Advanced Vehicle Safety Control System

Hiroshi Kuroda, Dr. Eng.
Atsushi Yokoyama
Taisetsu Tanimichi
Yuji Otsuka

OVERVIEW: Hitachi has been working on the development of integrated control systems for advanced vehicle safety since the latter half of the 1990s. Hitachi has already commercialized an ADAS controller incorporating a system that uses an "environmental recognition" stereo camera and data from various sensors for vehicle control. Development of the stereo camera included works on improving accuracy and increasing speed. Development of the ADAS controller, meanwhile, included creating an architecture that facilitated the inclusion a wide range of different functions to suit different vehicle models and markets. Building on these developments, Hitachi is now working on creating safer and more comfortable vehicles through the development of integrated vehicle control technologies designed to achieve 360° collision avoidance, and easy-to-use human-machine interfaces.

INTRODUCTION

ADAPTIVE cruise control (ACC) systems that use vehicle-mounted "environmental recognition" sensors (sensors for detecting objects in the region around the vehicle) to control the distance between preceding vehicles were first commercialized by DaimlerChrysler AG (now Daimler AG) in 1999. The vehicle control system was subsequently enhanced to apply the brake automatically in order to minimize damage in situations where a collision cannot be avoided outright, and a version was released that could prevent low-speed collisions. Another new function assists with the horizontal movement of the vehicle by detecting features such as road lanes.

Systems like these are called advanced safety systems. In addition to sensor technology for detecting objects in the region around the vehicle, they also require the fusion of control techniques for processing information from various other sensors with technology for using actuators to control the vehicle.

This article describes the environmental recognition stereo camera sensor, the advanced driver assistance system (ADAS) controller, and the integrated control system for advanced safety.

STEREO CAMERA

The following sections focus on the stereo camera jointly developed with Fuji Heavy Industries Ltd.

Overview of Stereo Camera

A stereo camera consists of separate left and right cameras. It can be used as an environmental recognition sensor capable of determining the position and three-dimensional shape of an object from the difference between the images of the object captured simultaneously by the two cameras (disparity)[1]. While other forms of environmental recognition sensors include laser radars, millimeter wave radars, and monocular cameras, the inherent strengths of stereo cameras include their ability to detect objects regardless of their composition or shape, and their high spatial resolution of depth and horizontal angle. On the other hand, stereo cameras also present a number of specific technical challenges before they can be adopted as vehicle-mounted sensors, including aiming and calibrating the optical axis, taking account of factors such as deterioration over time, and achieving fast and accurate image matching to determine disparity.

Fuji Heavy Industries, manufacturer of the Subaru brand of vehicles, has been working on the research and development of stereo cameras for many years. Hitachi Automotive Systems, Ltd. has been collaborating with the company on joint development since 2004, and through this work has overcome the problems mentioned above. The resulting stereo camera has been installed in numerous different models since first appearing on the Subaru Legacy in May 2008[1].

Design of Stereo Camera

The stereo camera consists of the left and right cameras and a main processing unit that handles image signal processing (see Fig.1).

The images from the left and right cameras are input to an image processing application-specific

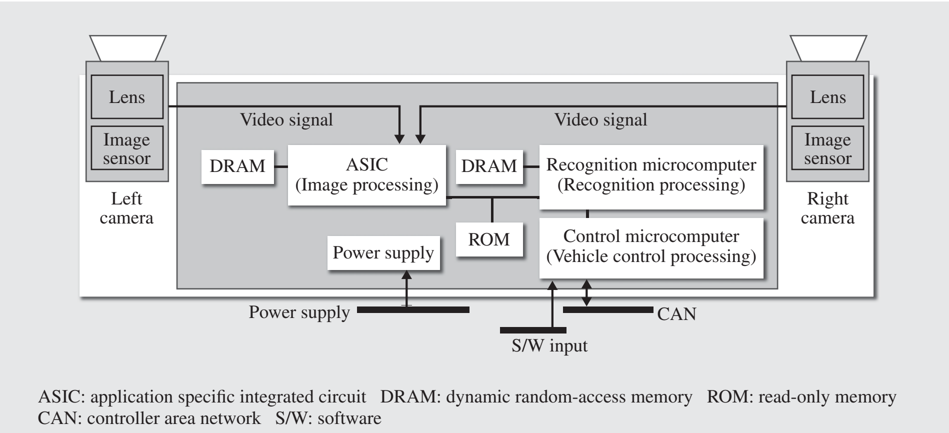


Fig. 1—Block Diagram of Stereo Camera.
This stereo camera jointly developed with Fuji Heavy Industries, Ltd. uses an ASIC to increase the speed of the disparity and other computationally intensive calculations.

integrated circuit (ASIC). The ASIC corrects distortion and peripheral darkening (lower light intensity around the edge of the lens) and then matches the two images to generate the disparity image. Here, a disparity image means one in which the disparity has been emphasized so that the distance can be determined for each pixel. The disparity image and other information required for recognition is stored in dynamic random-access memory (DRAM) by the recognition microcomputer. The recognition microcomputer then uses this information to detect obstacles such as other vehicles and pedestrians, identify white lines, and so on. The control microcomputer outputs control commands based on the recognition information, such as a command to issue a warning or apply the brakes.

Fig. 2—ADAS ECU Hardware.
The vehicle is controlled by a dedicated ECU designed for use with ADASs.

Future Development

While the stereo camera needs to be made smaller and lighter if it is to be adopted on a wider range of vehicle models, this raises problems such as a reduced range of object recognition if making the unit smaller results in a shorter baseline length (distance between left and the right cameras).

With the aim of producing small stereo cameras, Hitachi is working on the development of new image processing techniques that can reliably detect preceding vehicles in far distance.

ADAS CONTROLLER

The next section describes the design concepts and technologies used in an ADAS controller supplied to Nissan Motor Co., Ltd.

Overview of ADAS Controller

The ADAS controller is a dedicated electronic control unit (ECU) designed for implementing advanced safety control applications, something that has become an increasingly frequent feature of vehicles in recent years (see Fig. 2).

The first such applications, used for ACC, appeared around 1999. These were followed by the introduction of pre-crash safety systems, with a further series of new systems emerging around 2005, including lane departure prevention (LDP), lane departure warning (LDW), lane keep assist (LKS), forward collision warning (FCW), traffic sign recognition (TSR), intelligent head lamp control (IHC), and curve overshoot prevention (COP). Initially, each of these systems was implemented on a different ECU, as shown in Table 1.

While these systems use the same software functions regardless of vehicle model or market, the controllers on which they run are often different, depending on factors such as model, market, and date of commencing production. Changing to a different controller means the software functions needs to be ported, and this results in increased cost in terms of both

Table 1. ECUs Used for Different Systems
Different systems for advanced safety control have run on different ECUs.

System	ECU
ACC, FCW Pre-crash safety system	Radar
LDP, LDW, LKS, TSR, and IHC	Monocular camera
COP	ESC

ECU: electronic control unit ACC: adaptive cruise control
FCW: forward collision warning LDP: lane departure prevention
LDW: lane departure warning LKS: lane keeping system
TSR: traffic sign recognition IHC: intelligent head lamp control
COP: curve overshoot prevention ESC: electric stability control

time and money because the software functions must be retested on the new ECU even if no changes were made during this porting process. The aims in developing the ADAS controller included minimizing this problem and providing more flexibility in the choice of sensors and actuators, so that system cost would be reduced.

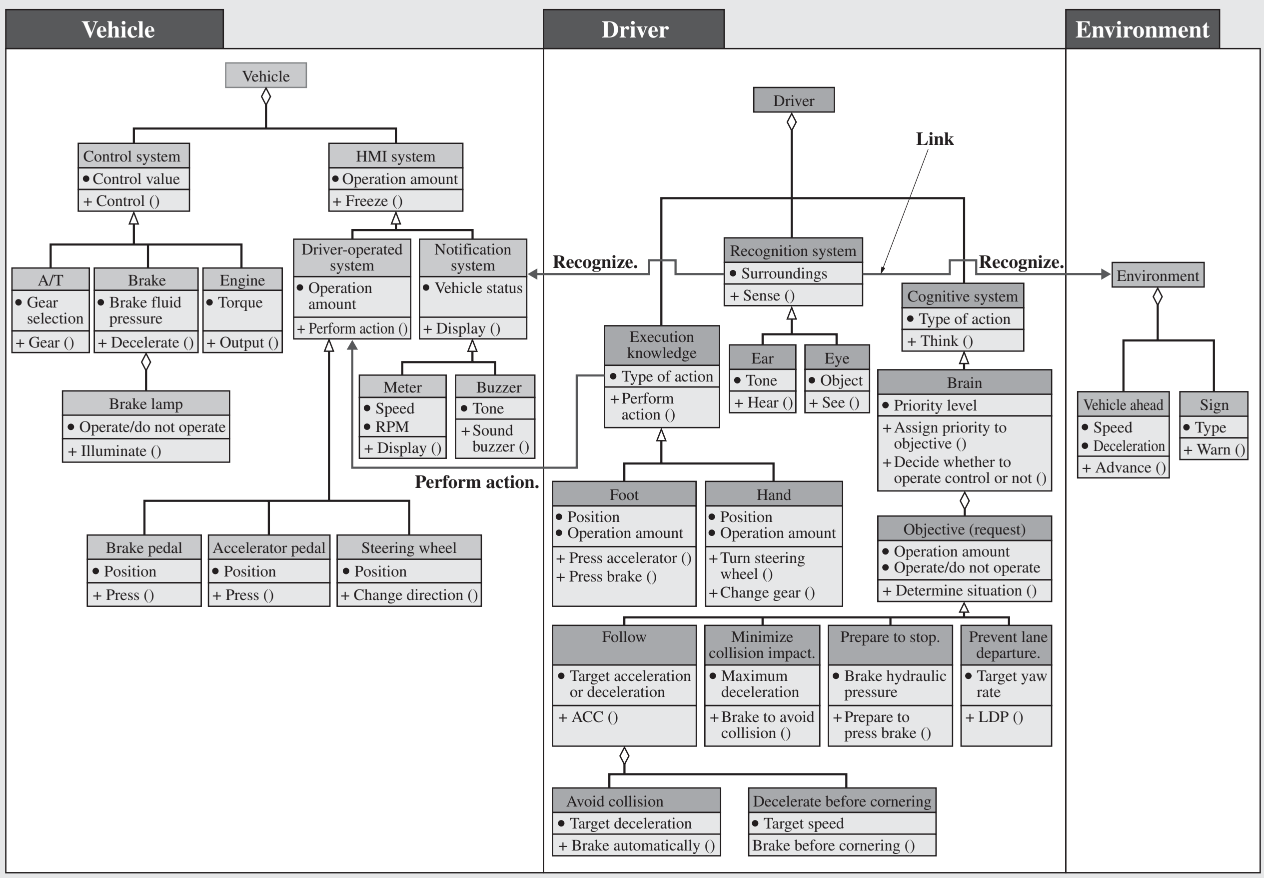
Development of ADAS Controller

The application software used on the ADAS controller has often been developed at different times and with different sensors, actuators, and other external devices in mind. This has resulted in complex interdependencies between different software systems, and with the sensors and actuators.

To deal with this, Hitachi undertook an analysis to determine which functions to include in the ADAS controller (see Fig. 3). To clarify the relative priority of each function and identify which functions were universal, the analysis used a class diagram to collate the functions that govern the movement of the vehicle, including those of the vehicle and driver.

The analysis succeeded in classifying functions into four categories. These are the sensor interface that encapsulates the functions dependent on sensors, the system section that provides the application's control functions, the arbitration section that handles the interdependencies between systems, and the output interface that provides the functions dependent on actuators.

Based on these results, the application software was structured along functional lines and re-implemented on the ADAS controller (see Fig. 4). This new structure



HMI: human machine interface A/T: automatic transmission RPM: revolution per minute

Fig. 3—Analysis of ADAS Systems.
The class diagram collates the functions that govern the movement of the vehicle, including those of the vehicle and driver.

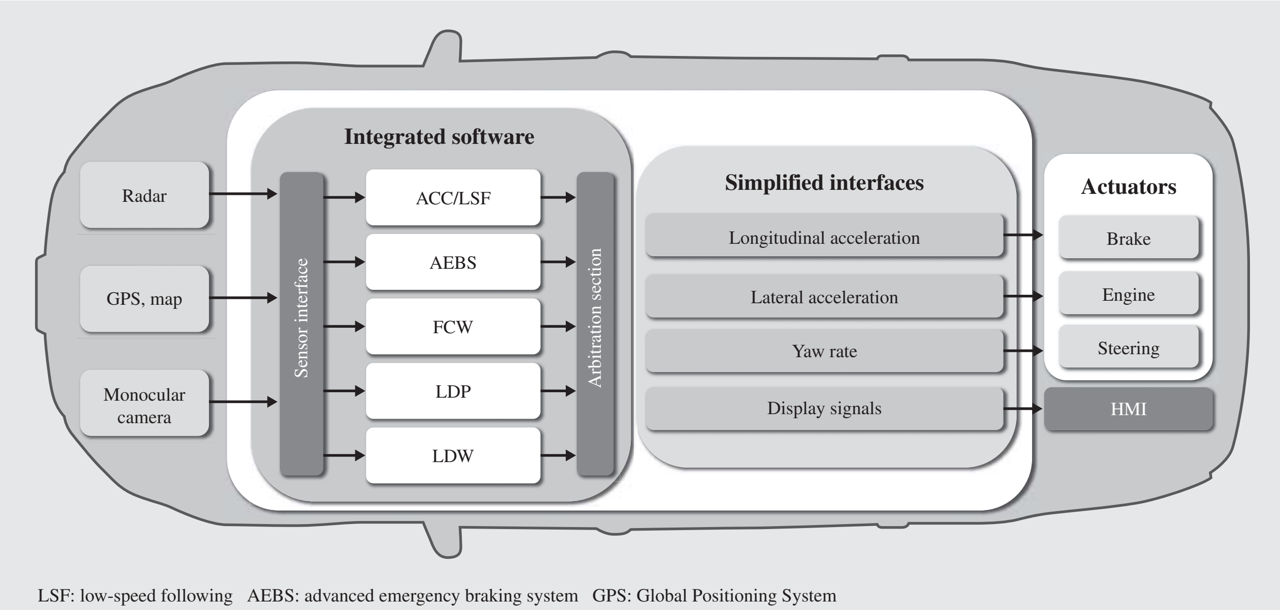


Fig. 4—Block Diagram of ADAS Controller.
The ADAS ECU is a general-purpose ECU used to consolidate software distributed around the vehicle into a single ECU.

minimized the dependencies between each part of the software and simplified the job of combining different systems and a variety of different sensors and actuators.

Future Development of ADAS Controller

It is anticipated that the ADAS controller will be further developed to become the "brain" of the vehicle in place of the driver, ultimately becoming a controller for autonomous vehicles. To this end, Hitachi is working on development that will be required in the future. These are (1) support for faster communication networks to allow the real-time acquisition of large amounts of information from around the vehicle, (2) more extensive functions for connecting to infrastructural communication systems to acquire information about areas not visible from the vehicle, and (3) incorporation of a real-time database able to select, in real-time, necessary information acquired by (1) and (2).

INTEGRATED CONTROL OF ADVANCED SAFETY

The integrated control system for advanced safety assists the driver by combining environmental recognition sensors, controllers, and actuators to partially replace the human functions of recognizing, deciding, and operating. Hitachi is working on expanding the functions of advanced safety systems, with a central role for its stereo cameras and ADAS controller.

Most advanced safety systems that have been developed to date are based on the combination of a forward-looking sensor, such as a stereo camera, with the engine, brake, and steering subsystems. In the future, however, the systems will require the integration of omnidirectional sensing systems such as radar or monitor cameras with a wide range of actuators, including inverters, electric motors, and suspensions.

One technique being pursued by Hitachi for expanding the range of sensing is the inclusion of an obstacle detection function in monitor cameras. Hitachi has already commercialized a function for detecting nearby obstacles that applies a recognition function to images from a rear-view camera or a bird's-eye-view (overview) image, and has implemented systems that issue a warning upon detecting a situation such as lane departure or a vehicle approaching from behind[2] (see Fig. 5).

In addition to expanding the sensing range of vehicle-mounted sensors, Hitachi is also developing car-to-X (C2X) systems for car-to-car or car-to-infrastructure communications. C2X technology can be used to develop safer driver assistance systems by providing drivers with information that was previously unavailable, such as the location of nearby cars at an intersection with poor visibility.

Development is also proceeding on G-Vectoring control, an advanced technology for enhancing vehicle driving performance. This control technique

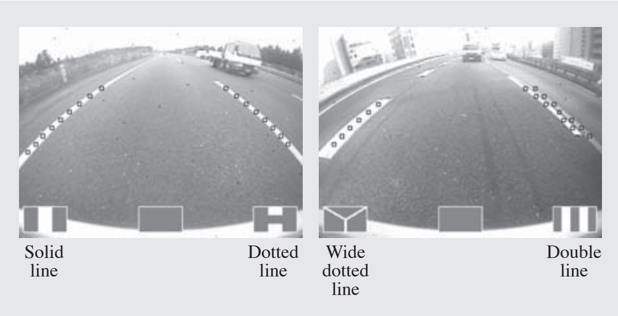


Fig. 5—Example of Road Marking Detection Using Rear Camera.
The system not only detects road marking but also determines their type.

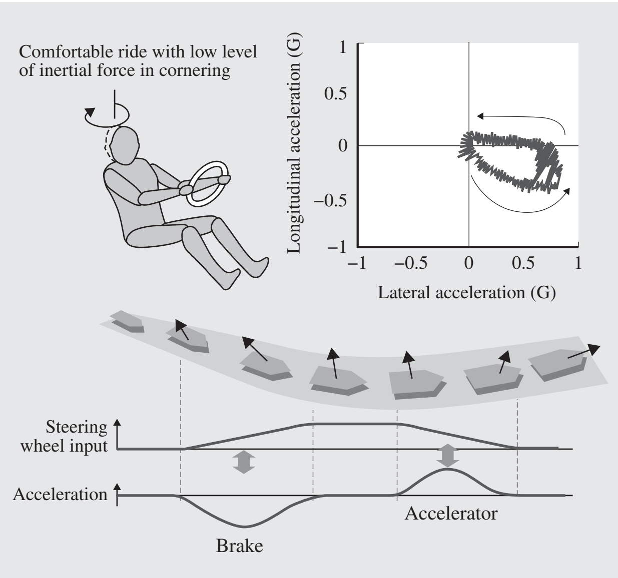


Fig. 6—G-Vectoring Control.
G-Vectoring provides smooth cornering by controlling the change in vehicle acceleration such that it traces a circular path.

achieves smooth and stable cornering by automatically decelerating through the corner in accordance with the driver's steering input[3] (see Fig. 6). There are also moves toward developing this into Preview G-Vectoring control whereby information about corners is obtained from map data and used to brake automatically before entering the corner[4].

Autonomous driving systems are progressive type of advanced safety system likely to be commercialized in the future. Whereas technologies such as ACC and LKS can be considered to be types of autonomous driving systems, manual and autonomous driving will continue to coexist until driving is completely automated from the time a passenger gets into the car until the time they get out. Because the human driver remains in charge of driving during this intermediate phase in the shift to autonomous driving, it is

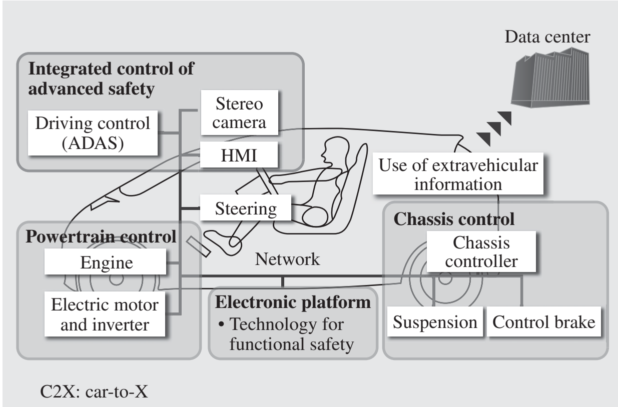


Fig. 7—Integrated Control System for Advanced Safety that Combines C2X and HMI.
A high level of performance in terms of safety, comfort, and the environment is achieved by integrating control of C2X with the HMI.

important that the system maintains an understanding of the driver's circumstances and presents appropriate information. Based on human-machine interface (HMI) technology that it has applied in fields like navigation systems and monitor cameras, Hitachi has proposed advances in HMIs for use in autonomous driving and is working on the implementation of comprehensive integrated control systems for advanced safety (see Fig. 7).

CONCLUSIONS

Autonomous driving will require environmental sensors able to cover the full 360° region around the vehicle along with the development of technologies that can process information and control vehicles safely while also using communications to handle the exchange of remote information not directly visible from the vehicle. The development of these technologies will need to include an understanding of the human functions of recognizing, deciding, and operating on the basis that the driver remains the one responsible for the driving.

REFERENCES

(1) S. Katahira et al., "Development of Hardware for a Driving Assistant System Using Stereo Image Recognition," The 14th Symposium on Sensing via Image Information, No. IN2-15 (Jun. 2008) in Japanese.

(2) M. Takemura et al., "Improvements to Durability of Lane Departure Warning System Using Rear-mounted Fish-eye Cameras," ViEW2012 Practical Workshop on Vision Technology, IS1-B5 (Dec. 2012) in Japanese.

(3) M. Yamakado et al., "Proposal of the Longitudinal Driver Model in Coordination with Vehicle Lateral Motion Based upon Jerk Information," Transactions of the Society of Automotive Engineers of Japan, Vol. 39, No. 3, pp.53–58 (May 2008) in Japanese.

(4) J. Takahashi et al., "A Study of Acceleration/Deceleration Model Based on the Time Variation of Road Curvature Ahead," Transactions of the Society of Automotive Engineers of Japan, Vol. 43, No. 1, pp.7–14 (Jan. 2012) in Japanese.

ABOUT THE AUTHORS

Hiroshi Kuroda, Dr. Eng.

Advanced Development Center, Hitachi Automotive Systems, Ltd. He is currently engaged in the development of the advanced vehicle safety control system. Dr. Kuroda is a member of The Institute of Electronics, Information and Communication Engineers (IEICE) and the Society of Automotive Engineers of Japan (JSAE).

Atsushi Yokoyama

Department of Green Mobility Research, Information and Control Systems Research Center, Hitachi Research Laboratory, Hitachi, Ltd. He is currently engaged in the development of a chassis control system. Mr. Yokoyama is a member of the JSAE.

Taisetsu Tanimichi

Advanced Development Center, Hitachi Automotive Systems, Ltd. He is currently engaged in the development of the advanced driving assistant system. Mr. Tanimichi is a member of the Information Processing Society of Japan (IPSJ) and the Society of Instrument and Control Engineers (SICE).

Yuji Otsuka

Advanced Development Center, Hitachi Automotive Systems, Ltd. He is currently engaged in the development of image processing software for stereo cameras. Mr. Otsuka is a member of the IEICE and JSAE.