Curved lane detection using robust feature extraction

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Abstract— **In this paper, we propose a robust curved lane marking detection method by first detecting a straight lane and applying a geometric model of that detected straight lane. In our proposed method, we first detect the straight line and generate 13 candidates of the curved lane by applying a geometric model. We then vote those candidates on the feature image and consider the candidate which acquires the highest number of votes as the final curved lane. The performance and the efficiency of the proposed algorithm are confirmed by the experimental results.**

Keywords - vision; lane detection; curved lane detection; robust lane feature extraction

I. INTRODUCTION

Recent automotive industry mainly concerns about the safety and convenience of the driver and much research work on systems such as ITS (Intelligent Transport System) and ADAS (Advanced Driver Assist System) have been conducted[1][2]. One of the main key technologies of ITS and ADAS is the LDWS (Lane Departure Warning System)[3], a system which detects information of the current driving lane and warns the driver when the vehicle begins to move out of its lane. This system has become more famous and many studies are underway as it is designed to minimize accidents caused by the unconsciousness of driver.

Some of the conventional methods for detecting curved lines are curved line fitting method using b-spline and a control point, feature based method, and etc. In b-spline method; control point detection becomes more difficult when many dot lines and neighborhood features exist and eventually the error detection rate increases. When dot lines are detected; the processing time in feature base method takes a long as it uses a very complicated algorithm to connect those dot lines.

In this paper, we use the distinguishing characteristics of the lane to find the straight line by detecting the features. We use a geometric model from the detected straight line to generate 13 curved candidates. Then we vote those curved candidates on the feature image and consider the curved candidate which acquires the highest vote as the curved lane.

Section 2 of the paper describes the process of feature extraction and section 3 describes the process of detecting the curved line by generating 13 curved candidates. Section 4 contains details about the experiment whereas section 5 is the conclusion.

II. FEATURE EXTRACTION

An input image is first converted into a gray image. The intensity difference of image $\mathrm{I}(x, y)$ and $\mathrm{I}(\mathrm{x} \pm \mathrm{d}, y)$ is calculated using equation (1) where $\mathrm{I}(\mathrm{x}, \mathrm{y})$ is pixel intensity and d is an offset value of x.

$$\mathrm{Val}(\mathrm{x},\mathrm{y}) = 2 \times \mathrm{I}(x,y) - \mathrm{I}(x+d,y) - \mathrm{I}(x-d,y) \quad (1)$$

After generating $\mathrm{D}(\mathrm{x},\mathrm{y})$ according to equation(2); equation (3) is used to create H(x,y) feature extraction image by increasing the value of d from d_{min} to d_{max}.

$$D(\mathrm{x},\mathrm{y}) = \begin{cases} 0, & \text{if } (\mathrm{I}(\mathrm{x},\mathrm{y}) < \mathrm{I}(\mathrm{x}+\mathrm{d},\mathrm{y}) \text{ or } (\mathrm{I}(x,y) < \mathrm{I}(\mathrm{x}-\mathrm{d},\mathrm{y}) \\ \mathrm{Val}(\mathrm{x},\mathrm{y}), & \text{otherwise} \end{cases} \quad (2)$$

$$\mathrm{H}(\mathrm{x},\mathrm{y}) = \sum_{d=d_{min}}^{d_{max}} D(\mathrm{x}+\mathrm{d},\mathrm{y}) + \sum_{d=d_{min}}^{d_{max}} D(\mathrm{x}-\mathrm{d},\mathrm{y}) \quad (3)$$

$$d_{min} = \mu \times (\mathrm{y} - \mathrm{V}_y)$$
$$d_{max} = \mu \times (\mathrm{y} - \mathrm{V}_y) + 3 \quad (4)$$

In equation (4), y is the y-axis coordinate used to calculate d and V_y is the y-axis coordinates of the vanishing point. Even though the width of the lane marking is said to be same; the width of the lane marking in image is proportional to the y-axis and as a result; d is changed according to the y-axis as it is expressed in equation (4). μ is a weight factor of the lane marking width, and it is determined by camera calibration.

The intensity value of the road area in the gray level image is low and the intensity value of the lane marking is high. As the intensity difference between these two values is high; it allows us to acquire a potential candidate region. In the detected $\mathrm{H}(\mathrm{x},\mathrm{y})$ image, one pixel can be a strong candidate of the lane marking if the intensity difference between the pixel and another pixel apart from d distance is high.

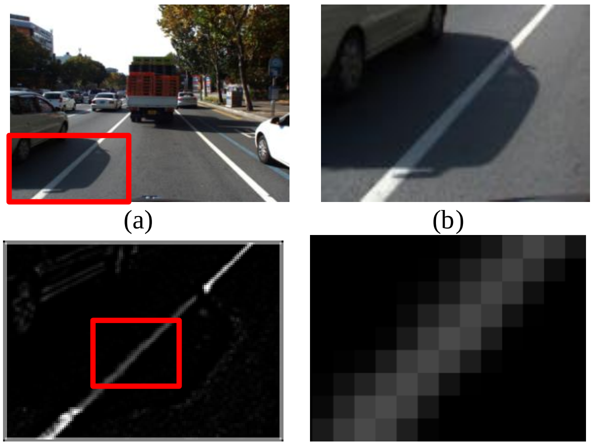
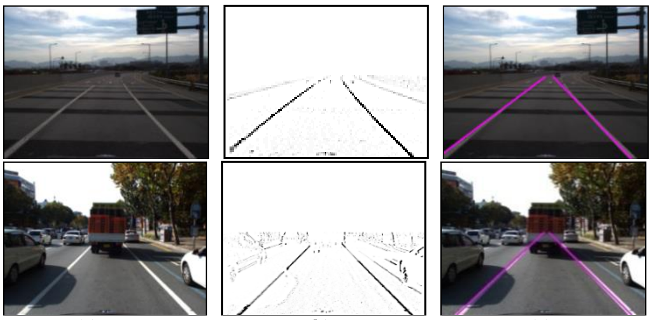


Figure 1. Result of feature extraction image. (a) input image. (b) cropped input image of the red box. (c) feature extraction image. (d) cropped feature extraction image of the red box.

Detected lane marking candidate area is shown in Figure.2 and the center point appears to have the highest intensity. As it contains the highest intensity, strong candidates can be detected without any difficulties even sunset or shadow areas contain lower intensity.

We refered paper [9] to get relevant information about how to detect the straight line from a feature image and Fig.2 shows some of the detection results.



(a) (b) (c)

Figure 2. Result of straight lane detection. (a) input image. (b) feature extraction image . (c) result of straight lane detection.

III. CURVED LANE DETECTION

A. model formation

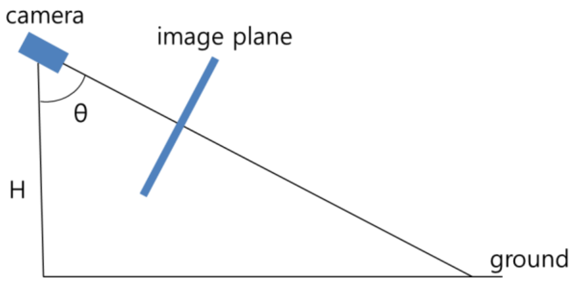


Figure 3. Relationship between the camera and road plane.

Fig.3 shows the relationship between the camera and the road plane. When the road is assumed to be flat, H represents the height of the camera from the ground and θ represents the pitch angle of the camera.

In this paper, we only consider the rotation of each pitch and the conversion relationship between the camera and the road plane can be represented by the equation (5).

$$\begin{bmatrix} X_{cam} \\ Y_{cam} \\ Z_{cam} \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & H \\ 0 & -\sin\theta & \cos\theta & 0 \end{bmatrix} \times \begin{bmatrix} X_{road} \\ Y_{road} \\ Z_{road} \\ 1 \end{bmatrix} \quad (5)$$

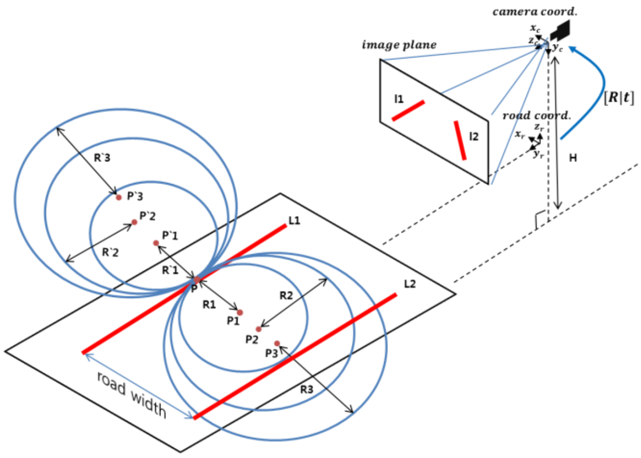


Figure 4. Curved lane candidate generation process.

Next we detect the curve line using the straight line we obtained in the previous section.

In Fig.4, L1 is the straight line which was detected in the previous section, P1,P2,P3 are the center points of the circles passing through point P which are in –R1,-R2,-R3 distance along the X direction. Similarly P`1,P`2,P`3 are the center points of the circles which are in +R1,+R2,+R3distance along the X direction.

In equation (6), x, y are the point position of the circle where as x0, y0 are the center points of the circle which is in ±r distance along the x direction from the point P

$$x = \pm\sqrt{r^2 - (y - y0)^2 + x0} \quad (6)$$

$$r = [R1, R2, R3, R4. R5, R6] \quad (7)$$

B. curved line candidate generation

Using equation (6); the method we propose to produce curved line candidates generates 12 circles which are in a distance of ±r along the X direction from the point P which is on the straight line L1. After projecting the 12 generated circles and L1 on the image using the projection matrix mentioned in equation (8); we manage to obtain 13 lane candidates[10] as shown in Fig.5.

$$\begin{bmatrix} X_{img} \\ Y_{img} \\ 1 \end{bmatrix} = \begin{bmatrix} s_x & 0 & c_x \\ 0 & s_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X_{cam} \\ Y_{cam} \\ Z_{cam} \\ 1 \end{bmatrix} \quad (8)$$

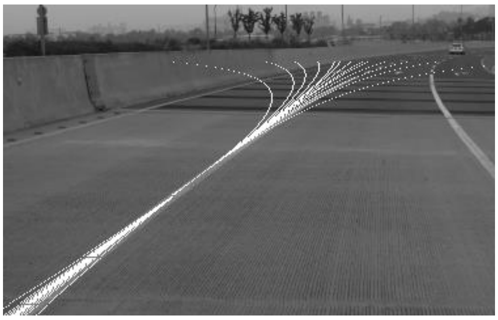


Figure 5. Result of curved lane candidate.

C. curved lane decision

After completing the generation of the lane candidates, we vote the curved line candidates and determine the curved candidate which has the maximum vote value as the curved line. Voting is performed on the feature image which we detected in the previous section.

Fig.6 shows the distribution of the lane area. The center point of the lane contains the highest intensity value compared to its boundary. Considering it as a fact; we use Gaussian distribution for correlation and accumulate the correlation results. The candidate which has the highest accumulated value is determined as the final curved lane.

Fig.7 shows the results of the final curved lane detection.

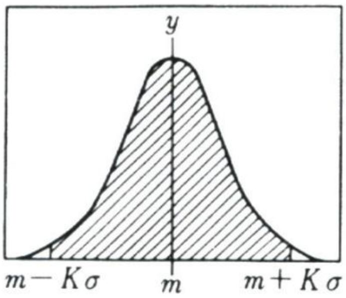


Figure 6. Gaussian normal distribution.

$$y = \frac{1}{\sigma \times \sqrt{2 \times \pi}} \times e^{-\frac{(x-m)^2}{2 \times \sigma}} \quad (9)$$

Figure 7. Result of the curved lane detection

IV. EXPERIMENT RESULT

After mounting the Pointgrey's Grasshopper2 and a lens with focal length of 8mm in the car, we performed the experiment by obtaining image at 30 fps in a 640 × 480 resolution in a PC running Windows7 containing an Intel Corei5-3470 3.20GHz with a 8GB RAM.

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Figure 8. Experiment Setup

Table 1. results of the experiment done in various road conditions.

frame	success	fail	detection rate
1800	1472	328	81.77%

If the real and detected lines are similar, we estimate that situation as success and if not; we estimate it as a fail situation. The detection rate of the estimated result is 81.77% and the processing rate is 20 FPS.

Some of the factors which could cause erroneous detection are, the case of guard rails, sidewalks - objects which contain similar features as road line - are detected; cases where the features are not detected in the feature extraction procedure due to faded lane paints; cases where the lane is covered by other vehicles.

V. CONCLUSION

This particular paper proposes a method to detect curved lines. The method generates curved line candidates by first using a robust feature extraction method to detect the straight line and then applying a geometric model. Then we project the generated candidates on the feature image and the final curved line is detected by voting.

The detection rate of the experiment results obtained using actual driving images is 81.77%. Curved line detection becomes more difficult when the lane is not visible or when noise; similar to the lane; exists.

VI. ACKNOWLEDGMENT

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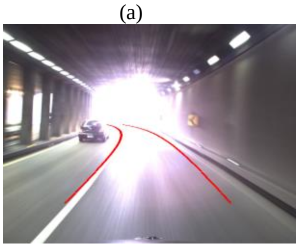
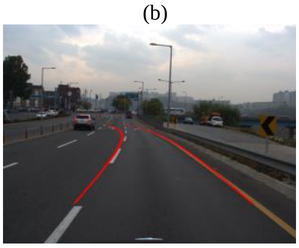
Figure 9. Result of the curved lane detection.

(a)

(b)



(c)



(d)

Figure 10. Result of error detection.
(a) lane is covered by the car. (b) When Guard rails, sidewalks exist.
(c) Invisible lane. (d) When similar features as lane exist.

VII. REFERENCE

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