# Study of Integrated Vehicle Image System Including LDW, FCW, and AFS

Yi-Feng Su, Chia-Tseng Chen, and Hsueh-Lung Liao

***Abstract*—**The objective of this research is to develop an advanced driver assistance system characterized with the functions of lane departure warning (LDW), forward collision warning (FCW) and adaptive front-lighting system (AFS). The system is mainly configured a CCD/CMOS camera to acquire the images of roadway ahead in association with the analysis made by an image-processing unit concerning the lane ahead and the preceding vehicles. The input image captured by a camera is used to recognize the lane and the preceding vehicle positions by image detection and DROI (Dynamic Range of Interesting) algorithms. Therefore, the system is able to issue real-time auditory and visual outputs of warning when a driver is departing the lane or driving too close to approach the preceding vehicle unwittingly so that the danger could be prevented from occurring. During the nighttime, in addition to the foregoing warning functions, the system is able to control the bending light of headlamp to provide an immediate light illumination when making a turn at a curved lane and adjust the level automatically to reduce the lighting interference against the oncoming vehicles driving in the opposite direction by the curvature of lane and the vanishing point estimations. The experimental results show that the integrated vehicle image system is robust to most environments such as the lane detection and preceding vehicle detection average accuracy performances are both above 90 %.

***Keywords*—**Lane mark detection, lane departure warning (LDW), dynamic range of interesting (DROI), forward collision warning (FCW), adaptive front-lighting system (AFS).

## I. Introduction

IN the wake of promoting the awareness for vehicular safety and the development of science & technology in recent years, many advanced countries actively invest in the application filed of ASV (Advanced Safety Vehicle) to stress the safety of vehicle. Especially, an integral solution for vehicle safety system as an application of vision-based science & technology has been launched to increase the driving safety of vehicle and reduce the occurrence rate of traffic accident. According to the advantages of vehicle image system, including low cost, multi-functions, and human-like features, many car manufacturers focus on the research with respect to the use of CCD/CMOS camera in association with various algorithms to make the driver assistance system for in-car safety realizable.

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The image process algorithm plays as a critical role as the system core technique and represents the sensitivity and the robustness of system performance.Many methods are used for lane markings recognition and each method has its own advantages and disadvantages according to its concept [1]. As described in [2] [3], the inverse perspective mapping (IPM) approach is adopted to generate the bird's eye image of the road plane so as to remove the perspective effect and extract lane markings through some constraints of road geometry. This method is time-consuming due to its complex computation. Other research combines road model and Hough Transformation to estimate the initial lane boundary and improve the availability of lane detection without the ability of curve lane recognition [4].

A feature-based approach [5] is applied to detect the preceding vehicle. The vehicle features, including texture, edge, symmetry and shadow of vehicle images, are used for vehicle segmentation and recognition. In generally, the single feature is not satisfied to detect a vehicle resulted from the variation of illumination or environment. The template-matching is the other solution to detect a vehicle by means of preparing numerous vehicular templates (such as: the characteristics of edge and wavelet, etc.) in advance to perform a match with the current images so as to locate the matching region with the maximum correlation as the vehicle-existing region [6]. Normally this approach can obtain a better reliability than the approach of feature-based detection. Recently, using a learning algorithm [7] for vehicular detection has become prevailing; therein, a neural network or other training mechanisms are taken to go through training from a large volume of vehicle images and then carry out the classification through a classifier.

Regard for the AFS (adaptive front-lighting system) as proposed in [8], many car manufacturers have researched & developed an adjustment system for thereof headlamp at the present time. For examples, the Benz's Adaptive Font Light System, BMW's Adaptive Lighting Control, and Opel's Adaptive Forward Lighting are serviced as the standard device in their limousine. The headlamp control is not only left and right adjustment by steer angle but also the level adjustment by the dynamic level angle of a vehicle according to the vehicle loading and level angle of road surface.

The integrated vehicle image system proposed in this study is mainly configured a camera with the functions of LDW (Lane Departure Warning), FCW (Forward Collision Warning) and AFS (adaptive front-lighting system) characterized that is able to detect the lane mark and the preceding vehicles while the information relevant to the relative distance between the vehicle and lane and the headway to the preceding vehicles are computed at the same time. Therefore, a timely warning can be given to the driver for alerting his unwittingly departing the lane or carelessly driving too close to approach the preceding vehicle so that the driver can correct his car-driving direction, brake to decelerate the speed in advance in time, and reduce the probability of traffic accident accordingly. The system is able to further follow the curvature of lane and the vanishing point of roadway ahead to control the light bending of headlamp timely and adjust thereof level automatically in order to provide an immediate light illumination when making a turn at a curved lane.

## II. System Overview

A Digital Image Processer (DSP) is used as the operating core in this research to implement the real-time lane recognition, location estimation of the preceding vehicles and detection for vehicle's angle of inclination to achieve the integrated vehicle image system. An algorithm that can keep away the noise interference from the background of road images is adopted to precisely recognize the lane ahead and the headway estimation of the preceding vehicles. In the meantime, a setup of DROI (Dynamic Region of Interest) is taken to increase the speed in processing the images and reduce the misjudgment rate from the image-processing algorithm so that the system is able to normally recognize any lane forms and react to function normally when mounted to various types of vehicle. Furthermore, a real-time control for bending the light of headlight plus an automatic adjustment of level can be enabled during the nighttime to provide the driver with a better field of vision.

### *1.1 System structure*

The hardware structure of this system is shown in Fig. 1. The major sensing & detecting device is a camera mounted between the front windshield and the rear-view mirror inside the car. The camera can acquire the roadway images in front of the vehicle and transmit the acquired images to a DSP for processing the images, analyzing the lane, position of preceding vehicles, lane curvature and vanishing point of roadway ahead from the images. Meanwhile, the information of lane curvature and vanishing point of roadway ahead can be further analyzed to derive the bending angle of headlight and the vehicle's angle of inclination (that is the level angle of headlight) for a motorized actuator to bend the headlight automatically so that an optimal illumination is available. With this hardware structure configured in association with the functions of LDW, FCW and AFS as shown in Fig. 2, the purposes of this integrated vehicle image system is achievable by applying the real-time image-processing method. Fig. 3 is a schematic diagram showing the function for the application of integrated images ahead the vehicle; wherein, Fig. 3(a) shows the lane recognition and headway estimation to the preceding vehicle while Fig. 3(b) shows the lane recognition and headlight pattern control.

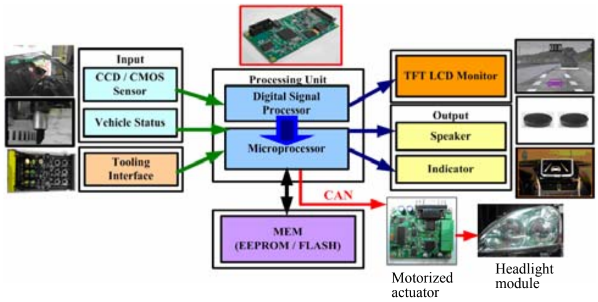



Fig. 1 Structure of the integrated vehicle image system

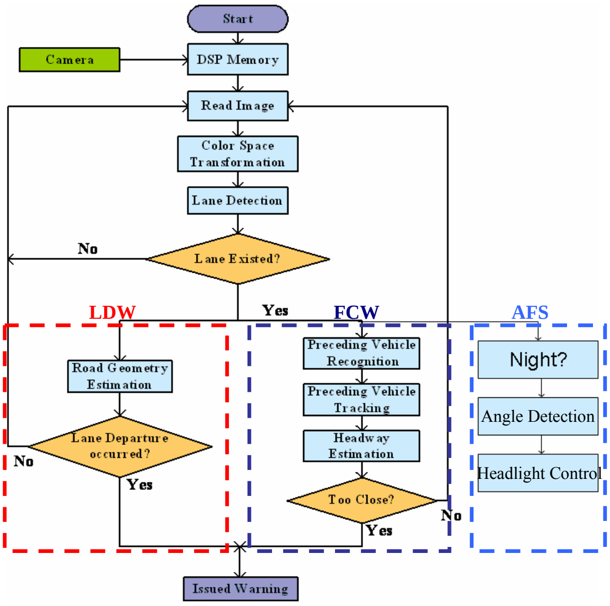



Fig. 2 Flowchart of the integrated vehicle image system


Fig. 3 Schematic diagram for the application of integrated images ahead the vehicle

### *1.2 Coordinates Conversion System*

The relation between the global coordinates and the planar coordinate of image is shown in Figure 4. Since the lane detection must be performed in the image coordinates, the 2-D information derived from the image-processing for lane mark should be transformed into 3-D spatial information through the Inverse Perspective Mapping (IPM) in order to obtain the position of lane in a real space (global coordinates). Parameters needed in the algorithm and thereof definitions are shown in Table I. Because the image recognition for lane detection is undertaken in the image plane, the objects in image plane is converted into a real object in global coordinates by Equation (1), (2) and (3).

$$X = \frac{uH}{e_v m_\theta - v} \cdot \frac{e_v}{e_u} \tag{1}$$

$$Y = \frac{e_v H}{e_v m_\theta - v} \tag{2}$$

$$Z = \frac{e_v m_\theta H}{e_v m_\theta - v} \tag{3}$$

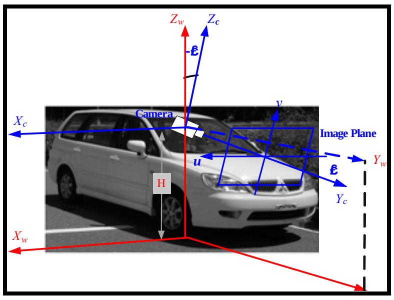



Fig. 4 Relation between the global coordinates and the image plane

TABLE I
PARAMETERS DEFINITION

| Name | Definition |
|---|---|
| u | x axis in Image plane |
| v | y axis in Image plane |
| H | Height of camera from ground |
| k, m, b | Coefficient of road geometry |
| $m_\theta$ | Tilt angle of camera |
| W | Actual lane width |
| $X_w$, $Y_w$, $Z_w$ | Global coordinates |
| $e_u$ | Pixel width of CMOS Sensor |
| $e_v$ | Pixel height of CMOS Sensor |

### *1.3 Lane Detection*

The lane detection is very important for the integrated vehicle image system. The algorithms are described as follows:

#### 1.3.1 Lane Mark Recognition

In order for the image processing unit to detect whether the vehicle has been departing from its driving lane, firstly it is necessary to identify the position of lane mark from the image plane. Some features of the roadway itself should be taken as the basis for image recognition when detecting the lane marks that mainly covers the following four cues for lane mark recognition.

##### 1.3.1.1 High-Grey Value

Regardless of the white or yellow lane markings appeared in the roadway image, all of them have a higher gray value than the road surface. Therefore, the statistics of gray scale can be utilized to identify the threshold value of lane marks and differentiate the lane marks from road surface.

##### 1.3.1.2 Edge Characteristic

A noticeable edge characteristic at the connecting point of the lane marks and the road surface can be taken to compute and mark the possible range of lane mark. The Sobel's horizontal edge-based detection technology was applied to detect the edge of lane marking in every row of image by the following equation:

$$E(\mathrm{u,v}) = \begin{cases} S * [\mathrm{I(u,v)}] & \mathit{if}\ \ \mathrm{I(u,v)} > 0 \\ 0 & \mathit{otherwise} \end{cases} \tag{4}$$

In the equation, I(u,v) is the original image, E(u,v) is the edge image. S*[I(u,v)] represents the Sobel's operation, and its horizontal mask is [-1 –2 –1; 0 0 0; 1 2 1].

##### 1.3.1.3 Range of Lane Mark Width

The actual lane mark width will be shown in the image plane through a conversion from the Equation (5) at a constant ratio. A determined interval can be used as the basis for determining if it is the lane mark or not even though it is a roadway with a very unstable marking quality.

$$\Delta u = \Delta X_w \cdot \frac{e_v m_\theta - v}{H} \frac{e_u}{e_v} \tag{5}$$

In the equation, $\Delta u$ is the width of lane marking in the image while $\Delta X_w$ is the actual lane marking width.

##### 1.3.1.4 Continuity

Lane marks usually appear within a specific range in the screen in a manner of segment-by-segment continuity and form the lane boundary accordingly that becomes an important cue for identifying if they are lane marks or not.

#### 1.3.2 Road Geometry Estimation

For the purpose of accelerating the searching speed for the lane marks, a road geometry model was used by this research to confine the basic detecting zone within the detectable range. The detecting zone was equally divided into several section from bottom to top, performed the lane searching in a manner of transverse line segment and defined the DROI by Equation (6) and (7) row by row:

$$ROI_{\mathrm{n}} = [u_{i-1} - \lambda_{\mathrm{n}} \cdot \mathrm{Mark}_I, u_{i-1} + \lambda_{\mathrm{n}} \cdot \mathrm{Mark}_I] \tag{6}$$

$$ROI_d = [u_{i-1} - \lambda_d \cdot \mathrm{Mark}_I, u_{i-1} + \lambda_d \cdot \mathrm{Mark}_I] \tag{7}$$

After that, the DROI will be performed the detection for existence of lane marks till the end row at the last block. When applied the image processing to recognize the lane marks, a good DROI setting not only can reduce the noise to locate the lane marks correctly, but also can shorten the processing time for image processor that further makes a real-time processing effect achievable. Fig. 5 exhibits the result after processing the images for lane recognition. The left line and the right line are the desired results from detection while the middle line is the estimated center line of the lane according to the left & right lines. Thus, the subsequent estimation for the amount of lane departure and the curvature of roadway is performable.

Once the lane marks were recognized in the image plane, the coordinate transformation Equations (1)~(3) and an iterative method can be taken to derive a lane-fitting equation as shown in Equation (8) to finish the lane modeling.

$$x = k \cdot y^2 + m \cdot y + b \tag{8}$$

Where $x$ and $y$ are the axis of ordinate and the axis of abscissas respectively; and $k$ , $m$ and $b$ are parameter values that vary with the time factor. Thus, the slope of the driving lane and the curvature of roadway can be calculated from Equation (8) as shown in Equation (9) and Equation (10):,

$$\varepsilon = 2 \cdot k \cdot y + m \tag{9}$$

$$\rho_L = \frac{2 \cdot k}{\left(1 + (2 \cdot k \cdot y + m)^2\right)^{3/2}} \tag{10}$$

Fig. 5 Fit results of the conical curve and the lane

## 1.4 Preceding Vehicle Detection

The primary work for preceding vehicle detection is to analyze the symmetry of potential vehicle in the image plane by Sobel vertical edge filter and its mask is [-1 –2 –1; 0 0 0; 1 2 1]$^T$. After a Sobel horizontal edge filter, the image is adopted to detect the continuous horizontal edge and the shape of potential preceding vehicle. After marking the vehicle position in the image plane, the height of preceding vehicle can be estimated by equation (11).

$$CarHi = \frac{(v_0 - v_b)(CarHw - H)}{H} \tag{11}$$

Where *CarHi* : Height of preceding vehicle;

*CarHw*: Height of host vehicle;

$V_0$: Center position of image plane;

$V_b$: Position of preceding vehicle in image plane;

If it is similar to the general vehicle height, the distance between vehicles can be estimated through the image of geometrical relation. After focusing vehicles on the host lane in the DROI, conducting vehicle recognition, measuring headway and estimating time of close in to preceding vehicle, can effectively reduce range for analysis. Focusing the DROI in the host lane can significantly improve processing speed of detection and accuracy, and avoid system making wrong warnings simultaneously.

The headway distance estimation model as shown in Fig. 6 mainly bases on the image of preceding vehicle in the image plane and the relation of equivalent triangle equation (12) to calculate the distance between the host and preceding vehicle.

$$d_2 = \frac{H \times f_c}{P_r \times (Y_{HV} - \frac{\Delta R}{2})} - d_1 \tag{12}$$

where $H$ is the height of mounted camera from the ground; $f_C$ is the focus length of camera; $d_1$ is the distance from the camera to the front tip of host vehicle; Pr is the size of every pixel in row direction of the monitor; □$R$ is the size of image in row direction, few parameters as listed below need to be obtained through calculating the collecting data from images; $D$ is the distance between the host camera and the tail of preceding vehicle; $d_2$ is the headway between two cars; and $Y_{HV}$ is the coordinate of image in row direction of the preceding vehicle bottom end point.

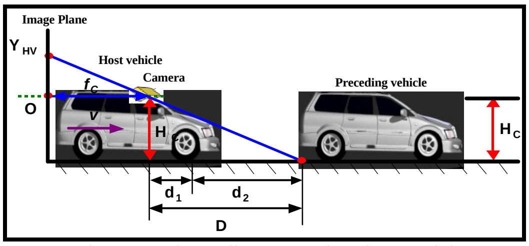



Fig. 6 Headway distance estimation model

## 1.5 Vision-based headlamp control

During the nighttime, the driver's field of vision will be narrowed due to a short illumination that leaves a forward collision easy to take place, and that is the reason why an aid from headlamp to shine on the roadway ahead is necessitated. Therefore, in the vehicles of medium and high classes, an advanced illumination system with a headlamp control system in possession of auto left and right bending light control and auto level adjustment function accessorized as the basic outfit has been very prevailing to those vehicles. However, an aid of signals from an expensive sensor for detecting the steering angle and a sensor for measuring the levelness of vehicular posture is required to achieve the auto bending light control. The electric signal in car is transmitted by CAN-bus that makes a bad commonality of headlamp, a difficult cost down and a slow promotion for popularizing the system. Moreover, the existing headlamp control system needs the driver's turning the steering wheel to control the bending of headlight that accesses a bad real-time response and often fails to adjust the illuminating position in time. This system is mainly designed to compute the angle needed for headlamp module to bend the lighting shape after finishing the lane recognition that can provide a real-time illumination at a curved roadway in advance so as to reinforce the safety when driving on a curved roadway during the night and avoid the glare issue as well. Additionally, a visually vanishing point converged in the image plane can be obtained to compute the displacement of visually vanishing point and fiducial point so that the vehicle's angle of inclination can be estimated as the basis to control the level angle of headlamp and the objective of auto level adjustment for headlight is achievable.

### 1.5.1 Auto Bending light control of headlight

Fig. 7 is the flowchart for bending light control of headlight. The recognized information of lane (curvature, transverse displacement, etc.) as shown in Equation (9) and (10) can be taken to move the original viewpoint A (direct shining position of headlamp) to the second viewpoint B (the position to be shined by headlamp at curved lane). The method specified by the laws and regulations (such as the American Standard FMVSS108) is used to firstly obtain the distance from the headlight to the original viewpoint A, and then obtain the second viewpoint B from the lane by drawing a circle with the center of circle at the headlamp and the radius is the distance R. After that, take the relative coordinate between the original viewpoint A and the second viewpoint B together with the distance R to obtain the angle between A and B; the computation is shown in Equation (13):

$$\beta = \frac{\sqrt{(x - x_0)^2 + (y - y_0)^2}}{R} \tag{13}$$

Where, $\beta$ is the angle between viewpoint A and viewpoint B, $(x_0, y_0)$ is the coordinate of the first viewpoint A, $(x, y)$ is the coordinate of viewpoint B, R is the distance from the headlight to the first viewpoint.

The angle obtained from Equation (13) will be sent to the bending light control mechanism that enables to actuate the bending motor so that the light pattern can shine the blind spot of curved lane ahead. As learned from the Figure 11, the system will record the angle bent each time in order to stabilize the bending control of headlight.

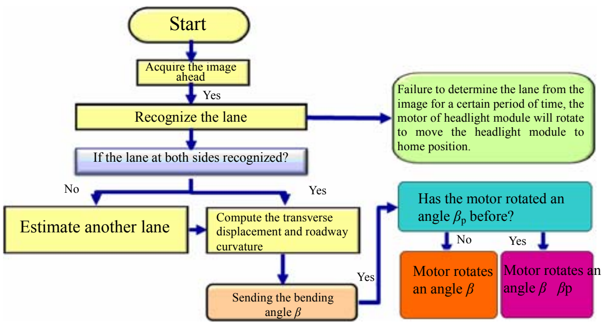



Fig. 7 Flowchart for bending control of headlight

### 1.5.2 Auto-level adjustment of headlamp

Fig. 8 is a flowchart for controlling the level adjustment of headlight; wherein, the recognized lane is extended to a momentary vanishing point (Px) at a distant place where a momentary horizontal line (Hx) is created through this vanishing point (Px). The displacement of fiducial horizontal line (H) and momentary horizontal line (Hx) is estimated from the image. Accordingly, the vehicle's angle of inclination can be computed by using the focus obtained from roadway image and the computed displacement as shown in equation (14). Consequently, a control signal will be generated to manipulate the level-adjustment controller that is connected to the headlight so that the headlight of vehicle can be varied thereof light-emitting direction according to this angle of inclination. Meanwhile, the system records the angle adjusted each time for stabilizing the headlight control and timely provide the driver with an optimal illumination when driving vehicle on a rugged roadway section or carrying an unbalanced load on vehicle. The driving safety during the nighttime for the driver can be highly secured.

$$\theta_{1}\times\tan^{-1}\frac{a-b}{f} \tag{14}$$

Where, $\theta$ is the included angle when rotating the center axis of the lens in camera; $b$ is the position of fiducial vanishing point in the image plane; $a$ is the position of momentary vanishing point in the image plane; therefore, $\overline{ab}=a\text{-}b$ is the displacement of horizontal line; f is the distance from the lens in camera to the image plane, that is, the focus.

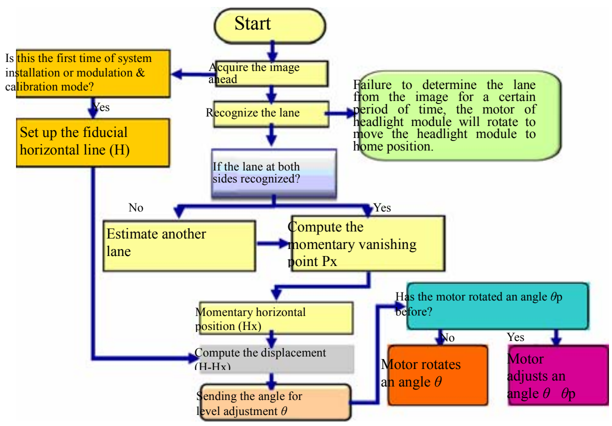


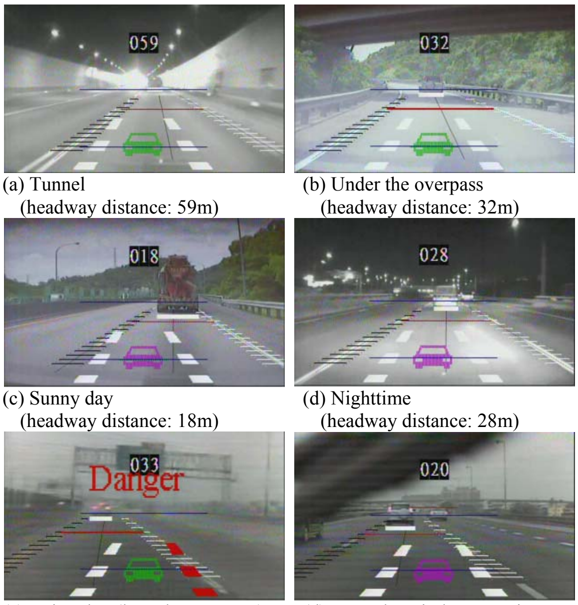

Fig. 8 Flowchart for controlling the level adjustment of headlight

## III. EXPERIMENTAL RESULTS

This system has been tested on real vehicles under various roads such as highway, speedway, urban roads and ARTC's (Automotive Research and Testing Center) proving ground. These test conditions include various lane markings, front vehicles and road curvatures in different weather conditions (e.g. daytime, nighttime, sunny and rainy days). The required visibility of roadway image has to be more than 120 m, and the results of accuracy statistics are made during the specific test procedures of lane departure and headway control. The test results of system accuracy are listed in Table II. The average accuracy of the lane detection is above 96.3%, and the average accuracy of preceding vehicle detection is more than 93.5% in sunny day. The results of the image processing are shown in Fig. 9.

TABLE II
AVAILABILITY OF THE INTEGRATED VEHICLE IMAGE SYSTEM

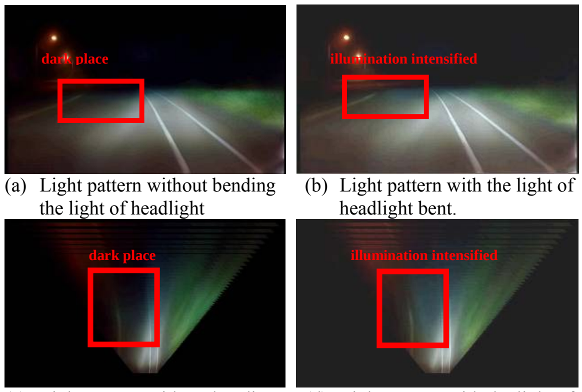
| Testing Conditions | lane detection (Sunny day) Availability | preceding vehicle detection (Sunny day) Availability | lane detection (Rainy day) Availability | preceding vehicle detection (Rainy day) Availability |
|---|---|---|---|---|
| Speedway | 98.2% | 95.2% | 92.4% | 90.2% |
| Highway | 98.6% | 95.8% | 91% | 87.8% |
| Urban Road1 (Well-Marked) | 95.6% | 92.2% | 86.2% | 83.4% |
| Urban Road2 (Poorly Marked) | 94.2% | 91.6% | 80.6% | 81.8% |
| ARTC High Speed Circuit Curvature=(1/250m) | 92% | 90.6% | 88% | 81.2% |
| ARTC Coast Down Track (1.5km) | 99.6% | 96% | 93.2% | 92% |




(a) Tunnel (headway distance: 59m)
(b) Under the overpass (headway distance: 32m)
(c) Sunny day (headway distance: 18m)
(d) Nighttime (headway distance: 28m)
(e) Rainy day (lane departure: R) (headway distance: 33m)
(d) Have the windscreen wiper (headway distance: 20m)

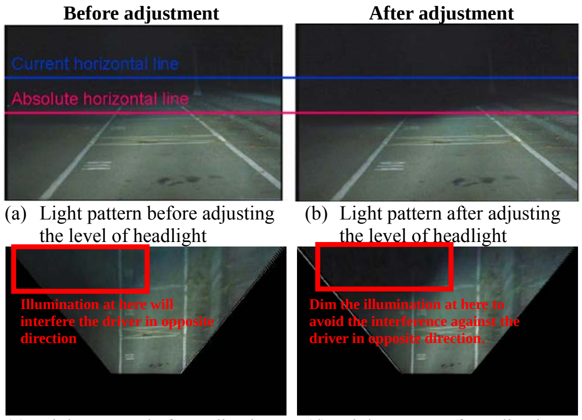
Fig. 9 On-vehicle testing results for the integrated vehicle image system image

Fig. 10 demonstrates the variation of light patterns before and after bending the headlight. Fig. 10(a) and Fig. 10(b) are the images taken by the front camera, Fig. 10(c) and Fig. 10(d) are the top view of Fig. 10(a) and Fig. 14(b) respectively. As results from the top views, the illumination at R distance in the left curved lane (the red-framed region) is noticeably enhanced after bending the headlamp. Fig. 11 shows the variation of light patterns before and after adjusting the level of headlight. Fig. 11(a) and Fig. 11(b) are the images taken by the front camera while Fig. 11(c) and Fig. 11(d) are the top view of Fig. 11(a) and Fig. 11(b) respectively. As results from the top views, when the vehicle is inclined, the illumination for the light pattern formed at R distance in the left curved lane (the red-framed region) is dimmed after adjusting the level of headlight so that the interference against the driving safety for the oncoming drivers driving on the opposite lanes can be avoided.




(a) Light pattern without bending the light of headlight
(b) Light pattern with the light of headlight bent.
(c) Light pattern without bending the light of headlight (top view)
(d) Light pattern with the light of headlight bent (top view)

Fig. 10 Variations of light pattern for bending light of headlight




(a) Light pattern before adjusting the level of headlight
(b) Light pattern after adjusting the level of headlight
(c) Light pattern before adjusting the level of headlight (top view)
(d) Light pattern after adjusting the level of headlight (top view)

Fig. 11 Variations of light pattern for level adjustment of headlight

According to the experimental results with the proposed methods in the research, the system performance is summarized:

(1) This system can be used under most of environments in the daylight, nighttime, sunny and raining day.
(2) This system can be used under various lane-markings and vehicles for lane boundary recognition and preceding vehicle detection.
(3) In various environments, the system can provide high availability, reliability and accuracy in lane deviation and headway distance estimation.
(4) The image-processing rate of the system is more than 20 fps (frame per second), and it meets the requirements of real-time computing in an embedded system.
(5) The curvature of lane and the angle of vehicle's inclination obtained from the lane recognition system indeed can be taken as the basis for headlamp control that allows the

driver to see clearly the roadway condition ahead the vehicle with thereof bare eyes during the nighttime.

## IV. CONCLUSIONS

This research has successfully developed an integrated vehicle image system in a DSP-based embedded platform. Based on a single CMOS camera mounted on the windscreen, the system can recognize lane boundary and preceding vehicle by proposed algorithms of image processing and provide the lane departure warning and forward collision warning functions. In lane departure detection, gray scale statistics, dynamic range of interesting (DROI) and featured-based approaches to recognize the lane boundaries and used road geometry model is used to detect the lane departure. In forward collision detection, Sobel edge-enhancement filters and optical flow analysis is used to detect the preceding vehicle and headway distance estimation model is used to detect the potential forward collision. Regard for the headlamp control, it is introduced the image recognition technology that is different from the typical adaptive front-lighting system (AFS) in the market. The functions of headlight's light bending and auto level adjustment are achievable without an expensive sensor, and a real-time response can be further achieved or predicted in advance.

In addition, the integrated vehicle image system has taken convenience installation into consideration. By simplified the installation steps, system can be adaptive to most of vehicles. The system will further advanced to an automatically parameter calibration in the near future, such as parameters of the altitude or view angle of the camera, and add on a self-diagnosis function, to conform with the needs of reliability, real time computing and convenience for advanced driver assistance system.

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