Environment Recognition Technologies for Supporting Safe Driving

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OVERVIEW: Safe driving support systems are already starting to appear on vehicles including ACC (adaptive cruise control) systems that maintain safe distance between you and the vehicle ahead, LKS (lane keep support) systems that prevent drivers from departing lane, and pre-crash brake systems that automatically tighten seat belts and apply brakes if a collision cannot be avoided. Radars and image processing cameras are the environment sensors with the key roles of recognizing and deciding what action to take in these safe driving support systems. These sensors must incorporate intelligent recognition technologies considering various complex external factors they might encounter in the real world: pedestrians darting out into the road, other vehicles cutting-in in front of you, poor visibility due to adverse weather conditions, etc. With its strong commitment to safety, Hitachi Group has focused its environment recognition sensor related R&D (research and development) on millimeter wave radar that provides stable recognition under the adverse weather conditions and image processing cameras that substitute for human vision where drivers have a hard time seeing. Indeed, these technologies have already been incorporated into products: millimeter wave radar provides the distance sensor in inter-vehicle distance warning and ACC systems, while image processing cameras are employed as lane recognition sensors in LKS systems. We are now working on a new generation of environment recognition sensors that will make safe driving systems even smarter in the years ahead.

INTRODUCTION

ENVIRONMENT recognition is absolutely essential to develop safe driving support systems, first to correctly recognize the potential risk of colliding with obstacles, straying out of one's lane, etc., and second to pass that information on to the control systems that warn the driver, make an evasive maneuver, or some other action to avoid an accident.

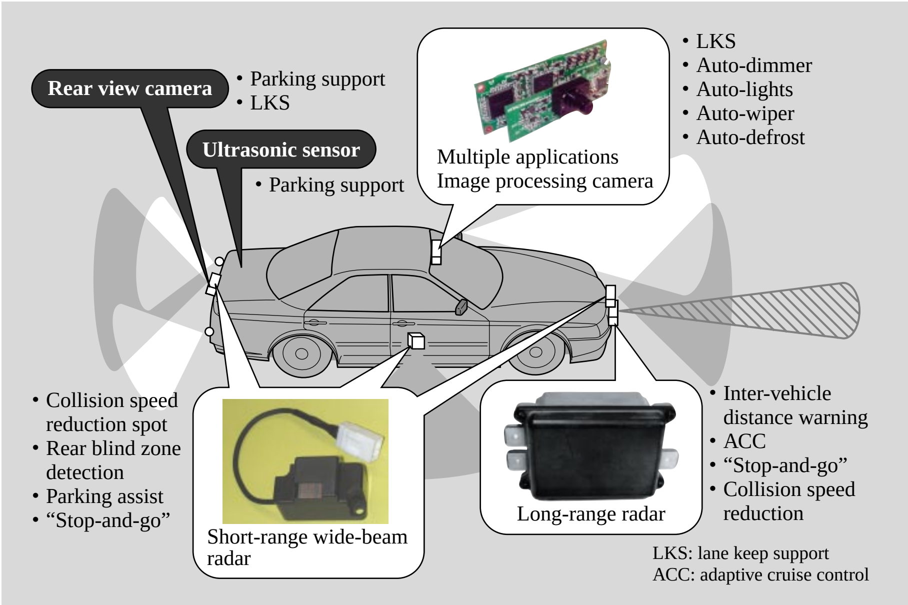

Fig. 1—Increasingly Diverse Range of Sensors Being Built into Vehicles. Vehicles are being equipped with various kinds of environment recognition sensors that support safe driving. Many sensors are already in practical use including ultrasonic sensors and rear-view cameras that support safe parking, radars for inter-vehicle distance warning and ACC systems, and image processing cameras for LKS systems. Work continues on more advanced environment recognitions sensors for applications that are smarter and more convenient.

In the act of driving, the driver recognizes a situation, decides what to do, and acts — a sequence that is repeated over and over — and accidents occur when a mistake is made in one of these crucial steps. We know that mistakes of recognition and judgment are the primary causes of close to 60% of traffic accidents[1)], so if we could find ways to reduce these kinds of mistakes and make drivers aware of the things they cannot directly perceive, then this would contribute enormously to improving vehicle safety.

Yet accurate recognition and decision-making require very advanced recognition technologies because there is such a diverse range of complex factors and things that can occur in the real-world driving environment: people can suddenly dart out in front of you, vehicles can suddenly cut into your lane, visibility can be impaired due to weather, etc.

The auto industry is currently supporting a number of public-private R&D (research and development) initiatives that are moving aggressively to make the above technologies a reality, including the ASV (advanced safety vehicle) initiative[2)] in Japan and the eSafety program[3)] in Europe. This paper describes some of Hitachi Group's recent work on environment recognition technologies (some of which are already being installed on vehicles) toward realization of a comprehensive safe driving support infrastructure.

NEED FOR ENVIRONMENT RECOGNITION SENSORS AND TYPES OF SENSORS

Two technologies that are already being applied to vehicles on the market as environment recognition sensors are ultrasonic sensors mounted on the bumper to detect the distance to an obstacle and rear-view cameras mounted on the back of vehicles that show the driver on a navigation screen what is behind the vehicle. Both of these technologies were designed for slow speed situations, mainly for detecting close-range distances when parking. Meanwhile, a number of sensors for longer range detection at higher speeds are nearly ready for the market including radars for ACC (adaptive cruise control) systems and lane recognition cameras for implementing LKS (lane keep support) systems. In fact, one implementation of an ACC system using radar is available in the form of a pre-crash brake system[4)].

With our primary concern for driving safety, Hitachi Group has focused its R&D resources on millimeter wave radars and image processing cameras as the technologies that we think are going to have the greatest impact on driving safety. Millimeter wave

CW: continuous wave

Modulation:	two-frequency CW
Angle detection:	monopulse
Power consumption:	under 6 W
Detection range:	1–127 meters
Mass:	0.55 kg

Fig. 2—Long-range Radar and Specifications.
A compact, lightweight, and highly reliable radar unit has been implemented using two-frequency CW, monopulse, and proprietary MMIC (microwave monolithic IC) design.

radar provides stable recognition in rain and fog and other adverse weather conditions, and image processing cameras provide drivers with eyes to see angles and places that otherwise are difficult or impossible to see.

MILLIMETER WAVE RADAR

Long-range Radar

Hitachi Group developed 76-GHz-band millimeter wave radars for application to inter-vehicle distance warning and ACC systems that comply with radio regulations of Japan, the U.S., and Europe[5)]. The radar measures the distance to the vehicle ahead up to about 120 m and the azimuth angle of 16 degrees. Combining a vehicle's traveling speed and yaw rate with distance, relative speed, and angular data detected by the radar, the vehicle in the same lane ahead is identified.

For distance and relative speed detection, we adopted a two-frequency CW (continuous wave) scheme that can measure targets at close range from about 1 m, and this can be applied to "stop-and-go" systems as well as to ACC systems. Then for angle detection, we adopted a monopulse scheme that does not require antenna drive or switching. Using these schemes in combination with a proprietary design MMIC (microwave monolithic integrated circuit), we have developed a highly reliable rugged radar unit that is very compact, lightweight, and can also be used on trucks (see Fig. 2).

This radar was used for the inter-vehicle distance warning system installed on Isuzu Motors Limited's Giga series heavy-duty trucks in 2003[6)], and more recently was adopted for the ADA (active driving assist) system on Fuji Heavy Industries Ltd's (SUBARU) Legacy models[7)].

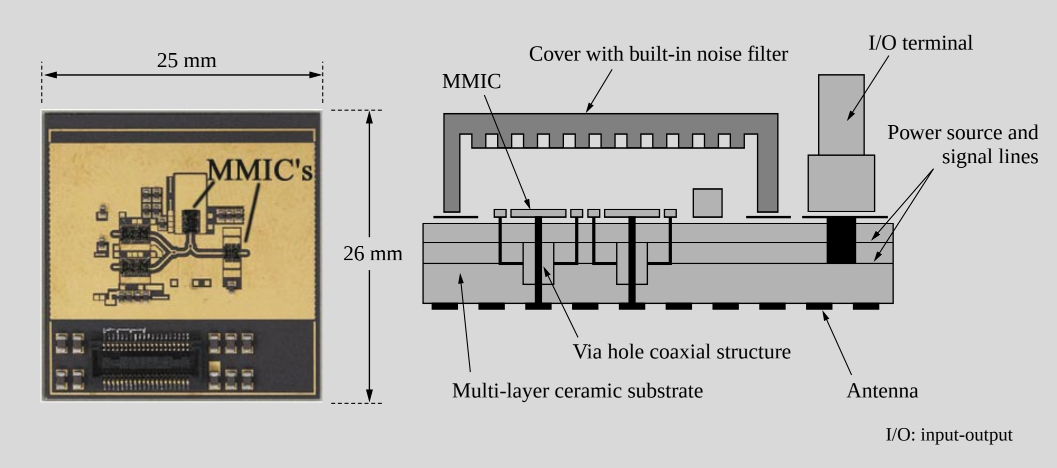

Fig. 3—Appearance and Cross Section of Short-range Wide-beam Radar Transceiver Module.
Using a multi-layer ceramic substrate and via hole interconnects, the module has been reduced to about one-fifth the size of the conventional transceiver module for ACC systems.

Short-range Wide-beam Radar

Besides long-range narrow-beam radars, advanced environment recognition for vehicle safety also require short-range wide-beam radars to check behind the vehicle for unseen obstacles and to cover blind spots for ACC systems. A number of proposals coming mainly out of Europe have suggested implementing an array of 24-GHz short-range wide-beam radars to cover these kinds of applications[8].

Hitachi Group has now developed an alternative and we think better compact radar module that uses 76-GHz band and is therefore in full compliance with radio regulations of Japan, the U.S., and Europe[9]. This radar module, shown in Fig. 3, has a number of significant advantages:

(1) MMICs are mounted directly on a multi-layer ceramic substrate and the interconnects are deployed in 3D fashion to the different layers, an approach that reduces the size of the module itself and also reduces the number of component parts.
(2) Antennas are connected to MMICs mounted on both front and back of the ceramic substrate layers through via holes, a design that makes the module easier to assemble.

With these innovations, we reduced the size of the high-frequency circuitry in the radar transceiver module to 26 (L) × 25 (W) × 3.4 (H) mm, about one-fifth the size of the conventional transceiver module for ACC systems.

One useful characteristic of the monopulse angle detection which incorporates ACC technologies is that the smaller the antenna size the greater the azimuth angle spreads, and this is exploited for closer range wider angle applications. To date we have implemented a monopulse antenna that fits into the transceiver module described above with a detection of azimuth angle of 80 degrees. We are now making good headway in developing a practical compact short-range wide-beam radar at low cost that can be applied to the following systems:

(1) Pre-crash brake and collision avoidance support
(2) Rear blind spot warning
(3) Parking assist
(4) Stop and go

IMAGE PROCESSING CAMERA

Hardware Features

Hitachi Group has developed an integrated image processing camera that combines a CCD (charge coupled device) camera that captures images from the front in the direction the vehicle is moving and an image processing unit that processes the received images and recognizes the lane, the vehicle ahead. The camera provides fast image processing by sharing the heavy processing loads between two processors: a 32-bit microprocessor SuperH* SH-3 that executes the lane recognition and other applications, and an image processing LSI (vision/video chip) optimized for parallel processing of the voluminous image data. The image processing camera was adopted for the LKS system installed on the Nissan Motor Co., Ltd.'s Cima[10] in 2001.

We anticipate a growing demand for image processing cameras that provide faster processing speed and better performance not only for lane recognition but across a diverse range of potential applications. At the same time, further reductions in

* SuperH is a trademark of Renesas Technology Corp.

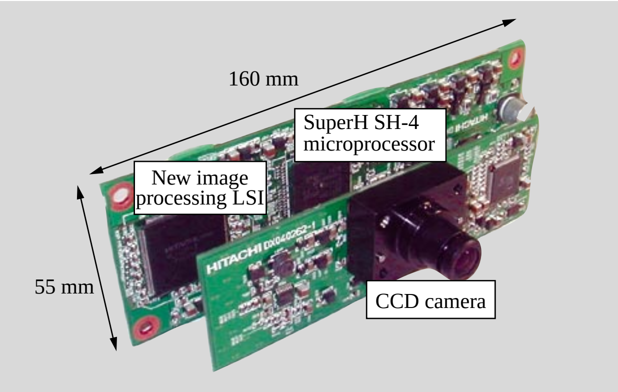

Fig. 4—Image Processing Camera and Circuit Board.
The new camera processes images four times faster than the old image processing LSI-based camera.

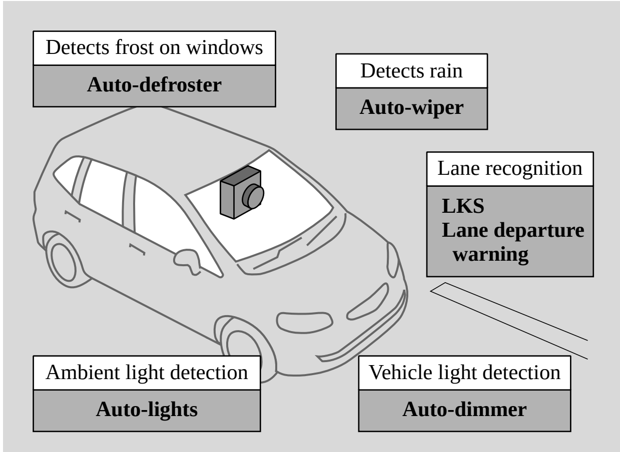

Fig. 5—Multiple Applications Supported by Image Processing Camera.
Multiple applications are implemented with a single camera.

cost and size of the cameras are necessary to sustain an expanding market for the image processing cameras. Challenged to meet these needs, we introduced in 2003 the new image processing camera shown in Fig. 4 built around a more powerful image processing LSI[11]. Performance of the new image processing camera with this new LSI has been significantly improved:

(1) Operating frequency was increased from 66 MHz to 133 MHz,
(2) Parallel processing and pipeline processing was enhanced,
(3) Detection along edges and a number of other image processing capabilities have been added, and
(4) The new camera accommodates SuperH SH-4 microprocessors.

Multi-application Approach

Images contain various kinds of information, so people are already beginning to anticipate a range of other potential recognition applications using image processing cameras. But so far, the only applications that have seen practical implementation are lane departure warning and LKS based on lane recognition technology. Some of the camera-based systems that are widely anticipated are ACC using vehicle detection technology, pre-crash brake systems, and vehicle approaching from the rear distance warning systems. Considering that all of these safety-related systems demand a very high degree of recognition reliability in the adverse weather conditions suggests that practical versions of these systems are still some ways off in the future.

Hitachi Group is addressing this issue from a different angle by developing the multi-application all-in-one scheme illustrated in Fig. 5 that uses a single image processing camera to support a number of different applications besides lane recognition, including support for an auto-dimmer, auto-lights, auto-windshield wipers, and auto-defroster. The idea is to automate these distracting tasks that can take the driver's mind off the road, and thus contribute to a safer, more enjoyable driving experience. Let us briefly describe these auto application functions:

(1) Auto-dimmer

Detects the tail-lights of the vehicle ahead or the headlights of an approaching vehicle, and automatically dims your vehicle's headlights at the proper distance.

(2) Auto-lights

Measures ambient brightness and automatically turns on tail lights and headlights as it gets darker and turns off lights as it gets lighter.

(3) Auto-wiper

Detects rain on the windshield and automatically adjusts wiper speed and interval to match the intensity of the rain.

(4) Auto-defroster

Detects frost on the windshield and automatically adjusts the defroster to match the conditions.

To integrate and implement all these applications at the same time is no trivial task: the hardware must be well configured to include camera lens, filters, auxiliary lighting and other optical systems, while the software requires fine-tuning of each algorithm and careful task scheduling optimization. Hitachi assembled in November 2003 a demonstration vehicle showing how these various applications could be implemented using a single camera.

This all-in-one approach not only greatly increases the value of image processing cameras, it also effectively eliminates the need for raindrop sensors and a host of other single-function sensors, and thus has the major benefit of reducing system cost.

CONCLUSIONS

This article gave an overview of environment recognition technologies essential for developing practical in-vehicle safe driving support systems, and highlighted Hitachi Group's priority R&D efforts to develop and deploy millimeter wave radar and image processing camera systems.

We anticipate the convergence of millimeter wave radar and cameras and a growing demand for even more reliable recognition systems that combine their own information with information obtained from other off-vehicle sources such as GPS (global positioning systems), and map databases, and telematics.

Hitachi Group is committed to the realization of a safer society with fewer traffic accidents, and feels this work of integrating various kinds of recognition technologies and developing and deploying more advanced recognition systems makes a valuable contribution toward this goal.

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