Technology Introduction

Development of Driving Safety Support System

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1 Introduction

KYB currently manufactures drive recorders to record and analyze accident images. In recent years, the automotive industry has been actively developing driving support systems utilizing sensing technologies, such as cameras and radars, with the aim of preventing accidents. KYB must also develop driving support functions utilizing sensing technologies in order to add greater values to drive recorders.

Due to this, in this "Development of Driving Safety Support System" (hereinafter referred to as "this development"), we developed an in-vehicle device with driving safety support functions. This device detects lanes during driving with image recognition based on images taken by a monocular camera and comes with the lane departure warning function, which warns the driver when the vehicle may depart from the lane.

2 Lane Departure Warning System

We mention below the defi nition, development goals, and issues in the development of the Lane Departure Warning System.

2.1 Definition

The Lane Departure Warning System (hereinafter referred to as "LDWS") refers to a system that detects the lane, in which the vehicle is driving, through sensing or other means and warns the driver when the vehicle departs from the lane.

LDWS definition is provided in "JIS D 0804: 2007 Intelligent Transport Systems - Lane Departure Warning Systems - Performance Requirements And Test Procedures". Fig. 1 shows the operation image of LDWS.

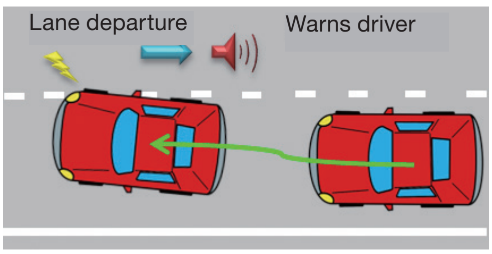


Fig. 1 LDWS operation image

2.2 Development goals

(1) Lane recognition rate of 90% or above
(2) Pass the JIS D 0804 test
(3) System structure, which can easily be transferred to other products

2.3 Issues in the development

Upon developing the LDWS, we extracted potential issues. Since it was difficult to respond to all natural conditions, such as weather and time, in this development, we first extracted issues by limiting to stable conditions. Table 1 shows the list of issues in this development.

Table 1 List of issues in the development of LDWS

No.	Issue	Description
1	Respond to broken lines	Detect in the same manner as solid lines
2	Respond to lines on one side	Interpolate the line on the other side
3	Respond to curves	Detect in the same manner as straight lines
4	Determine lane departure	Establish the detection method
5	Respond to lane changes	Withhold warning during lane changes
6	Differentiate expressways	Withhold warning on general roads

3 Algorithm

This development utilized a monocular color camera as a sensing means. By processing the images of the traveling direction, which are taken by the camera, the device detects lane markings. By calculating the distance between the lane markings and the sides (tires) of the vehicle, it determines the risk of lane departure. Fig. 2 shows the LDWS algorithm summary flow, which was established in this development.

3.1 Preprocessing (Identifying the lane region)

While this development used a camera that can acquire HD-size (1280×720 pixel) images, processing this size would take a long time. Therefore, we reduced the processing time by identifying the region, which applied

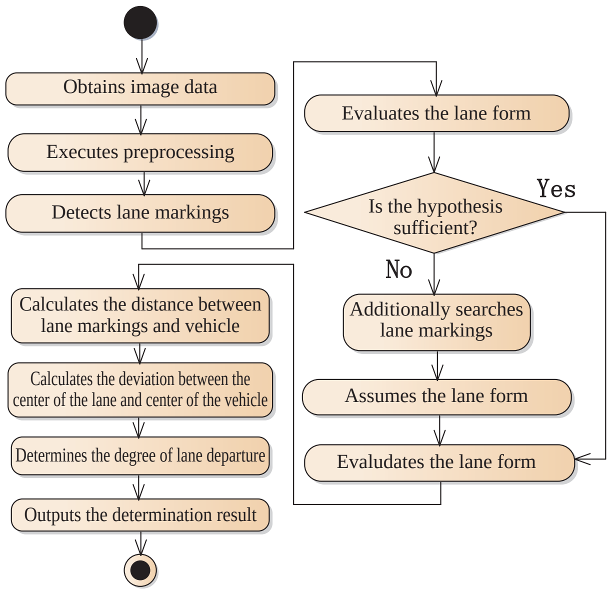


Fig. 2 LDWS algorithm flow

to the lane, from the acquired images, performing the search process in this region, and finally overlapping the search result on the original image. Fig. 3 shows the concept of lane region identification.

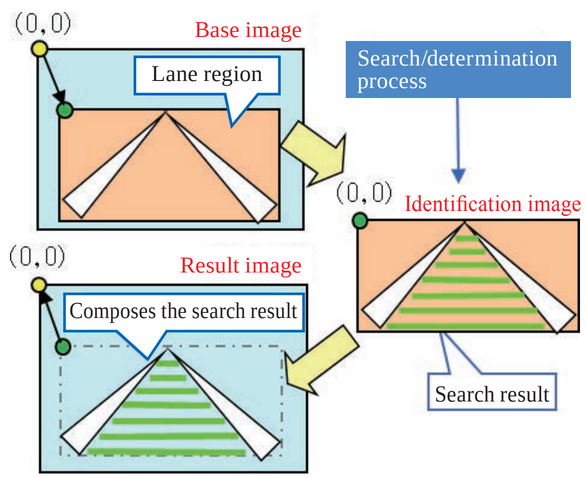
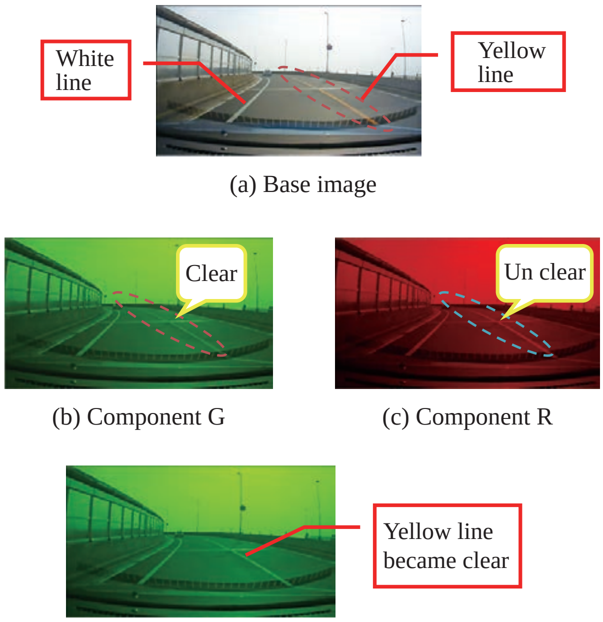


Fig. 3 Identifying the lane region

3.2 Preprocessing (Composing color components)

Regular methods perform binarization in gray scale, in which images are converted into black and white. However, gray scale uses all of the red (hereinafter referred to as "R"), green (hereinafter referred to as "G"), and blue (hereinafter referred to as "B") components, which are the 3 primary colors of light, increasing the process time. Therefore, this algorithm performs binarization by only using specific color components. There are 2 types (white and yellow) of lane markings, which are the detection targets. While only component G is required to detect white lines, component R greatly contributes to the detection of yellow lines. Therefore, we made it possible to detect both white lines and yellow lines by comparing the pixel values of component G and component R and preparing a composite image with a greater value. Fig. 4 shows the composition result of component G and component R.



(a) Base image

(b) Component G

(c) Component R

(d) Example of color component composition process result (Integrated with component G)

Fig. 4 Composition of color components

3.3 Detecting lane markings

In order to detect lane markings, the device first searches for edges, which are used as candidate points for lane markings, on both sides from the center of the search (=center of the vehicle). Fig. 5 shows the concept of the search for candidate points. Detection of lane markings follow the following process.

(1) It searches change points in brightness from the center of the vehicle toward both sides and uses the discovered change points in brightness as candidate points for lane markings.

(2) Points that greatly differ from other candidate points are excluded.

(3) It determines the linearity of the remaining candidate points and detects them as lines. Capturing lane markings as groups of candidate points instead of straight lines enables the device to make detection that doesn't differentiate solid lines/broken lines, which was issue No.1.

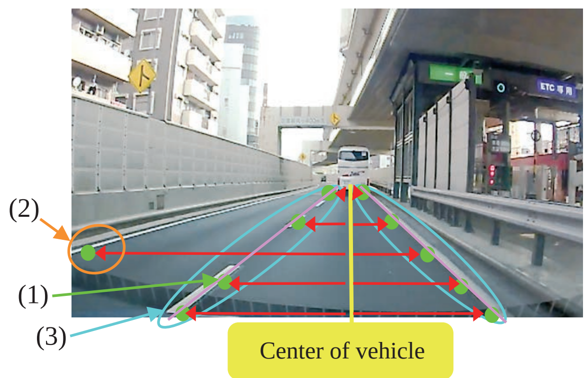


Fig. 5 Detecting lane markings

3.4 Assuming lane forms

Lanes are recognized by forming multiple hypotheses according to the lane forms (straight line/curve) and obtaining the optimal solution by evaluating each hypothesis. In this algorithm, curves are approximated in polygonal lines. Table 2 shows the list of hypotheses. By assuming the form and employing the optimal hypothesis, line on one side as well as curves, which are issues No. 2 and 3, in Table 1 can be recognized with high accuracy.

Table 2 List of lane form hypotheses

No.	Form
1	Form employed in the previous process
2	Straight line approximation
3	Polygonal line approximation
4	Straight line approximation (one-sided prediction)
5	Polygonal line approximation (one-sided prediction)

Form that was previously employed is entered as hypothesis No.1 in case there is no appropriate hypothesis. Hypothesis No.2 assumes based on the presupposition that lanes are straight. Hypothesis No.3 assumes based on the presupposition that lanes are curved. When doing so, curves are approximated in polygonal lines. Hypotheses No.4 and 5 use the form, in which the opposite line is assumed based on the detected lane markings in case the lane markings on one side does not exist or cannot be detected due to poor condition in each of hypotheses No.2 and 3.

3.5 Evaluation of lane forms and determining the solution

In order to obtain the optimal form among the form hypotheses, which were obtained in section 3.4,evaluation is conducted on each item shown in Table 3. The results are scored. Each result is summed, and the hypothesis with the highest points is determined as the correct form.

Table 3 Evaluation items for lane form hypotheses

No.	Item
1	Lane width
2	Lane smoothness
3	Brightness difference between lane markings and road surface
4	Lane tilt
5	Temporal change in lane width
6	Temporal change in lane position
7	Road surface texture (pattern)
8	Lane marking texture (pattern)
9	Position for lane marking candidate point

3.6 Determining lane departure

Fig. 6 shows the concept of lane departure. "Wr" represents the detected lane width, and "Wc" represents the vehicle width. Lane departure is determined based on the remaining distance "d" between the side of the vehicle and the lane markings. Below items were employed in order to respond to the lane departure determination, lane changes, and differentiation of expressways under issues No. 4, 5, and 6 in Table 1.

1. Composite determination process for the deviation of the vehicle and the center axis of the lane by assuming a large vehicle
2. Lane change determination process by blinker signal
3. Warning issuance control process based on the vehicle speed information

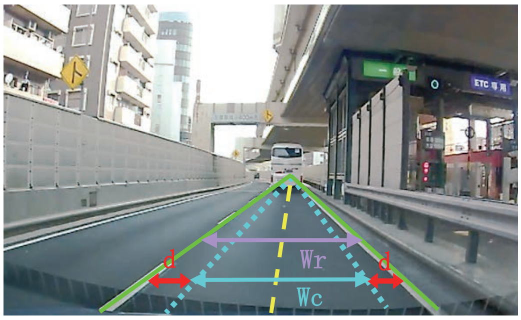
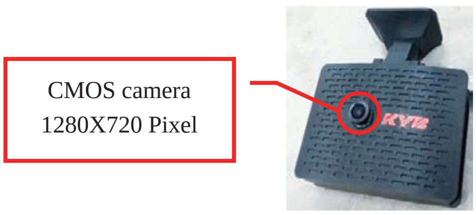


Fig. 6 Lane departure determination based on the remaining distance to the lane marking

4 Prototype

We manufactured a prototype of the lane departure warning device in order to install the developed algorithm on actual vehicles for evaluation. Photo 1 shows the appearance of the prototype.

As a characteristic of the hardware, we used Visconti2™, which is an image recognition processor made by



(a) Front appearance

(b) Back appearance and each function

Photo 1 Prototype for the lane departure warning device

TOSHIBA CORPORATION, as the processor to perform recognition processes. Since this processor comes with the hardware to perform general image processes, it achieves faster processes compared to general processors. In addition, by using an another IC to control the peripheral hardware, we made the processes, which are required to recognize images, independent for better portability with other products.

5 Result

We installed the manufactured prototype on actual vehicles to measure the lane recognition rate and conduct the performance evaluation tests based on JIS D 0804. We colored traffic lane according to the recognition status, as shown in Fig. 7, in these tests to determine the lane recognition status. When the lane markings on both sides are recognized, it shows the image in green. When the prediction is for one side, it shows in blue. When it determines lane departure, it shows in red. Since this algorithm assumes the use on expressways, we performed the driving evaluation on expressways, using vehicles with the prototype installed. As a result, it achieved the high lane recognition rate of over 90%, including recognition on both sides and prediction on one side. In addition, the prototype also passed the performance test based on JIS D 0804 and safisfied the specified perfonmance below.

1. Reproducibility test to confirm variations in the warning points
2. False alarm test to confirm that warning is not issued during normal driving

(a) Line recognition on both sides

(b) Line prediction on one side

(c) Departed state

Fig. 7 Differentiation of the lane recognition state

6 In Closing

In this development, we performed the system evaluation by limiting the field to expressways, in which the lane marking condition is relatively stable. However, we must also respond to issues in general roads, due to the fact that general roads (especially arterial roads, etc.) also have needs for lane departure prevention.

In addition, since adjustment of various parameters in this development was mostly the so-called "sensory evaluation adjustment" based on actual vehicle driving results, we must establish indexes that would enable us to evaluate the recognition results and performance in a quantitative manner in the future.

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