Vehicle Control and Information Systems for Safe Driving

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OVERVIEW: Recently, there has been an increase in the practical application of ACC (adaptive cruise control) systems, which measure the following distance to the preceding vehicle by radar and automatically maintain an appropriate following distance, and lane keeping systems, which recognize lanes using vision sensors and keep the vehicle from deviating from the lane. Current systems are based on the premise of highway driving, but in the future, we can expect that these systems will come to be used on regular roads as well, in pursuit of even greater safety and comfort. Achieving this goal will require advancements in various related fields, including: (1) technologies for accurately recognizing the environment surrounding the vehicle; (2) technologies for controlling the vehicle's speed by controlling engine, transmission, and brake operations; and (3) technologies for controlling vehicle dynamics. In "vehicle dynamics control," driving dynamics information is passed between various components via an on-board network. Services are gradually being developed to analyze and utilize this driving dynamics information based on ITs (see Fig. 1). Hitachi, Ltd. is developing three types of sensor technologies for recognizing the conditions around the vehicle: millimeter wave radar, vision sensors, and sensor fusion. The company is also developing technologies for controlling the vehicle's movements, as well as driving recorder technologies for analyzing vehicle dynamics control information (physical values recorded in the driving recorder that express the vehicle's behavior) and diagnosing driving conditions and drivers' characteristics, and services that apply these technologies.

INTRODUCTION

IN the automotive field, universities, automobile manufacturers, and others have been conducting research and development in ASV (advanced safety vehicle) and AHS (advanced cruise-assist highway systems), which establish links between vehicles and roads[1, 2]. The aim of these systems is to improve driving safety and comfort through the use of information communications and control technologies.

Autonomous driving is the ultimate form of vehicle

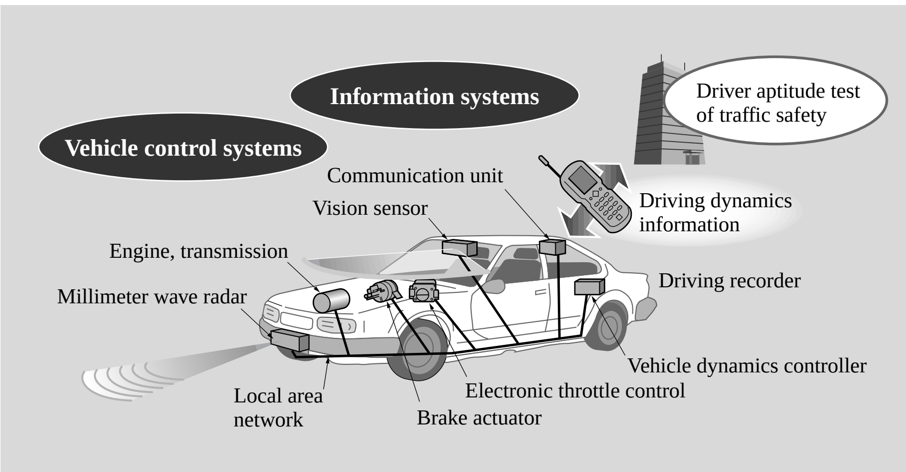

Fig. 1—Vehicle Control Systems and Information Systems.
Systems that use information communication and control technologies to improve driving safety and comfort have gradually moved into the practical application stage. Based on these types of information, services for analyzing driving characteristics and road environment characteristics suting IT are also becoming available.

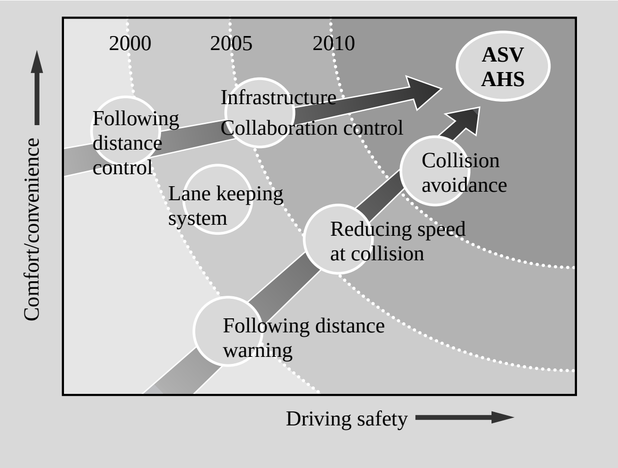

Fig. 2—Development of Vehicle Dynamics Control Systems.
Vehicle dynamics control systems are expected to evolve as a result of developments in vehicle dynamics control technologies, actuators, and sensors for recognizing the vehicle's surrounding environment, as well as links with information systems.

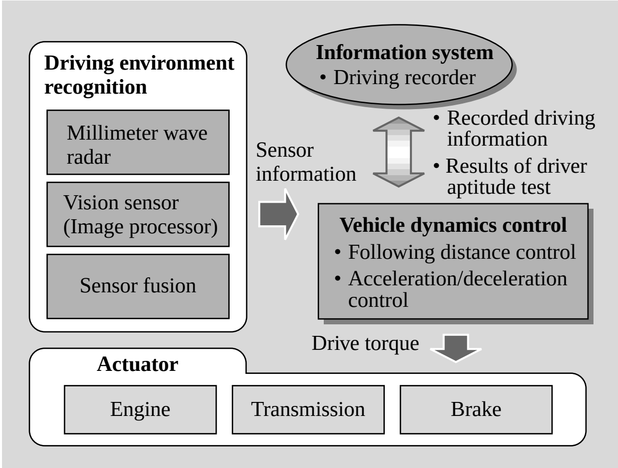

Fig. 3—Configuration of Vehicle Dynamics Control Systems and Information Systems.
Various types of businesses can be developed by linking vehicle dynamics control systems and information systems.

dynamics control system, but there are many issues to be overcome before it will be possible to entirely replace highly intelligent human driving behaviors with computer control, and this can be expected to take some time.

Fig. 2 is a graphic illustration of the development of vehicle dynamics control systems, with driving safety on the x-axis, and comfort/convenience on the y-axis. Up to now, laser radar and millimeter wave radar have already been developed as sensors for measuring following distance; collision warning systems and adaptive cruise control systems using these technologies have already moved into the practical application stage. Lane keeping systems that recognize lanes using vision sensors are also being used in practical applications. In the future, we can expect to see collision avoidance systems, as well as systems that will detect a risk of collision before they occur and reduce speed at collision if the collision itself cannot be avoided. Advanced driving support systems, which offer increased driving comfortability by incorporating external infrastructures, navigation, and forms of information, are also expected to enter the practical application phase. In the very near future, the development of these systems may very well bring about the arrival of an era in which autonomous driving systems that were once the stuff of science fiction stories are well within our reach.

Here, we will discuss vehicle dynamics control and information systems, as well as sensor technologies that are installed in vehicles to recognize the surrounding environment, and service business targeting driver support through the use of vehicle dynamics control technologies and driving dynamics information.

VEHICLE DYNAMICS CONTROL SYSTEMS

Elemental Technologies That Support Vehicle Dynamics Control

Three main technologies will be required to achieve effective vehicle dynamics control:
(1) technologies for recognizing the external driving environment;
(2) vehicle control technology; and
(3) actuator technology.

Furthermore, it will be necessary to construct vehicle dynamics control systems that conform to the individual sensibilities of each driver.

Hitachi Group companies are working to develop these technologies by utilizing technologies in an integrated framework, and through joint development activities with outside manufacturers.

Fig. 3 shows the conceptual configuration required to make vehicle dynamics control systems a reality.

As an environmental recognition sensor, Hitachi has developed a new millimeter wave radar that links its own original microwave semiconductor technology with a signal processing technology created by Eaton VORAD Technologies, L.L.C. of the United States. Hitachi is also developing a vision sensor for automotive applications that makes use of the image recognition technologies and semiconductor technologies that it has cultivated through experience in industrial applications and other fields. Furthermore, the company is working to develop sensor fusion technologies that will enable sensing by combining vision sensors and millimeter wave radar.

For vehicle control, Hitachi is developing vehicle control technologies that control the engine, transmission, and brakes based on the principle of wheel torque management. By using wheel torque management, the company succeeded in achieving vehicle acceleration and deceleration as required, with a lesser dependency on vehicle type compliance. Adaptive cruise control systems using this vehicle control technology have already been released to the commercial market.

Regarding the actuator, Hitachi has completed development of an electronically controllable brake booster, and, in terms of future technologies, is currently developing an electric mechanical brake that satisfies high-level environmental and safety requirements.

Vehicle Dynamics Control and Information Systems

In this way, various types of driving information are gathered together within the vehicle dynamics control segment, which centrally manages the vehicle's behavior. This driving information is analyzed using ITs, making it possible to introduce new services by developing technologies for predicting driving situations and executing vehicle control in keeping with the driver's preferences.

ON-BOARD ENVIRONMENTAL RECOGNITION SENSORS

Environmental recognition sensors designed to correctly recognize the driving lane, obstacles around the vehicle, and the preceding vehicle that the driver is trying to follow are essential to the development of vehicle dynamics control systems. Here, we will discuss the millimeter wave radar and vision sensor that Hitachi is currently focusing its energies on developing and marketing, as well as sensor fusion, which combines these two elements.

Millimeter Wave Radar

Features

Millimeter wave radar measures distance, speed, and azimuth in reference to a target object, by emitting 76-GHz band radio waves (millimeter waves), which have been allocated for automobile radar applications

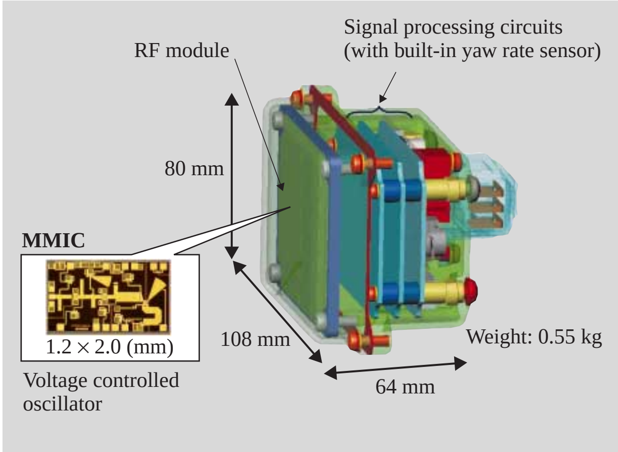

Fig. 4—Internal View of Millimeter Wave Radar and MMIC.
Hitachi achieved greater compactness and lighter weight through the use of a newly developed MMIC.

in Japan, the U.S., and Europe, and applying signal processing to the reflected waves that are received.

Hitachi has developed a compact radar that transmits and receives millimeter waves and calculates the distance and azimuth in a single unit[3]. Fig. 4 shows the internal construction of this radar as well as the MMIC (microwave monolithic IC).

The radar is comprised of an RF (radio frequency) module for transmitting and receiving millimeter waves and a signal processing circuits for handling the beat signals in the IF (intermediate frequency) band. The signal processing circuits detect the peak signal of targets using FFT (fast Fourier transform) processing, and then define the target using various types of filter processing. The radar also selects targets in the host lane by combining vehicle speed signals with signals from the yaw rate sensor built into the unit.

The dual frequency continuous wave method, which has been adopted for modulation, utilizes time-division switching between two frequencies in a narrow band region (approximately 300 kHz) centered around 76.5 GHz. This enables close-range detection from a distance of one meter, and allows applications in ACC as well as stop and go systems. This system also features increased robustness against interference with other millimeter wave radars. For angle detection, in order to increase reliability during on-board operations, Hitachi adopted a monopulse method that does not require a scanning mechanism. This method uses a stereovision perspective based on two receiving antennas to measure the target azimuth. A unique feature of the monopulse method is that the antenna size decreases as the detection angle increases, thus enabling simultaneous detection of multiple targets across a broad angle range.

The MMIC module employs a single cavity structure for low cost manufacturing to house a dielectric interconnecting sheet and four MMIC chips consisting of a 76-GHz VCO (voltage controlled oscillator), a power amplifier, and two receivers. It also incorporates numerous new technologies — including a hermetically sealed MMIC construction, a resonator to reduce phase noise in the signal generator, and a filtering lid to prevent internal interference — which serve to increase both performance and reliability[4].

With the development of these technologies, Hitachi has achieved radar performance with a horizontal azimuth detection range of 16° and a maximum detection distance of over 120 m.

Future developments

Plans call for the recently developed millimeter wave radar to first be commercially released as a following distance warning sensor for trucks being driven in Japan by professional drivers, and later to be installed in trucks operating overseas, as well as passenger vehicles in Japan. Hitachi also plans to expand applications to include wide beam short-range radar for rear and side detection[5].

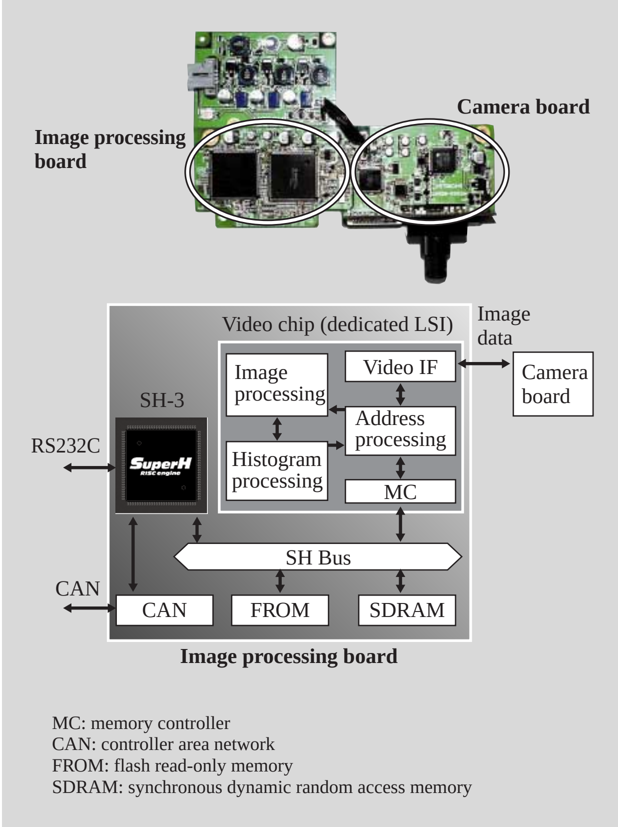

Fig. 5—External View and Block Diagram of Vision Sensor.
Both high-speed processing and versatility have been assured through the use of a video chip and SH-3 microcomputer.

Vision Sensor

Features

The vision sensor recognizes the driving lane, the preceding vehicle, and other targets by applying signal processing to the image of the road ahead photographed by the CCD (charge coupled device) or other types of cameras. Hitachi has developed a miniature vision sensor for recognizing the above-mentioned targets, which has been adopted as a lane recognition sensor for the lane keeping system in Nissan Motor Co., Ltd.'s sedan-type vehicle. Fig. 5 shows an external view of this product, along with a block diagram.

The hardware consists of a camera board and an image processing board. The photographed image is converted into a digital format by the camera board, and is then sent to the image processing board. The image processing board is equipped with a dedicated LSI (large-scale integration): video chip for high-speed image processing (60 MHz/pixel) and a 32-bit Hitachi SH series microcomputer for lane recognition and other applications, and achieves both high-speed processing and versatility by sharing functions between these two processors[6].

Expansion into the U.S.

The commercial version of Hitachi's lane recognition vision sensor was designed based on a premise of recognition functions on highways in Japan, which have comparatively clear lane markings, but in order to enable applications in the U.S., which has a high demand for lane departure warning systems, it was necessary for the system to recognize lane markings other than white lines.

Specifically, in California, the U.S., raised pavement markers called "Botts Dots" have been laid on many roads (see Fig. 6). It order to detect the slight difference in level between the road and the Botts Dots, the recognition value extracted as the road edge points must be lowered considerably in comparison to traditional white line processing. This lower value, however, resulted in a larger noise component. To eliminate this noise, Hitachi developed a new lane mark recognition algorithm that calculates the edge

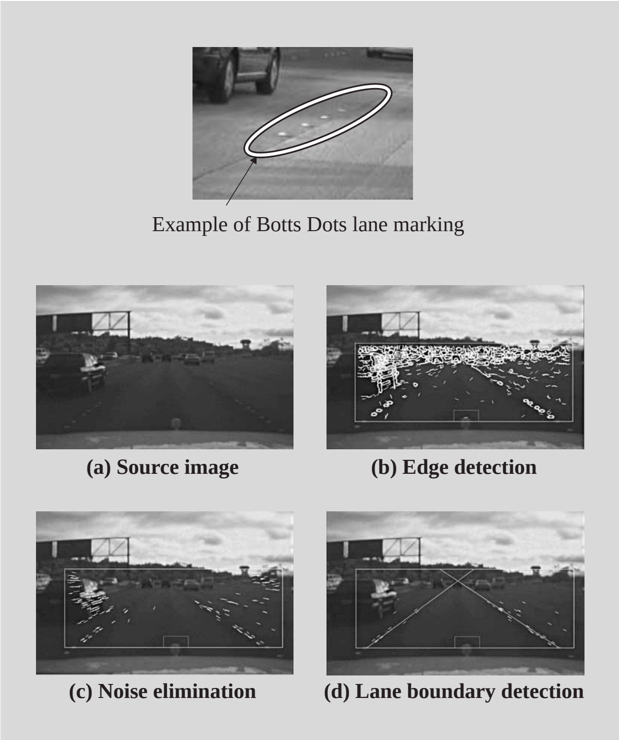

Fig. 6—Recognition of the US's "Botts Dots" Lanes.
Hitachi has developed a new algorithm for recognizing Botts Dots lanes.

point angle in advance, and uses this information for recognition. Figs. 6 (a)–(d) show examples of Botts Dots recognition using this algorithm[7].

Future developments

Regarding the vision sensor, concurrent with the improvements in performance described above, there has been a growing demand for even more compact size and lower cost. To respond to these demands, Hitachi has been promoting further development in a number of related areas, including the selection of a CMOS (complementary metal-oxide semiconductor) image sensor, adoption of a highly reliable single chip microcomputer for automotive use such as engine control, and development of a new image processing LSI. The company is currently developing a vision sensor that offers high reliability while maintaining low cost and a compact size[8].

Sensor Fusion

Sensor fusion technology combines several environmental recognition sensors to achieve high-level recognition. Hitachi has developed a sensor fusion technology that takes advantage of the unique features of the millimeter wave radar and vision sensor — the company's two key sensor types — and to achieve recognition of the preceding vehicle. Millimeter wave radar can correctly measure distance, speed and azimuth in relation to the preceding vehicle even under adverse weather conditions, such as rain or fog. Due to its narrow field of view (20° or less), however, millimeter wave radar has a tendency to be late in detecting cut-in vehicles, and on roads with tight curves, the preceding vehicle sometimes falls outside of the radar's field of view even when it is within the host lane.

The vision sensor, on the other hand, not only detects the preceding vehicle and other objects across a broad field of vision, but can also detect flat targets such as lanes or road shapes. Visions sensors, however, have difficulty in measuring relative speed and distance from the target with a high degree of accuracy.

The newly developed sensor fusion algorithm uses the difference between the two sensors' fields of view — when the preceding vehicle falls within the field of view of the millimeter wave radar, the radar measures the distance and azimuth, and at the same time the pattern of the preceding vehicle as measured by the radar is recognized as the preceding vehicle by the vision sensor. After this, when the preceding vehicle moves outside of the radar's field of vision, the system tracks the preceding vehicle recognized by the vision sensor. In regions where sensing by both radar and vision sensor is possible, even in one of the sensors loses track of the preceding vehicle, the other sensor acts as a backup, enabling improved reliability in recognition (see Fig. 7)[9].

Vehicle dynamics control systems are expected to evolve from current ACC systems designed mainly for convenience into safety-oriented pre-crash systems that reduce collision speed, and then into collision avoidance systems. In keeping with these developments, we can expect to see increasing demands for greater performance and reliability in environmental recognition sensors as well. In the future, it will be necessary to develop sensors that take these system requirements into consideration.

LINKS BETWEEN VEHICLE DYNAMICS CONTROL AND INFORMATION SYSTEMS

By linking the vehicle dynamics control system with information systems, it becomes possible to gather vehicle driving information, and applications of this information in turn enable the development of various types of business. Here, as one example of these applications, we will discuss services that

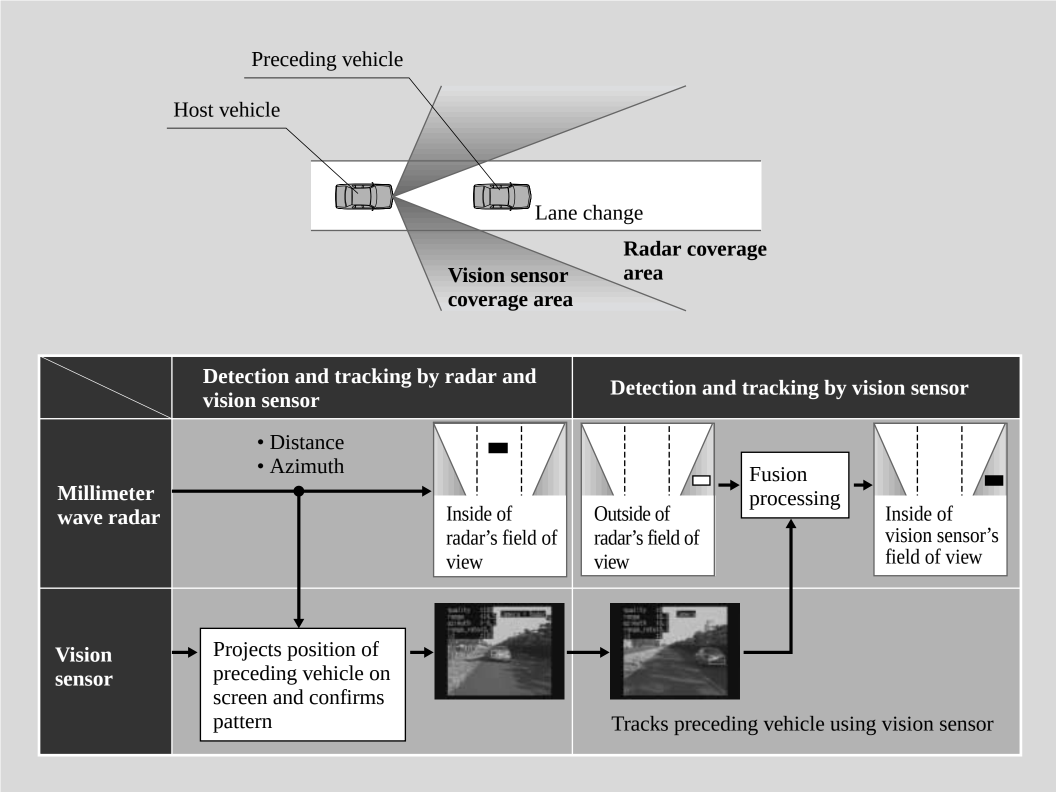

Fig. 7—Sensor Fusion Algorithm. Enables the vehicle to follow the preceding vehicle using a vision sensor even if the preceding vehicle is out of sight.

incorporate the "driving recorder" — a device currently being developed by Hitachi that records values expressing the vehicle's behavior.

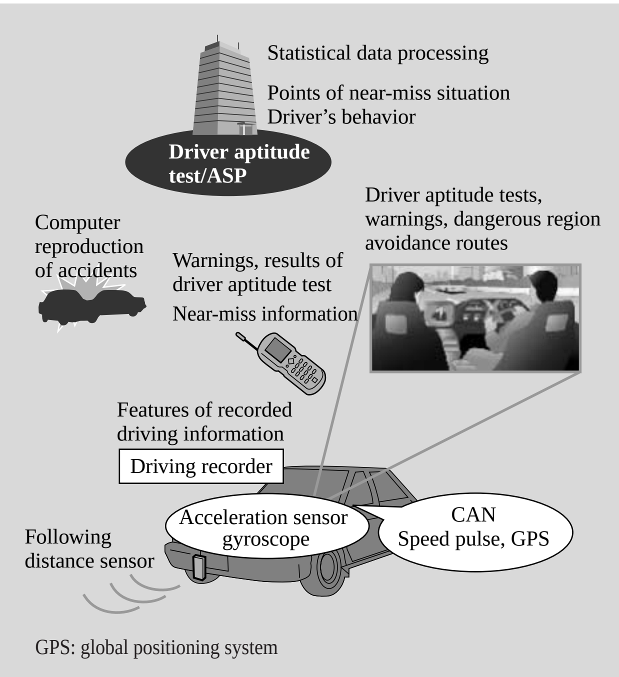

Fig. 8—Driving Recorder.
Enables diagnosis of the driver's driving characteristics and safety in the driving zone through the analysis of driving dynamics information.

Driving Recorders

By linking vehicle dynamics control with the navigation system, the driving recorder is able to incorporate the following types of vehicle information (see Fig. 8).

(1) Following distance from the vehicle ahead, determined using a following distance sensor
(2) Vehicle driving region and absolute vehicle speed, determined using GPS
(3) Tire speed, determined using speed pulse
(4) Acceleration, determined using acceleration sensors
(5) Roll, yaw, and pitch rate speed, determined using a gyroscope

Driving Recorder Analysis Technology

Based on the vehicle information described above, analysis items services can be achieved through the use of ITs (see Table 1). The following is a brief description of each analysis item.

Acceleration skewness* is defined as the 3D moment sum of vertical acceleration. We found that in the case of people who tend to apply the brake too hard (drivers who do not apply the brake until the

*skewness: degree of asymmetry about the distributions average value

TABLE 1. Items for Analysis of Driver Characteristics Using Vehicle Information
Enables analysis in keeping with the goals of each service.

Analysis item (feature)	Sensor information	Descriptions
Acceleration skewness	Vertical acceleration	Characteristics (strength, bias) of brake/accelerator operations
Car following model	Following distance, speed	Fixed following distance vs. fixed following time characteristics
Fractal dimension	Speed	Driving with awareness of fixed speed, or driving in location with many external disturbances?
Extraction of near-miss region	Position, acceleration gyroscope	Locations demanding frequent urgent acceleration/deceleration, urgent steering

following distance is very short), skewness is negative, and that in the case of people who tend to apply the accelerator too hard (drivers who accelerate quickly when starting from a full stop), skewness is positive. Driver behavior can be assessed using this acceleration skewness. That is to say, the closer this value is to zero, the better is the driver's skill.

In terms of car following model types, a judgment is made as to whether the driver tends to drive while maintaining a fixed following distance, or while maintaining a fixed following time (i.e., following distance/speed). This can be determined based on the following distance and speed while driving behind another vehicle. Following distance type is frequently seen among seniors, and is recognized as being susceptible to accidents[10].

The fractal dimension is an index that expresses the complexity of the curve (time series). We have determined the following: In the time series for speed, when the driver is driving without an awareness of his surroundings during free driving (when not following the vehicle ahead), there is a tendency to exhibit Brownian motion. When the driver consciously maintains a fixed speed, the fractal dimension of the time series tends to be lower than that of Brownian motion, and when many disturbances are present (traffic jams, stop and start due to traffic signals, frequent incidents of near miss), the fractal dimension of the time series tends to be higher than that of Brownian motion. For this reason, based on the fractal dimension of the time series, it is possible to determine whether the driver is consciously maintaining a fixed speed, or is driving in a situation with many disturbances.

Finally, we will discuss the extraction of near-miss regions. Urgent acceleration and deceleration points can be assessed by acceleration sensors and GPS, and urgent steering points can be determined using a gyroscope, making it possible to gather a wide range of information on urgent acceleration/deceleration and urgent steering points in a driver safety aptitude test ASP (application service provider). The geographical locations where urgent acceleration/deceleration and urgent steering occur frequently can be tabulated statistically, enabling these locations to be identified as near-miss regions and automatically registered on a map.

Services Using the Driving Recorder

By using these analysis technologies, it is possible to warn drivers of dangerous driving situations, implement driver aptitude tests, or offer services such as route selection for avoiding near-miss regions.

Warnings of dangerous driving situations are provided by sending a message to the driver while driving or after driving is complete. In this case, the dangerous situation refers to cases in which the following distance is too short, or when driving in a near-miss region.

The driver aptitude test enables an assessment of driving characteristics based on acceleration skewness and car following model type. An assessment of the driving conditions can also be made based on the fractal dimension, according to the number of near-miss situations. These assessments can then facilitate services for suggesting safer driving routes.

CONCLUSIONS

Here, we have discussed trends in the development of vehicle dynamics control and information systems, and Hitachi's efforts to respond to these trends, as well as the outlook for the future.

Vehicle dynamics control systems, including lane keeping support systems and adaptive cruise control systems, have recently moved into the practical application stage. These systems can be expected to evolve through integration with information systems and communication infrastructures, in keeping with the development of on-board and off-board communication technologies.

The development of various components — particularly increased performance in environmental recognition sensors — are important in terms of achieving these types of systems. Furthermore, the effective application of information gathered through these sensors can be considered a crucial factor in the popularization and expansion of these systems.

In the future, Hitachi will continue to combine infrastructures and on-board components in an effort to develop services and systems that will improve driving comfort as well as safety.

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