LANE INDICATION/RECOGNITION SYSTEM BY USING IMAGE SENSORS: EVALUATION OF INDICATION PERFORMANCE OF LANE MARKS IN THE REAL WORLD

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ABSTRACT

Studies of motor vehicle automatic driving technology, using image sensors such as CCD cameras, are underway. In order to establish automatic driving technology, which is based on image sensors, improving lane recognition performance under a wide variety of meteorological environments is a key technology. To improve the reliability of image sensors, we decided to investigate the following three areas: (1) improving the performance of the CCD image sensor, (2) developing recognition logic, (3) evaluating the visibility(indication performance) of lane marks. In order to quantify lane recognition performance, we designed a measurement system for the contrast in luminance between lane marks and the road surface. Experimenting with this measurement system in the real world was an effective way of evaluating lane recognition performance. The contrast in luminance of the lane marks changed greatly according to the type of road surface and the meteorological conditions. We therefore propose a performance requirement for the image sensor to improve the reliability of the lane recognition performance and the improvement item of a traffic environment.

KEYWORDS

Indication, Recognition, Visibility, Lane mark, Contrast, Image sensor, Luminance
1. INTRODUCTION

A lane recognition system using image sensors such as on-board CCD cameras aimed achieving an advanced driving support system for automatic driving was studied. Indeed, a lane departure warning system with a lane recognition system using image sensors is already being used in some top-end vehicles in Japan. This system is designed to recognize a lane based on images, but its lane recognition performance is not sufficient, especially at night or in bad weather when the lane marks on the road are not clearly visible, or in environments where there is opposing light, such as sunshine from the west (refer to Figure 1).

In order to solve these problems it is necessary to improve the individual elements that comprise the system such as the image sensors, CCD cameras, headlamps, and also the lane marks that are used to indicate the lane. In addition, it is necessary to study related issues such as infrastructure and road facilities during bad weather. By making the lane marks readily identifiable by drivers and improving the image sensors, a sophisticated driving support system allowing automatic driving will become possible in the future.

The Association of Electronic Technology for Traffic and Driving therefore launched the “Study Group of Next-Generation Lane Indication/Recognition System” (refer to Appendix) in fiscal 1994, and invited the official research institutions related to road traffic systems, auto manufacturers, auto parts manufacturers, and road materials manufacturers to join the study, and various research activities have since been conducted.

In Phase I from FY 1994 to 1998, basic research on the driving road indication and recognition system was conducted. In Phase II, which is a three-year project that started in FY 1999, field studies are being conducted.

This report outlines the results of the Phase II field studies. The purpose of the study group is to conduct basic studies that will contribute to creating the next-generation lane recognition system for easy identification by image sensors and drivers.

Each participating enterprise specializes in a different technical field, so it was decided that the Study Group would study those items shared by the participating enterprises. The contents of the Phase I study [1] were as follows.

(1) Investigating the environmental factors that will affect the performance of the lane recognition system;

(2) Research and investigation of methods of evaluating the lane indicators and lane recognition;

(3) Research and investigation of promising technologies concerning the new generation system.
The outcome of the Phase I study were as follows.

(1) Environmental factors that will affect the lane recognition system and associated problems were studied intensively. (Refer to Table 1.)
(2) Lane recognition using image sensors is affected by the indication performance of lane marks. Therefore, the Study Group initially focused on evaluating these, particularly the luminance of the road surface and lane marks as well as the contrast in luminance between them. A system for measuring these factors using image sensors was manufactured.
(3) With regard to promising technologies concerning the new generation system, the following were proven to be effective.

1) Image sensors: highly sensitive, near-infrared cameras.
2) Headlamps: high luminance headlamps, such as discharge headlamps.
3) Lane marks: high luminance lane marks with high luminance emissions that are unlikely to be submerged during rainfall. The need to improve road facilities such as road surfaces was also confirmed.

Table 1  Problems of lane recognition system and environmental conditions

<table>
<thead>
<tr>
<th>Illumination conditions</th>
<th>Sunlight</th>
<th>Nighttime</th>
<th>Dusk</th>
<th>Daytime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental illumination (lx)</td>
<td>0.1</td>
<td>5</td>
<td>30</td>
<td>1000 10000</td>
</tr>
<tr>
<td>Road illumination</td>
<td>No illumination</td>
<td>Road illumination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headlamps</td>
<td>Lit</td>
<td>Not lit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2  Study Plan and Contents of Phase II

<table>
<thead>
<tr>
<th>Fiscal year</th>
<th>Contents of study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Preparation of onboard type experimental vehicle for collecting driving environment data [3]</td>
</tr>
<tr>
<td>2000</td>
<td>Research of current lane indicator visibility on actual roads under various driving environments and research of preparation requirements for roads [4]</td>
</tr>
<tr>
<td>2001</td>
<td>Selection of next-generation system technologies that are promising and evaluation thereof on actual roads Determination of road facility preparation requirements</td>
</tr>
</tbody>
</table>
To utilize the results and findings acquired by the Phase I studies in public activities, another three-year study project was planned for Phase II and was started in FY 1999. Table 2 outlines this project.

As is evident from Table 1, the performance of the lane recognition system largely depends upon environmental conditions, such as meteorological conditions (visibility distance) and illumination conditions. It is also affected by road surface materials and the road structure. When developing the next generation system, the effects of such factors on lane marker visibility (indication performance) and recognition systems must be fully considered. However, there have been no reports of research on the relation between the lane marker visibility and changes in environmental conditions and road conditions. Hence, the Study Group prepared an experimental vehicle for collecting driving environment data on-board so as to investigate the changes in lane marker visibility on actual roads due to changes in these factors.

The visibility of lane marks can be estimated from their reflectance characteristics and the distribution of illuminance on the road surface [2]. Though this technique cannot be applied to measurements in the actual environment, it is useful as a method of calibrating the measurement procedures for luminance distributions.

The function of image sensors is to obtain two-dimensional data equivalent to human retinal images. The image sensors used for the measurement of the luminance of road surfaces should be capable of the following.

(1) The two-dimensional distribution of luminance should be measured in one try.
(2) It should be possible to carry out real-time measurement which copes with changes in the actual road environment.
(3) It may be possible to carry out evaluations of the visibility of lane marks with unequal reflectivity.
(4) It is easy to process data for visibility evaluations using image processing techniques.

![Figure 2 Onboard type experimental vehicle for collecting driving environmental data](image-url)
2. MEASUREMENT SYSTEM CONFIGURATION

2.1 Measurement system

In order to evaluate the visibility of lane marks, we prepared the experimental vehicle for collecting driving environment data on-board shown in Figure 2. Table 3 lists the onboard equipment and the measurement and control items. The experimental vehicle was able to use either headlamps containing discharge bulbs or halogen bulbs as light sources.

The Study Group assumed that luminance contrast is the main factor affecting the lane indicator visibility, and therefore lane recognition performance, and so conducted research under various driving environment conditions.

Two light meters measured the environmental illumination of the horizontal surface, and the illumination of a point immediately in front of the eyes. Also, two luminance meters (with a view angle of $2^\circ$) measured the background luminance and the luminance of the road surface 20 m ahead. An onboard CCD camera analyzed the acquired pictures and calculated the luminance of the road surface and the lane marks on the driving course. Then the camera finally calculated the contrast in luminance between the road surface and the lane marks. To implement the above, the exposure of the camera must be continuously optimized. Also a highly-sensitive camera is required for night-time photography.

<table>
<thead>
<tr>
<th>Onboard measurement &amp; control equipment</th>
<th>Name of product</th>
<th>Measurement &amp; control items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CCD camera</td>
<td>Panasonic GP-MF602</td>
<td>Luminance of road surface and lane marks</td>
</tr>
<tr>
<td>2 Image input board</td>
<td>NI PCI-1409</td>
<td>Digital image collection</td>
</tr>
<tr>
<td>3 Luminance meter (view angle $2^\circ$) × 2</td>
<td>Topcon BM-8</td>
<td>Luminance of road surface 20 m ahead, background luminance</td>
</tr>
<tr>
<td>4 Light meter × 2</td>
<td>Topcon IM-5</td>
<td>Environmental illumination, illumination of a point immediately in front of the eyes</td>
</tr>
<tr>
<td>5 Multi-I/O board</td>
<td>NI PCI-6025E</td>
<td>Collection of environmental data</td>
</tr>
<tr>
<td>6 Onboard PC</td>
<td>Development software (NI Labview)</td>
<td>Measurement and control, data recording</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Camera type</th>
<th>Near-infrared CCD camera (FA Camera) (Non infrared cut filter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCD element</td>
<td>Chip size : 1/2-inch</td>
</tr>
<tr>
<td></td>
<td>Number of effective pixels : 300,000 pixels</td>
</tr>
<tr>
<td>Picture output</td>
<td>1.0 Vp-p/75 Composite signal</td>
</tr>
<tr>
<td>Electronic shutter</td>
<td>Shutter speed: variable between 1/10,000s and 60s, externally controllable</td>
</tr>
<tr>
<td>Minimum illumination of object</td>
<td>0.5 lx (F/1.4)</td>
</tr>
<tr>
<td>Lens used</td>
<td>f12.5</td>
</tr>
</tbody>
</table>
Table 4 shows the main specifications of the CCD camera adopted for measurement. This camera is a near-infrared camera for industrial measurement (for FA). For a luminance measurement system with a CCD image sensor, the image sensor should have the following functions: (1) Excellent sensitivity to brightness. (2) Image collection at night is possible. (3) The range of luminance measurement in the same exposure setting is wide. (4) A linear relationship can be established between the output voltage of the image and the brightness of the object. We selected a commercially available GP-MF605 camera based on these items.

Figure 3 is a schematic diagram of the measuring system. The measuring system was designed so that the CCD camera is controlled by the onboard PC, its digital image data is captured by an image input board, and the data from the illumination meter and luminance meter are captured by an I/O board. The sampling time of the image data and luminance/illumination data was set to 2 times/sec. The data and control processing was designed using Labview software language.

![Figure 3 Schematic diagram of measurement system of experimental vehicle](image)

### 2.2 Calibration of CCD camera

Figure 4 shows the luminance contrast measurement scheme. The off-line part of Figure 4 shows the flow of the calibration procedure for the output (gray level) of the CCD camera. For the first subject, we propose that the image sensor be calibrated using a high reliability, lens-type luminance meter with a field angle of 0.1 or 0.2 as a standard source. In this study, we used a Topcon BM-5 luminance meter.

In order to use a CCD camera as a luminance measuring device, it is necessary to obtain the relationship between the image output value of the CCD element and the object luminance. Therefore, we conducted experiments using an 11-stage gray scale that was illuminated evenly and obtained the relationship between the object (gray scale) luminance and the picture output value (10-bit data output).

Figure 5 shows an example of the results. A correlation exists between the image output value and the object luminance. In particular there is a proportional relation between their logarithmic values in the range of image output value of 70 to 700.
In this experiment, therefore, the exposure conditions were set such that the road surface and lane marks of the driving course came within this range. Actually, the shutter speed and aperture were set so that the image output value at the road surface 20 m ahead was 200.

Figure 4 Scheme of luminance contrast measurement

Figure 5 Relation between object luminance and image output value (image brightness)
2.3 Calculus of luminance contrast

The luminance contrast $C$ between the road surface and the lane marks is defined by

$$C = \frac{L_L - L_R}{L_R}.$$  

(1)

where, $L_R$ and $L_L$ are the road surface luminance and lane marker luminance, respectively [5].

In this experimental study, the luminance of road surfaces and the luminance of lane marks were calculated as follows. We set a region in the image, based on the human central vision angle, where the luminance of the road surface and luminance of lane marks. It was assumed that a human recognizes the lane marks in the central vision. The region of the human central vision angle for a certain distance from camera is set as the area of the luminance measurement as shown in Figure 6. Though the field angle for human central vision is 2 degrees, we used a region for $1 \times 3$ degrees as the calculated area, because the illuminance distribution of a headlight is not uniform. The performance of the low beam of the headlamp influences the brightness of lane marks at night.

The luminance of a road surface is given by the mean value of the luminance of an area of road 20 m ahead, as shown in Figure 6. The road area is $23 \times 78$ (V x H) pixels in this image. The luminance of lane marks was also calculated from the lane area 20 m ahead. The luminance of a lane marker is given by the mean value of the luminance of about 280 pixels with which the lane marker is defined in the image.

![Figure 6 Calculus of luminance of road surface and lane mark](image-url)

3. EXPERIMENTAL STUDIES

The lane recognition performance of an image sensor is affected by meteorological and road illumination conditions. The performance suffers on road sections where the environmental illumination changes suddenly, such as in a tunnel or under bridge. As can be seen in Table 1, the illuminance can exceed 10,000 lx in daytime. In the real world, there are many road sections where the environmental illumination changes suddenly. However, the present CCD image sensor suffers under drastic changes of environmental illumination. Therefore, we have to explore variations of luminance and illuminance in the real world.
Furthermore, we know experientially that the performance is different according to the kind of road surface and lane marker. To improve lane recognition performance in the rain, a high-performance paved road with improved drainage, called the porous asphalt pavement, has attracted attention.

Therefore, taking into consideration the road structure, the meteorological and environmental conditions and so forth, the sections used for sampling driving environmental data were selected as indicated in Table 5, centering on expressways in Shizuoka prefecture. The sections are classified into 3 kinds: (1) The environmental illumination changes suddenly. (2) The variation of the road luminance is large. (3) The kind of surface is different.

Table 5 Sections Used for Sampling Driving Environmental Data.

<table>
<thead>
<tr>
<th>Road features</th>
<th>Roads and positions where measurements were conducted</th>
<th>Meteorological and environmental conditions</th>
<th>Street lighting present or absent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Daytime</td>
<td>Night-time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fine</td>
<td>Rain</td>
</tr>
<tr>
<td>Road structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tunnel</td>
<td>Nihon-zaka tunnel of Tomei Expressway</td>
<td>O</td>
<td>–</td>
</tr>
<tr>
<td>Crossing under a bridge</td>
<td>Tomei Expressway</td>
<td>O</td>
<td>–</td>
</tr>
<tr>
<td>Shadow of noise barrier</td>
<td>Tomei Expressway</td>
<td>O</td>
<td>–</td>
</tr>
<tr>
<td>Road pavement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General paved roads (dense graded asphalt)</td>
<td>Tomei Expressway</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>High-performance paved roads (porous asphalt)</td>
<td>Tomei Expressway</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>

4. RESULTS OF EXPERIMENT

This section describes the results obtained using the measurement system on an actual vehicle, together with typical examples of images captured during the experiment. The sampling time of the image data and luminance/illumination data was set to 2 times/sec. Five images without noise were used for the analysis in each measurement section. The mean of the luminance contrast calculated from these five images was used as the luminance contrast for each measurement section. Typical images of the road sections, such as the road structure or the luminance distribution, are shown into Figure 7.

4.1 Road section where the environmental illumination changes suddenly

Figures 7a, and 7b show images of the entrance and exit of the Nihon-zaka tunnel of the Tomei expressway. The Tomei expressway is a main trunk road in Japan. Figure 7c shows a road section which is shaded by a noise barrier. Figure 8 indicates the changes in road surface luminance and environmental illumination while the vehicle is being driven in a tunnel. Table 6 shows the data of road surface luminance in the vicinity of road construction features, such as a tunnel and bridge.
At the entrance of a tunnel as well as where a bridge crosses above, the amount of daytime illumination light is drastically reduced. Therefore, it is sometimes difficult for the image sensor to recognize the lane. In addition, when the sun shines from the west, the road surface reflects the sunlight or sunear occurs, making it difficult to recognize the lane marks.

Moreover, at the entrance of the tunnel, the road surface luminance drops to 1/88 within a driving distance of 80 m (2.2 sec. at 100 kph), and under a bridge it drops to 1/12.3. In the shade of a noise barrier, the luminance drops to 1/2.3.
**Figure 8** Measurement results of road surface luminance when driving in a tunnel

**Table 6** Measurement results of road surface luminance on road sections where the environmental illuminance changes greatly

<table>
<thead>
<tr>
<th>Tunnel (Nihon-zaka tunnel of Tomei Expressway)</th>
<th>Before entrance of tunnel</th>
<th>Immediately after entering tunnel</th>
<th>Rate of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road surface luminance (cd/m²)</td>
<td>3370</td>
<td>38.1</td>
<td>88.5</td>
</tr>
<tr>
<td>Environmental illumination (lx)</td>
<td>94300</td>
<td>1460</td>
<td>64.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crossing section of overhead bridge (Tomei Expressway 151.5 KP)</th>
<th>Before bridge</th>
<th>Immediately under bridge</th>
<th>Rate of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road surface luminance (cd/m²)</td>
<td>2390</td>
<td>195</td>
<td>12.3</td>
</tr>
<tr>
<td>Environmental illumination (lx)</td>
<td>67400</td>
<td>1465</td>
<td>46.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shadow of noise barrier (Tomei Expressway 154.0 KP)</th>
<th>Outside the shadow</th>
<th>Inside the shadow</th>
<th>Rate of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road surface luminance (cd/m²)</td>
<td>1190</td>
<td>516</td>
<td>2.3</td>
</tr>
<tr>
<td>Environmental illumination (lx)</td>
<td>47600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Paper revised from original submittal.
4.2 Road sections where the variation of the road luminance is large

Figure 7e shows the inside of the Happuzan tunnel of the Jyo-shin-etsu Expressway. This is a road section where the luminance contrast has deteriorated due to aging. Table 7 shows the measurement results of the luminance contrast on all roads shown in Figures 7e - 7i. The luminance contrast in these road sections was incapable measurement. Therefore, it is sometimes difficult for the image sensor to recognize the lane.

Table 7 Results of luminance and contrast of lane mark(LM) and road surface at road section where the variation of the road luminance is large

<table>
<thead>
<tr>
<th>Image #</th>
<th>Side of LM</th>
<th>Luminance(cd/m²)</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LM Road</td>
<td></td>
</tr>
<tr>
<td>(e)</td>
<td>Right</td>
<td>0.76 0.762</td>
<td>-0.003</td>
</tr>
<tr>
<td>(f)</td>
<td>Right</td>
<td>6608 6640</td>
<td>-0.005</td>
</tr>
<tr>
<td>(g)</td>
<td>Right</td>
<td>924 746</td>
<td>0.27</td>
</tr>
<tr>
<td>(h)</td>
<td>Left</td>
<td>0.52 0.45</td>
<td>0.14</td>
</tr>
<tr>
<td>(i)</td>
<td>Right</td>
<td>- -</td>
<td>-</td>
</tr>
</tbody>
</table>

4.3 Influence of type of road surface and various weather conditions

This section explains how the type of road surface and various weather conditions, such as fine or rainy weather, affect the luminance contrast of the lane marks, based on the example images obtained. The road surfaces used were dense-grade asphalt on concrete that is employed on general roads, and high-performance water drainage pavement (porous asphalt) that is becoming widely used on principal expressways. In this water drainage pavement, voids are provided in the asphalt aggregates to suppress noise such as tire noise, and to improve road surface visibility in rainy weather.

On normal dense-graded asphalt-concrete, rainwater collects on the road surface in rainy weather. However, on the water drainage pavement, the pores prevent rainwater from collecting on the road surface, thus preventing the visibility from dropping.

Figure 9 shows examples of the images obtained for both road surfaces. The numerical value shown in the figure is the measured luminance contrast. Table 8 shows the measurement results of the luminance contrast on all roads where measurements were carried out, including the above results. The luminance contrast drops drastically in rainy weather, regardless of the type of road surface. Therefore, it is necessary to improve the visibility of the lane indicators in rainy weather.

Table 8 Measurement results of luminance contrast

<table>
<thead>
<tr>
<th>Type of road pavement</th>
<th>Road location</th>
<th>Luminance (cd/m²) &amp; Contrast</th>
<th>Daytime</th>
<th>Night-time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fine</td>
<td>Rain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>General paved road</td>
<td>Abe-gawa bridge of Tomei Expressway</td>
<td>Luminance (LM)</td>
<td>4181</td>
<td>2202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Luminance (Road)</td>
<td>1686</td>
<td>1547</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contrast</td>
<td>1.48 0.42</td>
<td>0.18</td>
</tr>
<tr>
<td>High-performance</td>
<td>Tomei Expressway 163.5 KP</td>
<td>Luminance (LM)</td>
<td>4566</td>
<td>4510</td>
</tr>
<tr>
<td>paved road</td>
<td></td>
<td>Luminance (Road)</td>
<td>1590</td>
<td>1487</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contrast</td>
<td>1.87 2.03</td>
<td>1.16 1.13</td>
</tr>
</tbody>
</table>
Figure 9  Examples of luminance contrast for 2 types of road pavement. Left: General paved road, Right: High-performance paved road
[1] Dense graded asphalt

The left side of Figure 9 shows images of a dense graded asphalt surface. The measurements were carried out near the Abe-gawa bridge on the Tomei Expressway. In Figure 9d, the numerical value “*1 or *2” means the luminance contrast could not be calculated because the lane marks could not be recognized due to the reflections on the road of the tail lights of the vehicle ahead or the lane marks were covered with rainwater. In fine weather, the visibility of lane marks is good, however in rainy weather the luminance contrast between the lane marks and the road surface luminance drops, thus causing the visibility to drop drastically. In rainy weather, in particular, the road surface reflects the street lights, and so uneven luminance occurs on the road surface.


The right of Figure 9 shows images of the high performance pavement (porous asphalt). The measurements were carried out at the 163.5 km post (KP) of the Tomei Expressway. The luminance contrast on the water drainage pavement is better than on non-porous, dense grade asphalt. At night in rainy weather, the road surface does not reflect the street lighting so much, which is an advantage of this pavement.


Figure 10 shows a comparison between the luminance contrast in fine weather and the luminance contrast in rain. The rate means lane indicator visibility. The lane indicator visibility on porous high performance pavement was better than on non-porous dense graded asphalt under varied conditions.

Figure 10 Comparison of contrasts between rainy condition and fine condition
6. DISCUSSION

To improve the lane recognition performance from the result of the experiment, we propose following.

[1] Road Structure

(1) It is necessary to install an illumination buffer zone at the sections where the road surface luminance changes quickly, such as tunnels and under bridges.

(2) A fence that prevents the glare from oncoming vehicles at night should be installed in the median strip.

(3) The water-drainage pavement is recommended for road surfaces because it does not flood and the light from street lighting and tail lamps of vehicles ahead do not reflect on the road surface at night and in rainy weather.

(4) It is desirable that lane marks have high brightness characteristics, even if they are flooded or the road surface is wet.

[2] Headlamps

(1) Very bright headlamps such as discharge headlamps are recommended. A light distribution that effectively irradiates lane marks in rain and fog is highly desirable.

(2) If a fence that prevents the glare from oncoming vehicles is installed on expressways, the optical axis of the headlamp is increased, and distant irradiation capability should be improved by not giving dazzling vehicles in front.

[3] Image Sensors

(1) An image sensor with a wide dynamic range is necessary in order to improve lane recognition performance in the mouths of tunnels and under bridges.

(2) Improving lane recognition by sensor fusion is necessary.

(3) A link between the navigation system and laser radar system is desirable in order to guess the lane when sufficient lane recognition is not obtained by the image sensor.

[4] Road maintenance

(1) The visibility of lane marks deteriorates with time. Periodic maintenance is desirable to maintain their high visibility.

(2) Periodic cleaning should be carried out, because fouling the lane marks lowers their visibility.

5. CONCLUSIONS

We prepared an experimental vehicle for collecting driving environment data on-board, and measured the luminance of the road surface and of the lane marks as well as the luminance contrast between them under various driving conditions mainly on an expressway.

The following results were obtained.

(1) It was confirmed that the experimental vehicle for collecting driving environmental data on-board is an effective method of measuring the road surface luminance environment, such as low-luminance environments at night and in rainy weather.

(2) We were able to collect data for sections where the road surface luminance changes quickly, such as in tunnels and under bridges, that affect the lane recognition performance.

(3) It was found that the luminance contrast drops drastically under rainy or foggy conditions. Furthermore, it is necessary to improve the road surface and lane marks, and also to enhance the street lights and headlamp illumination.

(4) The luminance of the lane marks and the road was measured on various sections of real roads, and the luminance contrast data was gathered. This data was then placed in a database.
Environments where the lane recognition is difficult for present image sensors

From the result of measuring the visibility of lane marks on real roads, a road situation when the lane could not be recognized was identified and its environmental factor was considered. As a result we obtained the following results.

1. In sections where the road surface luminance changes quickly, such as in tunnels and under bridges (places where the luminance of the road surface changes by ten times or more), there are places where lane recognition becomes impossible.
2. There are places where lane recognition becomes impossible under the situation in which the smear occurs by backlights such as the setting sun.
3. When the sun shines from the west or the east, the road surface reflects the sunlight occurs, making it difficult to recognize the lane marks.
4. The glare from oncoming vehicles at night, street lights and the tail lamps of vehicles in front reflecting on the road surface, all make it difficult to recognize the lane marks.
5. At night, when the road surface is flooded by torrential rain or the road is covered with dense fog, it is difficult to recognize the lane marks.

Visibility of lane marks in the weather environment

1. The contrast in luminance between the lane marks and the road surface is higher at night than during the day because the headlight beams are reflected by the glass beads in the lane marks.
2. From the results of measurement the luminance contrast between the road and the lane marks the following order was obtained: (1) wet roads at night with headlights, (2) dry roads at night with headlights (3) foggy roads and roads flooded by torrential rain.
3. The luminance of the lane marks decreases according to the density of the fog, however the luminance of the road increased. Both luminance is settled at the identical luminance in long way road surface, making it difficult to recognize the lane mark.

Visibility of lane marks according to road surface

1. The luminance contrast of water drainage pavement was high compared with the luminance contrast of the dense grade asphalt in roads without street lighting at night and in fine weather. It is expected that the visibility of lane marks on water drainage pavement at night and in fine weather will improve.
2. At night and in rainy weather the luminance contrast of water drainage pavement is higher than that of the dense grade asphalt.
3. Since the visibility of the lanes of water drainage pavement road is stabilized in ant environment, it was thought to be desirable from the viewpoint of lane recognition. However, it is necessary to further improve lane visibility.
REFERENCES:

1. Shoji Kobayashi, et. al.; EVALUATION OF LANE MARKING DETECTION WITH MACHINE VISION UNDER POOR VISIBILITY, 1997 ITS World Congress Seoul
2. H.T. Zwalen, et al., The visibility of road markers as a function of age, retroreflectivity under low-beam and high-beam illumination at night, TRB 7 the annual meeting, Washington D.C., January 2003

APPENDIX

The member of the “Study Group of Next-Generation Lane Indication/Recognition System” launched by The Association of Electronic Technology for Traffic and Driving is as follows.

♦ Composition of Study Group (FY 2001)
  • Secretariat: Association of Electronic Technology for Traffic and Driving
  • Members
    Official study institutes: National Institute of Advanced Industrial Science and Technology (AIST, Independent Administrative Institution), Japan Highway Public Corp., Shinshu University
    Road materials manufacturers: Sumitomo 3M Ltd., Hitachi Chemical Co., Ltd., Nippon Signal Co., Ltd.