1. Advanced Driver Assistance Systems (ADAS) & autonomous driving

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1. Introduction

In recent years, various companies have introduced technologies that support automated driving via electronic control of the vehicle's movement. This was achieved by using electronic technologies that have rapidly developed since the 1980s to solve social issues stemming from the development of motorization, such as traffic crashes, environmental degradation, and traffic congestion.

To further support these endeavors, Nissan has defined its ultimate goal of "Zero Fatality," wherein the number of fatalities caused by traffic crashes involving Nissan cars is reduced to virtually zero. Since the early stages of the development of electronic control technologies, Nissan has been working to decrease the number of crashes by making vehicles intelligent, and Nissan has also recognized the importance of these technologies for revolutionizing mobility. Accordingly, Nissan has developed advanced driver assistance systems, such as ProPILOT Park, which automates parking operations, and ProPILOT Assist 2.0, which enables hands-off driving on highways. These technologies were not developed overnight, but were realized through a vast amount of technological expertise accumulated over many years. This article provides an overview of the company's long-standing efforts and technological foundations.

Nissan's efforts to advance autonomous driving and driver assistance technologies can be divided into the following three general time periods: (1) the early days of technology research (in the 1990s) when the foundations of environment recognition technologies were consolidated while a mechanical framework for controlling vehicle movements was built, (2) the adaptation and commercialization period (in the 2000s) when many preventive safety technologies were put into practical use based on the advancement of environment recognition technologies and the creation of the "Safety Shield" concept, and (3) a progressive period since the mid-2010s when various driving support technologies were implemented for specific driving scenarios, such as highway driving and parking. The following sections provide an overview of Nissan's efforts during each period and the key aspects of the corresponding technology.

2. Evolution of driver assistance technologies

Since the late 1980s, the control of driving functions has been performed electronically. This update enabled the brake oil pressure and drive torque to be adjusted according to the road conditions, thus preventing the wheel from locking while braking and from slipping while accelerating. In addition, improving the maneuverability and stabilizing the turning motions has become possible via sensing the motion of the vehicle and generating a moment in the rotational direction by finely steering the rear wheels and controlling the brake hydraulic pressure individually for each wheel. Nissan has introduced various electronic control devices, including the anti-lock braking system (ABS), traction control system (TCS), high capacity actively controlled steering (HICAS), and vehicle dynamic control (VDC)[(1), (2), (3), (4)].

This period also witnessed the introduction of new technologies, such as camera image processing and distance measurements made by emitting laser light and capturing the reflected light (i.e., light detection and ranging, or LiDAR). At the end of the 1980s, Nissan commenced basic research on the technology required to detect white lines on roads via camera images and to measure the distance between vehicles using laser light.

One outcome of this basic research and development effort that has been incorporated into the modern autonomous driving capability was the function to automatically follow the vehicle ahead and drive in the center of the lane, which was manifested in the Advanced cruise-assist Highway Systems (AHS) project led by the former Ministry of Construction. In September 1996, a autonomous driving demonstration was jointly conducted with other companies on a section of the Joshinetsu Expressway before it was opened for regular use,, demonstrating the possibility of stable and smooth autonomous driving[(5)].

By initiating early efforts, Nissan was able to swiftly use these technologies for practical applications. In 1997,

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Nissan implemented adaptive cruise control coupled with brake control, which could regulate both regulates the driving and braking forces to maintain a safe distance from the vehicle ahead[6),(7]. In 2001, a lane-keeping support system, which used a charge-coupled device camera to detect white lines on the road and assist in the steering operations to help ensure the car stayed inside the lane, was implemented in commercial applications[8].

Nissan expects these electronic control technologies to gradually support or automate vehicle control and to enable autonomous driving in the future. To sequentially build these functions, Nissan positioned each function of the control system hierarchically in relation to the mechanisms responsible for human motor control (as shown in Fig. 1).

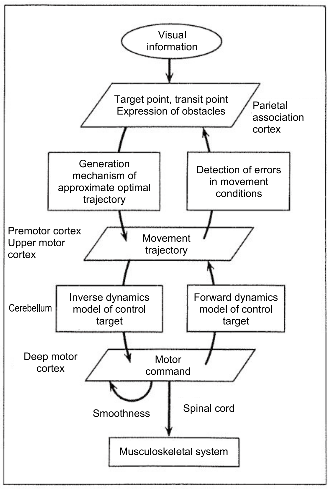


Fig. 1 Hierarchical model of human neural circuit[9]

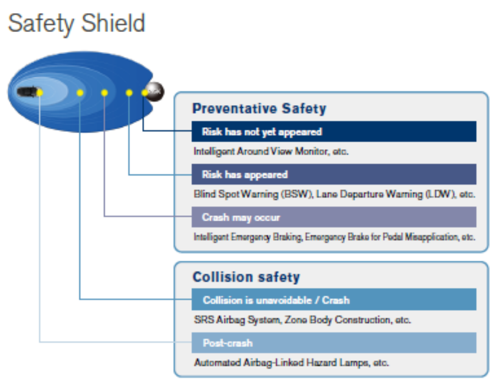
The control system of the human body consists of a musculoskeletal system that performs fine force adjustments based on spinal reflexes, a motor control system in the cerebellum that accounts for the dynamics of the object under control, and an upper-layer control system that determines target values based on visual information, generates trajectories, and provides error feedback. The vehicle control system can be correlated with that of a human as follows: ABS and TCS, both of which adjust the tire slip ratio, and the rear wheel angle servo in HICAS, which accurately controls the tire angle, correspond to the lower-layer musculoskeletal system; VDC and HICAS, which control the rigid body motion of a vehicle by accounting for the vehicle dynamics, correspond to the middle-layer motion control system; and driving assistance, which controls the distance between vehicles and the position within the lane based on external information, corresponds to the function of the upper layer.

In these early stages of technological development, Nissan built the lower- and middle-layer functions to control acceleration, deceleration, and yaw motion according to the target values without compromising vehicle stability. This laid the foundation of vehicle control technologies, which led to future driving assistance and autonomous driving capabilities, which in turn resulted in the subsequent development of many practical driving assistance systems.

3. Adaptation and commercialization of preventive safety technologies

The use of an environment recognition function that detects vehicles and white lines on the road ahead, along with functions that control the braking force, driving force, and steering angle, enabled the development of adaptive cruise control and lane-keeping support systems. These environment recognition technologies are rapidly progressing. For example, they can accurately detect vehicles and objects not only ahead but also behind and on the sides, as well as vehicles and objects further ahead. Based on these technologies, Nissan has developed the concept of "Safety Shield," which aims to support the safety of occupants based on the idea that cars should protect people[11].

In this concept, environmental conditions are categorized into the stages labeled as "risk has not yet appeared," "risk has appeared," "crash may occur," "crash is unavoidable," "crash," and "post-crash." In each stage, the features optimized for the risk factors are activated, which provides comprehensive assistance to the driver in avoiding the risks and protecting the passengers.



Risk has not yet appeared ProPILOT (ProPILOT Assist / ProPILOT Assist with Navi-link/ ProPILOT Assist 2.0) ProPILOT Park (ProPILOT Park/ ProPILOT Remote Park) Intelligent Distance Control Navigation-enabled Intelligent Cruise control with fullspeed range following capability Adaptive Front-Lighting System (AFS) Intelligent Around View Monitor Intelligent Rear View Mirror	elps the driver drive with peace of mind
Risk has appeared Intelligent Forward Collision Warning Lane Departure Warning Intelligent Lane Intervention Blind Spot Warning Intelligent Blind Spot Intervention Intelligent Back-up Intervention Intelligent Driver Alertness Rear Cross Traffic Alert **Crash may occur** Intelligent Emergency Braking Anti-lock Braking System (ABS) Vehicle Dynamics Control (VDC) Emergency Brake for Pedal Misapplication	Helps the driver avoid or lessen the severity of an accident
Crash is unavoidable Front Pre-Crash Seatbelts **Crash** Zone Body Construction SRS Airbag Systems Pop Up Engine Hood **Post-crash** Automated Airbag-Linked Hazard Lamps SOS Call (HELPNET)	Helps reduce injuries when a collision is unavoidable

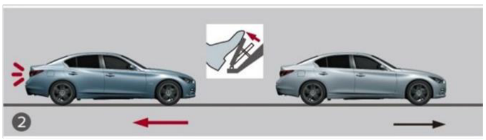
Fig. 2 Safety Shield concept

As shown in Fig. 2, the concept has adopted many driver assistance technologies. Although such technologies are very effective in mitigating risks during driving, the driver may distrust the system because of unexpected vehicle motion caused by the system, or the driver may be too confident in the system owing to excessive expectations of the system's effectiveness. Therefore, to develop these technologies, Nissan has actively addressed human factor issues.

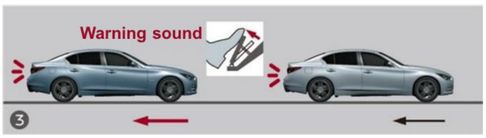
Intelligent pedals, a technology used in Safety Shield, are an example of a system that fully accounts for human factors (Fig. 3). In intelligent pedal technology, the perceived risk from an approaching vehicle ahead is quantified and transmitted to the driver through the reaction force on the accelerator pedal, and the deceleration is controlled in response to the driver's operation of the accelerator pedal. Essentially, it incorporates the driver into the control loop to maintain a safe distance from the vehicle ahead. The system easily enables a safe distance from the vehicle ahead to be maintained; thus, it reduces the burden on the driver, even in traffic situations in which vehicles frequently accelerate and decelerate[12].

This technology was realized by accounting for various human factors, including the driver's risk perception caused by the relative speed and distance from the vehicle ahead, the driver's judgement exercised in response to the changes in the reaction force exerted by the accelerator pedal, the changes in the driver's driving behavior and vehicle-to-vehicle distance caused by the use of the system, and the quantitative evaluation of the changes in the driver's cognitive load resulting from the use of the system[13],[14].

(1) When the vehicle ahead approaches, releasing the accelerator pedal will cause the system to smoothly apply the brake to decelerate.



(2) If the driver pushes the accelerator pedal further, the system pushes it back, assisting the driver in releasing it. When the driver releases the accelerator pedal, the system smoothly applies the brakes.



(3) When the system determines that the driver needs to push the brake, the driver is alerted via the display and various sounds. Subsequently, the system pushes the accelerator pedal back to prompt the driver to push the brake pedal instead.

Fig. 3 Intelligent pedal technology

4. Development of driver assistance technologies

In the previous sections, various driver assistance technologies were introduced. These technologies provide separate assistance for each driving behavior and risk category, such as maintaining a safe vehicle-to-vehicle distance, drifting from the center of the lane, and approaching vehicles from the side or rear. For example, ProPILOT Assist, which was introduced in 2016, integrated driver assistance technologies for single-lane driving on expressways[15].

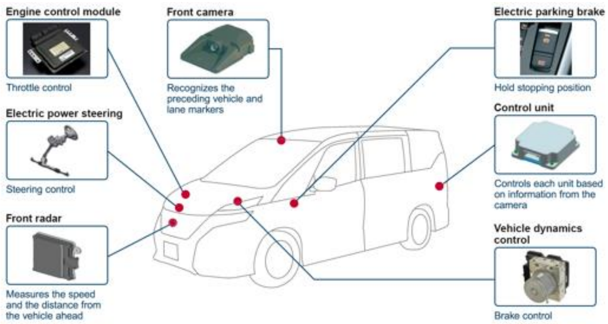


Fig. 4 Components of the ProPILOT Assist system

The ProPILOT Assist system significantly reduces the operational load of the driver when cruising on expressways or driving in traffic jams. This is accomplished by recognizing the road and traffic conditions using advanced environment recognition technology and automatically controlling the entire system, including the accelerator, brakes, and steering.

As driver assistance technologies become more advanced, the driver's understanding of the state of the system and the kind of assistance available will become increasingly important. In ProPILOT Assist, a dedicated display indicates the system status in a way that can be easily understood.

In 2019, ProPILOT Assist 2.0 was introduced to assist driving on multiple-lane highways in conjunction with navigation. Under certain conditions, it also assists with hands-free driving within the same lane and steering when switching lines[16]. Once a destination is selected, ProPILOT Assist follows the navigation system to provide comprehensive driving assistance while on the expressway.

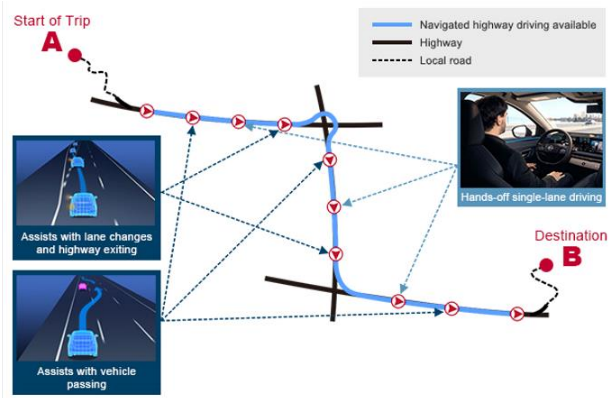


Fig. 5 Navigation-linked route generated by ProPILOT Assist 2.0

Fig. 6 ProPILOT Park

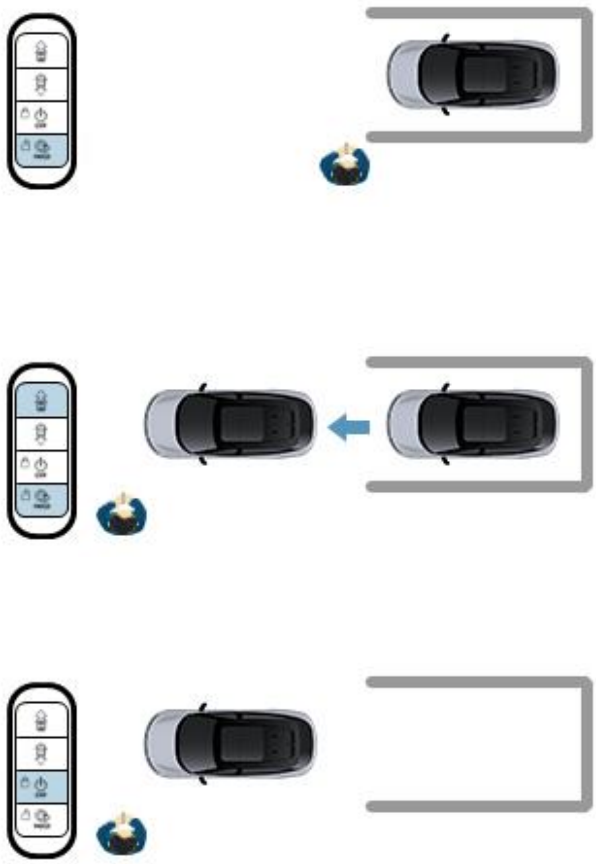


Fig. 7 ProPILOT Remote Park

Furthermore, ProPILOT Assist 2.0 can obtain information 360° around the vehicle using cameras, radar, sonar, the global navigation satellite system (GNSS), and 3D high-definition maps. This combination identifies the exact positional relationships between the vehicle and road and recognizes the road structure, including the number of lanes and whether they are merging, branching, or crossing. Additionally, a driver monitor checks whether or not the driver is paying attention to the road ahead, and a dedicated human-machine interface (HMI) clearly communicates the status of complex systems.

The aim for ProPILOT Assist 2.0 was not to simply upgrade the functions but to provide new value that allows driving on expressways to be safe, secure, convenient, and comfortable. This was achieved by adding a steering control mechanism that performed more smoothly than an experienced driver and by using an HMI to clearly communicate to the driver the system's environmental perceptions and its decision-making algorithm[(17),(18),(19),(20),(21),(22)].

ProPILOT Assist and ProPILOT Assist 2.0 deliver comprehensive driving assistance on expressways. In addition, ProPILOT Park[(23)] and ProPILOT Remote Park[(24)] are driving assistance functions that automate parking operations.

With a simple switch, the ProPILOT Park automatically controls the steering, accelerator, brakes, gear shift, and parking brake, assisting the driver until parking is completed. Control is executed by calculating the driving distance according to the surroundings of the vehicle (including for reversing vehicles), and by precisely maneuvering the vehicle through the coordination of the accelerator, brakes, steering, and gear shift. Similarly, ProPILOT Remote Park assists in moving the vehicle in and out of a narrow garage via a remote control with an intelligent key held outside the car.

Thus, by combining sensor, control, navigation, HMI, and other technologies, Nissan has been producing comprehensive driver assistance technologies applicable to various driving scenarios, including expressway cruising and parking.

5. Future work

Through constant efforts over the past 30 years, Nissan has been advancing its technologies and moving toward its ultimate goal of "Zero Fatality." However, approximately 300,000 traffic crashes occur annually in Japan, resulting in the loss of many lives[25].

To decrease the number of traffic crashes while continuing to increase the application of existing technologies, Nissan is developing a more advanced driving assistance technology called ground truth perception, which will contribute to preventing multidimensional and complex crashes. With this technology, cognitive abilities are upgraded to the next level using stable and smooth next-generation LiDAR[26]

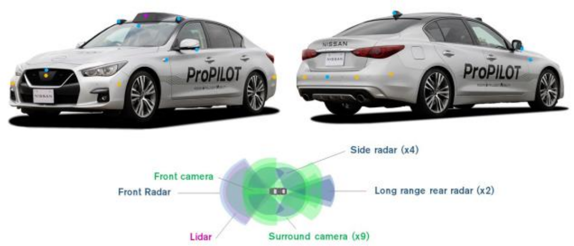


Fig. 8 Ground truth perception

As autonomous driving technologies continue to be developed, cars are becoming a major component of social infrastructure that supports people's mobility, which improves their quality of life in both cities and rural areas.

Nissan is currently working on Easy Ride®*, a mobility service that utilizes autonomous driving technology. Feasibility experiments were started in the Yokohama area in 2017[27),(28].

(*Easy Ride® is a trademark of DeNA Co., Ltd. and Nissan Motor Co., Ltd.)

Fig. 9 Easy Ride®

Currently, demonstrations of SAE Level 2 autonomous driving technology are being conducted by Nissan with an onboard driver to help ensure safety. In the future, while continuing to develop technologies and accumulate track records, Nissan intends to promote autonomous driving technologies to provide sustainable transportation services that support movement between cities and rural areas.

Furthermore, Nissan has been collaborating with NASA (USA) to develop a Seamless Autonomous Mobility (SAM) system that supports autonomous driving mobility services by making full use of AI in the cloud[29].

In this system, when an autonomous vehicle faces an unexpected situation, such as a crash or road obstacle, humans can intervene by remotely controlling the vehicle and connecting all related vehicles to collect information in the cloud and guide the vehicles to safety.

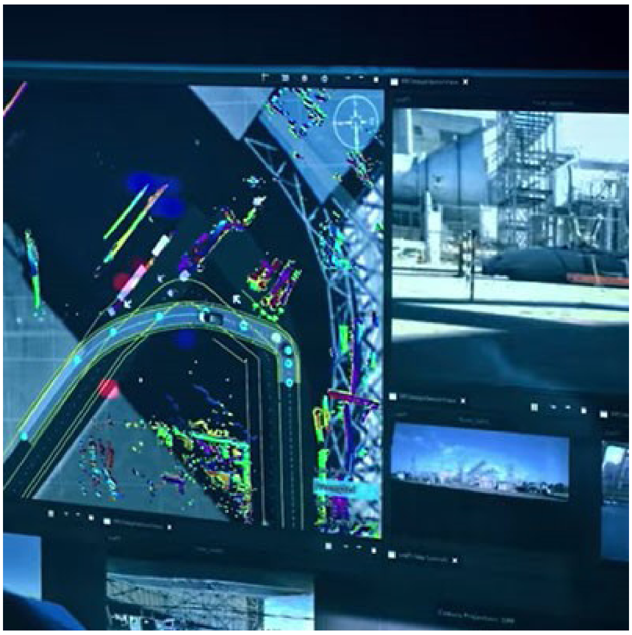


Fig. 10 Seamless Autonomous Mobility (SAM) system

6. Summary

In an effort to reach its ultimate goal of "Zero Fatality," driver assistance technologies that electronically control vehicle driving functions and promote their advancement are being developed by Nissan. To further decrease the number of future crashes, Nissan is improving driver assistance technologies to prevent multidimensional and complex crashes. Nissan will also continue to work on mobility services using autonomous driving vehicles to provide sustainable transportation in cities and rural areas.

In recent years, the capabilities of technologies known as the third and fourth AI revolutions, which originated from deep learning technologies, have been increasing daily. Detecting objects via environmental recognition and predicting the behavior of other vehicles and pedestrians are now possible. Furthermore, with faster wireless communications and the prevalence of cloud computing, accumulating and learning from a large amount of driving data and improving system functionality on a daily basis has become possible as well. By introducing these new technologies without delay and further advancing driving assistance and autonomous driving functions, Nissan will continue its efforts to deliver sustainable transportation and to decrease the number of traffic crashes in pursuit of its "Zero Fatality" goal.

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2. ProPILOT Assist

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1. Introduction

For more than 20 years, Nissan has developed many world-first technologies to lead technological innovation as a pioneer in driver assistance technologies. In 2016, Nissan commercialized ProPILOT Assist (Fig. 1), an integrated driving assistance technology for single-lane highways, and in 2019, Nissan launched ProPILOT Assist 2.0 (Fig. 2), which operates in conjunction with the navigation system to offer the world's first driving assistance system that enables vehicles to follow a route on multi-lane highways while, under certain conditions, performing hands-off driving within the same lane. This chapter introduces the ProPILOT Assist and ProPILOT Assist 2.0 technologies.

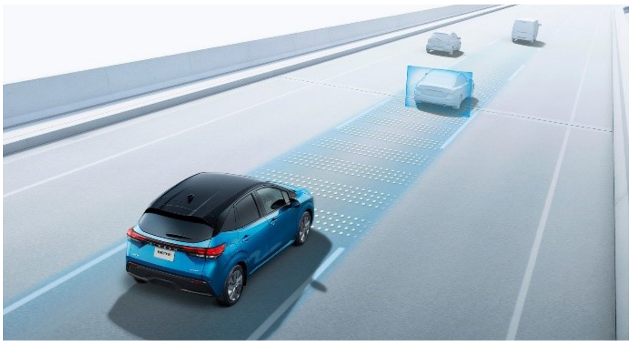

Fig. 1 Illustration of ProPILOT Assist capabilities

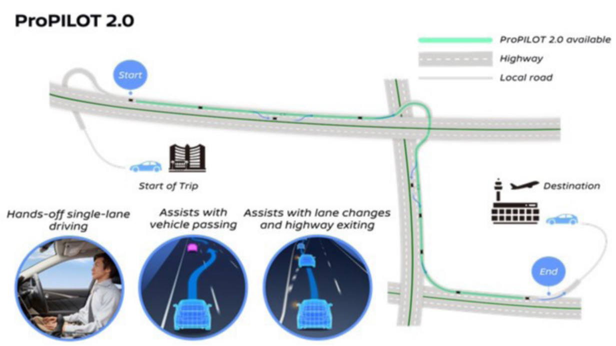

Fig. 2 Illustration of ProPILOT Assist 2.0 capabilities

2. ProPILOT Assist

This section provides an overview of the functions, driver interactions, and recognition and control technologies associated with ProPILOT Assist (PPA 1.0).

2.1 System overview

By automatically and simultaneously controlling the accelerator, brakes, and steering, PPA1.0 reduces the driver's burden in two of the most stressful situations on the highway: traffic jams and long-distance cruising. It utilizes a front camera and radar to recognize the exterior environment as well as a vehicle control unit, electric power steering unit, brake control unit, and electric parking brake, all connected to an advanced driver assistance system controller that manages each unit based on the sensor information (Fig. 3). As a result, PPA1.0 can recognize the vehicle in front as well as the white lane marking in three-dimensional space, use that information to accurately control the vehicle, and provide a comfortable drive.

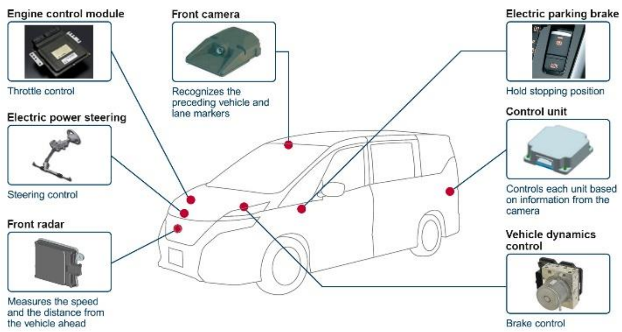

Fig. 3 Structure of the PPA1.0 system

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2.2 Functions of PPA1.0

PPA1.0 provides two functions: vehicle speed and distance control and lane keeping.

2.2.1 Vehicle speed and distance control

The vehicle speed and distance control function maintains the speed set by the driver. When the system detects a vehicle ahead, it controls the vehicle speed to maintain a safe inter-vehicle distance using the speed set by the driver as the upper limit. The PPA1.0-equipped vehicle stops when the vehicle ahead stops and can resume moving with the vehicle ahead up to 30 s after that. Furthermore, in conjunction with the navigation system, PPA1.0 assists the driver's speed adjustment operations by switching the set speed when the speed limit changes and controlling deceleration according to road features such as tight curves and freeway off-ramps.

2.2.2 Lane keeping

The lane-keeping function of PPA1.0 helps the driver to maintain the vehicle in the middle of the driving lane on straight roads by controlling the steering wheel, though the driver must remain engaged with the wheel at all times.

2.3 Driver engagement

To prevent the driver from neglecting to take appropriate actions in response to the surrounding traffic conditions while driving with PPA1.0, a steering torque sensor or steering touch sensor is used to confirm that the driver is actively operating the vehicle. If the system determines that the driver is not, it issues a warning that prompts the driver to act. If the driver does not respond, the system issues an emergency warning, slows down, and stops the vehicle while alerting the surrounding vehicles using the hazard lights. These safety measures allow drivers to use the PPA1.0 advanced driver assistance system with peace of mind.

The next section details the sensors and vehicle control technologies employed to achieve safe and comfortable driving using PPA1.0.

2.4 Recognition and control technologies

To achieve seamless driving while controlling the distance to the vehicle ahead, it's position and movement must be accurately detected. Thus, PPA1.0 promptly and accurately detects the vehicle ahead by processing sensor signals and maximizing on the advantages of the front camera and radar systems: the front camera excels at recognizing the type of object and detecting its lateral position in and positional relationship with the lane; while radar systems excels at detecting the distance and relative speed of objects at farther distances with high accuracy. By combining these advantages, PPA1.0 can appropriately respond to vehicles a long distance ahead, which is necessary when driving at highway speed. Simultaneously, the system can suitably respond to certain movements of vehicles a short distance ahead, such as cutting-in and lane changes.

In addition, the lane-keeping function provides feedback based on vehicle information to properly respond to changes in conditions, such as roadway cant. For example, when overtaking a large vehicle such as a truck, the resistance to lateral position control changes owing to the changes in airflow, but PPA1.0 recognizes the truck in the adjacent lane and feeds this information forward to the steering control, which suppresses any disturbances in lateral position to pass alongside the larger vehicle safely.

Moreover, using navigation map data and global navigation satellite system (GNSS) signals, PPA1.0 obtains information such as the current location and attributes of the road ahead, including curve tightness, branching points, and speed limits, allowing it to control the vehicle speed according to the traffic environment. This eases the driver's workload, making driving safer and more comfortable.

3. ProPILOT Assist 2.0

This section provides an overview of the functions, technological features, and driver interactions of ProPILOT Assist 2.0 (PPA2.0).

3.1 System overview

While following the route set by the navigation system when a destination is entered, PPA2.0 assists a wide range of driving operations from when the driver gets on the main highway until they get off. It collects information not only from in front of the vehicle but also virtually 360° around the vehicle as well as the precise vehicle location on the road using seven cameras, five radars, and twelve sonars installed on the vehicle together with GNSS and three-dimensional high-definition (3DHD) map data. The 3DHD map data describe the road structures, number of lanes, and locations of merging, branching, and crossing points. This information allows the vehicle to be controlled according to the road conditions ahead and provides smooth driving similar to that performed by an experienced driver. The PPA2.0 system also constantly monitors whether the driver is paying attention to the situation ahead using an installed driver monitor camera. Figures 4, 5, and 6 show the PPA2.0 sensor locations, a representation of the 360° sensing coverage, and a 3DHD map image, respectively.

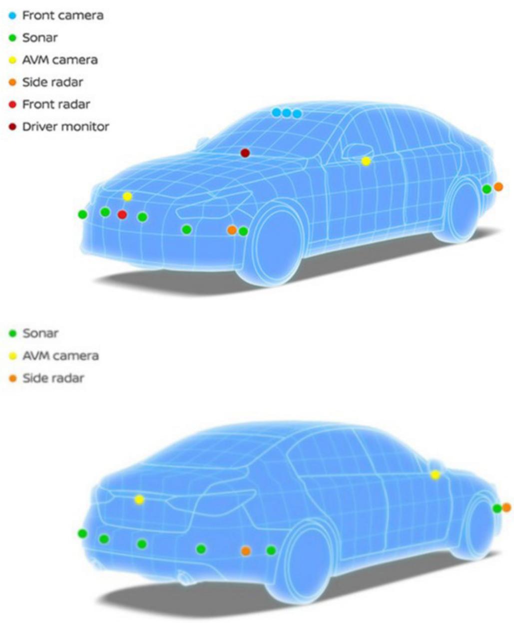

Fig. 4 Sensor locations for PPA2.0

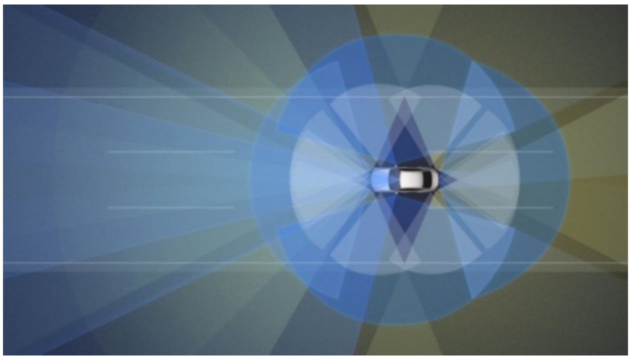

Fig. 5 360° sensing with PPA2.0

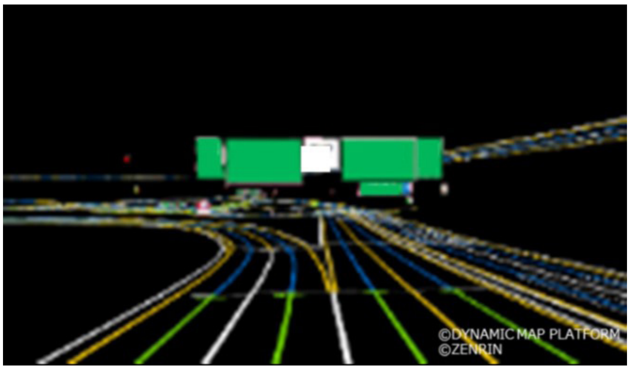

Fig. 6 3DHD map for PPA2.0

3.2 Functions of PPA2.0

In addition to providing the vehicle speed and distance control and lane-keeping functions of PPA1.0, PPA2.0 includes lane-change assistance, route-following assistance, and overtaking assistance functions.

3.2.1 Vehicle speed and distance control

As in PPA1.0, the vehicle speed and distance control function of PPA2.0 maintains the vehicle speed set by the driver. When the system detects a vehicle ahead, it controls the vehicle speed to maintain a safe inter-vehicle distance using the speed set by the driver as the upper limit. The PPA2.0-equipped vehicle stops when the vehicle ahead stops and can resume moving with the vehicle ahead for up to 30 s thereafter. In addition, PPA2.0 uses the 3DHD map and navigation route information to control the vehicle speed according to the present road configuration as well as the road conditions after a branching point.

3.2.2 Lane keeping

As in PPA1.0, the lane-keeping function of PPA2.0 helps the driver to keep the vehicle in the middle of the traveling lane on straight roads by controlling the steering wheel. Furthermore, PPA2.0 make allows the driver to take their hands off the steering wheel as long as they are constantly attentive to the road ahead and can immediately operate the steering wheel in response to road, traffic, and vehicle conditions.

3.2.3 Lane-change assistance

When the driver places their hands on the steering wheel and activates the turn signal in the direction of the desired lane, PPA2.0 controls the steering and assists with the operations necessary to change lanes.

3.2.4 Route-following assistance

After the driver has provided a destination to the navigation system, PPA2.0 suggests lane changes required to continue following the predetermined route, such as at exit ramps or branch points or where the number of lanes decreases. When the driver places their hands on the steering wheel and presses the lane-change assist button, the turn signal is activated in the direction of the desired lane, and PPA2.0 controls the steering wheel to assist in changing lanes accordingly. If the vehicle must change lanes multiple times to reach the desired lane, PPA2.0 can assist in consecutive lane changes.

3.2.5 Overtaking assistance

If PPA2.0 detects a vehicle ahead, that is slower than the speed set by the driver, it suggests that the driver overtakes the vehicle. When the driver places their hands on the steering wheel and presses the lane-change assist button, the turn signal is activated in the direction of the desired lane and the system controls the steering wheel to assist in changing lanes. Once the slower vehicle is passed, the system suggests that the driver returns to the original lane. When the driver presses the lane-change assist button, the left-turn signal is activated, and PPA2.0 controls the steering wheel to assist the driver in returning to the original lane.

The next section discusses the use of 3DHD map data, which are essential for the lane-change, route-following, and overtaking assistance functions.

3.3 Application of 3DHD map data to the lane change assistance function

This section explains how the PPA2.0 lane-change assistance function uses 3DHD map data to determine the feasibility of lane changes and plan lane-level driving.

3.3.1 Determination of lane-change feasibility

One of the challenges of implementing lane-change assistance is obtaining adequate information describing the lane conditions ahead. When a lane change begins, the camera could be unable to collect comprehensive lane information from the point at which the lane change will end, such as lane markings indicating the disallowance of lane changes. Thus, the information the camera provides may be insufficient to inform safe lane changing. However, 3DHD map data contain information such as road curvature and lane markings at the local level, allowing for the assessment of road configurations beyond the camera's detection range and enabling PPA2.0 to determine whether lane changes are possible by considering the starting and ending points of the relevant lanes.

3.3.2 Lane-level driving plan

The lane-change assistance function determines the appropriate timing for suggesting lane changes to assist in overtaking or following the route the navigation system recommends. This determination is enabled by creating a lane-level driving plan using the lane-level data in the 3DHD map. The driving plan determines which lane the vehicle should use in which road section and decides how to guide the vehicle to that lane.

Figure 7 illustrates the process of generating a lane-level driving plan. First, when a branching point, such as an exit ramp, exists on an expressway, the system calculates the number of lane changes required to move to the route recommended by the navigation system as well as the distance along the road to the branching point, then selects a lane accordingly.

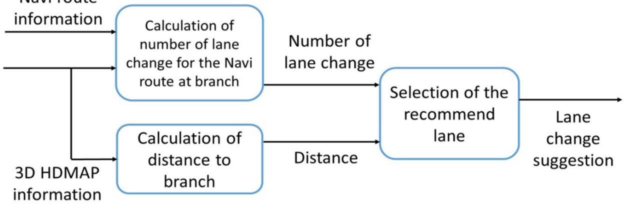

Fig. 7 Block diagram depicting the generation of a lane-level driving plan

For example, Fig. 8 shows a schematic road configuration near a highway junction. The route recommended by the navigation system is set to proceed to exit P in the diagram at the exit ramp. If the vehicle is in the rightmost through-traffic lane when it approaches the exit, PPA2.0 suggests changing lanes to the left until it is in lane A. The system does not recommend moving to lane B because doing so would increase the number of lane changes needed to exit at point P. If the vehicle initially travels in lane B, PPA2.0 suggests a lane change to the right and guides the vehicle to lane A. In this manner, regardless of the lane in which the vehicle is traveling, a lane-change proposal is ultimately made to guide the vehicle to exit P.

In addition, using a lane-level driving plan allows PPA2.0 to provide suggestions when overtaking a vehicle at appropriate times. For example, if the route to be followed requires taking a branch road to the left and the distance to the branching point is small, the system does not suggest overtaking.

Thus, constructing a lane-level driving plan using 3DHD map data allows PPA2.0 to determine the most desirable lane to follow the navigation route, facilitating the suggestion of lane changes at the appropriate times.

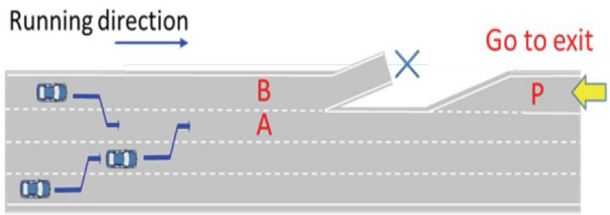

Fig. 8 Planning of a lane-level driving near a branching point

3.4 Off-board linkage function

To provide functions such as updating 3DHD map data, PPA2.0 has an off-board linkage function that enables constant telematic communication with the map server. This off-board linkage function comprises vehicle-side data storage for the 3DHD map, a 3DHD map electronic control unit (ECU) for outputting map data, a telematics control unit for communication, and a server for storing and distributing the latest map data (Fig. 9).

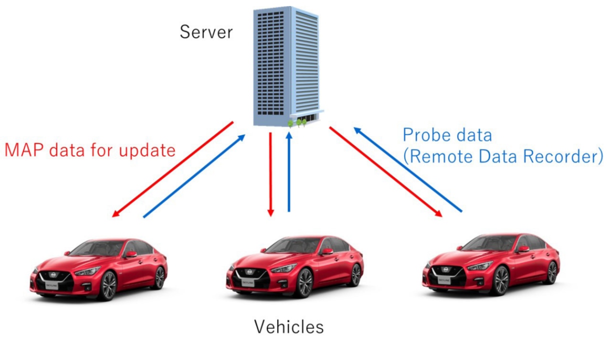

Fig. 9 Off-board linkage function

The 3DHD map data are updated several times a year to help ensure that the latest maps matching the actual road configuration are available promptly, even when the road configuration changes owing to construction or other reasons.

The 3DHD map ECU checks for differences between its map and the latest map version on the server for each operation. If the ECU map version is already updated when the navigation destination is set, priority is given to the map on the ECU, whereas when no destination is set, the latest map for a location close to the vehicle is downloaded from the server to update the ECU map. This help ensures that the latest 3DHD map data are always used for driver assistance.

3.5 Relationship between PPA2.0 and the driver

The intelligent interface for PPA2.0 is a unique human–machine interface (HMI) designed in-house at Nissan to facilitate the appropriate use of its advanced driver assistance functions. The intelligent interface comprises a heads-up display (HUD), meter display information, steering wheel button operations, and driver monitoring system warnings (Fig. 10).

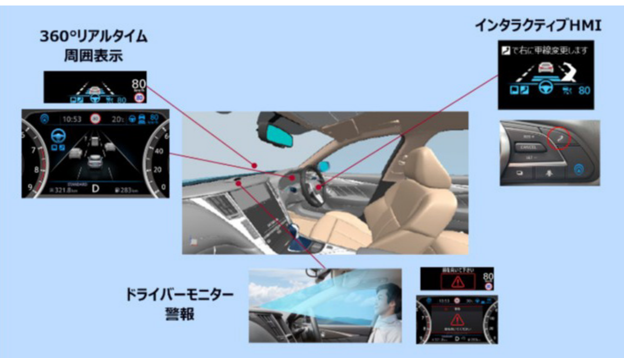

Fig. 10 Intelligent interface

There are three activation states in PPA2.0 compared to the two in PPA1.0, owing to the addition of the hands-off function for single-lane driving. These three modes comprise intelligent cruise control (ICC) mode, in which only the vehicle speed and distance control are activated; hands-on mode, in which vehicle speed and distance control, as well as steering control, are activated, but the driver must maintain steering control at all times; and hands-off mode, in which vehicle speed and distance control as well as steering control are activated and allow the driver to take their hands off the steering wheel in certain situations, assuming that they maintain attention on the road ahead and remain ready to take over vehicle operation when required. To facilitate mode identification, Nissan adopted different color schemes for display elements such as icons and indicators on the HUD and meter displays: ICC mode is white, hands-on mode is green, and hands-off mode is blue (Fig. 11).

Fig. 11 Color schemes indicating operation status

Furthermore, a driver monitoring system is included to help ensure that the driver remains attentive to the road ahead. If they do not, the system warns the driver to be more attentive, thereby preventing them from neglecting to monitor the surrounding traffic conditions when driving in hands-off mode (Fig. 12).

Fig. 12 Warning issued by the driver monitoring system prompting the driver to attend to the road ahead

3.5.1 Interactive HMI

During the branching or overtaking stages of navigated-route driving, PPA2.0 considers the planned route, the speed of the vehicle ahead, and surrounding traffic conditions to suggest the use of lane-change assistance at appropriate times via the HUD and meter displays (Fig. 13).

Fig. 13 Suggestions from the lane-change assistance system

Arrow-shaped graphics in the HUD provide suggestions for lane-change assistance, and text at the top prompts for driver approval. The number of display elements in the HUD was minimized to help ensure the driver can readily recognize system suggestions while retaining their forward view. Each lane-change assistance suggestion is also provided on the meter display to allow the driver to confirm its necessity. Upon reviewing the suggestion, the driver checks the safety of their surroundings and presses the lane-change assist button. Because this button often operates relatively quickly after the driver receives a system suggestion, the suggestion is located in the upper region of the display near the periphery of the steering wheel to link its visibility with button operability. Thus, once the driver is familiar with button operation, it can be pressed without looking.

During lane-change assistance, the driver must place their hands on the steering wheel to override the system. Therefore, once lane-change assistance is initiated, the color of the HUD and meter display change from blue for the hands-off mode to green for the hands-on mode to prompt the driver to grip the steering wheel. Indeed, the color-coding scheme is most effective in this situation. From the time the driver's approval is received until the lane change begins, an arrow-shaped graphic on the HUD is animated to flow from front to back while a text message is displayed urging safety confirmation. Furthermore, when PPA2.0 flashes the turn signal and initiates a lane change, the arrow-shaped graphic on the HUD turns green and flashes at the same frequency as the turn signal, indicating that a lane change is in progress (Fig. 14).

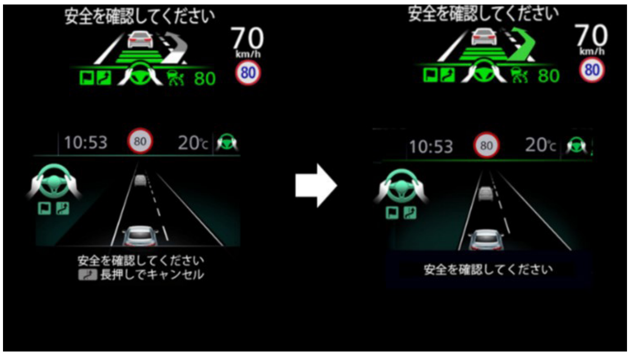

Fig. 14 Display during lane-change assistance

3.5.2 360° real-time surrounding display

To provide the driver with an accurate understanding of the capabilities of PPA2.0, the detected road environment and traffic conditions are shown in real time using a virtual 360° view on the meter display. To depict the road environment, PPA2.0 uses the 3DHD map data and front camera to display the presence or absence of lanes adjacent to the traveling lane and the type of lane marking (single or double solid/dashed white lines and solid/dashed yellow lines), as shown in Fig. 15.

Fig. 15 Example of 360° real-time surrounding display (distinguishing line markings)

To depict the traffic situation, PPA2.0 displays the other vehicles detected in the traveling and adjacent lanes according to vehicle type (passenger car, truck, motorcycle, or unknown) using fusion processing of sensor data from the front camera and front and side radars. The locations and sizes of these depicted vehicles are repeatedly tuned using nonlinear scaling such that the apparent distance to the other vehicles on the display approximately matches the actual surroundings. This allows the driver to develop an intuitive understanding of the detection range and identification capabilities of the system by comparing the actual and displayed spaces.

Therefore, the virtual 360° real-time display helps drivers to gradually learn the capabilities of PPA2.0 as they experience various situations, promoting the appropriate use of and fostering a sense of trust in the system.

4. Summary

The ProPILOT Assist system has been developed considering the concepts of “wider situations,” “easier use,” and “more users.” By commercializing ProPILOT Assist and ProPILOT Assist 2.0, Nissan provides customers with a safer, more comfortable, and stress-free driving experience that has received great positive feedback.

Nissan will continue developing such technologies to assist driving operations in a broader range of situations and provide new benefits toward realizing a safer motorized society.

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3. ProPILOT parking

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1. Introduction

Parking is a difficult driving operation for many drivers. Because they must appropriately plan their turning locations based on the shape of the parking spot and the presence or absence of adjacent vehicles. In particular, when parking in a narrow space, the driver must turn the steering wheel repeatedly while shifting the vehicle forward and backward. Therefore, research and development on parking assistance is being actively conducted. Memory functions have recently been developed to detect parking locations without markings, such as those in residential environments. These functions allow the driver to register the parking location, allowing the system to detect the parking location and provide parking assistance automatically. In one type of memory function, the driver registers the parking location by operating the cursor on the navigation screen; in another, the driver's parking route is memorized and accurately reproduced.

2. Nissan ProPILOT Park

ProPILOT Park was first installed on the second-generation LEAF released in 2017. A parking assistance system(2) automatically detects the target parking location and calculates the optimal parking route, including forward and reverse pull-ins, by detecting parking space lines using the Around View System(1) and assessing the available space, such as between vehicles, using sonar. The driver presses the “parking start” button, and the system automatically controls the driving operations (steering wheel, accelerator, brakes, and shift switching) to assist the parking process at the target parking location (Figs. 1 and 2). ProPILOT Park was later installed in SAKURA, X-TRAIL, and ARIYA.

In 2023, Nissan’s first ProPILOT Park with memory functions was installed in SERENA (Fig. 3). This chapter introduces the latest memory function technology used for registering and detecting parking locations.

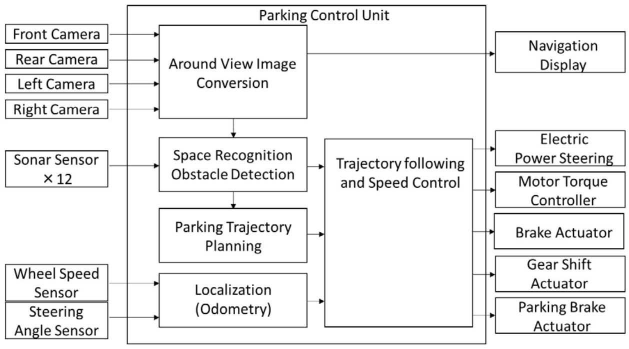
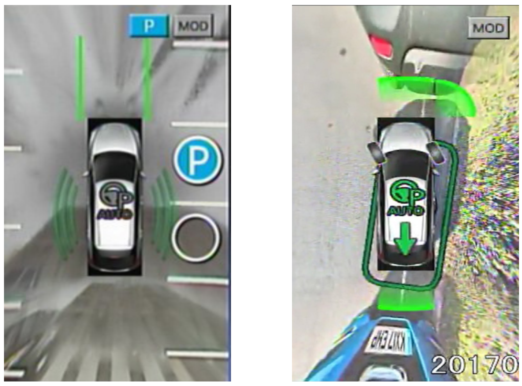


Fig. 1 System configuration of ProPILOT Park



Detection of target parking location　Parking control (parallel parking)

Fig. 2 Parking location detection and parking control

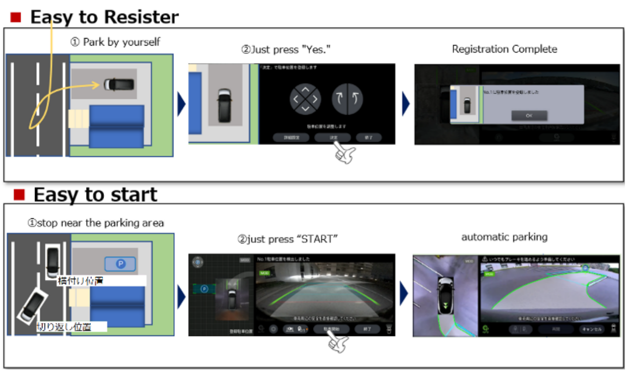


Fig. 3 ProPILOT Park with memory function

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3. ProPILOT Park with memory function*

The memory function was designed that the driver can register a parking location easily and seamlessly transit from normal driving operation to parking assistance. This system is running in the background automatically while the driver is driving at low speeds. And drivers can do one-touch registration of the parking location. (Fig. 3, top). Afterward, whenever the driver stops near the registered parking location, the system automatically detects the parking location via the global navigation satellite system (GNSS) and automatic memory selection (Fig. 3, bottom) to initiate parking assistance. The system can detect the registered location as long as the vehicle is near it in a standstill condition.

*equipped in Serena (as of July 2024).

4. System configuration

Fig. 4 shows the configuration of the ProPILOT Park system with a memory function. Equipped with a newly developed 3-megapixel around view camera, this system captures detailed images of nearly the entire vehicle surroundings, including the road surface. In addition, the left and right door mirrors are equipped with infrared light emitters for nighttime sensing. Furthermore, GNSS information is acquired, linked to the memory information, and used to detect the parking location automatically.

5. Registration and detection of parking location

The memory function uses the around view camera to capture the road surface images and extracts its features. Then it compares the registered road surface features with the current ones to determine the parking location. These features are mapped and saved for a maximum distance of approximately 40 m, near the parking location. Using this wide-area road surface map, the parking location can be detected from the parallel position and forward and reverse pull-in positions (Fig. 3, bottom).

5.1 Road surface maps

The road surface map is consist of keypoints and their descriptors with each coordinates along the driving route. Two different types of the maps are employed for registration and detection. In the registration phase, the map is created up to 20 m regarding forward and backward maneuvering from a switchback point, respectively. It includes all parking pathways from the switchback position on the road to the parking location (Fig. 5, Fig. 6(a)). In the detection phase, the map is created to specify registered target position and its range is consecutive 20 m including the vehicle position at the time of detection (Fig. 6(b)). The system automatically accumulates around view images at fixed distance intervals when driving at low speeds. Drivers do not need to perform any operations to begin recording or detection.

Fig. 4 Arrangement of the components of ProPILOT Park with memory function

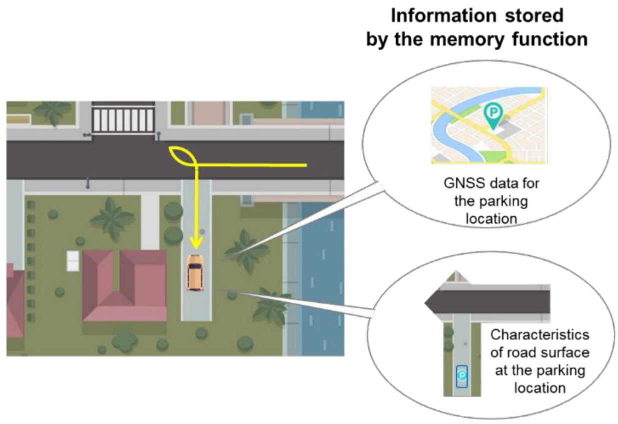

Fig. 5 Information registered in the memory function

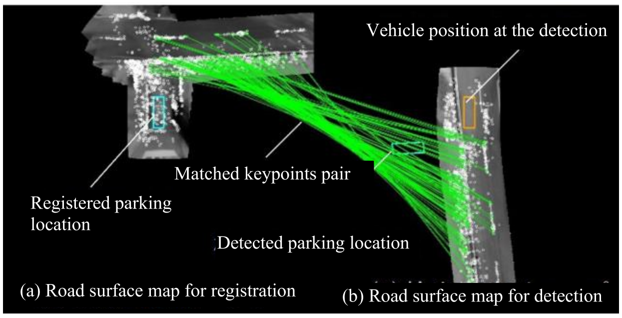

Fig. 6 Comparison of road surface maps

5.2 Detection of parking locations

The system compares the detected road surface with the registered road surface map to detect the parking location and connects the most similar pairs of image features. Here, an "image feature" refers to keypoints indicating the locations of corners, edges, etc., in the road surface map and the feature descriptors for identifying these points. However, if there are changes in the images owing to shifting 3D objects such as parked vehicles or bicycles or changes in sunlight conditions in the morning, day, or night, the performance of this comparison process can be poor. To overcome this issue, the automatic detection process is designed to extract robust keypoints(3).

5.3 Automatic detection of registered parking locations

At the registration of a parking location, the system links to and saves the GNSS location information (latitude, longitude, and vehicle orientation) obtained from the navigation system. After registration, the system automatically searches for a registered parking location within a certain distance from the vehicle using the present GNSS location information. When the vehicle stops near the registered parking location, the system automatically compares the detected road map with the registered one to identify the parking location. It displays it on the navigation screen (Fig. 7). If there are multiple registered locations within a certain distance from the vehicle, all registered locations within the range are compared with the detected road map, and the location with the closest distance is preferentially displayed. The driver can also manually select a parking location from the system memory.

5.4 Real-time correction

During the parking manuever, the parking location is detected by sequentially comparing the registered road surface map with the current image. As the vehicle approaches the parking location, this image can be directly compared to the parking location, thereby improving the accuracy of the parking operation. (Fig. 8)

6. Summary

This chapter describes the functions of Nissan ProPILOT Park and the latest recognition technologies enabling its memory function. This function allows the driver to register a parking location with a simple operation after parking and thereafter have the vehicle automatically detect when it approaches the same location (Figs. 9, 10, 11) to provide easy-to-operate parking assistance.

Fig. 7 Display when a parking location is automatically detected

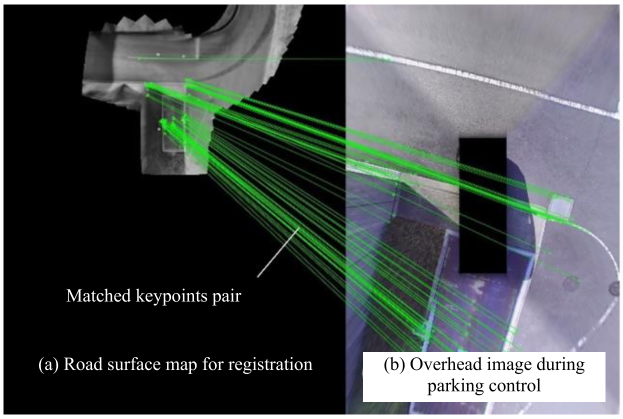

Fig. 8 Comparison of road surface maps with real-time correction

Fig. 9 Detection from the side-facing position

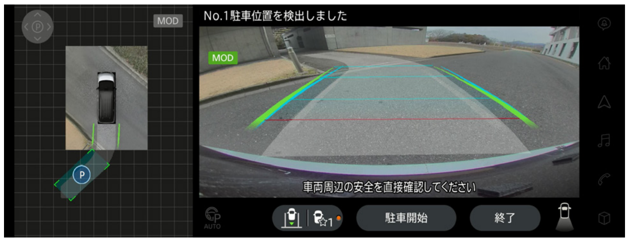

Fig. 10 Detection from the switchback position

Fig. 11 Detection of a deep parking position

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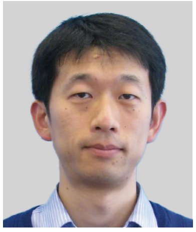
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4. The latest driver assistance technology aimed at achieving zero accidents

Nariaki Etori*

1. Introduction

In pursuit of its Nissan Ambition 2030 long-term vision, Nissan is developing high-performance next-generation LiDAR-based vehicle control technologies that will help to reduce traffic crashes significantly. As customers will need to use their cars confidently in the approaching era of autonomous driving, driver assistance technologies must be improved to avoid multi-dimensional and complex crashes that can occur in the real world. Nissan is working to provide higher levels of safety in real-world situations through two initiatives (Table 1).

The first initiative for ensuring a high level of safety is to clarify the nature of real-world traffic situations. A wide variety of crashes occur in the real world, ranging from frequent and simple to infrequent and highly complex situations. Due to the inherent challenges of conducting a comprehensive desktop study encompassing all potential complex scenarios that may result in severe crashes, statistical methods are often regarded as viable alternative research approaches. Nonetheless, the implementation of these statistical methods presents its own set of challenges. For instance, in the context of Japan, traffic crash statistics reveal an average distance traveled of approximately 240 million meters per fatal accident. This distance is equivalent to the total annual mileage of approximately 30,000 vehicles. Thus, many datasets are required to model infrequent crashes situations, and Nissan is working to collect data from mass-produced vehicles and conduct driving experiments accordingly.

The second initiative is to improve safety performance through automation. Under the “Safety Shield Concept,” Nissan is developing and commercializing technologies appropriate to the likelihood of different collision risks.

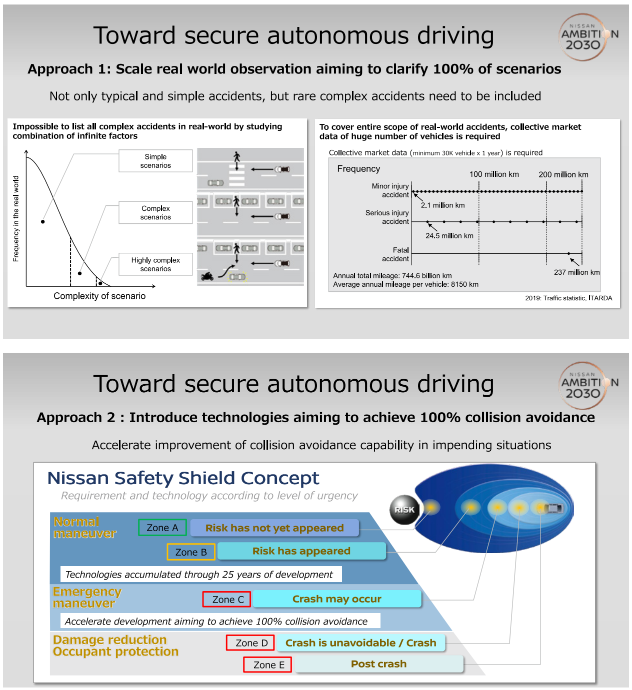

Table 1 Activities for delivering safe autonomous driving

Following approximately 25 years of technological advancements, Nissan is making significant strides towards achieving automation in regular usage. Nevertheless, there is a pressing need to expedite the development of accident avoidance technologies. This chapter introduces Nissan’s latest work on ground truth perception technology to further the automation of accident avoidance maneuvers.

2. Examples of complex crashes

Figures 1 and 2 show two examples of rare, complex crashes. In Fig. 1, the left lane is congested at a certain distance from a vehicle pulling a trailer. The vehicle notices the congestion late, swerves suddenly, and overturns the towed trailer, blocking three lanes in front of the vehicle of interest (autonomous driving vehicle).

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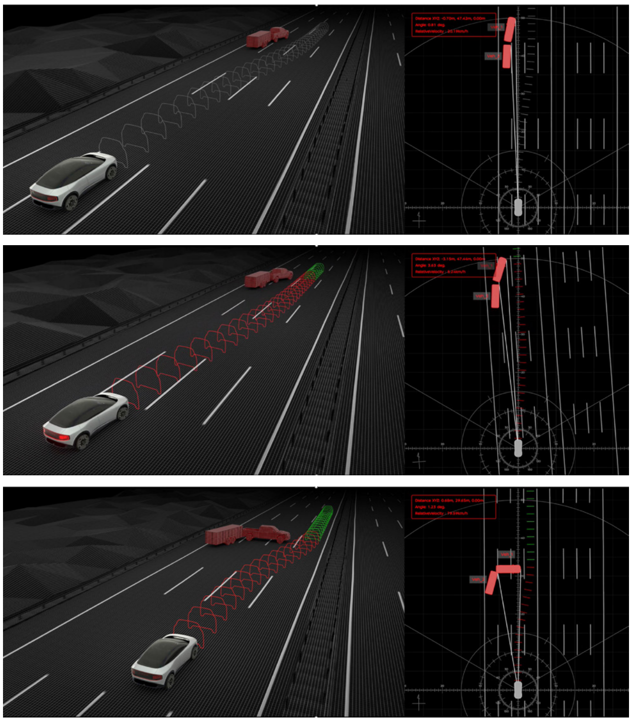

Fig. 1 Complex accident example 1

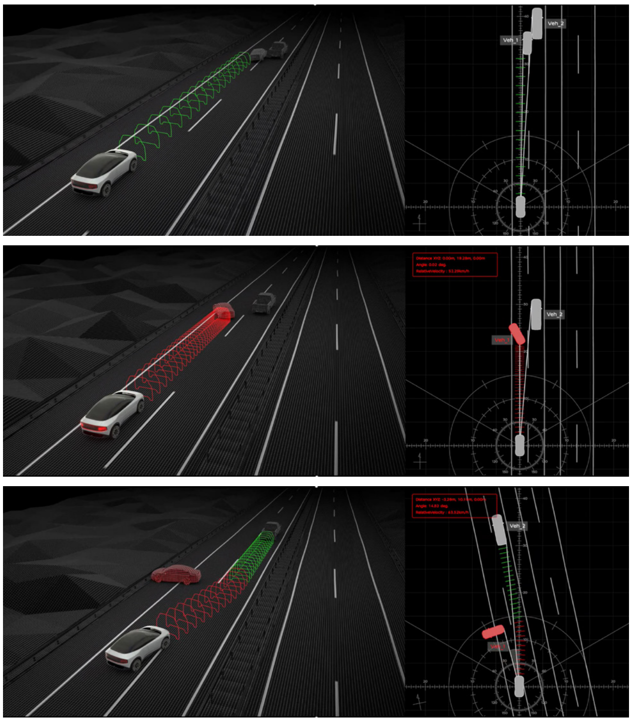

Fig. 2 Complex accident example 2

An autonomous driving vehicle should react to such a scenario by first attempting to avoid the trailer using the steering wheel as the trailer initially veers into the vehicle's traveling lane. However, further avoidance is required because the trailer overturns and blocks three lanes of traffic. Thus, the autonomous driving system must grasp the constantly changing situation accurately and near-instantaneously to take the appropriate evasive action.

In the second example, the vehicle running in front of the autonomous driving vehicle is distracted and collides with a truck in the adjacent lane, then slows down and collides with a guardrail, causing it to come to halt more abruptly than anticipated. (Fig. 2)

In this situation, the autonomous driving vehicle should first attempt to avoid collision by braking because the vehicle in front slows down after its collision with the truck. However, the vehicle in front subsequently stops suddenly, requiring the autonomous driving vehicle to avoid collision by making an urgent avoidance maneuver. Given that the vehicle in front veers into the traveling lane of the autonomous driving vehicle, the steering wheel is used in this maneuver. Again, the constantly changing situation must be grasped accurately and near-instantaneously to inform evasive action according to the situation.

As indicated by these examples, the accident avoidance maneuvers required of autonomous vehicles involve accurate and rapid recognition of space and objects in three dimensions and the performance of continuous evasive maneuvers based on instantaneous judgments under ever-changing conditions.

3. Ground truth perception technology

Innovation in recognition performance is critical for delivering the accident-avoidance maneuvers required from autonomous driving vehicles. Thus, Nissan’s newly developed ground truth perception technology uses next-generation high-performance LiDAR in addition to conventional cameras and radar to gather data describing the vehicle surroundings, as shown in Fig. 3.

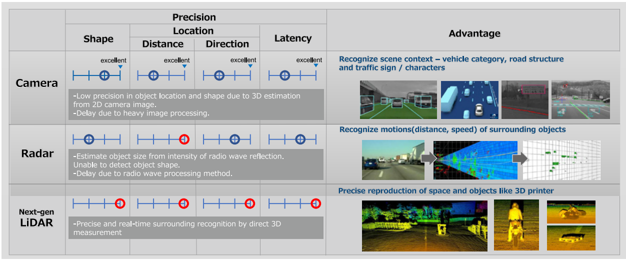

Fig. 3 Features of camera, radar, and LiDAR systems

As cameras capture a large quantity of information, they can clarify the meaning (context) of a situation. However, shape and position accuracy is lost when creating 3D information from 2D images. In addition, the algorithms for converting camera data into 3D information are complex. Therefore, cameras are unable to track objects during sudden changes in situation. Furthermore, though radar is excellent at capturing the movement of objects, it cannot determine accurate shapes because the strength of the radio wave reflection can only be used to determine the size of an object. The complex algorithms employed for radar data processing also make tracking objects difficult when they move suddenly. In contrast, LiDAR can directly measure spatial structures without requiring complex interpretation, allowing it to quickly follow changes in the situation and reproduce spatial structures in the processor of an autonomous driving vehicle analogous to the accuracy of a 3D printer. By integrating and maximizing the advantages of these three sensor types, autonomous driving vehicles can expand their capabilities to match or exceed those of humans.

While conventional LiDAR cuts space into extremely thin angles, hindering its understanding of space and objects and thereby limiting its potential capabilities, next-generation high-performance LiDAR can capture the environment from a wide angle, similar to cameras, with a vertical detection angle of 25° or more. Furthermore, next-generation high-performance LiDAR can achieve a detection distance of 300 m, more than twice that of conventional LiDAR. This increased distance allows vehicles at the tail end of traffic jams to be detected early and subsequently avoided by making normal lane changes at speeds of up to 130 km/h, the typical maximum speed on highways worldwide. Because doubling the detection distance causes the LiDAR beam to spread farther, its resolution must also be doubled and reached 0.05° or less in next-generation LiDAR systems accordingly (Fig. 4).

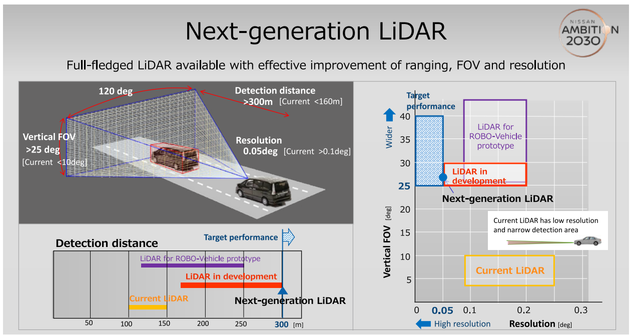

Fig. 4 Next generation LiDAR

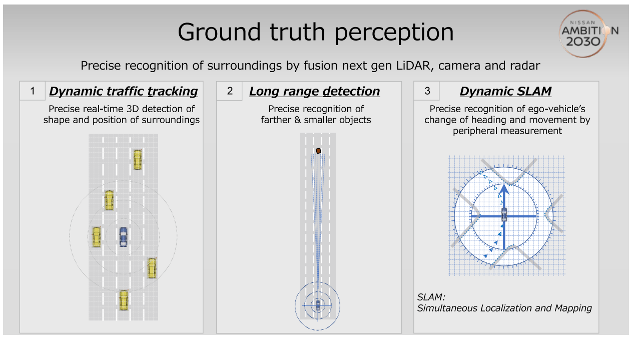

Fig. 5 Ground truth perception

Sensing technology combining cameras, radar, and next-generation LiDAR enables dynamic traffic tracking, long-range detection, and dynamic simultaneous localization and mapping (SLAM), as illustrated in Fig. 5.

Dynamic traffic tracking accurately captures road configurations as well as the movement of surrounding vehicles without delay, improving emergency response performance. Long-range detection identifies vehicles more than 300 m away, facilitating the management of most incidents on highways. Finally, dynamic SLAM detects obstacles in the area by accurately measuring the surrounding space and tracks the vehicle's movement based on changes in its spatial view. This accurate tracking of self-movement allows autonomous driving even in areas where no map is available, such as hotel premises, making door-to-door driving functions possible.

4. Ground truth perception prototype vehicle

This section introduces a prototype vehicle equipped with ground truth perception technology. The vehicle system configuration is shown in Fig. 6.

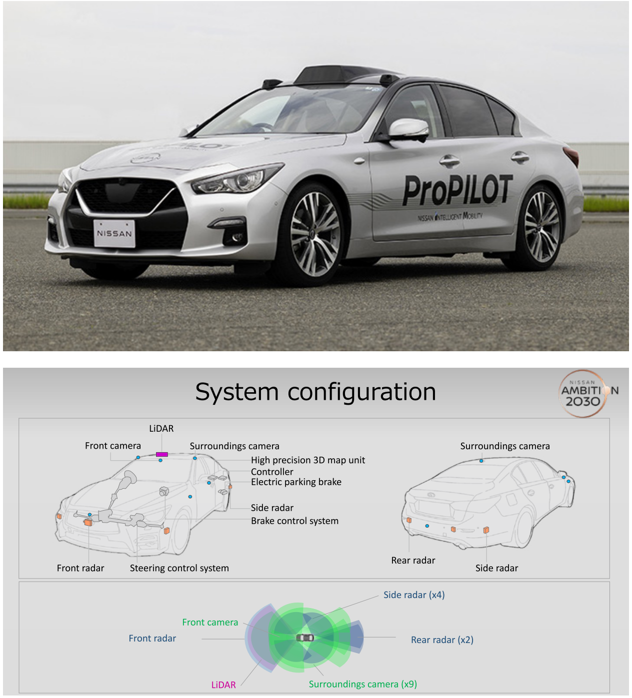

Fig. 6 Appearance and system configuration of the prototype vehicle

This prototype vehicle was equipped with seven radars, ten cameras around the car body, and a next-generation LiDAR mounted on the rooftop to help ensure that surrounding vehicles do not block the beam and provide long-distance spatial recognition.

5. Latest driver assistance technologies using ground truth perception technology

This section describes the performance of the prototype vehicle in three scenarios.

The first scenario (Fig. 7) involved avoiding a vehicle being backed out of a parking lot along the road and then making an emergency stop responding to a pedestrian suddenly appearing ahead. In this scenario, the shape and position of the surrounding objects were accurately recognized without delay, and emergency operations were continuously performed based on instantaneous judgments, thereby allowing automated continuous maneuvers to avoid the backing vehicle and pedestrian.

Fig. 7 Automated emergency maneuvers to avoid a vehicle and pedestrian

The second scenario (Fig. 8) considered a rolling tire detached from a vehicle running in the oncoming lane. First, the tire approached the front of the prototype vehicle, and then the oncoming vehicle (without its tire) crossed the median strip into the traveling lane. In this scenario, the system accurately recognized the shapes and positions of the surrounding objects without delay and again conducted successive avoidance maneuvers based on instantaneous judgments.

Fig. 8 Detection and avoidance of an approaching tire

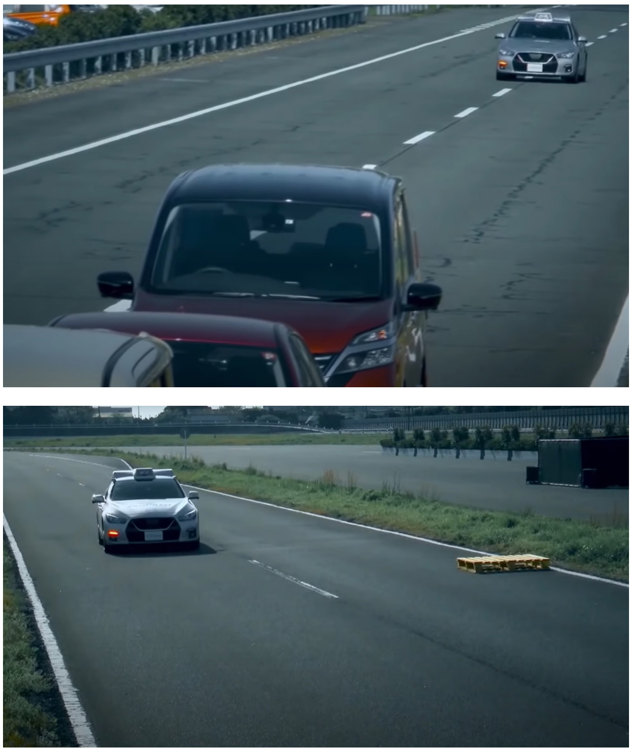

Fig. 9 Avoidance of traffic jams and obstacles on the road via lane-changing operations

In the third scenario, the prototype vehicle quickly detected the end of a traffic jam as well as obstacles on the road while driving at high speed (Fig. 9). The vehicle first moved to a safe lane using a normal lane-changing operation, then recognized the surrounding road structure on an unmapped road, calculated the route to take, and autonomously traveled to the destination the front of a door (Fig. 10).

These scenarios illustrate the evolution of driver assistance technologies by developing ground truth perception technology, which will eventually realize address-to-address autonomous driving.

Fig. 10 Automated emergency maneuvers of the prototype vehicle to arrive at destination

6. Conclusion

Nissan believes that the automation of accident avoidance maneuvers is the first task that must be achieved to deliver a reliable autonomous driving experience and intends to accelerate further the progress of technological development introduced here to advance the evolution of autonomous driving technologies steadily.

Authors

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