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Driving Environment Recognition for Active Safety

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Peripheral Recognition for Active Safety Peripheral enhancement/advisory systems which provide perceptual enhancements and warnings of hazards for drivers are expected to contribute to active safety. This paper describes three types of peripheral recognition techniques which have been researched and developed by TOYOTA Motor Corp. since 1980's, that is, millimeter-wave radar and laser radar based on active-sensing and CCD image processing based on passive-sensing. Both millimeter-wave radar and laser radar feature excellent weather resistance and provide range detection for relatively far objects. The CCD image processing system adopts template matching method to perform lane-line recognition and approaching vehicle detection by stereo vision and optical-flow detection.

1. Introduction

It has been well known that driving operation by a driver is performed in three steps: perception/recognition, decision making and control/response. Along with complication of driving environment due to increasing traffic in recent years, the driver's load for perception/recognition and decision making has been increasing. One of Japanese highway accident statistics shows that collisions with roadside structures and rear-end collisions account for over 50% of total accidents. Most of fatal accidents may be avoided by preventing departure from the traveling lane and rear-end collisions.

One conceivable method for preventing these is to install electronic perceptual enhancement/advisory systems for active safety. In other words, it is to make vehicles have intelligence for recognizing the driving environment and informing drivers of the surrounding conditions and any possible danger.

Such a perceptual enhancement/advisory system, however, is to provide the driver with only the information required for safe driving, and the driver must assume the final responsibility for driving operation.

Sufficient discussion may be required for obtaining social consensus on the system reliability and resultant change in the driver's safety consciousness while clarifying the scope of responsibility.

To make perceptual enhancement/advisory systems more reliable, infrastructure such as roadside monitoring and vehicle/roadway communication systems should be implemented.

Intelligent vehicle systems can be used more efficiently when they are well coordinated with the roadside infrastructure.

Fig. 1 shows four definite types of perceptual enhancement/advisory systems that may be put into practical use.

The peripheral recognition technologies for such systems must involve minimum lowering of the detecting performance due to changes in weather and other environmental conditions and less cost burden on the user side. Manufacturers have been studying various methods, but they have not been established as technologies for recognition of vehicle peripheral conditions.

Toyota Motor Corp. has been studying and developing millimeter-wave radar, laser radar and image processing technologies shown in **Table 1** as peripheral recognition technologies for perceptual enhancement/recognition systems.

While active-sensing systems detect the electromagnetic wave (beam) emitted from the built-in device and reflected from targets, passive-sensing systems detect reflected electromagnetic waves existing in the ordinary state or and the electromagnetic wave radiated from targets. Because an active-sensing system irradiates the wave itself, the S/N of the received signal is high. As compared with a passive-sensing system, an active-sensing system is less affected by changes in weather conditions such as rain and fog. The existing active-sensing systems have problems such as insufficient resolution for accurate locating of targets and difficulty in mounting on vehicles.

This paper describes the results of our studies on various peripheral recognition methods and themes to be studied in the future.

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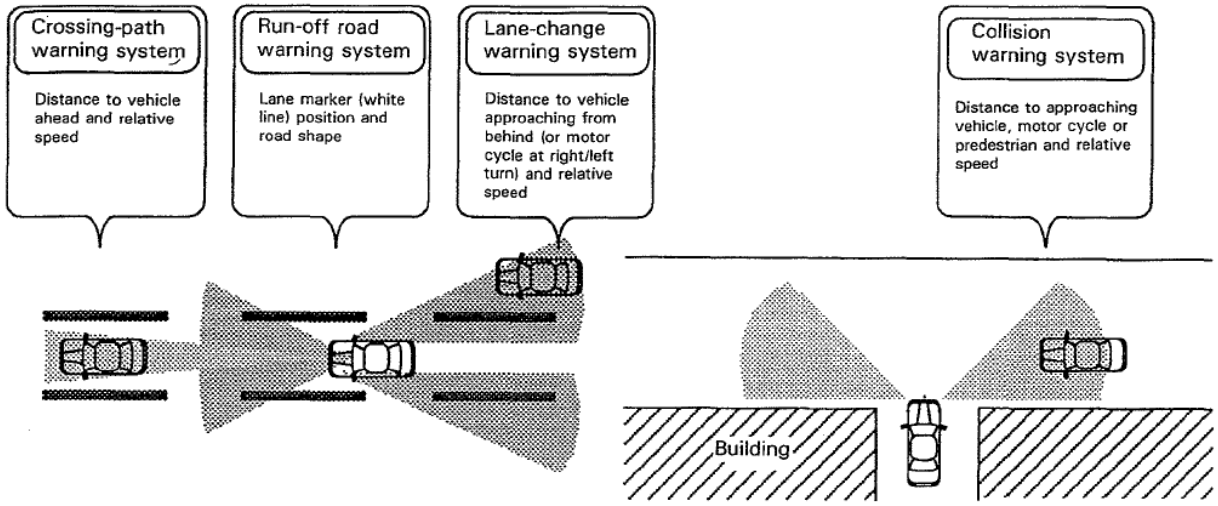


Fig. 1 Perceptual Enhancement/Advisory System

2. Millimeter-Wave Radar[1],[2]

This system allows relatively long range detection with less influence by environmental conditions such as rain, fog and snow.

The FM-CW type millimeter-wave radar we have been developing detects the relative speed by sensing the variation of the phase according to the moving speed of the target. For actual application to the collision warning system, however, electromagnetic interference with the radars on other vehicles exists as a big problem.

To solve this problem, we have developed a system using 45° polarization to prevent interference with opposing vehicles by 90° difference in polarization.

Table 1 Recognition Methods for Perceptual Enhancement/Advisory System

	Method		Applied system
Active methods	Millimeter-wave radar		•Collision warning system •Lane-change warning system
	Laser radar		•Collision warning system
Passive methods	Image processing	Template-matching	•Run-off road warning system
		Stereo ision	•Collision warning system •Lane-change warning system
		Optical flow detection	•Collision warning system •Lane-change warning system •Crossing-path warning system

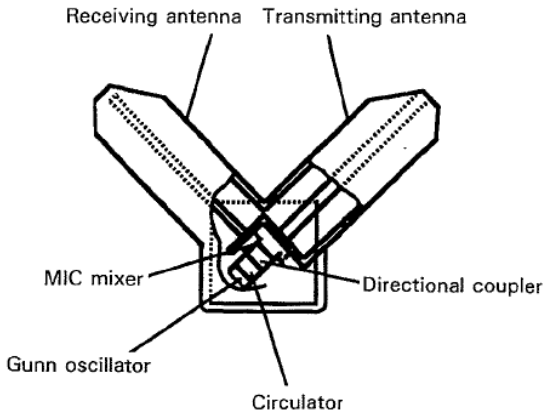


Fig. 2 Millimeter-wave Radar

Fig. 2 shows the exterior view of the millimeter-wave radar in V shape for 45° polarization. **Fig. 3** shows the method of experiment and an example of evaluation results of the effect of suppressing interference from other vehicles by adoption of this system. **Fig. 4** shows the case where the radar on the vehicle running in parallel is directed to the same target vehicle.

The experimental results indicate almost no electromagnetic interference with the radars on other vehicles.

Future themes to be studied are how to improve the signal processing method and antenna shape for recognition performance improvement and how to facilitate installation on vehicles.

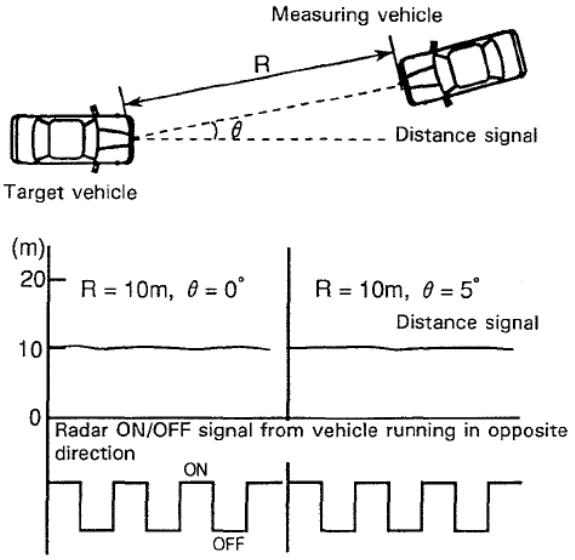
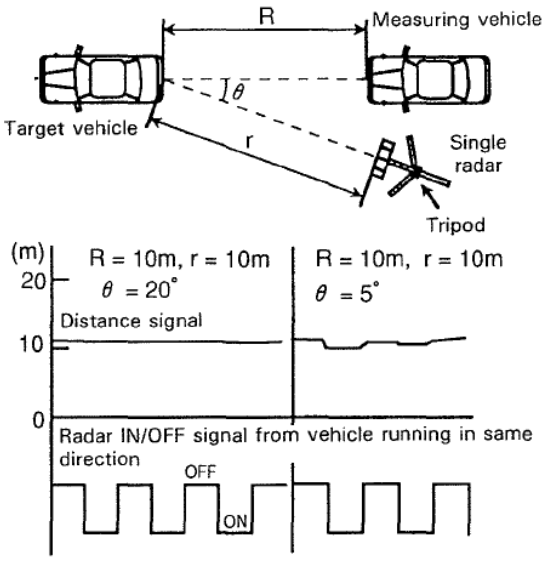


Fig. 3 Electromagnetic Interference (from Vehicle Running in Opposite Direction) Evaluation Result



3. Laser Radar[3]

This system will reduce the size and weight of the active-sensing range monitoring system in comparison with the case of millimeter-wave radar. It is not subject to frequency regulation, signal processing is easy, and narrow range detection is possible by concentrating beam irradiation.

Fig. 5 shows the principle of detection. The pulse method is adopted to increase the measurable distance and to improve the reliability.

This system involves possible lowering of the detecting precision due to variation in the receiving level resulting from change in the laser beam reflection factor of the target and environmental changes such as rainfall.

We have, therefore, improved the AGC (automatic gain control) and STC (sensitivity time control) circuits to reduce the error to within ±2 m for a detecting distance of 100 m.

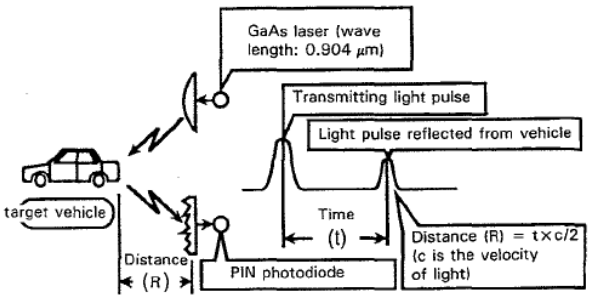


Fig. 5 Principle of Detection by Laser Radar

4. Image Recognition[4]

For image recognition, feature extraction from the image data for recognition is necessary. The methods for feature recognition can roughly be classified into the boundary extraction method and region segmentation method as shown in **Fig. 6.** We have adopted the template matching method which is one of the simplest region segmentation methods. **Fig. 7** shows the basic principle. This method is capable of simultaneous processing of feature extraction and initial recognition for simplification of the whole processing as it searches the region having the highest correlation with the template image.

Table 3 shows three characteristics that can be detected by using the template matching method. These are because the stereo vision and optical flow can be detected in the same way as template matching.

The template matching method enables a single processor to perform multiple types of recognition jobs as its merit. We have made a prototype compact compact high-speed processor board using a special IC for calculating correlation between images that would otherwise require high operation load. **(Photo. 1)**

In comparison with other recognition methods, the image processing system using a CCD camera as the input device has the following features:

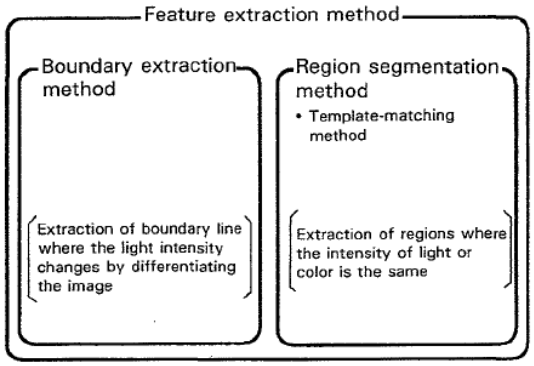


Fig. 6 Feature Extraction Method for Image Recognition

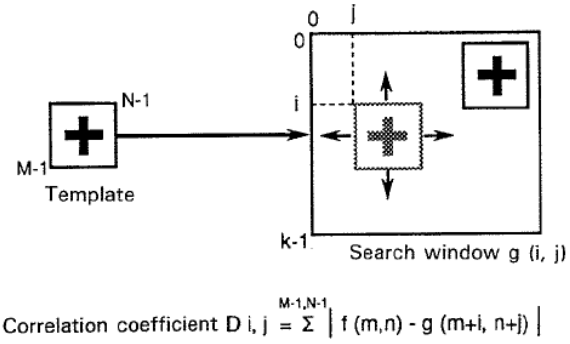


Fig. 7 Principle of Template-matching Method

Table 2 Application of Template-matching Method

Template-matching	Object detection/recognition
Stereo vision	Detection of 2-dimensional depth (distance)
Optical flow	Detection of motion vector of moving object

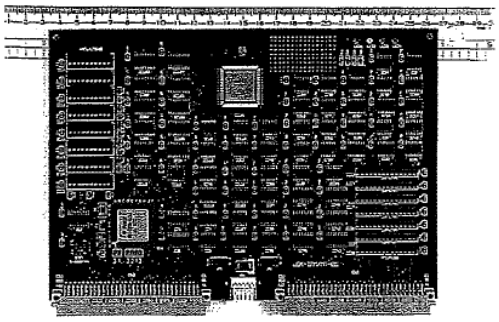


Photo. 1 Image Recognition Board

(1) Capability of lane marker and road sign recognition
(2) Concurrent high-speed pick-up of various image signals in a wide range
(3) Relatively low cost because of the construction using general parts for consumer products

Basically drivers operate according to visual information.

Thus the image recognition system has wide applicability for use other than perceptual enhancement/advisory systems shown in **Fig. 1**.

4.1 Lane-Line Recognition by Template-Matching

Lane recognition by the lane line provides the most basic information for recognition of run-off (lane departure) and obstacles in peripheral recognition. One of the important factors in lane-line recognition is the robustness against changes in shade/brightness of the road surface and in lane-line shape at curved portions.

Fig. 8 shows the template image update method we have

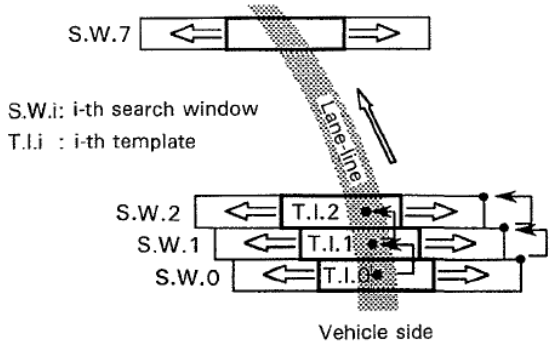


Fig. 8 Template Image Updating Method

developed. Knowledge on continuous variation of the position and shape of the lane line on the road surface is used as a basic premise.

The area to be searched in front of the vehicle is divided into plural narrow search windows for speedy processing and minimization of the influence of change in shape. In each search window, the template moves only in the horizontal direction to search the position where the correlation is maximized. To cope with any change in the lane line shape, search windows are searched in the ascending order of the distance from the vehicle. The lane line image obtained in the search window nearer from the vehicle is used for updating the template for use in the next window. To stabilize the lane-line position in the updated template image, a predefined image is used as the template for the search window nearest to the

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