lane in near field. Therefore, the lanes are detected efficiently more than conventional method.

## 4. Conclusion

In this study, we introduced a robust real-time straight lane detection algorithm based on triangular lane model for local roads and freeways. Also, new feature points extraction method by hyperbolic curve model has been proposed, which can search feature points efficiently in the far vision field of curve lane. B-spline could fit lane markings fast and accurately using these feature points. The results of test indicate that our algorithm is robust and meets the requirement of accuracy, and it can provide good information of current lanes for driver and is suitable for lane departure warning system (LDWS) and forward collision warning system (FCWS). The future works should focus on the lane tracking methods and vehicle detection with tracking methods to promote the lane detection performance. First, the ROI is designated for detection of lane on the near and far field. The Figure 7 show result of applied ROI. The ROI is affected to detect the lane. Second, the feature points by hyperbola model are dependent for extraction of curve lane at straight lane that is extracted in near and intermediate field. Therefore, the feature points have a weak correlation with the pixel information of the curve lane in the far field. In order to solve this problem, the further studies are needed to determine the optimal ROI and develop a fitting algorithm with high correlation between feature points and pixel information.

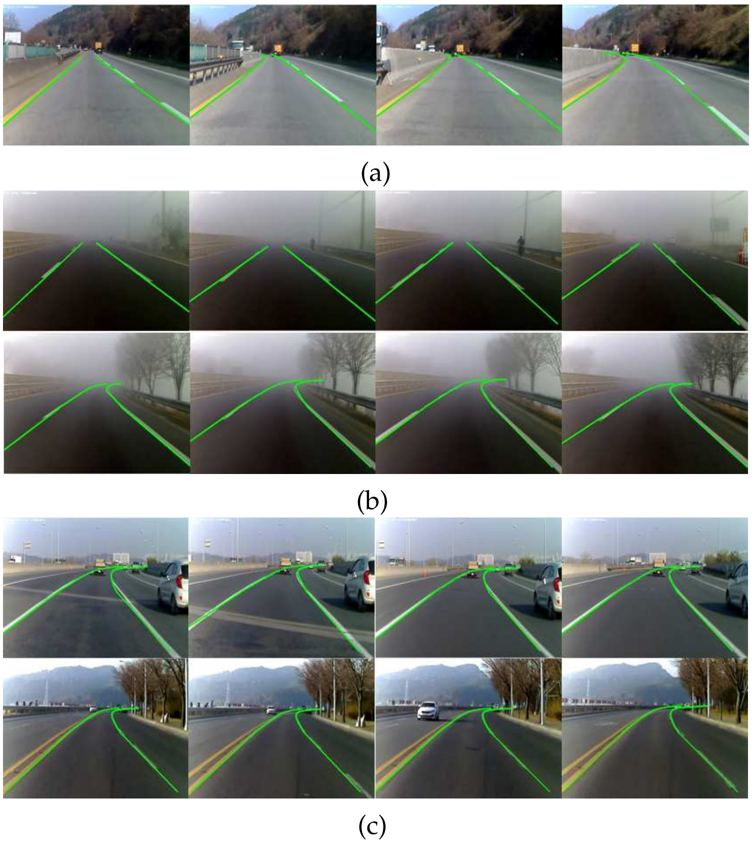



Figure 7: Result of proposed method, (a) result of normal situation, (b) result at cloudy weather, (c) result at existing other cars.

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