Development and Experiment of ADAS and Autonomous Driving System

Authors: *Fumiaki Kadoya** and *Kazuo Hitosugi**

To realize autonomous driving, technologies for determining the position of one's own vehicle and information on the surroundings with high accuracy are required. Mitsubishi Electric Corporation has developed an autonomous driving system and verified its feasibility in demonstration experiments on public roads. In this system, self-sensing technologies using onboard sensors (e.g., cameras and radar) are combined with infrastructure-linked technologies utilizing infrastructure such as artificial satellites and intelligent transportation systems.

1. Definition of levels of driving automation

Autonomous driving is divided into various levels depending on the extent to which drivers are involved and operations that the system performs. The research and development plan for autonomous driving systems under the Cross-Ministerial Strategic Innovation Promotion Program (SIP) led by the Japanese Cabinet Office adopted J3016 (U.S.) (September 2016) of the Society of Automotive Engineers (SAE) as the definitions of the levels of driving automation (Table 1). In addition, the program aims to commercialize SAE Level 3 in 2020 and SAE Level 4 in 2025.

2. Utilization of quasi-zenith satellite system

To establish the infrastructure-linked autonomous driving system, the centimeter level augmentation service (CLAS) of the quasi-zenith satellite system (QZSS) was used. Formal operation of the QZSS in Japan began in November 2018. The system has a supplement function that sends positioning signals

Table 1 Definitions of Autonomous Driving Level

Level	Outline	Entity that performs monitoring and operation for safety driving
The driver performs all or some driving tasks.		
SAE Level 0 No automation	• The driver performs all driving tasks.	Driver
SAE Level 1 Driver assistance	• The system performs sub-tasks of driving tasks for vehicle control of any of the front, rear and sides.	Driver
SAE Level 2 Partial automation	• The system performs sub-tasks of driving tasks for vehicle control of both the front and rear and sides.	Driver
The autonomous driving system performs all driving tasks.		
SAE Level 3 Conditional automation	• The system performs all driving tasks (within a limited range*). • When continuous operation is difficult, the driver is expected to respond appropriately to a system request to intervene.	System (When continuous operation is difficult, the driver)
SAE Level 4 High automation	• The system performs all driving tasks (within a limited range*). • When continuous operation is difficult, the user is not expected to respond.	System
SAE Level 5 Full automation	• The system performs all driving tasks (not within a limited range). • When continuous operation is difficult, the user is not expected to respond.	System

Note: The term "range" is not limited to a geographical area and includes environmental, traffic condition, speed, and temporal factors.

Source: Research and development plan 2018 for autonomous driving systems in the Cross-Ministerial Strategic Innovation Promotion Program under the Japanese Cabinet Office

**Automotive Electronics Development Center*

compatible with the GPS of the U.S. and an augmentation function that sends augmentation signals for improving the positioning accuracy within Japan. Conventional satellite positioning uses positioning signals from global navigation satellite systems (GNSSs) such as GPS. Such positioning includes errors of the satellites (errors of satellite orbit, satellite clock, and satellite signal bias) and errors due to positioning areas (ionospheric delay and tropospheric delay errors). Positioning errors are in the order of several meters. The CLAS uses the electronic reference point network provided by the Geospatial Information Authority of Japan to create augmentation signals to correct errors for each satellite and area and sends them via the QZSS to improve the positioning accuracy with errors in the order of centimeters (Fig. 1).

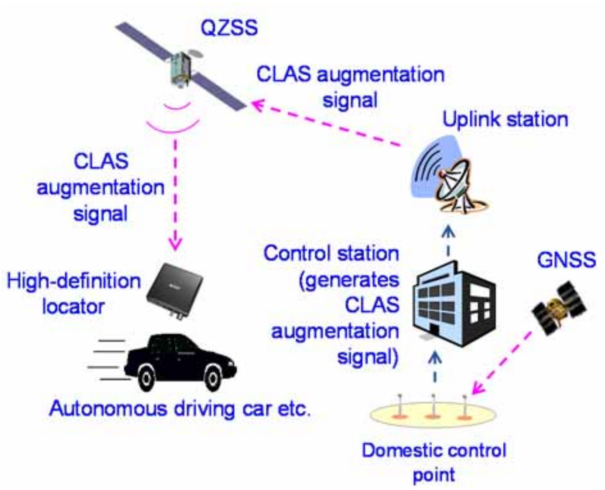

Fig. 1 Centimeter Level Augmentation Service

Four companies including Mitsubishi Electric have established Sapcorda Services GmbH to provide high-accuracy positioning services that allow satellite positioning with centimeter order also outside Japan. These services make it possible to use satellite augmentation signals that are compatible with the CLAS and to establish the infrastructure-linked autonomous driving system outside Japan.

3. Infrastructure-linked autonomous driving system

When a GNSS is used to estimate the position of a vehicle, the absolute position is expected to be highly accurate. However, signals may be blocked by obstacles on the road and the output of the satellite signals may be delayed. Mitsubishi Electric has developed GNSS/INS (autonomous navigation system) compound navigation in which the vehicle state obtained by the inertial sensor is used to compensate the satellite positioning signals in order to handle interruptions of satellite signals and output delays.

It has been verified that the combination of high-accuracy vehicle position estimation technologies based on GNSS/INS compound navigation with high-definition 3D maps, which are called dynamic maps, makes it possible to identify the self-positions of vehicles in lanes on expressways. To date, Mitsubishi Electric has developed high-accuracy lane-keeping and autonomous lane change systems for expressways by combining high-accuracy identification of the self-positions of vehicles with information provided from the roadside and nearby vehicles. Examples of assistance operations expected in the future are the creation of routes to target destinations (target exit ramps) for which even the lanes are selected, and application to autonomous driving when vehicles merge with and leave other traffic.

In addition, Mitsubishi Electric has been working to expand the use of high-accuracy positional information services around the world in cooperation with Here Technologies. We are working to provide smooth guidance on a recommended lane in case of an accident and traffic congestion through high-accuracy positioning in real time by combining high-definition maps and high-accuracy satellite positioning technologies with cloud positional information services.

4. Self-sensing autonomous driving system

The driving functions of vehicles are broadly divided into recognition, judgment, and manipulation. When a human driver drives a vehicle, the driver recognizes the road environment, traffic signals, pedestrians, and other factors in front of the vehicle from perceptual information, judges with the brain to what extent the steering wheel and other components need to be manipulated, and uses the hands and feet to manipulate the vehicle's devices. The aforementioned satellite positioning system is equivalent to the recognition function in autonomous driving.

As self-sensing devices to handle the recognition function, Mitsubishi Electric has been developing technologies such as millimeter wave radar (object identification function), forward-looking cameras, vehicle periphery monitoring cameras, ultrasonic sensors, and driver monitors. By combining information from such self-sensing devices, electric power steering (EPS) control technologies, and advanced driving assistance system-ECU (ADAS-ECU), a sophisticated driving assistance system that leads to autonomous driving technologies has been developed. Examples of such technologies are autonomous emergency braking to avoid collision with a pedestrian in front of the vehicle, lane-keeping system, adaptive cruise control system, and autonomous parking system. In addition to these systems, we are developing human machine interface (HMI) systems that notify the states of the autonomous driving systems to the occupants while traveling.

5. Vehicle control system

Mitsubishi Electric developed the xAUTO autonomous driving demonstration vehicle that has infrastructure-linked and self-sensing autonomous driving systems and verified the feasibility of the autonomous driving system through experiments on public roads. The vehicle control system on xAUTO consists of the three functions of the sensor section, locator section, and ADAS-ECU (Fig. 2).

The sensor sections refer to self-sensing devices such as a QZSS antenna, inertial sensor, forward-looking camera, and millimeter wave radar. The locator section accurately estimates the self-position of the vehicle on the map by combining high-precision position calculation by satellite positioning, vehicle state, shape of the road (white line), and high-definition 3D maps provided in the system; and outputs positional information on the vehicle, target route, and information on surrounding roads (e.g., speed limit). The ADAS-ECU calculates control amounts (e.g., steering amount, acceleration amount, and braking amount) for various driving assistance systems based on the information from the locator section, vehicle state, and other information and issues commands to the actuators on the vehicle. In addition, the ADAS-ECU ensures mutual cooperation between the infrastructure-linked autonomous driving system and the self-sensing autonomous driving system and makes judgments to provide autonomous driving appropriate for the environment in which the vehicle is traveling (Fig. 3).

For example, when an old white line is faded or cannot be seen due to snow, the infrastructure-linked autonomous driving system using satellites is mainly used for autonomous driving. On the other hand, when

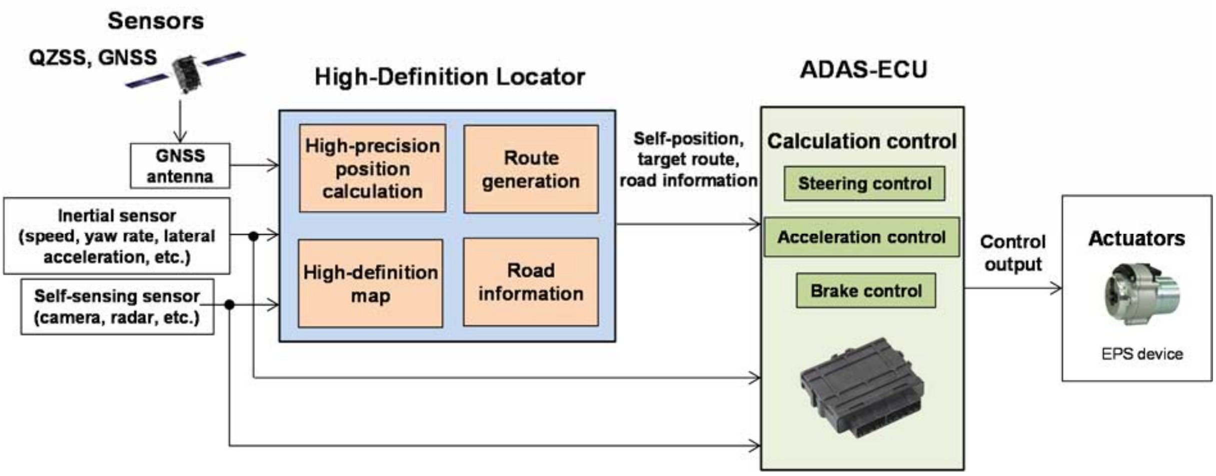

Fig. 2 xAUTO vehicle control system

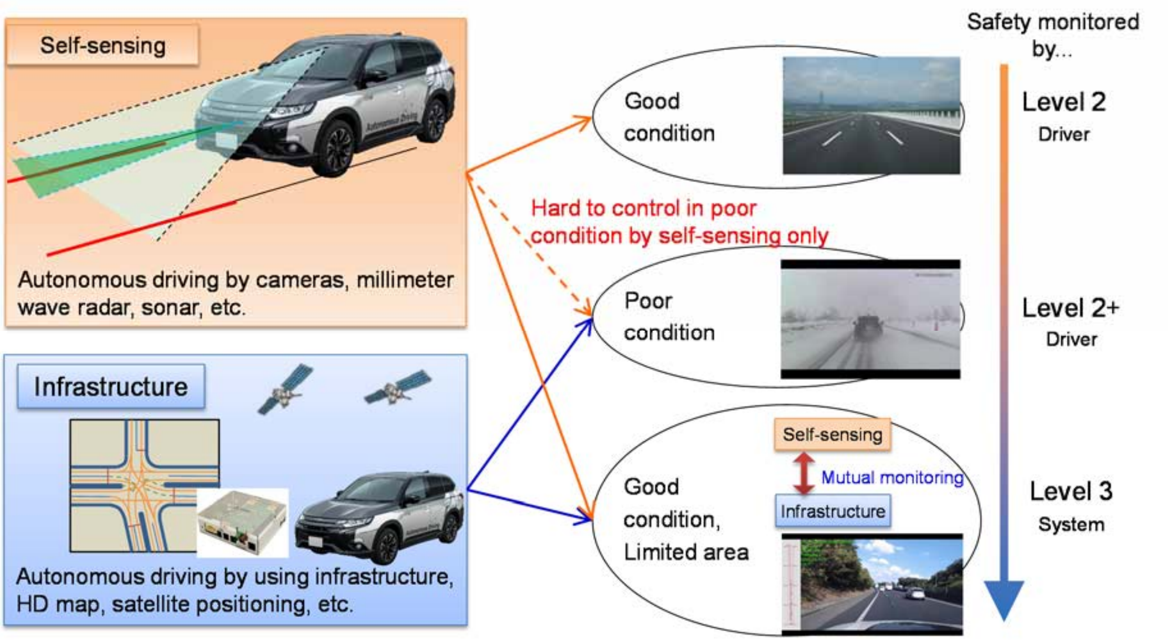

Fig. 3 Combination of autonomous driving technology

satellite signals cannot be received while passing through a tunnel or due to other reasons, the self-sensing system is mainly used for autonomous driving.

6. Demonstration experiments on public roads

A demonstration experiment on public roads using xAUTO and CLAS signals from the QZSS during test operation was conducted for the first time in the world in September 2017. In addition, an autonomous driving experiment using dynamic maps was performed by participating in a SIP's large-scale demonstration experiment and autonomous driving was tested under conditions of poor visibility due to snow and a snowstorm. The feasibility and robustness of the xAUTO's autonomous driving system were verified through these experiments on public roads (Fig. 4).

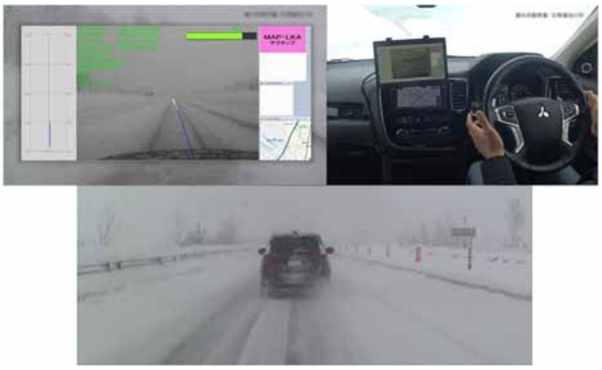

Fig. 4 Field test on a snowy road

Autonomous driving has been tested on roads around the world using the infrastructure-linked and self-sensing autonomous driving systems to verify both safety and comfort in various environments.