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Lane departure warning system using front-view and two mirror-view cameras

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Abstract. This study proposes a vehicle Lane Departure Warning System (LDWS) that sends a warning to drivers using the road marking recognition system of two cameras installed on the left and right sides of the vehicle. LWDS aims to solve various problems that may possibly arise when driving on the road, including, mainly, unexpected conditions. This system generates warnings using cameras to capture images continuously by identifying the movement direction of a vehicle using left and right road markings and predicting the driving direction of the vehicle. Two cameras are installed on the right and left side mirrors of the vehicle to promote Advanced Driver Assistance Systems (ADAS). The left mirror-view camera detects movement in the right lane, whereas the right mirror-view camera detects movement in the other. These two cameras detect the movement of a vehicle using algorithms and send warning signals to the driver independently. Our algorithm combines these signals to analyze environmental conditions. The used algorithms include brightness adjustment, binarization, dilation, erosion, and edge detection image processing techniques. We tested the LUXGEN M7 in an experiment to verify the feasibility of our proposed system.

1. Introduction

With an increasing number of individuals showing a growing dependence on transport, it obviously serves an important function in our daily lives However, such increasing dependence has also increased traffic accident occurrence and fatality rates. The Fatality Analysis Reporting System data of the National Highway Traffic Safety Administration (NHTSA) show that traffic accidents caused by driver negligence and unintentional lane deviations account for 41% of all traffic accidents in the United States, as shown in Figure 1 [1]. To prevent these unintentional lane deviations, as well as to reduce traffic accidents and casualty rates, this paper proposes a lane departure warning system (LWDS) that alerts and guides the driver in navigating his or her vehicle when he or she is facing such a situation.

Driver assistance systems reduce vehicle crashes by helping to avoid such accidents preemptively. A Lane Departure Detection System (LDS) is an alarm system that helps drivers avoid switching lanes unintentionally. Many vehicle roadway departure crashes occur during light traffic and favorable weather conditions. A survey by Mercedes-Benz suggests that 90% of road collisions can be avoided if the driver can be effectively warned one second before the accident [2]. These accidents can be effectively prevented by installing an active safety system in the vehicle to warn the driver of upcoming danger. Many automobile manufacturers have installed the LDWS in their vehicles to reduce the frequency of accidents caused by the inattention

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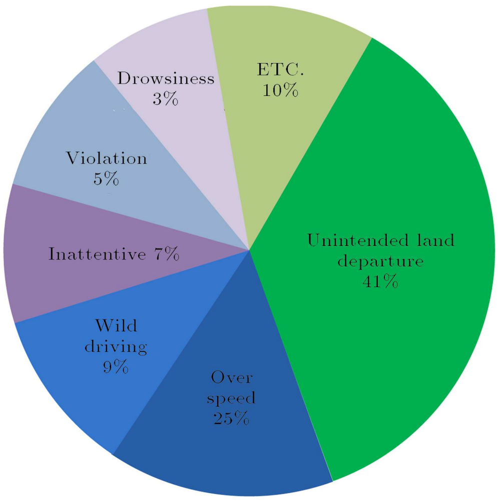

Figure 1. NHTSA data.

of the driver. The main function of LDWS is to warn and allow the driver to take responsive measures in advance when his or her vehicle is about to depart from the correct lane, hence, preventing vehicular accidents caused by unintentional lane departures. In February 2007, ISO issued ISO 17361 [3], which was the first version of the LDWS standard [4]. This standard regulates the vehicle and road lane relative to the location and rate of lane departure in order to prevent the system from warning the driver too early or too late. In 2005, the U.S. Federal Motor Carrier Safety Administration also set reference standards regarding the LDWS operating requirements [5] with reference to ISO 17361.

This paper is organized as follows: Section 1 introduces the importance of LDWS. Section 2 describes the system model, LDWS, Hough transform, and road marking recognition system. Section 3 discusses the experimental procedures, and provides and verifies the results. Section 4 offers several conclusions.

2. Advanced driver assistance system

The Advanced Driver Assistance System (ADAS) is actively developed by major automobile manufacturers worldwide for intelligent vehicle technology. ADAS is considered the first step in the future development of unmanned intelligent vehicles. Currently, ADAS cannot control a vehicle independently from the driver. The system provides several working and environmental situations around a vehicle which can be analyzed and determined by a microprocessor. ADAS warns drivers of traffic accidents in advance. The system has more than nine functions, including a blind spot system (BSD), a Backup Parking Aid System (BPAS), a Rear Crash Collision Warning System (RCCWS), a Lane Departure detection System (LDS), a Collision Mitigation System (CMS), an Adaptive Front-lighting System (AFS), a Night Vision System (NVS), an Adaptive Cruise Control System (ACCS), a Pre-Crash System (PCS), and a Parking Aid System (PAS). This system has three main processes, which are discussed in Subsections 2.1 and 2.2 [6-8].

2.1. Information collection

The first process in ADAS is the information collection process. Different systems must use different types of vehicle sensor, such as image sensors, wheel speed sensors, Millimeter Wave (MMW) radar, ultrasonic wave radar, infrared ray radar, and laser radar, to determine the function and parameter-varying situation of a vehicle. LDS, NVS, ACCS, and PAS use CMOS image sensors, infrared ray sensors, and radar. The second process of ADAS is the electronic control unit, which aims to collect information from the sensors for data analysis and processing. The data processing generates controlling signals that are transmitted to various devices installed in the vehicle. The final process of ADAS is the operating process. The devices that are installed on a vehicle are operated by control signals. Vehicle radar is classified into several types, such as laser radar, MMW radar, ultrasonic wave radar, and infrared ray radar, in terms of their transition medium. The laser radar is known for its high measuring precision, long measuring distance, and high direction. However, this radar generates inaccurate measurement data under poor road environments and conditions, such as blizzards, storms, and fogs. The laser radar is always used for BSD and CMS. The MMW radar can sort pulse frequency modulation and frequency modulation continuous waves by applying a measuring method. The radar uses frequency bandwidths of 23 GHz to 24 GHz, 60 GHz to 61 GHz, and 76 GHz to 77 GHz. This radar has been termed the "millimeter wave radar" because of its usage of an average millimeter wavelength. The MMW radar has a far measuring distance, a high operating stability to resist environmental effects, and the capability of measuring the distance and relative velocity between two vehicles. However, this radar has a poor penetrating capability. The MMW radar is always applied for BPAS, RCCWS, CMS, and ACCS. The ultrasonic wave and infrared ray radar have a shorter measuring distance compared to the other radar. The ultrasonic wave radar is used for BPAS, while the infrared ray radar is used for NVS. An increasing number of major vehicle sellers, including LUXGEN U6/U7 [9], Volvo, Mercedes-Benz, BMW, and Audi, are beginning to promote ADAS to increase the utility rate of their vehicles.

2.2. Lane departure detection and warning system

In ADAS terminology, LDS is a mechanism that is designed to warn a driver when position detection,

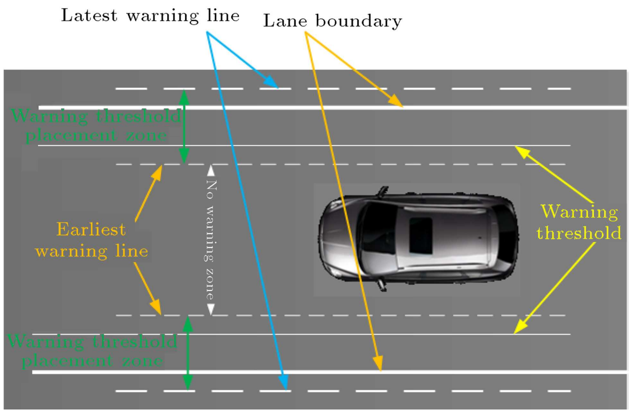

Figure 2. Warning thresholds and placement zones in ISO 17361.

lane departure warning, status monitoring, and alert his or her vehicle begins to move out from its lane without showing a turn signal. LDS aims to minimize accidents by addressing the three primary causes of collision, namely, driver error, distractions, and drowsiness. In 2009, NHTSA began to investigate whether they should mandate lane departure detection and frontal collision warning systems on automobiles. LDS has also become a standard technology of the European New Car Assessment Program (EURO-NCAP). This paper designs an LDS according to the specified guidelines of the ISO standard 17361:2007(E). All our tests are validated under ISO 17361, as shown in Figure 2.

The LDWS architecture follows the recommendations of ISO 17361, as shown in Figure 3. The proposed system consists of several components, such as lane systems. The lane position detection system continuously detects the relative location of the vehicle and the lane, and then inputs the detection results in the LDS for recognition. This system also determines whether the vehicle has departed the lane unintentionally or without showing turn signals, according to pre-defined rules for differentiating the warning area from the non-warning area. If the vehicle is determined by the LDS as having entered the warning area, the system will automatically warn the driver to respond immediately

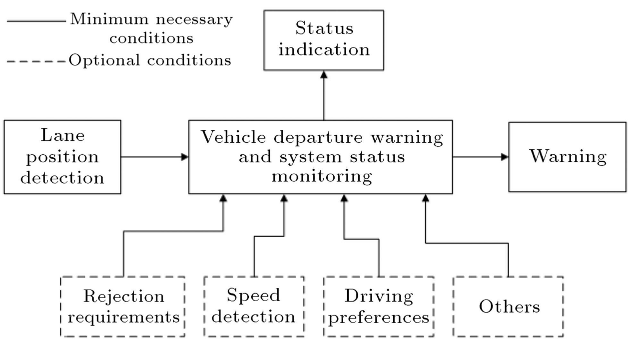

Figure 3. System structure of LDWS.

to the situation or to change the direction of his or her vehicle [10,11].

In this study, we propose a safer LDS for monitoring road conditions and for warning drivers about impending danger. A Canny edge detection algorithm and Hough transform are implemented in this system to detect the lane that is located nearest to the vehicle. Developed by John F. Canny in 1986, the Canny edge detector is an edge detection operator that uses a multi-stage algorithm to detect a wide range of edges in images. Canny also introduced a computational theory of edge detection that explains how his technique works. Given that an edge in an image may point towards several directions, the Canny algorithm uses four filters to detect horizontal, vertical, and diagonal edges in a blurred image. The edge detection operator (i.e., Roberts, Prewitt, and Sobel) returns a value for the first derivative in the horizontal direction (S_1) and the vertical direction (S_2). The edge gradient and direction can be determined as follows:

$$\text{Edge magnitude} = \sqrt{S_1^2 + S_2^2}, \tag{1}$$

$$\text{Edge direction} = \tan^{-1}\left[\frac{S_1}{S_2}\right]. \tag{2}$$

Hough transform is a technique that isolates the features of a particular shape within an image. Given that this technique requires the desired features to be specified in a parametric form, the classical Hough transform is most commonly used for the detection of regular curves, such as lines, circles, and ellipses. A generalized Hough transform can be employed in applications where a simple analytic description of a feature is impossible. Given the computational complexity of the generalized Hough algorithm, we restrict the main focus of this study to the classical Hough transform. The main advantages of the Hough transform technique are its tolerance of gaps in feature boundary descriptions and its resistance of image noise.

An LDW system aims to monitor the risk of an inadvertent deviation from a lane, resulting from the inattention of the driver. Current systems either use an audible beep or a rumbling stripe noise, which sounds similar to the noise that a vehicle makes when running on a lane divider. The system typically uses a forward-looking camera that compares the lane marking with the direction of the vehicle to evaluate a possible deviation. A forward-looking camera is also used in our proposed system to help monitor the front situation of the vehicle. We have added side-view cameras, including a left side-view camera and a right side-view camera, to increase the reliability of ADAS. Our proposed system aims to prevent drivers from driving on curved lanes or branch roads. The front camera captures the basic view for the proposed system. The basic view is then transformed into a Hough parameter through Hough translation. The side-view cameras of the vehicle capture the views from the left and right lanes. These views are also transformed into Hough parameters through Hough translation. We set the boundary conditions for choosing the correct parameters to detect the lanes. These boundary conditions ignore extremely large values, limit the training number of objections, and offset the lane position [12,13].

In the next step, the system computes the distance between the right lane and the left lane from the front camera, the distance between the right lane and the right vehicle door, and the distance between the left lane and the left vehicle door. Hough parameters can draw the lane and fetch the coordinates of the top and bottom points. We apply a point-to-point distance theorem to compute the distance. We design a threshold to confirm a vehicle lane departure, and more than five occurrences of lane departures are observed.

Finally, the system combines the three departure warning signals to confirm the departure of a vehicle from its lane. The system will issue a right departure warning when departure warnings are generated in the right side and front views. The system will issue a left departure warning when departure warnings are generated in the left side and front views. The system will not issue a departure warning when departure warnings are generated in either the right or left sides. The system combines all signals to produce the output image that is shown in Figure 4.

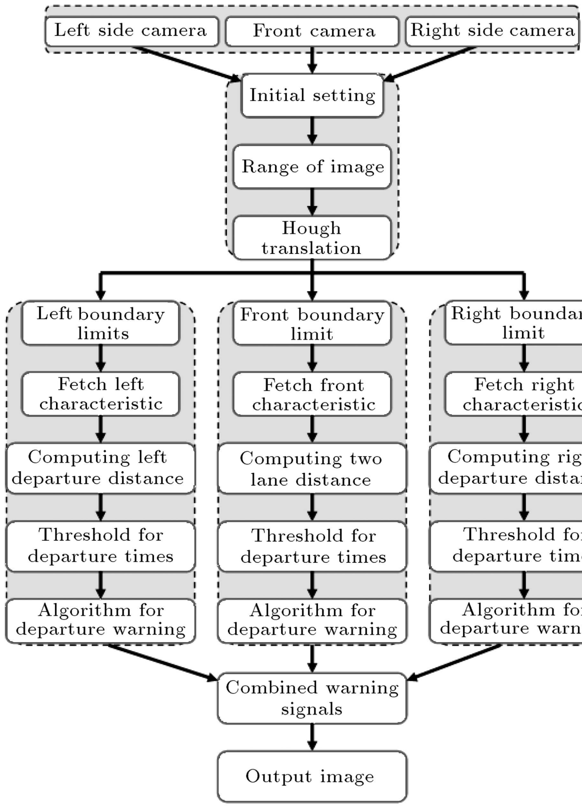

Figure 4. Block diagram of ADAS.

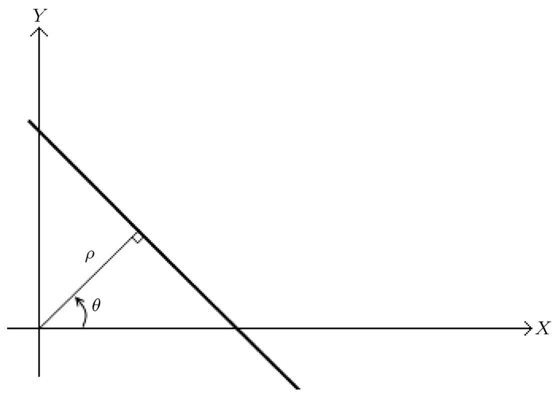

Figure 5. Schematic diagram of normal line representation.

2.3. Hough transform

The Hough transformation [14,15] flowchart was proposed in 1962 to determine possible lines in an image. By using the common $x - y$ plane as an example, the linear equation, by the inclined interception of a point (x, y) in the $x - y$ plane, is computed as $y = ax + b$. An infinite number of lines pass through (x, y) and all the a, b values can satisfy the equation, $y = ax + b$. Therefore, rewriting the equation into $b = -ax + y$ and using the plane of a, b as the parameter space can produce a single line equation of the fixed coordinates of (x, y). All the points in the plane of $x-y$ (x, y) correspond to their counterparts in the parameter space. The main lines of the plane have intersection points in the parameter space. Given that a (linear slope) will approach infinity when the straight line points towards the vertical direction, this study uses the following normal line representation of a straight line, as Eq. (3):

$$\rho = x \cos\theta + y \sin\theta, \tag{3}$$

where θ is the angle of the straight normal line and of the X-axis, while ρ is the normal length. The computation is confined to a limited range of angles and uses the characteristics of the triangular function to solve the infinite problem, as shown in Figure 5.

Hough transformation maps each point, (x, y), to multiple parameter space coordinates, (ρ_i, θ_j). Therefore, the cumulative matrix value, $A(i, j)$, is used to record the occurrence of (ρ_i, θ_j). The range of Hough transformation in the $\rho\theta$ parameter space can be expected as $-90° \leq \theta \leq 90°$ and $-D \leq \rho \leq D$, where D is the maximum distance of the diagonal line in the image. This diagonal line is located in the coordinates of (i, j), with the cumulative value array, $A(i, j)$, corresponding to the accompanying parameter space coordinates, (ρ_i, θ_j). These cumulative arrays are initially set as zero. With regard to all points, (x_k, y_k), on the plane of $x - y$, if θ is equivalent to the segmentation value on the axis of θ, equation $\rho = x_k \cos\theta + y_k \sin\theta$ can be used to determine the corresponding ρ. The produced ρ will be rounded to the tolerable value of the axis of ρ. The two points of the same straight line on plane $x - y$ will converge in a single point when the value of two curves in the parameter space, (ρ, θ), namely, the cumulative matrix, is equivalent to 2.

After the Hough transformation, the value of B in $A(i, j)$ shows B points on the straight line, $\rho_i = x \cos\theta_j + y \sin\theta_j$, on the plane of $x - y$. The images are segmented before the markings on the lane are identified. Given that the camera is installed in the vehicle facing the road in a head-on position, the part of the road is captured in the lower part of the image. Given that lane markings often appear in pairs, and the vehicle is assumed to be driving in the center of the road, the two sub-images in the lower part of the image can capture the markings on the left and right sides of the road. Therefore, the Y- and X-axes of the coordinate system are set in the center and bottom of the image, respectively, to segment the image into two parts for the Hough transformation of $0° \leq \theta_r \leq 90°$ at the right part and for the Hough transformation of $-90° \leq \theta_l \leq 0°$ at the left part. The Hough transformation of the two sub-images can determine multiple groups of possible (ρ_r, θ_r) and (ρ_l, θ_l). The top five groups of cumulative values are selected as the candidate road marking groups. Given that lane markings are usually found in pairs, this study compares (ρ_r, θ_r) with (ρ_l, θ_l) to determine which of these two groups has the closest θ angle to the lane markings in the left and right sub-images. The two groups of (ρ_i, θ_j) are re-matched with the road edges that are produced by the plane of $x - y$, as shown in Figure 6.

3. Experimental result

Given that the side-view cameras are standard equipment in LUXGEN MPV, we can easily obtain the mounted data from the cameras by measurement. Figure 7 shows the original view in our testing vehicle. The left image is our left-view camera output, the middle image is our front camera output, and right image is our right-view camera output. Each image has a value in the left-up position. These values indicate a distance between two lanes. Each image can detect and mark their two lanes. Figures 8 and 9 show the left side-view camera detecting the attempt of the vehicle to depart from the left lane. In other words, the left body of the vehicle is over the earliest warning line. Figures 10 and 11 show the vehicle attempting to depart from the right lane.

The experiments are conducted in both daytime and nighttime environments. According to the Hough transform algorithms, candidates (ρ_r, θ_r) and (ρ_l, θ_l) can be found in the daytime and nighttime environments, respectively. The parameters are shown in Tables 1 and 2.

In the daytime environment, by comparing the difference between θ_r and θ_l, the right side of the second group and the left side of the second candidate are selected for the marking group. The standard line drawing images are shown in Figure 12 to obtain the identification results and to further offset the vehicle warning. In the nighttime environment, Table 2 shows that the first group to the right and left sides is selected for the marking group. Figure 13 shows the results.

By obtaining the marking detection results, the proposed system is placed in the marking point of error,

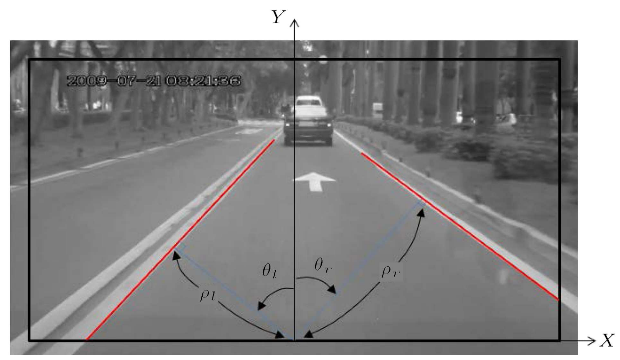

Figure 6. Definitions of the lane marking parameter.

Table 1. The parameters (ρ_r, θ_r) and (ρ_l, θ_l) in daytime environment.

	Left part		Right part	
	ρ_l	θ_l	ρ_r	θ_r
No. 1	174	-35	144	34
No. 2	175	-35	145	34
No. 3	171	-36	139	36
No. 4	169	-38	138	36
No. 5	170	-36	143	33

Table 2. The parameters (ρ_r, θ_r) and (ρ_l, θ_l) in nighttime environment.

	Left part		Right part	
	ρ_l	θ_l	ρ_r	θ_r
No. 1	152	-45	162	33
No. 2	154	-48	159	33
No. 3	230	-4	163	33
No. 4	231	-4	162	32
No. 5	153	-48	163	32

Figure 7. Output image on the testing vehicle.

Figure 8. Left side-view departure warning test 1.

Figure 9. Left side-view departure warning test 2.

Figure 10. Right side-view departure warning test 1.

particularly side-by-side in the double yellow or white lines, to detect the two parallel lines as a straight line. From a macroscopic perspective, the lead angle error can affect the offset warning of the other vehicles when these vehicles move forward when the offset angle is less than the error, and when the yaw error is much larger than the error. In this way, such error can be avoided by using an offset threshold.

4. Conclusion

This study proposes a new LDS that uses side-view cameras. We use the LUXGEN MPV as a test vehicle to validate our proposed system. The results of our experiment are similar to those of the LDS that uses a front camera. The proposed system can successfully detect road markings under adequate daytime lighting

Figure 11. Right side-view departure warning test 2.

Figure 12. Daytime image road edge detection results.

Figure 13. Nighttime image road edge detection results.

conditions. However, the road marking detection accuracy of the system is affected by several factors, such as dirt, vehicle type, or aging of the road markings. Our proposed system enhances the unilateral marking detection and assists in the virtual marking process to improve the detection rate of the complete offset warning. However, limited ambient lighting during nighttime, even with the aid of headlamps, significantly affects the detection of road markings. Adjusting the brightness and enhancing the glare filter can help address this problem.

The proposed system can successfully detect road markings during both daytime and nighttime, as long as a sufficient amount of light is present. Future endeavors can be undertaken to improve this system, particularly in terms of identifying environmental masking, detecting road markings under low light during nighttime, adjusting brightness, and increasing the system response speed.

Author contributions

The authors have worked together, and their contribution to this paper is equal. Jia-Shing Sheu developed the modeling and performed the algorithms. Chih-Han Chang and Tsong-Liang Huang discussed and investigated the research work, in particular for design of the simulation and test procedures. Hsin-Jung Lin has been responsible for the simulation and testing. All the authors have read and approved the final manuscript.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Biographies

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