Fusion Sensor for Driving Assistance System

●Nobukazu Shima ●Masahiro Babasaki ●Yoshiki Akidzuki

●Kanako F. Honda ●Takashi Higuchi ●Hirofumi Higashida

●Ryuichi Nakamura

Abstract

The development of driving assistance systems that improve automobile convenience and safety is being promoted throughout the world, primarily by automobile manufacturers. One such system is the Adaptive Cruise Control (ACC) System, which controls the vehicle speed and maintains a safe head-up distance while driving at high speeds.

The ACC has been installed in luxury cars, and its recognition capabilities have been improved. This system makes use of state-of-the-art sensing technologies such as laser radar and millimeter-wave radar.

With the aim of creating a "Driving Support System for Congested Traffic" as a next-generation driving assistance system, we have developed a "fusion sensor" as an optimal sensor for this system by blending millimeter-wave radar with an image recognition sensor. This sensor achieves both distance and angle accuracy, which an independent sensor cannot achieve. We manufactured a test vehicle that was equipped with the Driving Support System for Congested Traffic and fusion sensor, and were thus able to verify the sensor's practical use. This report will introduce the Driving Support System for Congested Traffic and fusion sensor that we have conceived.

1. Introduction

Practical driving assistance systems are being developed in order to improve automobile safety and convenience. One such driving assistance system is the "Traffic Congestion Assistance System," which assistances driving during periods of traffic congestion.

In this report we will introduce the "fusion sensor," which blends millimeter-wave radar and image recognition technology as a sensor that is suitable for this Traffic Congestion Assistance System.

2. Aim

In recent years, efforts have been made to develop new transit systems in order to alleviate transportation problems such as traffic accidents and congestion. One such development is the Intelligent Transport Systems (ITS), which includes a field called "safe driving assistance" whose purpose is to improve automobile safety and driver convenience by providing functions such as travel environment information, danger warnings, and driving assistance. The overall aim is to reduce the number of traffic accidents and make driving easier for vehicle operators.

2.1 Trends in technology

Representative of research and development in the field of safe driving assistance are the advanced safety vehicle (ASV), which increases safety through the development of "intelligent" vehicles; and advanced cruise-assistance highway systems (AHS), which makes use of communications technology. These developments are integrated systems that combine our driving assistance system. A separate driving assistance system, the Adaptive Cruise Control (ACC) System, which controls the vehicle speed while maintaining safe vehicle-to-vehicle spacing during high-speed driving, has already come into practical use.

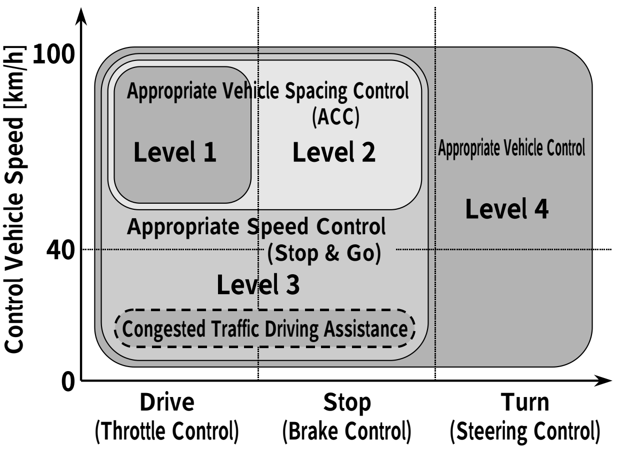

Fig.1 Control range and vehicle's three major functions

We expect the driving assistance system to come into practical use, advancing in development from level 1 to level 4, as shown in Figure 1. Levels 1 and 2 are ACC which are already in practical use, and Level 2 includes brake control. At level 3, the control area expands to the low-speed area; and at level 4, the system is very close to being automatic operation.

The transition from level 2 to level 3, however, includes deceleration control as well as complete stops that are made during high-speed travel. Thus, from the user's perspective, these may appear to be types of automatic operations without steering control, while from the automobile manufacturer's perspective, it is considered difficult to acquire adequate safety. Obstacles in reaching its practical use seem large at this point.

Thus, we concluded that if we limited the system to level 3, and particularly to low-speed periods (traffic congestion), this would reduce the impression that this is a fully automatic driving system, reduce the number of technical problems, and enable the system to be developed for practical use sooner.

2.2 Traffic Congestion Assistance System

Using this concept as a basis, we examined the basic functions of a Traffic Congestion Assistance System. We decided that the system should achieve the following two aims:

(1) Alleviate the annoyance of having to repeatedly stop and accelerate during periods of congestion, and thus reduce the burden on the driver.

(2) Prevent or reduce accidents due to dozing or inattentiveness by issuing alarms during dangerous situations, such as when a car ahead cuts into one's lane.

Figure 2 shows an operation example of the basic system.

Limiting the number of actions should improve the ease of use and understanding of the driver, and should make the system more acceptable to the market. The system is still based on the premise, however, that the driver is at the core of the driving actions, including starting up and turning off the system.

With the objective of developing such a Traffic Congestion

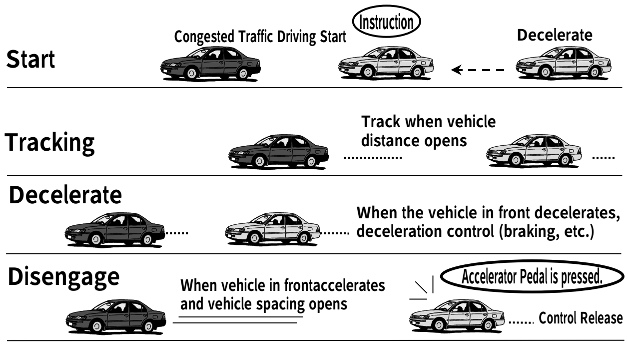

Fig.2 System operation (example)

Assistance System, we decided to begin developing a sensor that would be suitable for the system.

3. Sensor development objective

When driving on a congested road, there is very little distance between cars, and drivers must watch for vehicles cutting into their lane. The sensor required by the Traffic Congestion Assistance System must have the capacity to make appropriate determinations under such conditions.

3.1 Required specifications

First, we created a model of the Traffic Congestion Assistance System control and derived required specifications for the sensor through simulation (Table 1).

Table 1 Sensor performance required by system

Item	Required Value
Distance Accuracy	20% or 2m, whichever is smaller
Detection Range	Detection Angle 40 °
Angle Accuracy	Less than 1 °in respect to object edge.
Relative Speed Accuracy	Less than ± 2km
Response Characteristics	500ms or less for vehicles moving into same lane
Recognition Targets	Cars / Motorcycles

The sensor required by the Traffic Congestion Assistance System must not only have distance accuracy but a wide visibility angle and lateral position angle accuracy, too

One such sensor that can recognize wide angles of visibility is the image recognition sensor. With an image recognition sensor, however, the accuracy of long-distance measurements worsens as the angle widens.

Thus, we focused our attention on the fact that ACC -equipped vehicles are already equipped with radar systems that provide high distance measurement accuracy, and concluded that the required specifications could be met by combining a wide-angle image recognition sensor to the radar.

For the radar, we used a millimeter-wave radar that was developed for ACC by our company. One feature of a millimeter-wave radar is that it can detect any type of object and is not affected by the weather.

If the advantages of each are blended (fused) together, even higher performance can be expected.

3.2 Sensor fusion

The aims of the fusion sensor are as follows:

(1) Achieve distance accuracy, detection range, and angle accuracy that a single sensor cannot achieve. Improve reliability.

(2) Reduce required performance of image recognition sensor, and price reduction. The development of a low-cost sensor will be a particularly important element of the system popularization process.

To satisfy ACC performance requirements, millimeter-wave radar has a narrow detection width but maintains detection accuracy up to a long distance.

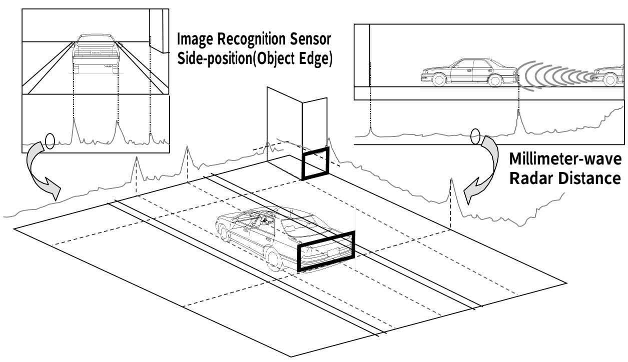

Fig.3 Concept of fusion

For this reason, the specifications of the image recognition sensor placed more emphasis on achieving accuracy in lateral position (target object edge) recognition than in distance measurements. Combining these lateral position and millimeter-wave radar distances makes it possible to accurately recognize target distances and positions (Figures 3 and 4).

Utilizing this concept, we believed that we could reduce the processing volume and cost of the image recognition sensor.

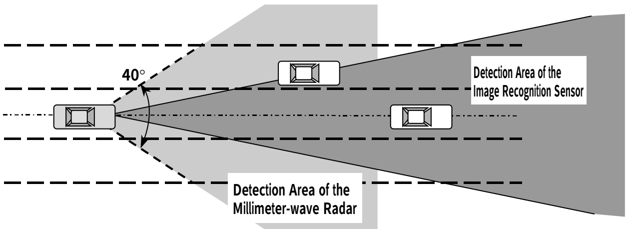

Fig.4 Detection area

4. Millimeter-wave radar

Our millimeter-wave radar uses the same sensors we developed for ACC except for the output signal.

Our millimeter-wave radar uses a frequency-modulated continuous wave (FM-CW) method to allow instant detection of distance and relative velocity regardless of whether the target is moving or stopped, and makes it harder for it to be affected by mutual interference. In order to ensure that the angle width can be detected even on curved roads, a mechanical scanning system is utilized.

Table 2 Millimeter-wave radar specifications

Item		Content
Maximum Detection Range		140m
Detection Width		±8 °
Relative Speed Range		-100km/h～+200km/h
Accuracy	Distance	±1m or ±5%, whichever is greater
	Angle	Less than ±5 °
	Speed	±5.5km/h or ±5%, whichever is greater

Fig.5 Millimeter-wave radar

5. Image recognition sensor

With the image recognition sensor, we aimed to drastically reduce the required performance and cost by specializing it for the Traffic Congestion Assistance System.

5.1 Development objective

The stereo camera and image processing ECU (electronic control unit) of the image recognition sensor were separated.

The stereo camera can now either be suspended from the roof or secured between the rearview mirror and windshield. In this case, we selected the latter method for ease of attachment.

Furthermore, because of the need to minimize the adverse effect on the driver's field of vision, the requirement for stereo camera compactness is extremely high. Taking into consideration the future integration of the stereo camera and recognition processor, we decided to secure the required space and make the unit more compact.

Table 3 Target specifications for image recognition sensor

Item		Content
Maximum Detection Range		30m
Detection Width(Angle)		±20 °
Accuracy	Distance	In a range under 12m, within 20%
	Angle	Less than ±1.0 °in respect to the object edge
Size Requirement		Must not interfere with the drivers field of vision. Must be a size where the necessary processing circuits for recognition can be integrated with the camera is possible in the future.

5.2 Stereoscopic ranging theory

With image recognition, the distance is found by using the principle of triangulation. Stereo cameras consisting of two image sensors are set up at the same level and at a certain distance apart (base length), and the optical axis is set up perpendicularly in the forward direction. At that time, the position of an object whose image is obtained mutually by the two cameras will appear to differ laterally. The amount of this difference is called the parallax*1. The distance from the parallax to the object ahead can be found by means of the equation below.

$$\text{Distance } D = \frac{f \cdot B}{F\ (X_b - X_a)} \quad [m]$$

f : Focal length of camera B : Base length

F : Pixel pitch

X_a, X_b : Coordinate in lateral direction of image

(*1: Parallax = Xb−Xa)

5.3 Stereo camera

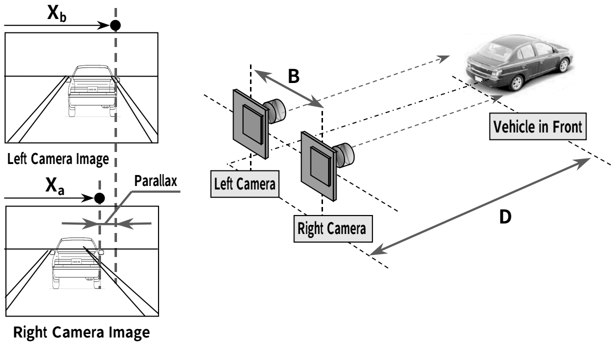

Fig.6 Stereoscopic ranging method

A complementary metal-oxide semiconductor (CMOS) sensor was adopted for use as the camera's image sensor. A CMOS sensor is inexpensive and consumes minimal energy. The image quality of a conventional CMOS sensor, however, is worse than that of a charge-coupled device (CCD), making such a sensor unsuitable for image recognition. But in recent years, advances have been made in the sensor's development for use with mobile equipment. Furthermore, during an in-house evaluation of its image quality, dynamic range, and other qualities, the performance of the sensor was found to be equivalent to that of a CCD. As a result, we decided to adopt it.

Table 4 Stereo camera specifications

Item	Content
Size	235×50×50mm
Weight	340g
Current Consumption	45mA(Typ.)
Base Line Length	200mm
Horizontal Image angle	41.3 °

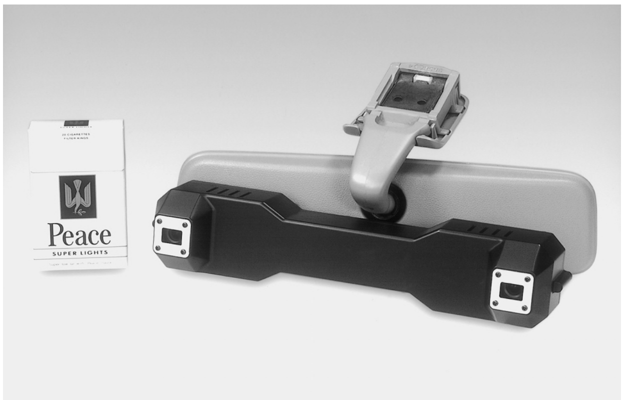

Fig.7 Stereo camera

The stereo camera is somewhat smaller than a rearview mirror, so its effect on the driver's visibility is minimal. Space was provided in the center of the unit to accommodate the processing circuit required by the image processing ECU for image recognition.

With a stereo-type camera, problems such as image sensor rotational deviation, lens deformation, and optical axis deviation occur, causing errors in distance measurements. Accuracy has been obtained, however, by implementing measures to reduce the causes of errors in the camera structure and by correcting errors by software.

5.4 Image processing ECU

An image processing ECU broadly consists of a field programmable gate array (FPGA), digital signal processor (DSP), and microprocessor, which handle picture signal processing, image processing, and fusion processing (Figure 8). To obtain stable picture input, the connection with the stereo camera was digitized. And for efficient on-vehicle evaluations, circuits for picture output and serial input-output are installed.

To reduce cost, standard CPUs were adopted for use in circuits required for recognition processing; and to achieve compactness, an FPGA was adopted to reduce the number of parts. The area of the circuit board in this portion has nearly been reduced to a target size that will fit in the stereo camera.

Table 5 Image processing ECU specifications

Item	Content
Size	335×150×31.5mm
Board Area (Recognition Processing Section)	14300mm²
Process Cycle	100ms
Image Signal Interface	Digital

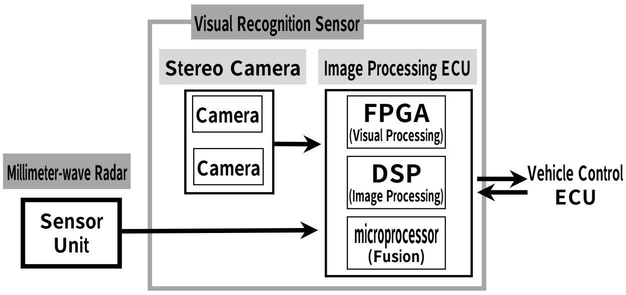

Fig.8 Signal processing structure

Fig.9 Image processing ECU

5.5 Recognition algorithm

A common method of measuring distance through image recognition is to divide the screen into smaller areas and then find the position from the image on the opposite side that corresponds to such area (pattern matching). When pattern matching is used for the entire screen and a distance distribution is found, this is called a distance image.

The method of finding the distance image requires an enormous amount of processing; consequently, it is difficult to achieve with a standard CPU. And even if it is achieved with hardware, the size of the circuit will enlarge, which is a drawback.

The fusion sensor does not require the image recognition sensor to have high distance resolution; thus, we decided to develop a recognition algorithm whose processing volume was minimal enough for a standard CPU to process.

To shorten the time for pattern matching, which requires a large volume of processing, we developed a method called "Edge + Pattern Matching." This method is processed as described below.

(1) Extraction of minimum-required characteristic position of object (Figure 10)

An object's outline is extracted through filtering (edge extraction). Then based on the continuity and coordinate positions of the extracted edges, the char-

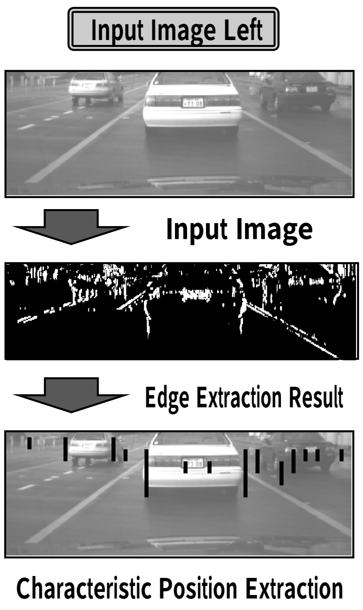

Fig.10 Results of edge processing and characteristic point extraction

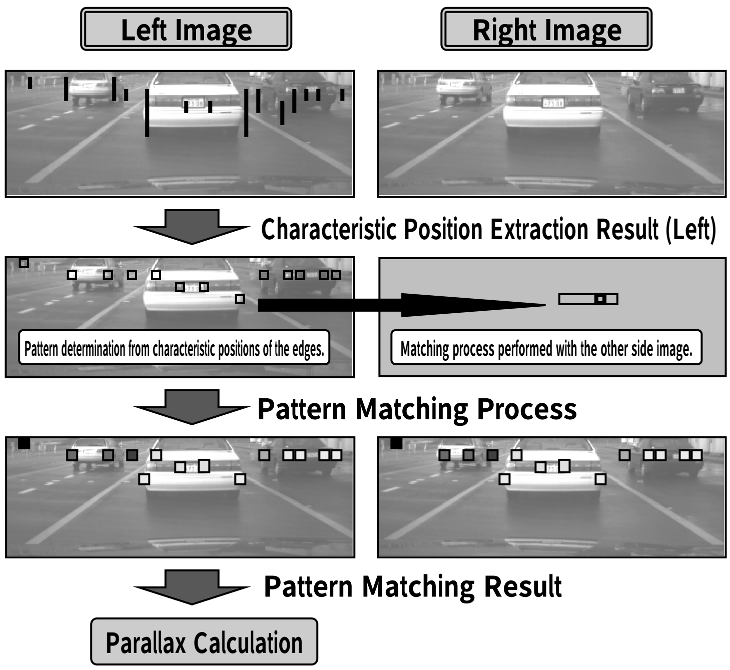

Fig.11 Pattern matching

acteristic position, including the object's edge points (target object edge), is extracted. Road lettering and white lines that do not need to be extracted as part of the characteristic position will also be extracted, but will be removed upon comparison with the results of white line recognition that is performed separately.

(2) Pattern matching using characteristic position (Figure 11)
When the pattern of a small area is extracted as the characteristic position, the position having the highest correlation is extracted from the area within the image on the opposite side in which the pattern may exist. From the various positions, the parallax is found and the distance is calculated.

Processing related to distance measurements uses the same technique as ordinary image recognition, so there is no drop in accuracy and the volume of processing can be drastically reduced.Furthermore, in order to gain the optimum image, camera control, height determination of the target object to identify shadows and inappropriate image input recognition diagnostic features are provided.

6. Fusion

The final output of the fusion sensor includes the distance to the target in front of the vehicle, relative velocity, and lateral position. In comparison a millimeter-wave radar and image recognition sensor can also output the distance and lateral position; however, better results could not be obtained even if the output of each sensor were to be combined after information was selected for recognition.

Thus, for the output of each sensor, we decided to include data that was upstream of processing. With correspondence obtained between the edge data that is output by the image recognition sensor and the power data of the millimeter-wave radar that exists nearby, the probability that an object exists to the left or right of the edge is calculated. If the probability of existence to the left and right of the edge differs by an amount that exceeds a certain value, an object's edge is assumed to be present and a surface is formed.

In this way, more accurate determinations can be made and recognition performance and reliability can be improved.

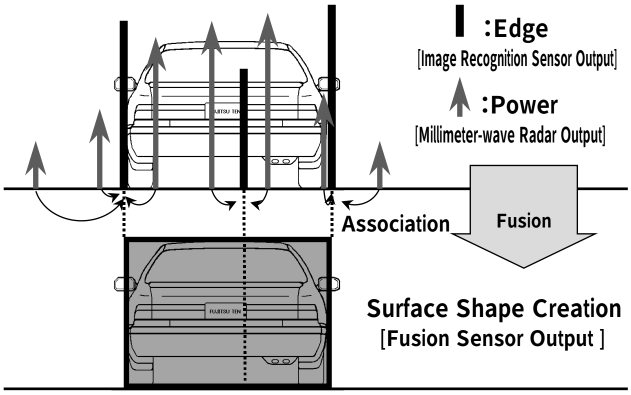

Fig.12 Fusion algorithm

7. Evaluation

The following evaluations were performed for recognition performance.

Test course:Quantitative evaluations such as distance, relative velocity, angle accuracy, and response when other vehicle cuts into one's lane.

Ordinary road:Dynamic sensor performance evaluations

Other evaluations under adverse conditions, such as night and rainy weather, have also been performed as

7.1 Quantitative evaluation

A standard target consisting of a rectangular plate of the same size as a vehicle was used to verify the accuracy of distance and angle measurements. During accuracy tests that were conducted using this object, the required specifications for distance and angle were satisfied.

Figure 13 shows a time sequence graph of the recognition results of a vehicle equipped with fusion sensors, when the target vehicle in front of it came to a stop. From the graph it is clear that the distance, relative velocity, and lateral position are being output with consistency.

Figure 14 shows the recognition results for a case in which there was a vehicle ahead and a vehicle cutting in between. The recognized edge of the target is shown as a line, and the length of the line changes according to the distance. Areas that were recognized as surfaces are enclosed by a frame, and areas in which the given vehicle could travel are shown by slanted lines. At the top of the screen, the speed of the given vehicle and the distance from the given vehicle to the vehicle ahead are shown. In this way it is clear that the vehicle ahead was recognized as a surface and that the distance to the front edge of the vehicle cutting in was being measured. The vehicle that

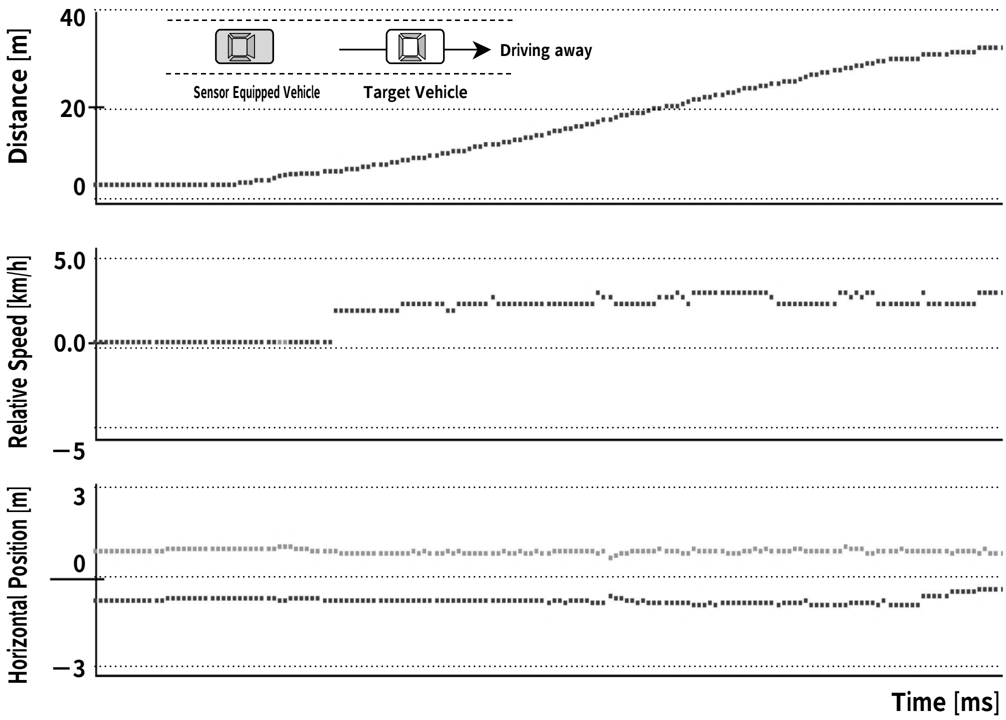

Fig.13 Sensor output when object is distant

cut into the area in which the given vehicle could travel (at a distance of about 10 meters ahead of the given vehicle) was recognized 500 ms faster than with a millimeter-wave radar alone.

Fig.14 Recognition results 1 (vehicle cut-in)

7.2 Performance evaluation using ordinary road

Figure 15 shows the recognition results for an ordinary road. On an ordinary road, there are distant views, guardrails, white lines, and many other things that can cause recognition errors. Even in such an environment, a fusion sensor can properly recognize an object from the image target object edge and status of the millimeter-wave radar power distribution.

Fig.15 Recognition results 2 (local traffic)

8. Experimental vehicle

An experimental vehicle was manufactured for the purpose of examining and evaluating the Traffic Congestion Assistance System. For the fusion sensor, a millimeter-wave radar was placed on the inside of the front grille, while a stereo camera was placed behind the rearview mirror (Figures 16 and 17).

With this experimental vehicle, we transmit the fusion sensor output to the vehicle control ECU. The vehicle control ECU assesses the conditions and controls the

Fig.16 Millimeter-wave radar attachment

Fig.17 Attachment of image recognition sensor

throttle and brakes. Using this structure, acceleration, tracking, and stopping while assuming an actual target system becomes possible.

This vehicle has been used not only to evaluate sensor performance but to evaluate the ease of use and ride comfort during system operation.

9. Summary

We developed a "fusion sensor" that fuses (integrates) the functions of a millimeter-wave radar and image recognition sensor. By fusing together the technologies of millimeter-wave radar and image recognition, this fusion sensor can accurately identify the distance to objects that are ahead, as well as relative velocity and lateral position, and is thus suitable for a Traffic Congestion Assistance System. Furthermore, the image recognition sensor achieves wide-angle recognition with a minimal amount of processing.

In the future we will promote the application of this fusion sensor and engage in the development of new sensing technologies in an effort to contribute to society by helping to create various driving assistance systems.

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Profiles of Writers

Nobukazu Shima

Joined company in 1991. Since that time, has engaged in development of image processing and on-vehicle signal processing equipment. Currently in the Research & Development Department.

Masahiro Babasaki

Joined company in 1990. Since that time, has engaged in development of noise control and image processing equipment. Currently in the Research & Development Department.

Yoshiki Akidzuki

Joined company in 1986. Was initially Since that time, has engaged in development and design of internally manufactured hybrid ICs as well as and development of image processing equipment. Currently in the Research & Development Department.

Kanako Honda

Joined company in 1988. Since that time, has engaged in development of millimeter wave millimeter-wave radar, fusion sensor, and equipment related to driving assistance systems.
Currently in the Engineering Department of ITS-Business Group.

Takashi Higuchi

Joined company in 1996. Since that time, has engaged in development of automobile driving assistance systems. Currently in the Engineering Department of ITS-Business Group.

Hirofumi Higashida

Joined company in 1984. Since that time, has engaged in development of on-vehicle control equipment and millimeter wave millimeter-waveradar software. Currently in the Project Manager of Engineering Department of ITS-Business Group.

Ryuichi Nakamura

Joined company in 1980. Since that time, has engaged in development of automobile electronic control equipment and on-vehicle signal processing equipment. Currently in the deputy department general Manager of Research & Development Department.