Real-time lane detection and departure warning system on embedded platform

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***Abstract*— Within the last few years, studies on Advanced Driver Assistance Systems (ADAS) have been actively conducted and deployed in modern vehicles; moreover, lane detection and departure warning systems are important modules of ADAS. However, most of the recent papers have only focused on PC-based lane detection modules, and very few concerns have been addressed for the customized embedded board. This paper proposes a real-time lane detection and departure warning technique on a commercial embedded board. The technique is based on Inverse Perspective Mapping (IPM) generating a top-view image of the road and Kalman filter tracking removing noise and enhancing accuracy. The experimental results show good performance with an average correct detection rate of 96% under various challenging urban and highway conditions while the processing time takes only 22.76 ms per frame (1280x720) on the embedded board which verifies that the proposed method could be feasible for real-time applications in commercial ADAS products.**

Keywords*— *Real-time, ADAS, LDWS, IPM, Kalman filter

I. INTRODUCTION

Due to car accidents, road injuries occurred in about 54 million people in 2013 [1]. This led to 1.4 million deaths in 2013, up from 1.1 million deaths in 1990, which is about 2.5% of all deaths. The Fatal Analysis Reporting system of the National Highway Traffic Safety Administration (NHTSA) reported that 20% of car accidents are caused as a result of driver distraction [2].Thus, in order to assist people driving safely, Advanced Driver Assist Systems (ADAS) are in great demand and actively studied. Especially, lane detection is a crucial component in terms of understanding the driving environment as well as independent driving for autonomous guided cars [3], [4].

There have been many studies on lane detection including everything from a single camera [5]–[7] to stereo vision [8], [9], 3D modeling of the road environment [10], [11] or even radar and lidar [12], [13]. However, most of these works have been done in real-time only on the PC and some of them not even real-time, which means these lane detection modules cannot be actually modularized in ADAS on commercial embedded systems due to their hardware limitations.

The main contributions of this study are as follows:

- Real-time processing on a commercial embedded board: the proposed method was tested on the commercial embedded board JETSON TK1 made by NVIDIA [14] and achieved about 43 frames per second on 1280x720 HD images.

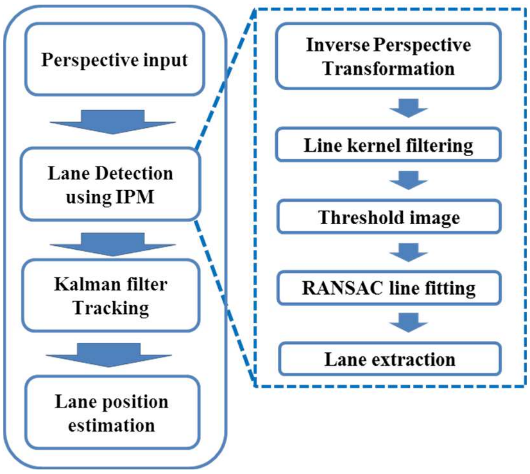

Figure 1. Overview of the proposed lane detection and tracking system.

- Robustness under challenging conditions: the proposed method works well even for various environmental conditions including rain, night, and sunset on highway and urban roads as well as various disturbances such as shadows, road markings, crosswalks, and faint lane markers.

II. PROPOSED METHOD

A. Detection

In the detection step as illustrated in Fig. 1, first, perspective input images captured by a camera are transformed to a bird-eye-view (or top-view) image by Inverse Perspective Mapping (IPM) [5] which consequently removes the perspective effect of the image shown in Fig. 2. The next step is filtering and thresholding the transformed IPM image for bright vertical

(a) Camera perspective view. (b) Bird-eye-view.

Figure 2. IPM transforms a camera perspective view into a bird's eye view image.

straight lines which could be candidate lane markers. Finally, it is followed by the Random Sample Consensus (RANSAC) [15,16] line fitting technique to estimate the parameters of a model by random sampling of the observed data. Assuming that these data contain both inliers points that approximately can be fitted to a line and outliers points which cannot be fitted to this line, RASNAC can produce a line model which is only computed with the inliers containing high probability while removing the outliers.

In addition, lane markers generally exist below the vanishing line of the captured image whereas regions that include landmarks and the sky appear above the vanishing line. Thus, it is reasonable to focus on only the bottom of the vanishing line in the input image to extract the lane markers. Thus, shown in Fig.3, the proposed system sets a Region of Interest (ROI) adaptively in the sub-regions below the vanishing line and computes using only those regions; thus, the computation is considerably reduced.

B. *Tracking*

In the tracking step, a Kalman filter is adapted to smooth and track the estimates of the detected lane points and slopes using the measurements. The state vector x, which contains the center point and slope of the lane, and the measurement vector z, which can be measured, are defined as

$$\mathrm{x} = \left[c\ d\ \dot{c}\ \dot{d}\,\right]^T \tag{1}$$

$$\mathrm{z} = [c\ d]^T \tag{2}$$

, where c is the center point of the lane, and d is the slope of the lane; $\dot{c}$ and $\dot{d}$ are the derivatives of c and d that are estimated from the difference between the current and previous frame. Assuming that the noise of the system and its measurement are white noise and each process is uncorrelated with the other, the state transition matrix A is defined as

$$\mathrm{A} = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{3}$$

In the case of not detecting lanes, the Kalman filter tracker will still yield an estimate based on its prediction variable. However, if an undetected state persists more than several frames, then the tracker turns back to the initial step, which prevents incorrect estimates. Finally, the estimated lane markers in the IPM image are inverse transformed to the original perspective view to show the detection results.

III. EXPERIMENTAL RESULTS

A. *testbed*

The testbed used to test and evaluate the proposed method was the NVIDIA JETSON TK1 board which was embedded I a Linux development platform with a quad-core 2.3 GHz ARM Cortex-A15 CPU, a Tegra K1 GPU, and 2 GB DDR3 memory.

B. *Accuracy & Speed*

To evaluate the performance of the proposed method, this paper used various challenges from the Inha dataset collected by

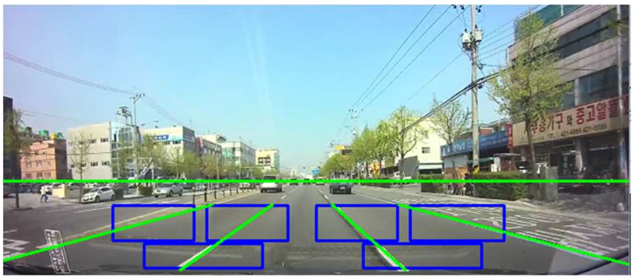

Figure 3. Adaptive ROI of the input image

the authors and the Caltech [12] public dataset providing 1280x720 and 640x480 resolution images, respectively. The Inha dataset has different illumination conditions such as clear, night, rainy, cloudy, and sunset as well as different road environments on urban streets and highways. Additionally, the Caltech and Inha dataset have road disturbances such as road markings, fainted lane markers, shadows, and crosswalks. As shown in Table 1, the proposed method, on average, ran in real-time at 43 frames per second on a Jetson TK1 embedded board. Furthermore, the correct rate, false positive and miss rate were 96%, 4% and 4%, respectively. Fig.4 shows the results of the lane detection with good results for various weather and road conditions. However, as shown Fig.5, the proposed method had some false positives due to crosswalks, near edges of cars and light reflection on the road.

TABLE 1. LANE DETECTION RESULT ON A JETSON TK1 EMBEDDED BOARD

dataset	**conditions**		**Correct Rate**	**False Positive**	**Run time (ms)**
Inha	***Urban***	***Clear***	0.94	0.05	20.38
		Rainy	0.94	0.06	23.35
		Night	0.93	0.07	25.11
	Highway	***Sunset***	0.94	0.059	20.68
		Cloudy	0.99	0.001	24.41
		Night	0.97	0.02	22.65
Caltech	***Urban***	***Clear***	0.98	0.014	22.71
Average			0.96	0.04	22.76

C. *Comparison*

This study also compared the accuracy and speed performance with the PathMark[17], which was proposed for lane detection

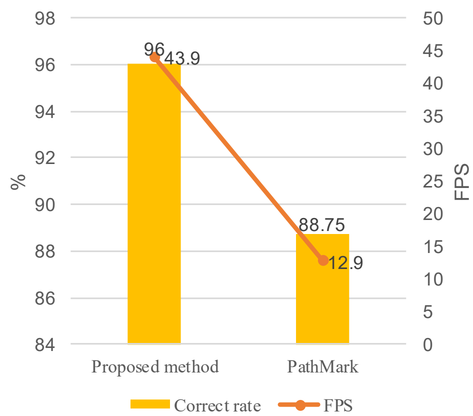

Figure 3. Comparison of the performance with PathMark.

Figure 4. Lane estimation results. First two rows are the results from the Inha dataset for clear, night, rainy, cloudy, and sunset conditions. The third row is the results from the Caltech dataset.

Figure 5. False positives by near car's edge, light reflection on the road, and cross-walk.

using TI OMAPP4430-based embedded board. The proposed method and PathMark algorithm are both tested in Caltech dataset. The experimental results are shown in Figure 3. It demonstrates that the proposed method outperforms PathMark algorithm significantly by not only improving the accuracy rate from 88% to 96% but also achieving 3 times speed up from 12.9 FPS(Frame Per Second) to 43.9 FPS.

IV. CONCLUSION

In this paper, a real-time lane detection module on a commercial embedded platform is presented using IPM, RANSAC line fitting and Kalman filter tracking. This work has achieved considerably a high accuracy of 96% and fast processing time, of about 44 FPS on the NVIDIA JETSON TK1 board even in challenging road and weather conditions. This paper shows that the proposed work is quite feasible for real-time application in commercial ADAS products.

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