Featured Articles

Fundamental Technologies Driving the Evolution of Autonomous Driving

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OVERVIEW: Autonomous driving will be decisive in preventing traffic accidents and providing for Japan's aging population in road traffic society, and companies are accelerating the pace of their technology development in this area to achieve autonomous driving at least level 3 by 2020 and after. Among those companies, Hitachi is focusing on creating applications and products based on the external sensing technology, recognition and control technologies, and AI technology that will become the platform for the evolution of autonomous driving. This article describes examples of the stereo camera imaging, image recognition technology, millimeter wave radar, trajectory generation technology, and AI technology that Hitachi is applying to autonomous driving, along with the future outlook for these areas.

INTRODUCTION

WITH over 500,000 traffic accidents and over 4,000 traffic fatalities a year occurring in Japan(1), research and development of preventive safety systems that reduce traffic accidents and autonomous driving to replaces the functions of human drivers is becoming very active. The fundamental technologies needed to achieve highly-reliable autonomous driving are external sensing technology (for detecting obstacles around the vehicle in realtime) and recognition and control technologies (enabling smooth vehicle control rivaling human operation), and the addition of artificial intelligence (AI) technology will enable autonomous driving in more complex environments.

This article presents the work being undertaken by Hitachi on these fundamental technologies, which underpin autonomous driving.

WORK ON AUTONOMOUS DRIVING

One example of the work being done on external sensing technology for preventive safety systems is the stereo camera system that Hitachi Automotive Systems, Ltd., released in 2008 that enables automatic emergency braking and front vehicle following operations using only stereo cameras. Another example of external sensing technology development is the technology developed by Clarion Co., Ltd. for detecting moving objects around the vehicle by using four wide-angle-lens cameras to monitor the entire vehicle perimeter. And, an autonomous driving system was also tested on public roads in Ibaraki prefecture in February 2016 as part of the Ibaraki Project for Promoting Verification of Near-future Technologies. The system integrates external sensing technology and recognition and control technologies(2).

EXTERNAL SENSING TECHNOLOGY

This section presents front sensing technology, a type of external sensing technology that monitors the area in front of the vehicle.

Hitachi's sensor configuration concept takes stereo cameras for front sensing as a base, supplemented by long-range millimeter wave radar that can detect vehicles over 150 m ahead. The advantage of stereo cameras is that they interpret the external environment using the same principle as the human eye, so they can detect the shape and appearance of any object. They can also acquire three-dimensional (3D) information and image density information at the same time, giving them high horizontal resolution.

Stereo Cameras

Stereo cameras use two cameras placed on the right and left of the vehicle and have sensors that use the principle of triangulation to measure the distance to an object based on the drift (disparity) between camera images of the same object (see Fig. 1). Using this

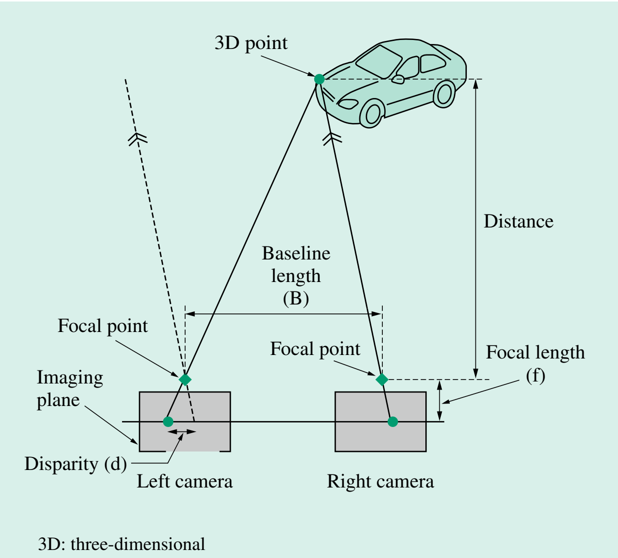

Fig. 1—Stereo Camera Measurement Principles.
The distance to a target object is measured using the disparity (d) of a point captured on the same object by right and left cameras, the distance (baseline length) between the left and right cameras (B), and the camera focal length (f).

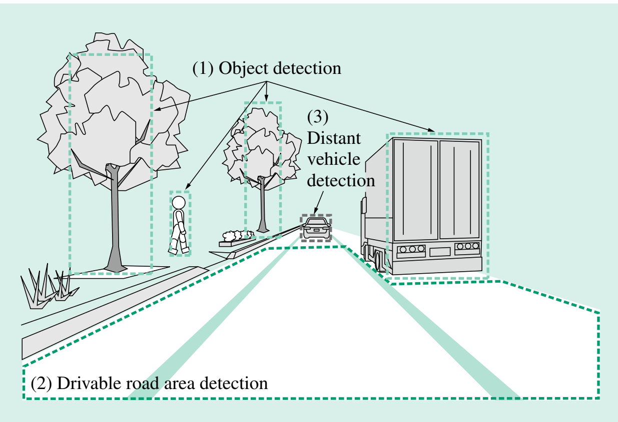

Fig. 2—Interpreting the Environment with Stereo Cameras.
Stereo cameras use information about the distance to the vehicle in front, calculated from the disparity, to interpret the environment by (1) detecting potential objects, (2) detecting the drivable road area, and (3) detecting distant vehicles.

distance information determined from the disparity of distances in front of the vehicle, the system interprets the environment in front of the vehicle by (1) detecting potential objects, (2) detecting the drivable road area, and (3) detecting distant vehicles that are difficult to detect by the disparity alone (described later) (see Fig. 2)[3].

Object detection

Detecting objects consists of two processes: The first is the disparity image (distance image) calculation process. A disparity image is an image that contains information about the disparity (distance to target

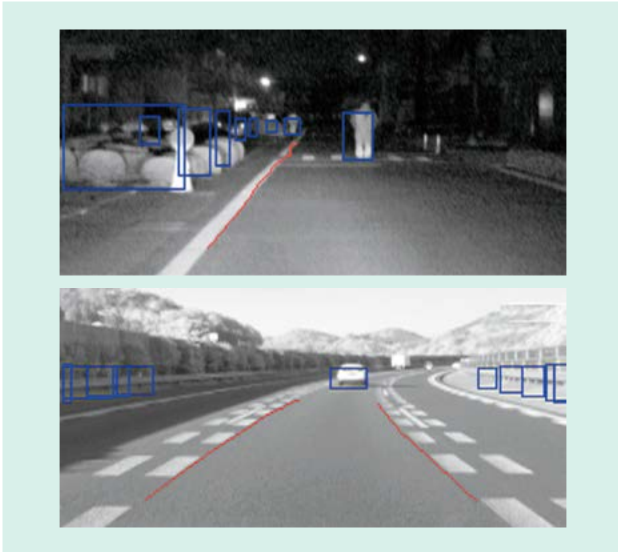

Fig. 3—Object Detection Using Stereo Cameras.
The stereo cameras can detect vehicles, pedestrians, and any other objects. The blue rectangles in the image indicate object detection results, and the red lines indicate the white line detection results.

object) of each pixel in the image. The left or right camera image is used as a reference image, and each point in the reference image is used to calculate and extract the corresponding point of the target objects captured in the other image to calculate the disparity of those target objects. The principle of triangulation can then be used to uniquely calculate the distances to the target objects from the disparity.

The second process performed is to group data about distances that are mutually close relative to the calculated disparity image (distance image). Since distance information can be acquired for the entire regions captured by the right and left cameras, any object can be detected without the need to hypothesize object properties such as shape.

Fig. 3 shows object detection results and white line detection results superimposed on images captured by the stereo cameras. The target objects used for vehicle control are mainly vehicles and pedestrians. Since the system does not depend on object shapes, vehicle control operations such as automatic emergency braking can be performed if the distance or relative speed of any detected object is determined to be dangerous.

Drivable road area detection

Detecting drivable road area is described next.

This function detects the road area the vehicle is physically able to drive on by analyzing information about the disparities (distances to target objects)

Fig. 4—Drivable Road Area Detection on Snow-covered Roads.
The image shows the detection result when the road surface and shoulder are covered by snow. The red lines indicate the detected road edges. The area shaded by the blue lines indicates the detected drivable road area.

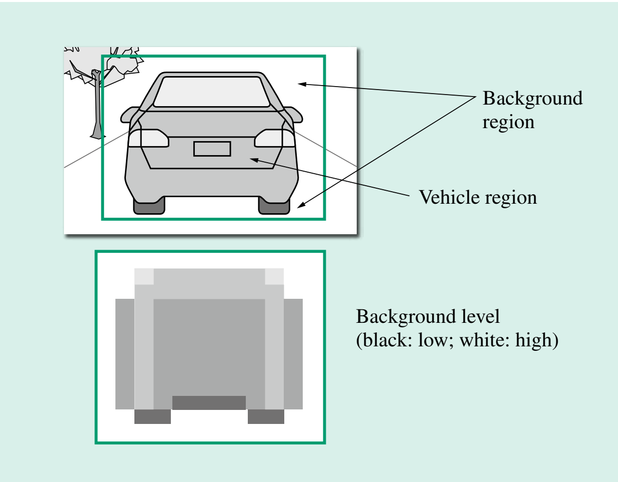

Fig. 5—Distant Vehicle Detection Using Image Density Information.
A distant vehicle is detected by using machine learning to detect the vehicle pattern, and separating the image into a vehicle region and background region.

calculated as described above, and by calculating factors such as the flatness and gradient of the terrain in front[4]. As a result, the drivable road area in front of the vehicle can be detected even if road boundary lines (white lines) have been rendered invisible by snow cover for example (see Fig. 4).

Distant vehicle detection

Since the stereo cameras use the principle of triangulation to calculate distances to target objects, in principle, the precision of their distance measurements for distant objects is reduced when the distance between the two cameras (baseline length) is shortened. Therefore, although the cameras can detect objects further away, longer baseline lengths call for scaling down the equipment housing due to vehicle mounting considerations. To solve this

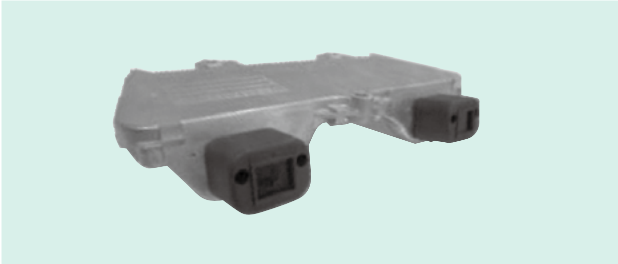

Fig. 6—Compact Stereo Cameras.
Functions such as automatic emergency braking and front vehicle following can be performed even with compact stereo cameras.

problem, a distant vehicle detection process (3) is performed to maintain detection performance for distant objects even for compact stereo cameras with a short baseline length.

This function works by using not only the disparity information, but also image density information. As one example of that, the function uses machine learning to detect vehicle patterns, separating the image into a vehicle region and a background region, and calculates an indicator called the background level. The function uses the mutual feedback between this indicator and the disparity information to improve the distant vehicle detection performance[3] (see Fig. 5).

Together, the object detection, drivable road area detection, and distant vehicle detection processes described above enable both the automatic emergency braking function and the front vehicle following function even when using the compact stereo cameras developed by Hitachi Automotive Systems, Ltd. (see Fig. 6).

Millimeter Wave Radar

Although millimeter wave radar has lower resolution than optical sensors, it features a long detection distance and little performance degradation even when the vehicle's surrounding environment is poor due to conditions such as backlight, low light, rain, and fog. There are two main types of millimeter wave radar that are used for vehicle environment sensing, each with different detection areas. One type is short-range radar, which detects obstacles within a short range (tens of meters away) over a 360-degree circumference around the vehicle. It is used for applications such as detecting passing vehicles during lane changes. The other type is long-range radar, which can detect obstacles at least 200 m in front of the vehicle. It is used for applications such as controlling the distance between vehicles. The rest of this section discusses long-range radar.

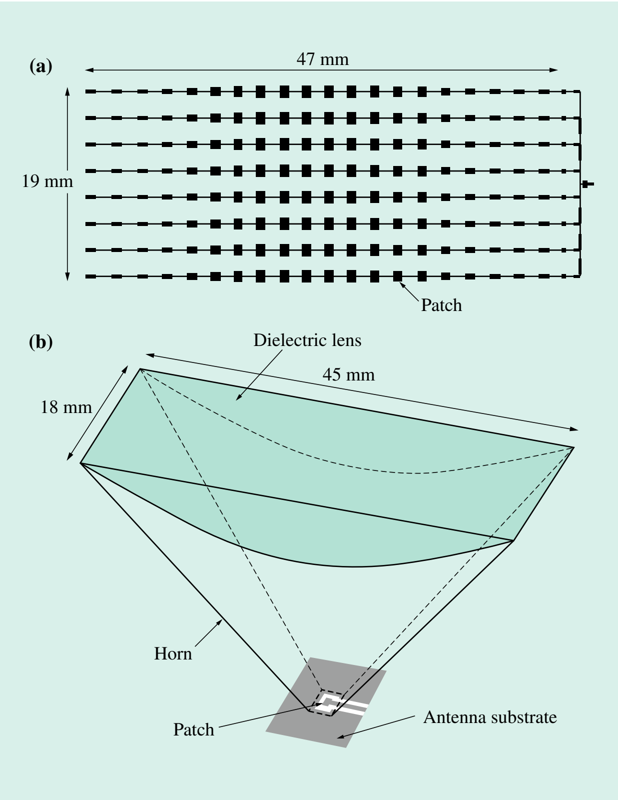

Fig. 7—Conventional Antenna Shape and the Structure of Developed Antenna.
(a) shows the conventional antenna shape, and (b) shows the structure of the developed antenna, respectively.

Long-range radar uses a high frequency (77 GHz) that is not used for anything other than radar, so the parts used in the antennas that affect the radar detection range are specialized and highly expensive. Reducing the cost of antennas while still maintaining high performance is therefore a challenge for long-range radar products.

To meet this challenge, Hitachi has focused on reducing the size of the antenna substrate that determines the antenna parts costs. Fig. 7 (a) shows the shape of a conventional antenna (series-fed antenna). Multiple conductor patterns (patches) that resonate at the desired frequency are formed on the surface of a dielectric substrate, and the substrate is irradiated with electromagnetic waves in the direction perpendicular to the substrate. For example, if the beam half-width is 5 degrees in the vertical direction and 10 degrees in the horizontal direction at 77 GHz, the antenna size is about 19 × 47 mm.

Fig. 7 (b) shows the structure of the antenna developed by Hitachi. While conventional antennas have multiple parallel rows of patches to improve the antenna gain, Hitachi used the horn and dielectric lens to condense the electromagnetic waves emitted from the patches to improve the antenna gain. By using this structure, only one patch needs to be formed on the antenna substrate, enabling a significant reduction in antenna substrate size. The horn can also be formed as a single unit together with the radar housing, and the dielectric lens as a single unit together with the radar enclosure (known as the radome), minimizing the cost increase from adding the horn and lens.

When a prototype of the developed antenna was evaluated in comparison with a conventional antenna, its measured antenna efficiency was 1.6 times higher than the conventional antenna's. Since antenna efficiency is proportional to antenna gain divided by antenna aperture area, it should be possible to increase radar performance while scaling down the antenna substrate size.

RECOGNITION AND CONTROL TECHNOLOGIES

Hitachi is also working on pilot research on technologies that will help autonomous driving expand from parking lots and highways, to become possible on local roads as well. It has developed a basic technology that prevents collisions at safe and practical speeds, and has verified its effectiveness in experimental vehicles. The technology works by measuring changes in the behaviors of pedestrians and other obstacles, and generating optimum speed patterns in realtime. In the future, it will accelerate technology development through repeated testing, which will help make autonomous driving a practical reality.

The challenge of achieving autonomous driving on local roads will be more complex than that on highways, since moving objects and various obstacles such as passing vehicles and pedestrians need to be recognized and their behaviors need to be predicted and evaluated while ensuring driving operations are safe and aligned with the surrounding traffic flow. Automating the high-level recognition, evaluation, operation and other driving processes performed by humans requires the ability to recognize moving objects and obstacles, predict changes in their behaviors, plan collision-preventing driving patterns based on the predictions, and travel at safe and practical speeds.

To create a basic technology for overcoming these challenges, Hitachi has developed a speed control technology based on behavioral change prediction, and its effectiveness has been verified in experimental vehicles. Its features are described below.

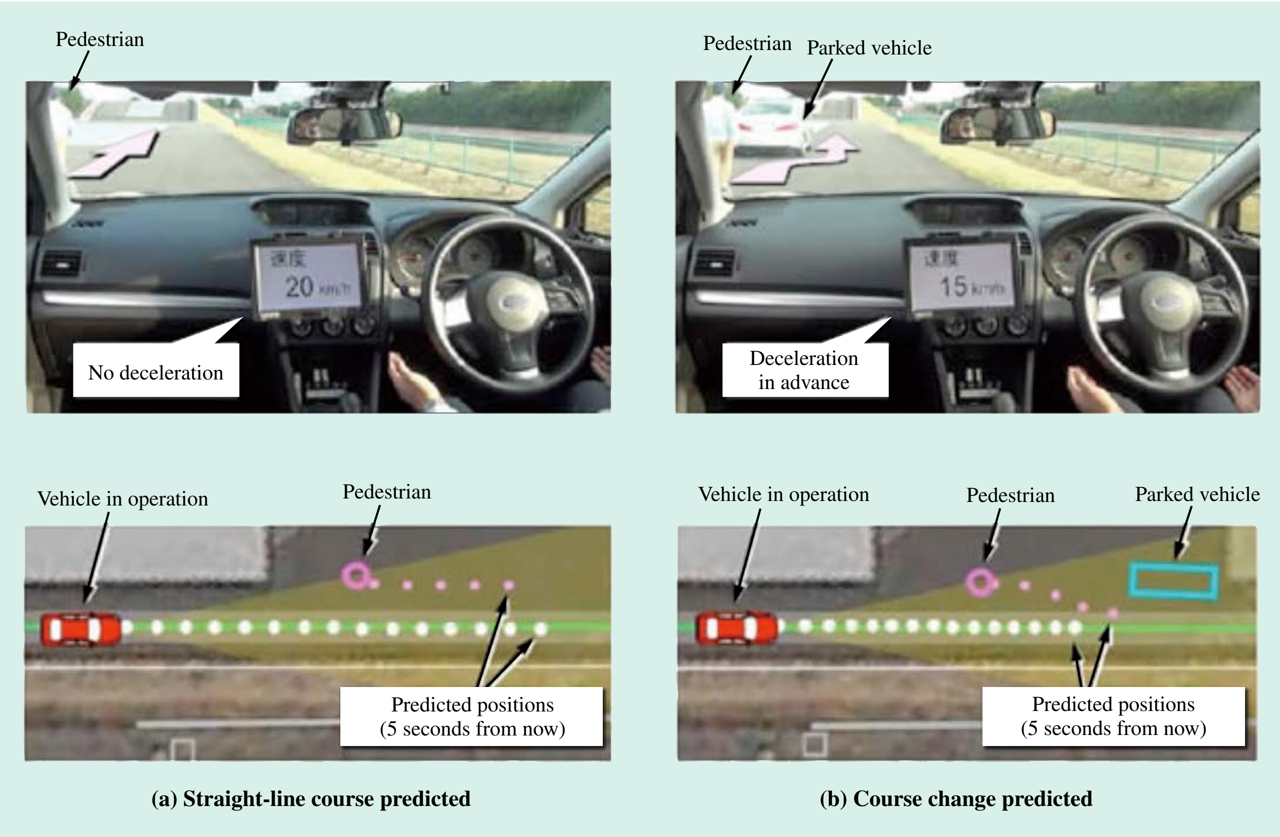

Fig. 8—Control Based on Predicting Pedestrian Behavior.
The system predicts a pedestrian course change, and decelerates in advance, before passing (top: experimental vehicle; bottom: predictive control information).

The basic technology Hitachi has developed prevents collisions with the vehicle by focusing on the potential method (a method used for planning robot movement paths) to predict the future behavior of a moving object from the positional relationship between the moving object and an obstacle. Specifically, the technology creates a model of the behavioral change of a pedestrian who avoids an obstacle such as a parked vehicle and changes course to a space of low risk potential. If the technology predicts a collision between the vehicle and the pedestrian, it can smoothly decelerate the vehicle using the optimum speed pattern that minimizes the change in acceleration. If safety can be maintained, the technology can maintain a practical speed without decelerating.

To verify the effectiveness of the developed technology, it has been tested using experimental vehicles (see Fig. 8). Control based on technology for predicting pedestrian behavior has achieved a practical pedestrian passing speed, along with acceleration (2.2 m/s^2 max.) and change in acceleration (2.0 m/s^3 max.) values conforming to good standards of ride comfort.

REFINING AUTONOMOUS DRIVING UTILIZING AI

Achieving autonomous driving level 3 requires vehicles that can be driven autonomously in complex driving environments, and perform operations such as merging onto trafficked highways, and making turns at local intersections traversed by other vehicles and pedestrians.

In recent years, the development of vehicle control systems has become increasingly model-driven. In model-driven development, experts build control models that are tested repeatedly using simulations, and then evaluated in actual vehicles. Building and evaluating control models take a very long time since complex driving environments involve a variety of interrelated factors. For example, the behavior of the vehicle in front needs to be considered when merging quickly onto a highway, and factors such as vehicle speed, vehicle interval, and remaining passing lane distance need to be considered when driving in traffic.

Hitachi is working on applying its proprietary artificial intelligence technology known as Hitachi AI

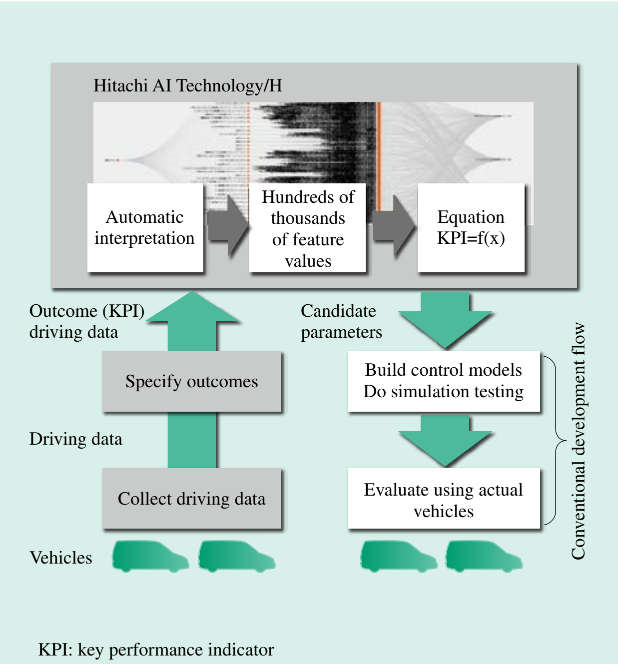

Fig. 9—Flow of Building Control Model Using Hitachi AI Technology/H.
This technology generates feature values by comprehensively combining driving data, and derives their relationships to outcomes (KPIs) as an equation.

Technology/H (hereafter referred to as H) to building control models. H is an AI that searches large volumes of complex data to automatically derive elements that have strong correlations to particular outcomes (key performance indicators, KPIs). H can be used with actual driving data to automatically extract control model candidate parameters, enabling control models to be built in a short period of time (see Fig. 9). For example, H can be used to achieve a control process in which the vehicle gains speed at a constant (low-variation) acceleration until reaching the same speed as the other vehicles in traffic, and then maintains that speed while smoothly merging into traffic. To achieve this control process, the vehicle's acceleration variation rate is used as the outcome, and parameters with strong correlations to this outcome are automatically extracted from the driving data acquired when merging. The control model for this process is then built by experts who refer to automatically extracted parameters such as the vehicle's relative speed and relative distance in relation to the vehicles in traffic. The time needed to build control models is reduced by using H to extract candidate parameters from among a countless number of parameters. Currently, Hitachi is working on testing the practicality of this technology by acquiring driving data from vehicle merge operations.

While safety is the current indicator for autonomous driving, ride comfort indicators such as vibration and noise will also become important in the future. H has the potential to become a general-purpose technology that can be applied to designing these control models, and Hitachi will continue to study it.

CONCLUSIONS

Hitachi aims to further expand the applicability and reliability of the fundamental technologies presented in this article through experimental demonstrations on public roads and other types of repeated evaluation and testing. Using the autonomous driving systems resulting from these fundamental technologies, Hitachi will continue working to help solve such societal challenges as reducing traffic accidents, alleviating congestion, and assisting with senior mobility.

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