Computational Intelligence-based Real-time Lane Departure Warning System Using Gabor Features

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***Abstract*—Lane detection and lane departure warning are crucial parts of Advanced Driver Assistance Systems (ADAS), which is designed to increase general safety on the road. This paper proposes a novel approach for lane detection, which boosts the accuracy of lane departure warning system, specifically on highway and urban road under sunny condition, using Gabor Filter and other image processing algorithms. Gabor Filter is implemented to enhance the directionality of lane marking patterns. This filter automatically eliminates shadows, road marker and other non-related objects due to lack of directionality. Canny edge detection is then applied to extract the edges of lane marking and enhance the lane marking pattern. Lastly, Probabilistic Hough Transform (PHT) is applied to identify the correct left and right lane candidates on the road. We have also implemented lane departure warning to alert the driver when the vehicle is veered out of the lane. We showed that our framework is capable of real-time implementation using a Raspberry pi 3B to achieve 93% for lane detection and 95% for lane departure warning with 20 frames per second (fps) and only 75% Central Processing Unit (CPU) utilization.**

I. Introduction

Intelligent Transportation System is made to ensure general safety on the road. Researches have been conducted to design intelligent solutions which reduce the accidents rate due to human error and achieves the desired safety measures. Advanced Driver Assistance Systems (ADAS) has been known for a long time to assist the driver while driving, which ultimately ensures the general safety on the road. Modern cars are usually equipped with this feature, which provides the vehicle's position with reference to the road lane. A study conducted by [1] examines the effects of Lane Departure Warning (LDW), which is one of the features in ADAS technology. This study reports that LDW reduces the accident involvement rates of all severities by 18%, injuries related to lane departure by 24%, and fatal accidents by 86% [1].

To perform LDW, a reliable lane detection algorithm is required as an initial step. One popular approach to this problem is Inverse Perspective Mapping (IPM), where it transforms the original image to the bird's eye view version of it. Several studies [2], [3], [4], [5] are conducted by implementing this method to perform lane detection. However, this method is not reliable when it is handling challenging road conditions such as faded or missing lane marking, shadow regions and other road markings that are present on the road.

To overcome these challenges, we introduce Gabor Filter method, which enhances the directionality of the lane marking, while eliminating other non-related objects or road markings that do not have the same directionality as the filter. This is a simple, fast and powerful filter that allows for an accurate lane detection in real-time. A reliable lane detection algorithm is necessary to create a good lane departure warning system so that it does not give false warnings to the user.

In this paper, we first introduce an image database of Malaysia roads, which consists of 568 frames acquired with the Raspberry pi v2 camera. This database contains the aforementioned challenging road conditions. We introduce Gabor filter to perform lane detection as our second major contribution. The proposed method is also compared with the simulated version of the popular lane detection method, namely the IPM method. As our next major contribution, we propose a lane departure algorithm, which is overlaid on top of the lane detection algorithm. Finally, we tested the real-time performance of our framework.

II. Related Works

Lane detection is an essential part of a lane departure warning system. There are several approaches to this lane detection problem such as Inverse Perspective Mapping (IPM), vanishing point detection, neural networks, etc.

Inverse Perspective Mapping - this is a popular lane detection method as it eliminates the perspective effect from the original image. This method is implemented in [3], [4], [5], [6] to perform lane detection. The improved version of IPM is done by author [7], which proposed a robust inverse perspective mapping based on the vanishing point. It improves the detection accuracy under different road conditions (uphill and downhill roads). However, this method does not work under heavy traffic condition and it is computationally expensive. A similar work is done by author [8], which proposed an adaptive inverse perspective mapping model based on motion estimation provided by Simultaneous Localization and Mapping (SLAM). However, this method suffers from heavy traffic conditions and it also has high computational cost.

Vanishing Point Detection - this method relies on the vanishing point of the image to perform lane detection. The studies [9], [10], [11] are related to vanishing point detection, where author [9] used stereo vision approach coupled with RANSAC to extract the vanishing point from the image. The author then transformed the lane detection problem into the problem of finding two shortest paths from the vanishing point to two pixels at the bottom of the image. On the other hand, authors of [10] utilized three cameras (front, left and right) to perform the lane detection and determine the vehicle's position. The vanishing points are estimated by extending the lines on the left and the right cluster of the image until they intersect with each other, while Kalman filter is applied to track the vehicle. However, this method is very costly as it requires three cameras and a strong processing unit to process the images. A new search algorithm invented by [11] to replace RANSAC for finding the vanishing point. The performance of RANSAC fluctuates as it implements a random selection technique hence does not give precise results. The author introduces Harmony search algorithm which produces better covariance (0.084 - 0.092) as compared to RANSAC (0.14 - 14.95) to determine the vanishing point. The testing environments for all three authors above are relatively vacant (i.e., low number of cars present in the image), therefore, their performance under challenging road conditions is undetermined.

Neural Networks - [12] and [13] presented a neural network approach to solve the lane detection problem. Author [12] converts lane detection problem into an instance segmentation problem, where left lane and right lane forms its own instance. Previously learned perspective transform is applied to ensure that the system is robust against changes in road plane, unlike the existing approach which relies on predefined transformation. It performs well on the tuSimple lane dataset, however, this dataset does not contain common challenging road conditions such as fading or missing lane markings, road bumps and other road lane markings. In additional, authors of [13] introduces a real-time lane detection network using a deep neural network. This network is a two stages encoder-decoder network which consist of lane edge proposal and lane line localization. Although it can perform lane detection task in real time, this network suffers from similar lane markings on the road such as characters, arrows and other road lane markings.

III. Proposed Algorithm

A. *Hardware and Software configurations*

We used Raspberry pi model 3B, Raspberry pi camera v2 and Raspberry pi 7-inch display for our processing unit, image acquisition media and display media respectively. This configuration is shown in Fig. 1.

Meanwhile, for software configuration, we standardize the frame size to be 640×480. Moreover, we use multithreading to reduce the latency in the main code by separating the main codes such as extracting the raw image and displaying the image into different threads.

B. *Lane Detection Algorithm*

Texture Analysis - road lane marking exhibits directional patterns, which can be further analyzed to determine the drivers position with reference to the left and right lane marks. Gabor filter enhanced these directional patterns and separates

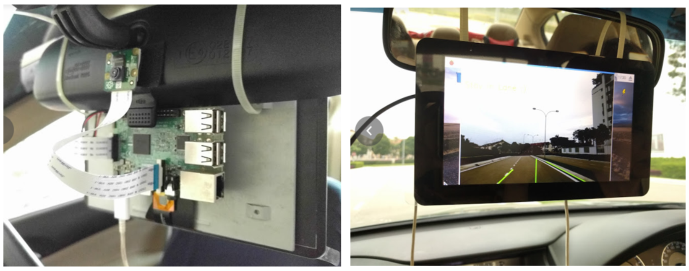
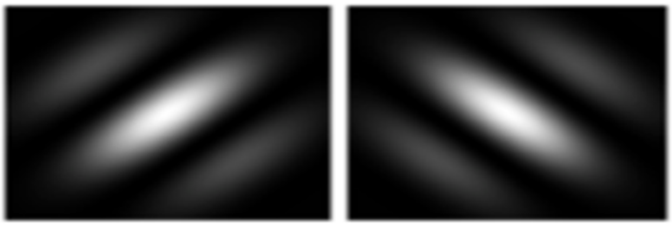


Fig. 1: Illustration of system setup.



(a) (b)

Fig. 2: Gaussian kernel for (a) left lane detection and (b) right lane detection.

the lane marking on the road surface from road bumps, vehicle and other road signs due to dissimilar patterns. The Gabor filter that we used is a Gaussian kernel with the rotational angle of 45° and 135° for left and right lane detection, respectively, as shown in Fig. 2

The robustness of this filter has been proven in the challenging road conditions from our image database, which include dark shadows, pedestrian, vanishing road lanes, road bumps, car lighting, dense traffic, a mix of white and yellow lanes and other road lane markings. Moreover, the edge response for the lane marking is emphasized with this filter, although the camera sensors might not capture sufficient threshold value for faded road lane markings and shadowed regions.

Canny Edge Detection - canny edge detection is a popular algorithm to detect edges and suppress noises that are present in the image. The edges of the lane mark are extracted, which in turn reduces the complexity of the image computation significantly. The upper and lower threshold values are introduced to determine the presence of edge based on the pixel's gradient value. Pixel that has gradient value greater than the upper threshold is considered as an edge, while the pixel with gradient value between the two thresholds is considered as an edge only if it is connected to the other edge pixel. Meanwhile, the pixel's gradient value below the lower threshold is suppressed.

Lane Candidate Selection - to determine the two best lane candidates which represent the left lane and the right lane from the image, PHT is implemented on the computed edge pixels. This method converts the lane detection problem to a simple peak point detection problem. The best lane candidate is chosen by voting in the Hough space coordinate and the votes have to be greater than the threshold value. Gradient

TABLE I: Conditions for different notification status

Notification status	Conditions
Safe (No departure)	$\lambda_l > \xi$, $\lambda_r > \xi$
Left Departure	$\theta_l - \theta_r > \phi$, $\lambda_l < \xi$
Right Departure	$\theta_r - \theta_l > \phi$, $\lambda_r < \xi$

Fig. 3: Results of PHT before line weighting selection (Left) and after line weighting selection (Right)

analysis is applied to the result of PHT (image coordinate of the lane candidate) to determine the left lane and the right lane.

To further simplify the lane candidates to 2 lane candidates only, weighting average is computed according to the length of the lanes using Eq. (1):

$$Wn = \sqrt{(V_{2n} - V_{1n})^2 + (U_{2n} - U_{1n})^2}, \tag{1}$$

where (U_{1n}, V_{1n}) and (U_{2n}, V_{2n}) denote the values of the edges of the lane candidates. These lane candidate selection steps are illustrated in Fig. 3.

C. Lane Departure Warning System

The left lane and right lane candidates extracted from the previous section are crucial in determining the position of the vehicle. The position of the vehicle can be represented by Euclidean distance (λ) and lane departure angle (θ), which is shown in Eq. (2):

$$\begin{aligned} \lambda_x &= \sqrt{\|O\|^2 + \|P_x\|^2 - 2\|OP_x\|} \\ \theta_x &= tan^{-1}\frac{-V2_x + V1_x}{U2_x - U1_x} \end{aligned} \tag{2}$$

where O and P are Euclidean vectors in Euclidean space, in which O represents the image coordinate of the vehicle origin, x denotes the left or right lane candidate, and P denotes the image coordinate of the lane candidate.

The system has three notifications status to alert the user regarding its current position relative to the road lanes. When the left or right departure warning is triggered because the vehicle moved out from its correct lane position without giving a signal, a 'left departure notification' or 'right departure notification' is sent to the user. Once the user has taken the corrective action and the vehicle is at the correct lane position, a 'safe' notification is issued to the user. Table I shows the conditions to be fulfilled for the system to issue the notification to the user. Here ξ denotes the threshold value for Euclidean distance and ϕ denotes the threshold value for lane departure angle. In our work, the threshold values are empirically found to be ξ = 155 and ϕ = 3. These values provide sufficient time for the driver to react and make corrective action before lane switching occurs. Varying these thresholds excessively result in inadequate response time for the driver to perform corrective action or causing the system to be overly sensitive.

(a) Highway

(b) Urban road

Fig. 4: Representative example of highway and urban road under sunny condition.

IV. Experimental Results

A. Image Database Setup

Images capturing various local road conditions are required to evaluate the lane detection and lane departure warning system. We examined sunny weather condition for both highway and urban road as our test subjects. These two types of road present different challenges that affect the accuracy of the system. Highway road does not pose a serious challenge to the system as the lane marking is relatively visible and the traffic is moderate. On the other hand, the urban road presents several challenges such as non-consistent lane marking, fading lane marking, numerous shadow regions, etc. These images of road conditions are captured by Raspberry pi v2 camera with the resolution of 640×480 at 20 fps. Fig. 4(a) and Fig. 4(b) show sample images from our image database illustrating the sunny condition for both highway and urban road.

B. Simulated Method Setup

The proposed method is compared against the commonly used method which is IPM as proposed in [3], [4], [5]. IPM method transforms the original image to the bird's eye view version of it. This method generally comprised of the following steps:

1) Homography and perspective transform
2) Gaussian blurring and adaptive thresholding
3) RANSAC line fitting

We simulate IPM by using the general framework above and compare the accuracy against our proposed method.

C. Lane Detection Results

Our image database consists of 568 frames with various road challenges as mentioned previously. The proposed method and IPM are tested on this dataset and the results are shown in Table II below.

TABLE II: Lane detection results for the proposed method and IPM under sunny condition.

Dataset	Highway-Sunny		Urban-Sunny	
Method	Proposed Method	IPM	Proposed Method	IPM
Total Frame	268	268	300	300
Fully detected frames	250	221	278	242
Accuracy (%)	93.28%	82.46%	92.66%	80.67%

Fig. 5: Lane departure warning for the urban road under sunny condition

Results suggest that our proposed method outperforms the IPM method. IPM method which is implemented by [3] and [5] are originally tested on Caltech dataset that has less traffics. Therefore, it performs poorly in our dataset because our dataset includes heavy traffics. Moreover, the IPM method often failed to detect the lane marking in dark shadow regions and uneven illumination conditions, especially the area where rumble strips are present on the road surface. Our proposed method resolves all these problems as it enhances the lane marking under the shadowed regions and eliminates the non-related objects.

D. Lane Departure Warning Results

For lane departure warning, we tested the performance of our system during sunny condition in the urban road only, since it poses more challenges and safety compared to highway road. A visual warning is issued when there is an unintended lane departure scenario. Figure. 5 shows the capability of the system to detect the vehicle that deviates to either one of the lane boundaries.

Table III records the accuracy of the lane departure warning system. Results suggest that our method achieved an average of 95.16% accuracy for lane departure warning system, which is significantly higher when compared to the method proposed by [14] that has an accuracy of 85.69%. This occurs due to inaccurate detection by [14] for the objects that are present on the road. On the other hand, our proposed method mitigated this issue by implementing the Euclidean distance based calculation.

TABLE III: Results for urban road under sunny condition

Condition	Total frames	Correct status	Incorrect status	Accuracy (%)
Vehicle stay in lane	350	334	16	95.42%
Vehicle crossing left lane	70	64	6	91.42%
Vehicle crossing right lane	117	113	4	96.58%
Total detection result	537	-	-	95.16%

V. Conclusion

We proposed a novel lane detection algorithm, which greatly improves the accuracy of lane departure warning system. The proposed method achieves an accuracy of 93% for lane detection task, which is 11% higher than the simulated IPM method and an accuracy of 95% for lane departure warning system. Gabor filter is an important element in our method as it reduces several challenging road conditions significantly, which in turns decrease the complexity of lane detection algorithm. With the aid of multithreading, our framework is able to achieve real-time performance with an average of 20 frames per second and 75% CPU utilization.

As future work, we want to improve our accuracy and cater for other weather condition such as raining and foggy day.

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