3 Ensuring the Safety of Automated Driving

Technological Development and Education for Enhanced Safety (Overview)

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1 Background and Significance

Ensuring safety and reliability is the most important issue in the practical implementation and deployment of automated vehicles, and there is an urgent need to establish a safety assurance method for automated vehicles. In addition, communication between automated vehicles and other traffic participants must be conducted flawlessly. Therefore, SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services) decided to address the following three issues for technological development for enhanced safety.[1]

(i) Building of safety assurance environments in virtual environments

(ii) Sustainable and effective measures against cyberattacks on connected cars (cybersecurity)

(iii) Establishment and dissemination of appropriate methods for communicating the intentions of automated vehicles to people, and effective education and awareness methods for people using automated vehicles and automated driving services (safety education)

Currently, addressing the building of a safety assurance method for automated driving is also the matter of greatest interest globally, and various initiatives are in progress. SIP-adus is also conducting safety assurance on public roads, such as the FOTs (Field Operational Tests) in the Tokyo waterfront area, and these driving tests on public roads and testing of actual cars at testing sites are also important, but evaluation via simulations that are reproduceable and that can also generate critical conditions are essential as well. Therefore, SIP-adus is particularly focusing on the evaluation of sensor performance, with the aim of building simulation models which are highly consistent with real environments and can be an alternative to test evaluations in real environments, and has commenced the development of a safety assurance simulation platform in a virtual environment that can perform evaluations under various conditions based on the relevant models.

Regarding cybersecurity, in the first phase of SIP-adus, the establishment of a method for evaluating the level of cybersecurity protection against cyberattacks from outside the vehicle was addressed, and an evaluation method for during the development phase was developed. On the other hand, because cyberattack technology continues to evolve, a system to detect and monitor cyberattacks during vehicle operation after a vehicle is on the market is also necessary.

Currently, Intrusion Detection Systems (IDS) for cyberattacks against vehicles by third parties in bad-faith are garnering attention as countermeasures against this issue. The development of a method to evaluate the performance of IDSs was addressed in the second phase of SIP-adus.

In addition, as a human-machine interface (HMI) issue, research and development was conducted on the appropriate indication and education methods to avoid communication errors when automated vehicles encounter other vehicles, pedestrians, etc. in mixed traffic.

The research and development of all three of these issues were progressed in cooperation with the German Federal Ministry of Education and Research (BMBF) under the Japanese-German cooperation framework. [See Section 6 2) for more details]

2 Building of safety assurance environments in virtual environments

Because the current evaluation method, which is centered around FOTs using actual vehicles on public roads, does not

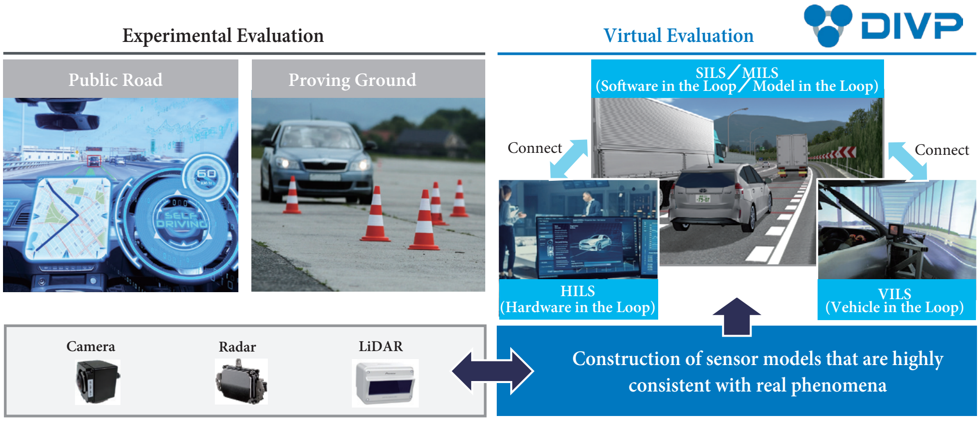


Fig.1: Consistency verification of DIVP's sensor model

allow for the intentional setting of the necessary driving environment conditions, which makes it difficult to determine whether or not an automated vehicle meets the required safety and to evaluate all of the various events that occur on public roads using actual vehicles, there was an urgent need to develop a method to assure the safety of automated vehicles under specific driving environment conditions. In addition, it is considered necessary to develop simulation tools that focus on sensor performance evaluation in order to improve the efficiency of safety assurance using actual vehicles, which takes an enormous amount of time in the current development of automated vehicles.

Therefore, SIP-adus program to develop simulation models which are highly consistent with real phenomena and can be an alternative to test evaluations in real environments, in order to conduct safety assurance with high reproducibility under various traffic environments. (Fig.1)

A consortium consisting of three universities (Kanagawa Institute of Technology, Ritsumeikan University, and Toyota Technological Institute) and ten companies (Hitachi Astemo, Sony Semiconductor Solutions, Denso, Toyota Technical Development, Pioneer, Biprogy, Mitsubishi Precision, Soken, Solize, and Yushin), led by Professor Hideo Inoue of the Kanagawa Institute of Technology, and the all-Japan organization commenced the building of the Driving Intelligence Validation Platform (DIVP®), a safety assurance environment platform in a virtual environment. This "virtual environment model" is a model that enables the safety assurance of an automated driving systems by modeling the geometric information and reflectance and spatial propagation properties of objects under traffic environment scenarios, and detecting them with a refined sensor model (Fig.2); by changing the various environmental factors such as time of day, the weather, vehicles, and infrastructure, it is possible to evaluate a system under any conditions.

In this model, in order to accurately simulate the sensor outputs, the detection principles of each sensor and physical phenomena in the electromagnetic wave band used are modeled based on the principle of reflectance properties, and consistency is verified by comparing the results with those of actual vehicle tests. In addition, there are "virtual environment models" which correspond to cameras, radar, and LiDAR respectively to make the simultaneous evaluation of these sensors possible. (Fig.2)

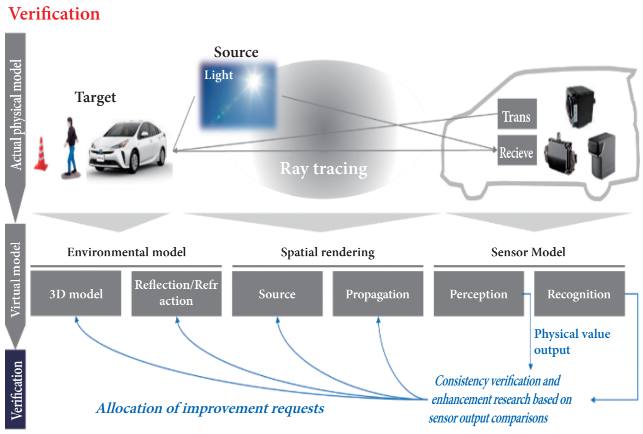


Fig.2: Virtual environment model and sensor model

From FY2021, we have cooperated with the AD-URBAN (FOT project of Automated Driving system Under Real city environment Based on Academic researcher's Neutral knowledge) step being undertaken by the Kanazawa University consortium to share scenarios where there was recognition failure in FOTs of LiDAR and cameras, evaluate the reproducibility in a virtual environment, verify the differences in recognition between the real environment and virtual environment, and improve the accuracy of the model. [See Section 3 2) for more details]

In addition, in order to ascertain the future needs of customers and to identify issues regarding the continuous operation of the DIVP data platform, a scenario package was prepared that stimulated sensor weakness scenarios in the Tokyo Waterfront City area, invited participants from automobile manufacturers and sensor manufacturers, and conducted a monitoring evaluation in two separate steps.

The results of the monitoring evaluation were generally

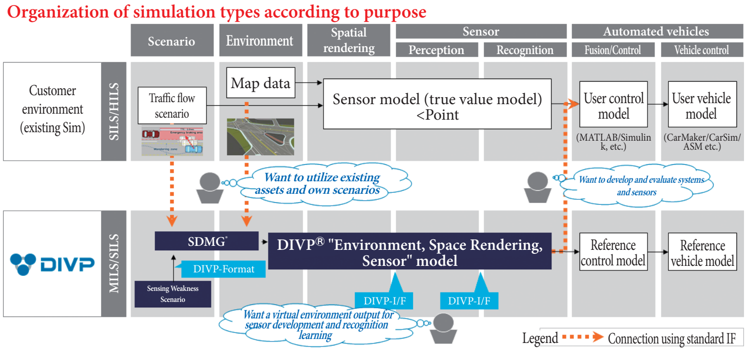


Fig.3: Connectivity between customer environment and DIVP

favorable, and the simulation experience conducted in STEP-1 was rated higher than other simulators in terms of the reliability of the simulation and the adequacy of the assets. In STEP-2, several companies from among the participants in STEP-1 were selected and a detailed evaluation verification was conducted on the connectivity of the system with various existing simulation environments, the output of simulation results when the scenario environment was arranged based on the virtual environment that had been prepared, and the connectivity of the system with the participants' various models and systems. (Fig.3)

Automated vehicles utilize a complex combination of sensors such as cameras, radar, and LiDAR, and it is essential to evaluate them via sensor fusion. In this case, evaluation of combinations of various sensors is necessary, and standardization of the interfaces is important to realize this in a simulation. For this reason, the standards of the German-based standardization organization Association for Standardization of Automation and Measuring Systems (ASAM) were used to ensure compatibility with existing simulations.

In addition, SIP-adus started a cooperative project called the VIrtual Validation methodology for Intelligent Driving systems (VIVID) with the German research project VIVALDI in October 2020, and the standardization of safety assurance systems and simulation interfaces for automated driving by organizations such as the International Organization for Standardization (ISO) and ASAM while strengthening international cooperation efforts was promoted through these activities. [See Section 6 5) for more details]

On the other hand, the establishment of safety assurance methods for automated vehicles requires verification of the validity of scenario definitions and evaluation criteria. To accelerate the practical implementation of safety assurance technology, DIVP has cooperated with the Safety Assurance KUdos for Reliable Autonomous Vehicles (SAKURA) Project being conducted by the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure and Transport, based on a proposal by the Safety Assurance Subcommittee of the Japan Automobile Manufacturers Association (JAMA), and established a working task force and steering committee to jointly promote the project in FY2021.

As a result of the DIVP activities over the past four years, the practical implementation of a platform that enables streamlined scenario generation, recognition performance evaluation, and vehicle control verification is in sight, and V-Drive Technologies, a new company (100% owned by Biprogy) that provides DIVP's research results as a tool chain, was established in July and started general sales in September.

3 Cybersecurity

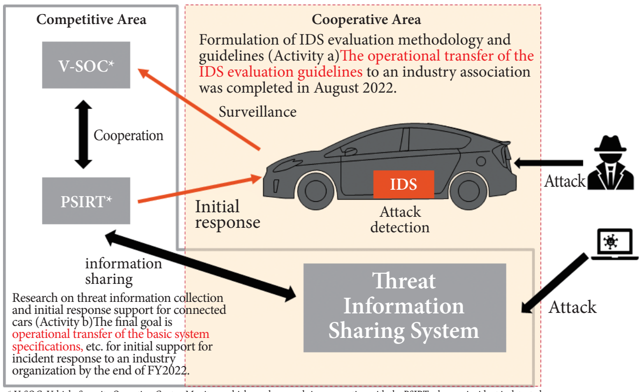
Automated vehicles need to acquire road traffic environment data such as high precision 3D maps and traffic signal information via communications. Cyberattacks are a major threat to automated vehicles and other vehicles with communication functions, and it is extremely important to take cybersecurity measures in anticipation of cyberattacks. Several cases of cyberattacks on vehicles have already been reported at international conferences, and Intrusion Detection Systems (IDS) are attracting attention as a countermeasure against cyberattack methods, which continue to evolve even after vehicles are put on the market.

On the other hand, since IDS is a countermeasure against unknown cyberattacks, it is difficult to evaluate its performance. Therefore, SIP-adus has worked on an evaluation guideline for IDSs. In this project, in addition to examining IDS in cooperation with an industry organization (JASPAR), IDS performance evaluation was conducted using a testbed and actual vehicles, IDS evaluation methods were established, and the formulation of IDS Evaluation Methodology and Guidelines was completed. The results of this research were transferred to JASPAR in August 2022 and are planned to be used as industry guidelines in the future.

Although the number of vehicles with communication functions is increasing each year, there have not been many hacking incidents that concerned safety because they have been used mainly for entertainment purposes. However, the number of such incidents is anticipated to increase as automated driving commences in the future and information obtained from communications is used for control.

Therefore, the active collection of threat information from cyberattacks on connected cars was attempted, and the development of observation, collection, analysis, and storage methods, as well as the definition of basic specifications for a threat information sharing system to support initial response activities was conducted.

The basic specifications of this threat information sharing system will be transferred to an industry organization (J-Auto-ISAC) at the end of FY2022, and the future improvement and utilization is also planned. (Fig.4)



* V-SOC: Vehicle-Security Operation Center. Monitors vehicles and responds in cooperation with the PSIRT when an incident is detected.
* PSIRT: Product Security Incident response Team. Receives incident reports from V-SOC and third parties and responds.

Fig.4: Scope and final goals of the activities (in red, within the dotted lines)

Regarding this project, based on the cooperation framework between SIP-adus and BMBF, a cooperation project called SAVE (Securing Automated Vehicles) was commenced in October 2020 with the German research project SecForCARs (Security For Connected, Autonomous Cars), and international cooperation was promoted through studies, etc. of threat information sharing systems. [See Section 6 7) for more details]

4 Safety education

Road safety is ensured by the three complementary elements of people, vehicles, and the traffic environment, and it is difficult to ensure safety through vehicles alone. Currently, various driving safety support systems such as Autonomous Emergency Braking (AEB) are widely used and are steadily contributing to the reduction of accidents, but conversely, accidents caused by overconfidence are sometimes seen. It is therefore necessary for all traffic participants to have a correct understanding of automated driving. Regarding this issue, SIP-adus investigated the ideal HMI, including appropriate indication and education methods, while taking international trends into consideration, and conducted studies toward the development of the necessary technology and creation of guidelines. The initiatives focused on the following three details as the cooperative area related to HMI.

(1) Assuming movement and logistics services that use automated vehicles equivalent to SAE Level 4™, smooth communication methods that ensure the safety of automated vehicles and surrounding traffic participants (pedestrians, bicycles, drivers of other vehicles, etc.) and that allow them to clearly understand each other's intentions were derived. [See Section 3 5) for more details]

(2) An HMI was developed for the appropriate taking over of driving when the driving environment conditions deviate or when the function of the automated driving system deteriorates, and education methods for drivers were derived. [See Section 3 6) for more details]

(3) As a preliminary step before the introduction and spread of vehicles with automated driving at SAE level 3™ or higher, the knowledge that drivers, pedestrians, etc. should acquire regarding driver assistance systems equivalent to SAE level 2™ and effective education methods for them were derived. [See Section 3 4) for more details]

Regarding this project, cooperation with a German research project was commenced in July 2019, based on the cooperation framework between SIP-adus and BMBF, and the setting of research topics and verification of the validity of the research methods for the three issues mentioned above was progressed. In addition, the results were widely disseminated worldwide, and international standardization was conducted while strengthening international cooperation efforts. [See section 6 4) for more details]

[References]

(1) Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services R&D Plan, https://www8.cao.go.jp/cstp/gaiyo/sip/keikaku2/4_jidosoko.pdf, (accessed 30th June 2022)

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1) Development of Driving Intelligence Validation Platform (DIVP®) for Automated Driving Safety Assurance

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(Abstract) As automated driving systems become more complex, there is a need to ensure the safety of countless driving environments. However, safety validation on current automated vehicle relies on comprehensive results evaluations in real driving environments and are quite costly in terms of people, material, money, and time. It is also difficult to test the physical perception and recognition performance limits of camera, radar, LiDAR, and other such external sensors with respect to physical phenomena that occur in the real world. In other words, there is the issue of how far to go in constructing systems to guarantee safety (How safe is safe enough?) Against this backdrop, this research project will build an assessment platform for virtual simulations that can achieve "highly consistent modeling of driving environments, spatial propagation, and sensors" with real phenomena, as is needed to conduct automated driving safety assurance. The goal is to enable detailed and efficient safety assurance for automated driving systems under a large number of scenarios.

Keywords: automated driving, virtual environment, external sensor, virtual simulation, safety assurance

1 Project Background and Overview

The National Highway Traffic Safety Administration (NHTSA) of U.S. Department of Transportation has investigated accidents involving self-driving vehicles and reported cases in which the sensors failed to detect objects and detected objects were not properly recognized.(1)(2) Currently, a variety of different approaches to safety assurance are being tried in countries around the world. As a typical example, the PEGASUS project, founded by Germany's Bundesministerium für Wirtschaft und Energie (BMWi) and its successor, the SET Level project, propose validation and verification methodologies based on driving scenarios.(3)(4)

Through these activities, it is essential to utilize a simulation evaluation environment to evaluate the safety of automated vehicles under weather conditions that are difficult to reproduce and accident/near-miss conditions that are dangerous to reproduce. In particular, whether sensors can correctly perceive and recognize objects is important point and a simulation infrastructure equipped with sensor models that are highly consistent with real phenomena supporting these processes, is needed. However, so far, there has been no full-scale research and development of a simulation with high fidelity on sensors' performance. As part of the second phase of SIP-adus, the Driving Intelligence Validation Platform ("DIVP®") project, a research and development project undertaken by a consortium of collaborating sensor manufacturers, software firms, universities, and other organizations, was launched at the end of 2018. (Fig.1) The project aims to build a simulation platform for automated driving safety evaluation in a virtual space focusing on sensor models that are highly consistent with actual phenomena.

In this project, above-mentioned 13 organizations in industry-academia collaboration (Fig.2), by connecting with each other by utilizing their respective expertise, work on the construction of interface specifications for the safety evaluation platform including automated driving control models in addition to a series of virtual space models of "driving environment-spatial propagation-sensors", with the aim of contributing to global standardization.

2 Highly consistent sensor modeling with real phenomena

External recognition sensors differ from standard vehicle component models and play a dynamic role in connecting driving environment models with automated driving control. Conventional simulators put an emphasis on evaluating whether or not system control functions properly, and sensor models based on true value (normal function) are often used. As mentioned above, automated vehicle safety assurance requires identifying the strengths and weaknesses (limits) of peripheral surveillance sensors and making improvements to system design, sensors, and sensory perception algorithms.

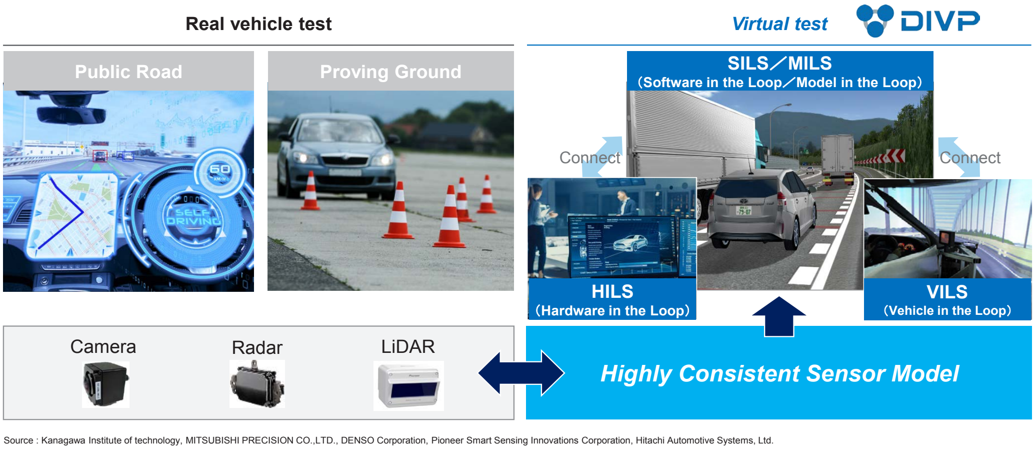

Fig.1: Necessity of sensor models highly consistent with real phenomena

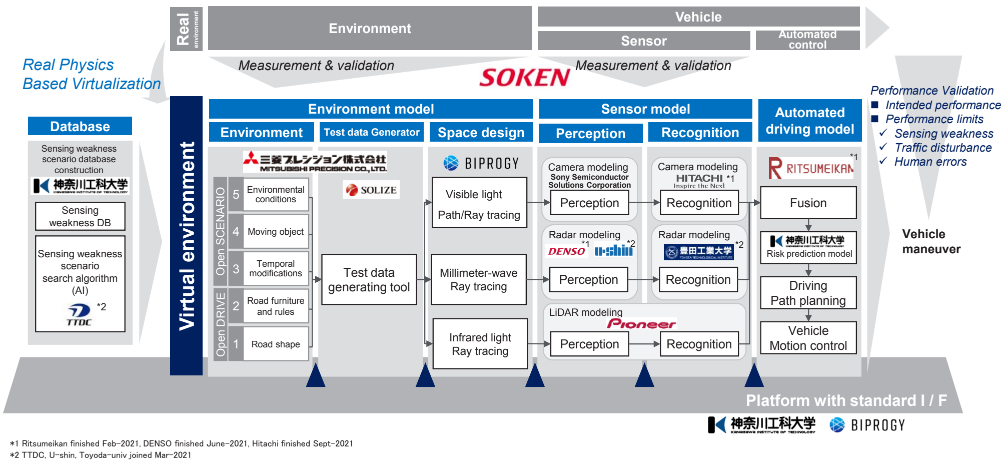

Fig.2: DIVP project structure

However, with true value-based sensor models, it is difficult to incorporate electromagnetic wave spatial propagation validation results into models. This presents problems for incorporating into models the kinds of scenarios that sensors struggle with. This project is taking the reflectance properties (retro, diffusion, specular reflection, etc.) and transmission properties of millimeter wave radar waves, visible light used in cameras, and near infrared light used in LiDAR, and is building a physical model and designing a spatial propagation model for ray tracing and other applications. Additionally, using sophisticated experimentation and measuring technologies, we are building a physical model for real phenomena that changes based on peripheral environment effects such as rain, fog, and peripheral illumination such as sunlight. This project's focus on incorporating spatial propagation properties as seen through sensors into a model consisting of driving environments, spatial propagation, and sensors based on electromagnetic principles sets the project apart from other DIVP simulation platforms. (Fig.3) Specific examples of each model are given below.

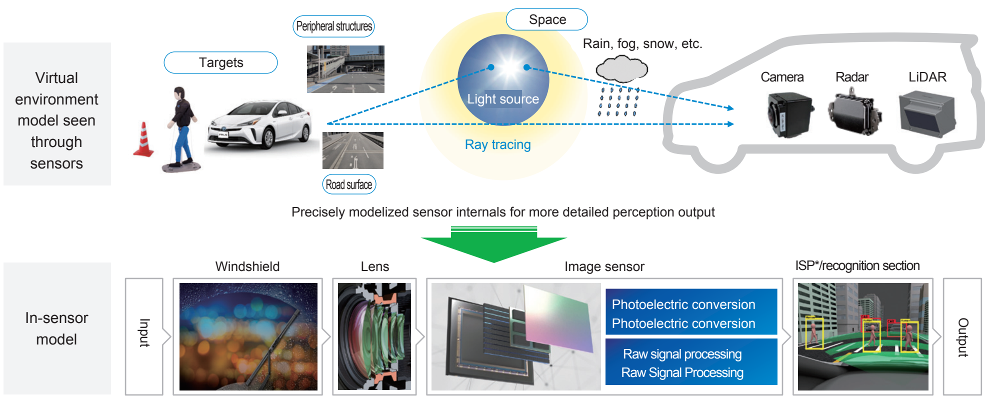

Fig.3: Sensor model for replicating spatial propagation (camera example)

2.1. Camera model

Rather than the RGB workflow which can show images to humans, the camera model in the DIVP simulates spectral properties that are input into CMOS and other semiconductors. Moreover, sunlight has been formulated as a sky model, allowing precise sunlight sources to be simulated by inputting the time of day, latitude, and longitude. As shown below, objects are given defined reflection properties and highly realistic simulation images are achieved. (Fig.4)

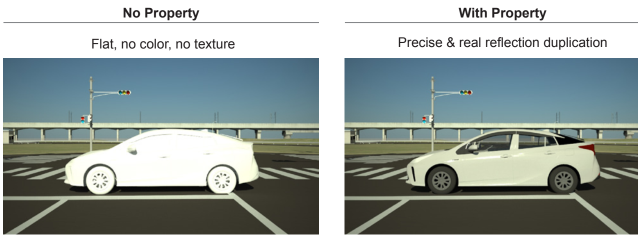

Fig.4: Impact from presence or absence of object reflection properties

This allows for replicating the darkness of a tunnel or the strong sunlight backlighting seen when exiting a tunnel, scenarios where obtaining visible light is problematic, and for validating that high dynamic range ("HDR") camera models have sufficient visibility to discern objects. (Fig.5)

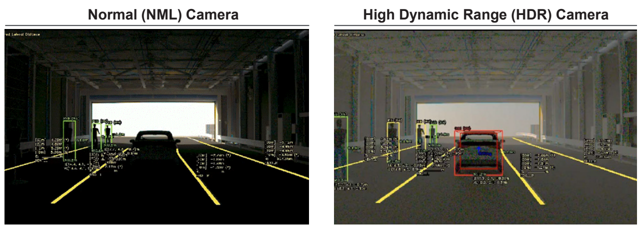

Fig.5: Sample image of Verification for HDR camera performance

2.2. Millimeter wave radar model

Millimeter wave radar is the sensor for which it is most difficult to create a model. We have defined three reflection models according to the behavior of radio waves on illuminated objects, and use them for each object accordingly. The physical optics approach is used as a setting model for small objects such as vehicles and people, while the geometric optics approach is used as a reflection model for roads and other large objects. The radar cross-section ("RCS") model uses predefined objects for purposes such as shortening analysis time. Each model is used for different scenario objects. (Fig.6)

The output of millimeter wave data is replicated well, including in the form of maps showing reflection intensity via X-Y coordinates (heat maps), as well as X-Y reflection point maps that show locations of strong reflection as target object reflection points. (Fig.7)

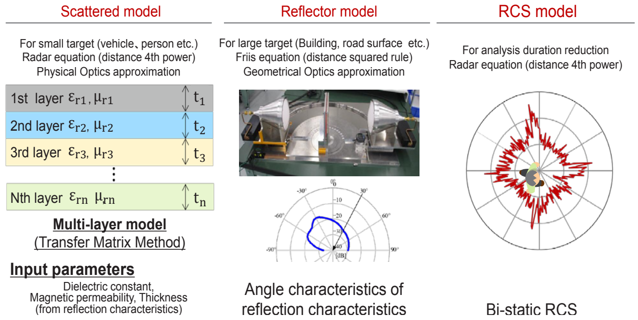

Fig.6: Three models for replicating precise reflection (millimeter wave radar)

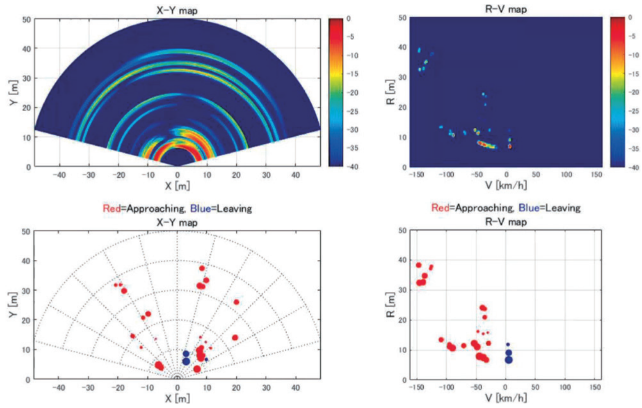

Fig.7: Examples of millimeter wave radar model output

2.3. LiDAR model

Near infrared light, which is used in LiDAR, is a sensor that is relatively easy to model due to its directivity properties. The LiDAR model shown below can assess background light and other environmental disturbances by performing 360° scans. By creating a model for scanning the near infrared light emitted by LiDAR and precisely replicating things like object footprint based on near-infrared light spread and the effects of sunlight and other background light, this project has made it possible to conduct simulations that are highly consistent with real phenomena, even for LiDAR. (Fig.8)

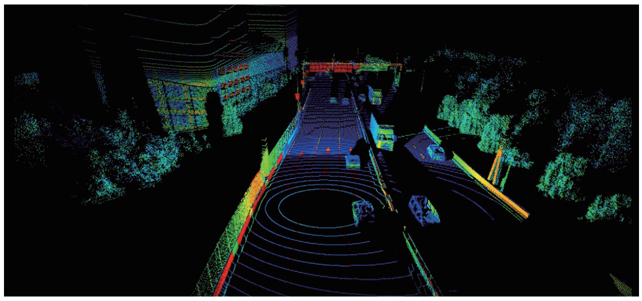

Fig.8: LiDAR model

2.4. Sensor output consistency validation

For the inputs and outputs of each sensor model, this project conducts quantitative consistency validations for simulation models by comparing test results in real environment. (Fig.9)

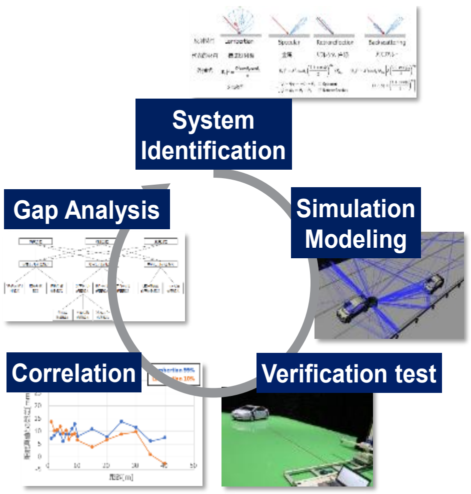

Fig.9: Efforts involving test-based consistency validation

Results show a high consistency with light source-related scenarios in which sensor use is problematic, including nighttime and back lighting such as from sunlight, as well as conditions such as rainwater deposited on glass surfaces. For falling snow scenarios and other phenomena difficult to replicate, we are validating consistency with models based on electromagnetic wave reflection and propagation analyses via test measurement.

3 Building a virtual environment model to address sensor detection weaknesses

3.1. Defining a virtual environment model

The European PEGASUS project defines six levels of driving environment scenarios and provides a high precision 3D map used for automated driving. These have defined driving environment data useful for automated driving control (self-location, traffic flow, routes, etc.), but there are few virtual environment models for which physical properties such as reflex, transmission, etc. from the perspective of external sensors have been defined. As virtual environment architecture as it relates to things such as sensor reflection properties, this project defines the following five areas and aims to build a virtual environment model that incorporates properties such as electromagnetic wave reflection, transmission, and attenuation.

(Fig.10)
(1) Traffic participants and other objects
(2) Peripheral structures
(3) Road surfaces
(4) Surrounding environment such as sunlight source, rain, fog
(5) Interface between sensor and environment (windshield, Radar snow and ice deposits, etc.)

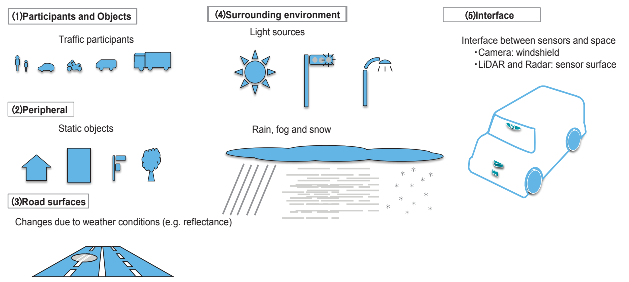

Fig.10: Virtual environment from the perspective of sensors

3.2. Environment model development process

Fig.11 shows the main components of the DIVP simulator structure. In addition to the OpenSCENARIO® and OpenDrive® data reading for scenarios defined in Germany's ASAM standard activities, there are seven characteristics of the structure: (1) a file defining the physical properties of materials validated based on reflection principles (commonly known as DIVP materials), (2) SDMG® (Space Designed Model Generator), (3) database of events with sensing weakness scenario and tools for compiling those events and generating a virtual environment model, (4) environment and space design model, (5) sensor perception model and recognition algorithm, (6) standardization of interfaces connecting inputs and outputs for each model, and (7) 3D model for objects and other assets.

Measurement and validation of reflection principles involves compiling a physical properties file (DIVP materials) as a simulation model consisting of reflex properties that are highly consistent with real phenomena. This is achieved by devising measurement systems for visible light, near-infrared light, and millimeter waves, and accurately measuring physical properties. (Fig.12)

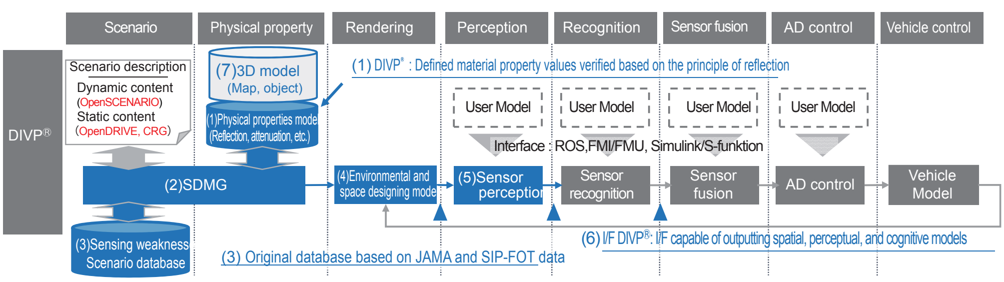

Fig.11: Structure of process from sensing weakness scenario description to virtual environment models generation

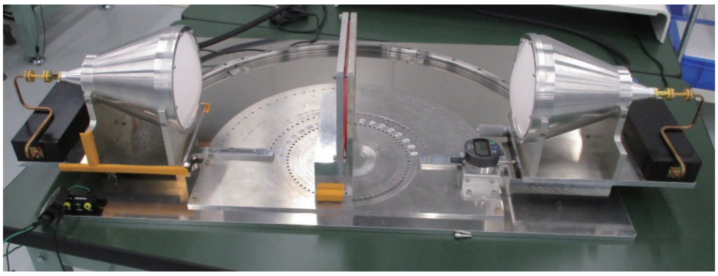

Fig.12: Millimeter wave measurement instruments

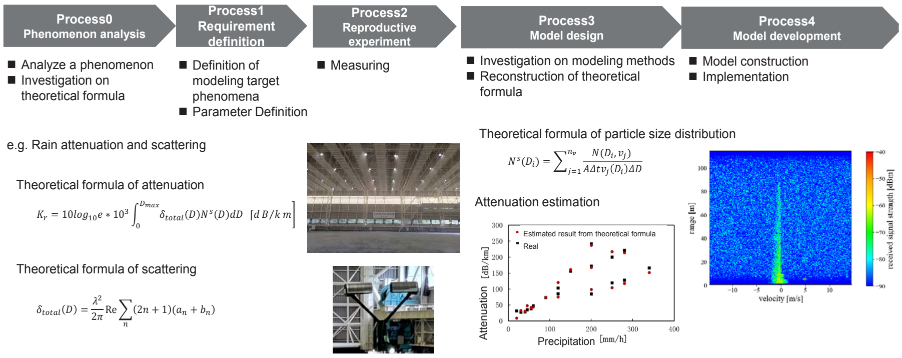

Fig.13: Space model development process

3.3. Development process for space models for propagation, attenuation, etc.

Replicating sensor detection with precision requires accurately replicating physical phenomena such as sunlight sources, rain, and fog. With cameras, for example, visible light emitted from light sources it propagates space and reaches object surfaces. After being reflected off of or passing through surfaces, propagates space and reaches the camera lens. Light passing through the lens undergoes photoelectric conversion, becomes electrical signals, and gets subjected to different kinds of control. (Fig.3)

Light diffusion, attenuation, etc. Events which occur at this time, such as light diffusion and attenuation, can have significant effects on the light input into cameras and therefore require precise replication. This is the case with millimeter-waveband radio waves in the case of millimeter wave radar, and with near infrared light in the case of LiDAR. This project is also defined by a development process for highly realistic propagation, attenuation, and other space models, with a focus on five areas: (1) analyzing phenomena and studying theoretical formulas, (2) defining phenomena for modeling, (3) replicating and measuring phenomena, (4) designing detailed models based on theoretical formulas, and (5) implementing models. (Fig.13)

3.4. Examples of nighttime road surface reflection models (cameras)

Precisely replicating road surface reflection properties for headlight light sources at night is important for camera and LiDAR models. As light sources hit surfaces at a low incidence angle when emitted from one's vehicle headlights, we optimized reflectance as a retroreflective model based on test values. This enabled camera simulation imaging highly consistent with real environments. (Fig.14)

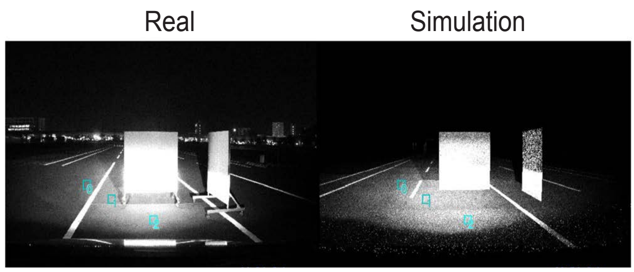

Fig.14: Nighttime image replication via optimization of headlight reflections on road surfaces

3.5. Examples of falling rain space models for LiDAR

This project is developing weather-related space models for such things as backlight, rain, and fog, which are difficult to replicate and evaluate using real vehicles. For a space model for falling rain, we are replicating and validating as a simulation model the effects on LiDAR signals by fake points caused by raindrop reflection according to real phenomena based on rainfall, as well as fake images caused by specular reflection on wet road surfaces. (Fig.15)

3.6. Building on 3D asset models for virtual environments

As mentioned above, this project is partly focused on models for virtual environment from the perspective of sensors, as well as sensor models to support those models. Through this

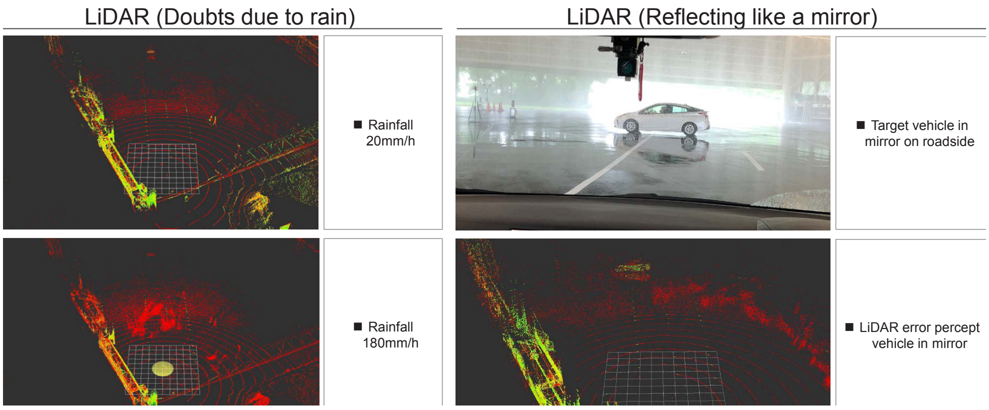

Fig.15: Effects of rainfall on LiDAR sensors (test)

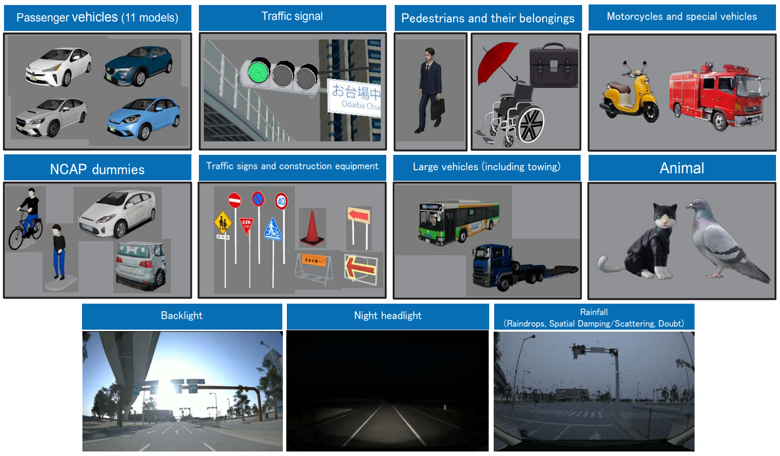

Fig.16: Replicable assets / space model expansion

project, we will gradually measure the reflection properties of objects needed for various kinds of evaluation environments, and will conduct comparative evaluations of real test values and simulation values while expanding our scope to include DIVP materials. For the 3D assets for the environmental models that will support these efforts, we are expanding these assets into a library that includes objects, roads, and peripheral structures. Being expended upon are assessment scenarios from things like the NCAP (New Car Assessment Programme), and high-priority asset models and space models for modeling of sensing weakness scenarios with, i.e., the Odaiba region and C1: the inner circular route of the Metropolitan Expressway, where the automated vehicle field operational tests (FOTs) are being conducted. (Fig.16)

4 Application of DIVP simulator towards automated driving safety assurance

Just how many safety assurance scenarios can be planned for remains a question to be answered, but assessment efficiency can be greatly improved by establishing high-consistency conditions in a virtual environment. For this reason, this project has established to build up evaluation scenarios—(1) NCAP and other such assessment, and (2) evaluations conducted via modeling communities of the FOTs at Odaiba and C1 Metropolitan expressway (to be focused on sensing weakness scenarios) —and work to create models consisting of driving environments, space propagation, and sensor perception and recognition. To create scenarios, it is important to establish virtual environment units as package scenarios in line with objectives, and conduct a series of reliable safety assurance using these package scenario units. (Fig.17)

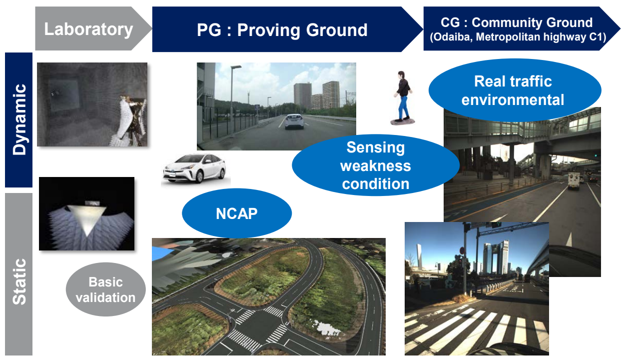

Fig.17: DIVP package scenario roadmap

	Scenario creation, unit validation for each asset / sensor			Closed-Loop validation	Scenario creation, unit validation for each asset / sensor	
	CPFA-50	CPNA-25	CPNA-75	CPNC-50	CPLA-25	CPLA-50
L1:Road Shape	No slopes, homogeneous / solid pavement, no irregularities (slopes, cracks, manholes), no features that could cause false sensor detection in the surrounding area					
L2: Objects / Rules	—					
L3: Temporal modifications	—	—	—	Obstacle vehicle	—	—
L4: Moving objects	Pedestrian (adult) runs and crosses the route from the driver's side (Far side). At a vehicle width of 50% without braking.	Pedestrian (adult) walks and crosses the route from the driver's side (Near side). At a vehicle width of 25% without braking.	Pedestrian (adult) walks and crosses the route from the driver's side (Near side). At a vehicle width of 75% without braking.	Pedestrian (child) runs and crosses the route from an obstacle (small and large vehicle) from the opposite side of the driver's seat (Near side). At a vehicle width of 50% without braking.	Pedestrian (adult) walking forward in the same direction. At a vehicle width of 25% without steering operation to avoid a collision after braking or FCW operation.	Pedestrian (adult) walking forward in the same direction. At a vehicle width of 50% without braking.
L5: Environmental conditions	Day	Day/Night	Day/Night	Day	Day/Night	Day/Night

Fig.18: NCAP evaluation environment modeling

4.1. Application toward NCAP assessment

As with advanced safety systems that have automated driving control such as AEB (Automated Emergency Break), ACC (Adaptive Cruise Control), and ALKS (Automated Lane Keeping System), assessment protocols are defined in detail under projects such as Euro-NCAP and J-NCAP. Although there is a small amount of variation with regard to traffic accident circumstances among countries, it is important to have protocols that incorporate accident information, including with respect to pedestrians, vehicles, and turning left or right at intersections, as well as scenarios such as cutting in and cutting out with automated driving ALKS. It is safe to say that this simulation can effectively replicate conditions such as when pedestrians suddenly step out into the street at night, a scenario where real vehicles are affected by peripheral light sources. This project is gradually creating models from NCAP scenarios, and 30 scenarios for existing Euro-NCAP protocols have been made into models. (Fig.18)

Shown below is an example of a simulation that incorporates a sensor model for a scenario where a pedestrian steps out from the shadow of a parked car. (Fig.19) Data can be output to cameras, Radar, and LiDAR simultaneously for one assessment scenario, enabling dynamic assessment.

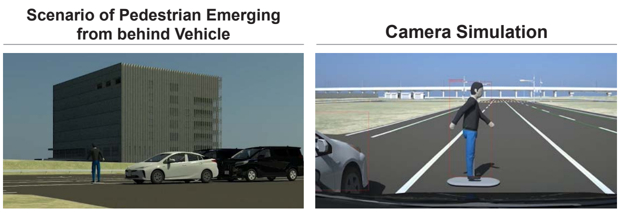

Fig.19: Simulation of a scenario involving a pedestrian stepping out from the shadow of a NCAP vehicle

4.2. Application toward real-world environment (Odaiba and C1 the Metropolitan Expressway) assessments

For the following package scenarios, we worked on building an environment model for Odaiba and the C1 Metropolitan Expressway, where the FOTs are being conducted. (Fig.20)

As virtual environments that provide a comprehensive combination of real world environmental factors (driving environment, roads, geographical features, dynamic objects, weather, etc.), these locations are useful in assessing scenarios that sensors struggle with. In coordination with other FOT projects that are part of SIP-adus, sensing weakness condition data (e.g., places, images, recognition output) generated in these real-world environments can be relayed to DIVP simulators, and can be sublimated to virtual environments that are assessed by a greater number of users as Virtual Community Grounds. The following shows examples of assessments conducted in virtual environments.

Fig.20: Odaiba driving environment model (camera simulation)

4.2.1. Applying toward white line detection weakness evaluation on road surfaces coated with heat resistant paint (LiDAR)

As part of automated driving field operational tests, our research has identified a phenomenon whereby LiDAR struggles to detect white lines on road surfaces coated with heat resistant paint in front of the Odaiba Telecom Center (data measured as part of "the 2nd phase of SIP-adus Research on the recognition technology required for automated driving technology (levels 3 and 4)" Kanazawa University (5). We determined that this is due to road surfaces coated with heat resistant paint tending to have stronger retroreflection components, and therefore approaching the reflection properties of white lines, and incorporated these findings into the simulation model. Fig.21 shows simulation results. While LiDAR can detect white lines on normal road surfaces (red lines in the Fig.), the simulation clearly shows that white lines are not being detected on road surfaces coated with heat resistant paint.

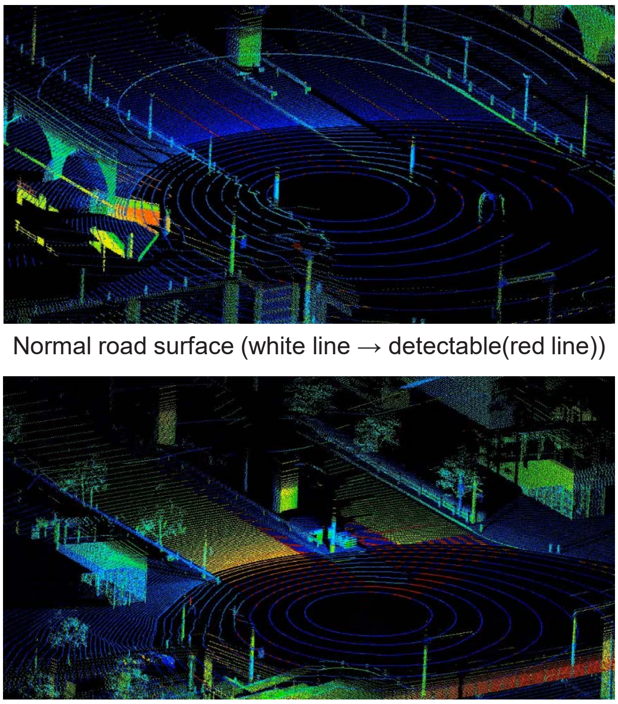

Fig.21: LiDAR simulation (area in front of Odaiba Station)

4.2.2. Applying toward signal recognition limit evaluation (identifying rainfall conditions)

Using the DIVP simulator for Kanazawa University's automated driving system ("AD-URBAN System," part of the AD-URBAN Project), we evaluated recognition limits based on the rainfall levels of a signal recognition algorithm. We replicated severe rainfall conditions that are not easily replicated in real-world vehicle evaluation by making modifications to these conditions as simulation parameters. We then derived evaluation conditions that arrive at signal recognition limits. In so doing, we were able to efficiently evaluate other algorithm and improvement conditions with good reproducibility, and were able to demonstrate the effectiveness of the DIVP simulator. (Fig.22)

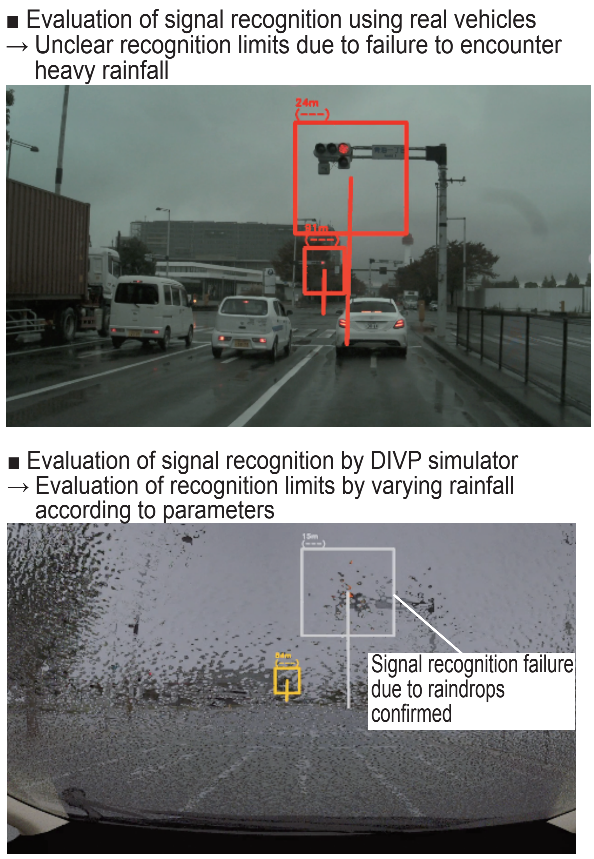

Fig.22: Signal recognition limit validation via DIVP simulator

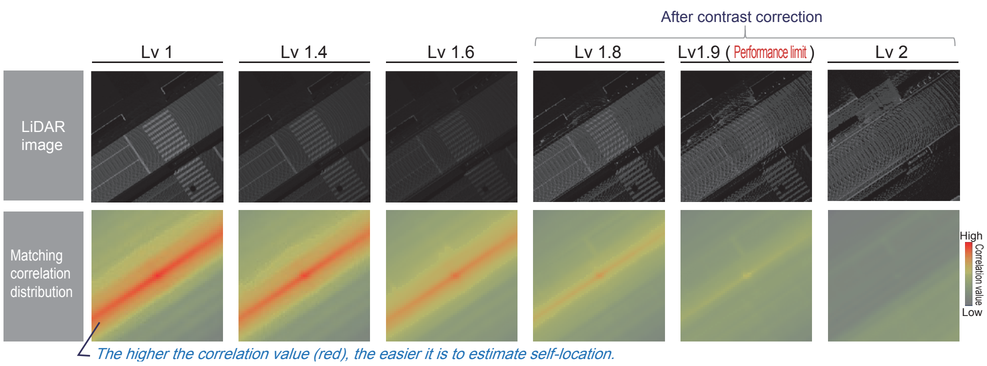

Fig.23: Validating LiDAR recognition limits at the road surface wetness level

4.2.3. Applying toward crosswalk recognition limit evaluation (identifying road surface wetness conditions)

As described in the previous section, we used a DIVP simulator to evaluate the recognition limits of an algorithm for matching locations of sidewalks and other features through LiDAR based on road surface wetness conditions in the AD-URBAN system with points on an ortho map. We were able to replicate wet road surfaces based on LiDAR output generated via the DIVP and validate recognition limits according to different contrast levels. (Fig.23 Lv.1.9)

4.2.4. Applying toward evaluation of self-location estimation algorithm robustness

The AD-URBAN system uses a self-location estimation algorithm that conducts map matching using LiDAR. For this robustness verification, we created a virtual environment model for LiDAR output in the DIVP simulator that modeled a severe condition wherein there were numerous parked cars lined up along the road so as to obscure the road surface. As a result of the assessment, we validated that AD-URBAN's self-location estimation algorithm is always highly consistent with correct values and has high robustness. (Fig.24) Consequently, as DIVP can be configured with conditions that are difficult to replicate in real-world spaces, it can contribute to system assessment.

It is therefore safe to say that SIP-adus is uniquely effective for how it can coordinate with other automated driving projects.

4.2.5. Evaluating safety when automated vehicles turn right at intersections

As another effort related to coordination with AD-URBAN, we are working to replicate traffic conditions via DIVP simulations from data obtained when real-world vehicles turn right at intersections, as well as replicate the ways in which cameras, millimeter wave radar, and LiDAR perceive and process the world. This will lead to our developing performance indicators for such things as recognition performance and safety margin with respect to oncoming vehicles and other objects. As ours will be a synchronized simulation platform, it should be able to handle safety assurance for both perception capability and safety margin at intersections in a range of traffic environments. (Fig.25) In the future, we will contribute to building intersection evaluation scenarios and developing algorithms for automated vehicles.

5 Results of the FOTs in the Tokyo waterfront area

5.1. Objectives and background

In preparation for commercializing DIVP and in order to evaluate the feasibility of using the technology in the business

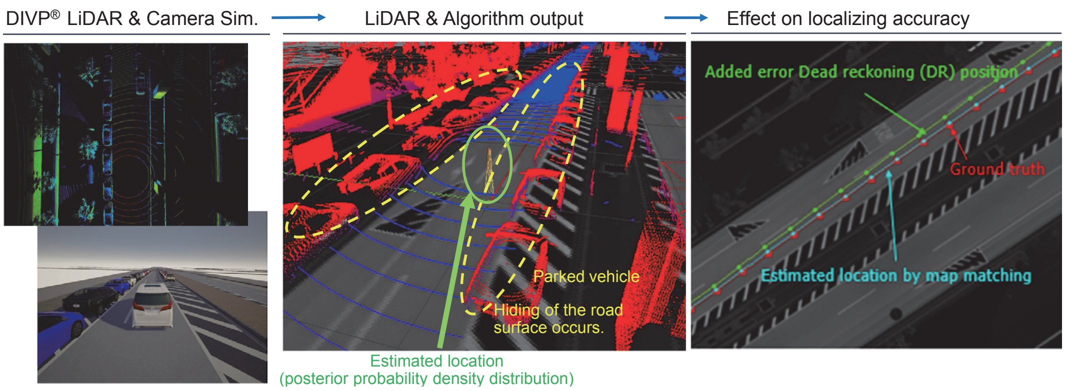

Fig.24: Evaluation of self-location estimation algorithm robustness

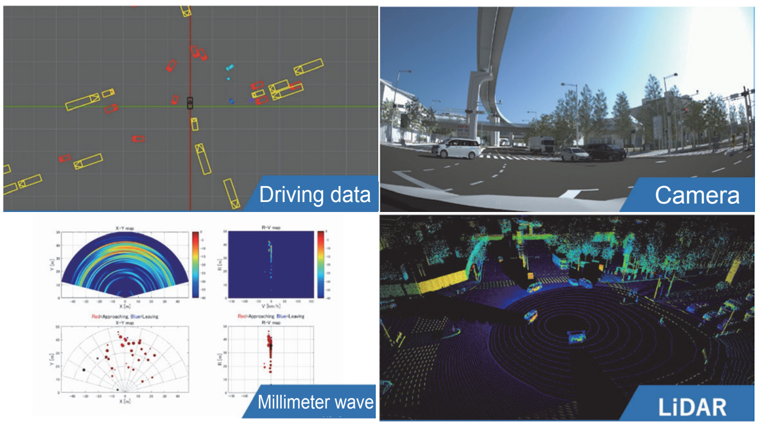

Fig.25: Safety evaluation conducted via DIVP simulation for when vehicles turn right at intersections

of OEMs and suppliers while encouraging its use in customer environments, we executed Step 1: Simulation trial in November 2021 then Step 2: Simulation evaluation in January 2022 as part of the FOTs in the Tokyo waterfront area.

5.2. STEP1: Simulation trial as FOTs in the Tokyo waterfront area

As shown in Fig.26, we conducted a trial use of a simulation model that replicated in a virtual space, the environment of the Tokyo waterfront city area, a field in the Tokyo waterfront area FOTs. The usability of model and the results of our simulations were evaluated. 81 people from 56 companies, including OEM companies, took part in this simulation trial.

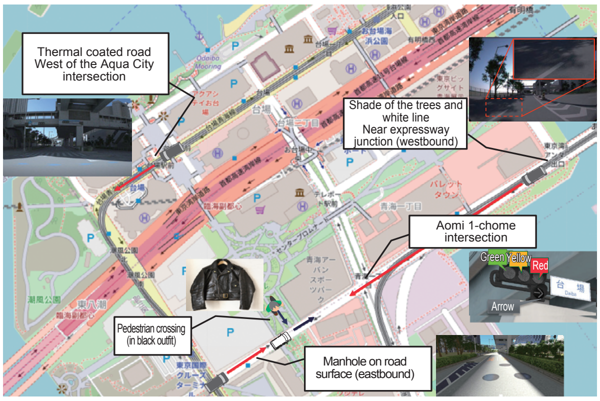

Fig.26: Sensing weakness scenario in Odaiba environments

To conduct the trial, we set up a special portal site where we mainly provided technical data concerning DIVP characteristics, particularly its consistency with real-world environments, and videos showing simulation results. Many participants were made aware of our model through our efforts to notify the high consistency of DIVP using data from consistency evaluation that measured to replicate physical phenomena.

The portal site also provided information through webinars. Through a questionnaire conducted at the end of the webinar, participants ask questions about the feasibility of using the DIVP simulator in their business. The results are shown in Fig.27. SDMG®, a tool for generating environment models and scenarios, shows promise for use in not just research but vehicle development and design, with the possibility for expanding the use of simulations in product development operations. We also confirmed the ability for SDMG to be used in real operations. Simulation platforms also show similar promise for use in research and vehicle development and design. In addition, we learned that, for research applications, simulation platforms could be used in processes ranging from evaluation to adaptation in new system and algorithm research and development, as well as vehicle development and design.

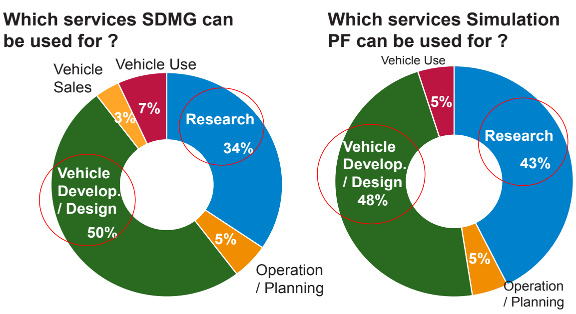

Fig.27: Questionnaire results

For the write-in questions, some questionnaire respondents said that the simulators had "been shown to be consistent and extremely useful," while others said things like "simulators were tool for quickly achieving what I want to do" and "I expect to get a lot of feedback from the users' point of view," these answers suggesting the potential for further development of simulators.

The questionnaire results also highlighted the fact that promoting the use of simulators for safety evaluation would need to be an area of focus going forward. Feedback shows good result the use of physical simulators to sensing weakness evaluation, so we will continue to coordinate with efforts such as the research of evaluation indicators while clearly communicating how this simulation platform can benefit safety assurance.

5.3. STEP2: Simulation evaluation as FOTs in the Tokyo waterfront area

In order to prepare DIVP for participating companies' work environments, in Step 2 we deployed DIVP into these environments and validated their connectivity. Using scenarios and environments that we modified based on prepared virtual environments, we attempted to link the outcomes of conducting DIVP simulations with participating companies' various models and systems. Furthermore, to promote further adoption in participating companies, we are also working to ensure connectivity among multiple existing simulation environments.

Eight companies participated in Step 2, and we conducted DIVP evaluation in line with their individual needs. Specifically, we validated the viability of data generation for machine learning, conducted comparative validation with real environment test results using the companies' own recognition models, and software coordination with Simulink®. (Fig.28)

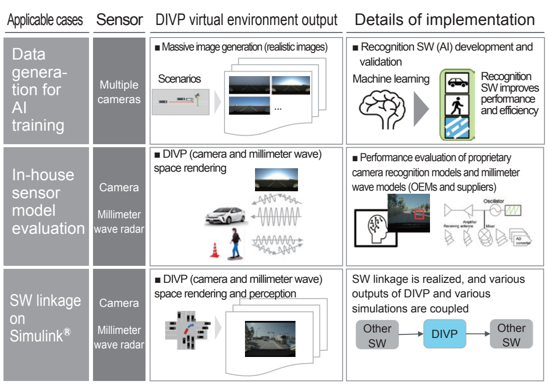

Fig.28: Examples of user needs as identified through the FOTs in the Tokyo waterfront area

Through these activities, we ascertained the needs of clients such as OEMs, suppliers, and universities for different types of systems with regard to the usage of DIVP virtual environments and space rendering outputs. We have also conducted different types of validations aimed at achieving automated driving safety validations for DIVP virtual environments. Certain validations are still being done based on requests from participating companies.

6 International cooperation and standardization

Different countries are trying different approaches to safety evaluation. It is a rivalry among powerful players: there is the PEGASUS project completed in 2019 and SET Level project that followed on, both funded by BMWi, and there have also been IEEE and ISO standardization and other developments by the U.S.'s Mobileye and Germany's BMW based on SaFAD. China is also planning its own safety assurance framework. (Fig.29)

Meanwhile, due to a number of automated vehicle accidents that have occurred in the U.S., the country's American Automobile Association (AAA) needs to conduct proper, objective safety evaluation that satisfy consumers, through measures that include reducing accidents by deploying automated driving technologies, and is disrupting the previously system-based, system builder-oriented approach to safety assurance.

While these efforts are happening overseas, DIVP project as part of SIP-adus makes efforts for joint research on safety evaluation through Japanese-Germany cooperation, while taking part to ASAM (Association for Standardization of Automation and Measuring Systems) for standardization activities based on the outcome of this cooperation.

6.1. Japanese-German cooperation VIVID project

DIVP and Germany's VIVALDI project are being jointly conducted as an International cooperation project known as VIVID, which aims to contribute to safety assurance for automated driving based on sensor modeling. The project, launched in October 2020 with support from SIP-adus and Germany's Bundesministerium für Bildung und Forschung (BMBF), is currently developing a standardized automated driving safety evaluation system and interface. (Fig.30)

At a joint meeting between Japan and Germany held in

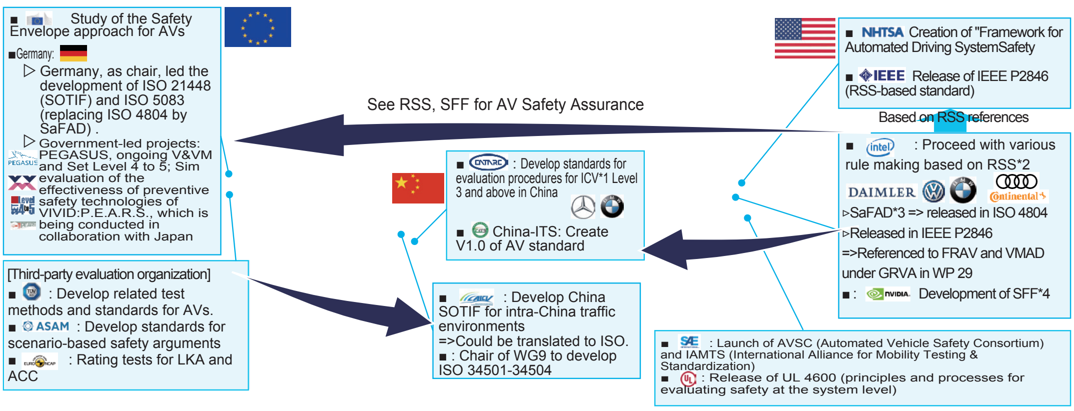

Fig.29: International trends study results

*1 ICV : Intelligent and Connected Vehicle. *2 RSS : Responsibility-Sensitive Safety.
*3 SaFAD : Safety First for Automated Driving. *4 SFF : Safety Force Field
Source: Prepared by Deloitte Tohmatsu Consulting LLC based on publicly available information

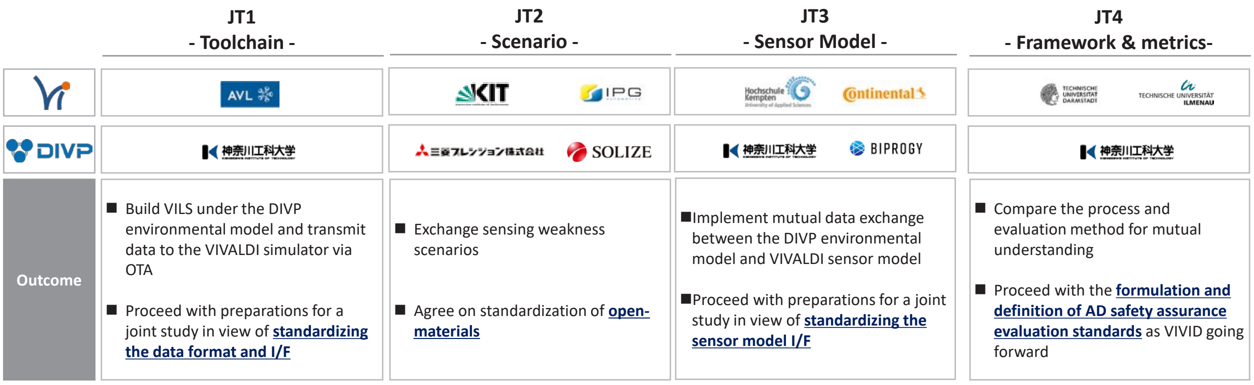

Fig.30: Organization for international cooperation and international standardization

Berlin in June 2022, automated driving project stakeholders in both countries were informed that the project had made major achievements, including having had an impact on the importance of sensors and environment models. (Fig.31)

6.2. Participation in the international standardization organization ASAM (Germany)

In response to ASAM, through which a broad range of standardization efforts are being made with regard to automated driving, DIVP project stakeholders are participating in major working groups for technologies such as OpenDRIVE/ OpenSCENARIO and OSI® (Open Simulation Interface). In these working groups, we are issuing proposals for standardization of such technologies linked to sensing weakness scenario description, reflective properties for different environment models, as well as I/F connecting different models such as sensors, which are included as property in DIVP. As for I/F related to camera input, our involvement to the organization was ended up with standardizing the technology as OSI ver.3.0.

This represents an epoc-making achievement that largely owes to the groundbreaking nature of DIVP and the winning of supporters through the VIVID project. Further efforts will be made toward research, development, and international standardization with the goal of standardizing AD safety evaluation. (Fig.32)

Fig.31: Organization for international cooperation and international standardization

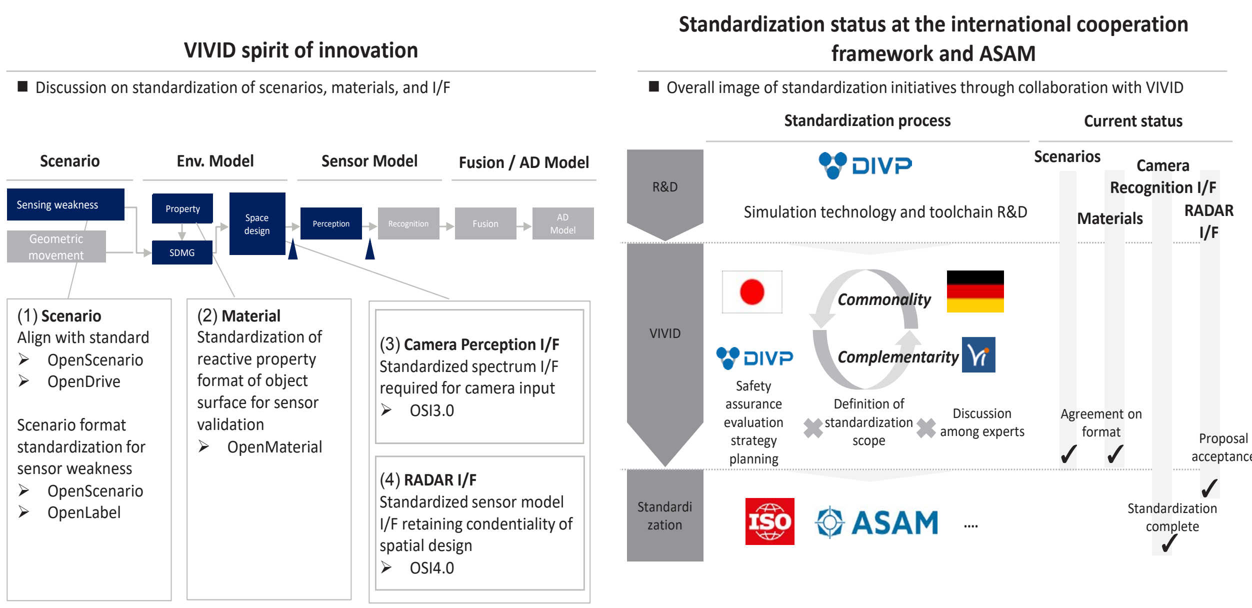

Fig.32: Japanese-Germany symposium overview

7 Conclusion

As a part of SIP-adus, this project has seen research and development efforts made through industry-academia-government collaboration. Our goal is to capitalize on the newness of models consisting of driving environments, space propagation, and sensor, ensure connectivity with other simulators, and develop core technologies for the efficient and widespread execution of increasingly complex automated driving safety validation. All DIVP project members fervently hope that virtual environment simulation technologies that can create detailed digital twins of real environments will make consumers more confident about automated driving safety, and promote more automated driving in the society.

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2) Research on the Recognition Technology Required for Automated Driving Technology (Levels 3 and 4)

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(Abstract) Automated driving equivalent to Level 4 in urban areas requires advanced and autonomous recognition functions using on-board AI, as well as road facilities, communication facilities, and other infrastructure to support these functions. At the same time, the installation of road and communication facilities throughout Japan requires massive budgets, so it is necessary to study the minimum necessary infrastructure and recognition technologies. Therefore, in this project, for the purpose of advancing discussions of future cooperative areas, we conducted research and investigations on the recognition technologies and infrastructure that will be essential for automated driving systems through public road tests of automated vehicles, chiefly through universities and other organizations that are capable of publishing a certain amount of acquired data and the technologies used to acquire that data. Based on the knowledge gained from the public road tests, we investigated the factors and issues that cause recognition failures in (non-cooperative) automated driving systems, and evaluated the effectiveness of road traffic environment data provided by the infrastructure.

Keywords: traffic light recognition, object recognition, Global Navigation Satellite System, localization, emergency vehicle recognition, virtual environment, recognition limits

1 Preface

Automated driving equivalent to Level 4 in urban areas requires advanced and autonomous recognition functions using on-board AI, as well as road facilities, communication facilities, and other infrastructure to support these functions. However, since massive budgets are required to install road and communication facilities throughout Japan, it is necessary to study the minimum necessary infrastructure and the recognition technologies required under that infrastructure. In this project, we collaborated with universities that are already testing automated driving on public roads and with universities that are conducting cutting-edge research on related elemental technologies to develop the recognition technologies required for an automated driving system equivalent to Level 4 in complex urban traffic environments with a mixture of ordinary traffic participants and other automated vehicles. In addition, we evaluated the marginal performance of various recognition technologies as well as the effectiveness of infrastructure-cooperative driving.

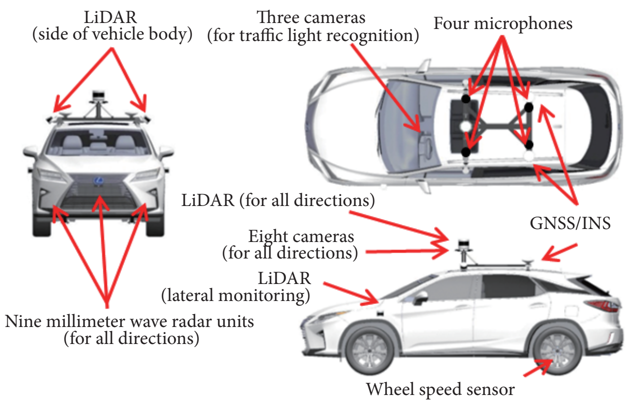
2 Overview and Results of the FOTs (Field Operational Tests)

2.1. Summary of the FOTs

This project aims to develop and verify recognition technologies for automated driving systems and technologies to link with infrastructure information such as V2I/V2N. We built a test vehicle equipped with multiple LiDAR units, millimeter wave radar, cameras, and other sensors for the recognition of the surrounding environment, GNSS/INS and other localization sensors, and V2X on-board terminals, and then conducted FOTs. Fig.1 (a) shows an overview of the test vehicle.

In July 2019, we began FOTs in the central part of Kanazawa City, Ishikawa Prefecture, and in September 2019 we also began FOTs in the Tokyo waterfront area. In the Tokyo waterfront area, the vehicle ran for 182 days over a three-year period through FY2021, covering approximately 3,212.8 km in automated driving mode. Fig.1(b) shows the automated driving in the Tokyo waterfront area.

Among the data collected in the FOTs, the driving data under adverse conditions that tend to cause recognition failures are considered to be useful data for general researchers who study recognition algorithms, irrespective of the implementers of this project. For this reason, from the sensor data collected in



(a) Installation of sensors in automated vehicles


(b) Automated driving in the Tokyo waterfront area

Fig.1: Overview of the automated vehicle developed in this project

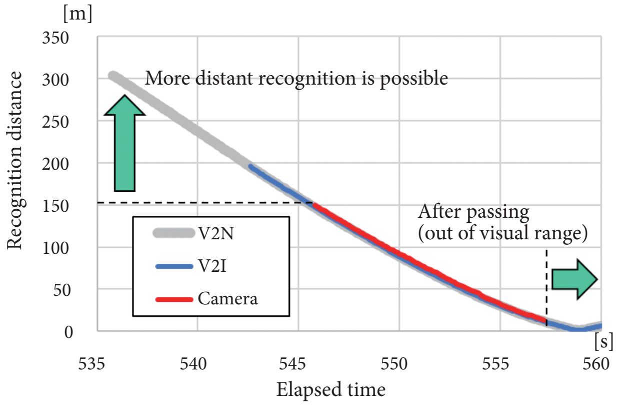
the various areas in this project, a dataset (AD-URBAN Open Image Dataset v1) that includes sensor data under adverse conditions such as backlighting, background assimilation, concealment, nighttime, rainy weather, etc., which tend to cause recognition errors, was constructed. It was made available beginning at the end of March 2022 to domestic institutions for the limited purpose of research activities.(1)

2.2. Evaluation of the Effectiveness of V2I/V2N Road Traffic Environment Data

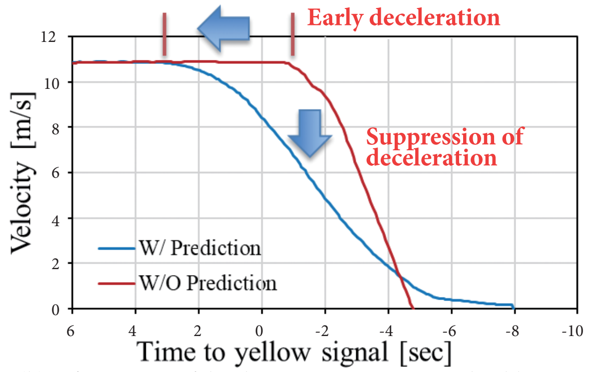
In the FOTs in the Tokyo waterfront area, it was possible to acquire road traffic environment data provided by wireless communications from infrastructure such as V2I (Vehicle to Infrastructure) and V2N (Vehicle to Network). Therefore, in addition to evaluating automated driving functions, we also conducted and evaluated infrastructure-cooperative driving using V2I/V2N.

V2I/V2N provide various types of road traffic environment data. In this project, we specifically evaluated the traffic light information provided by V2I/V2N and the emergency vehicle location information provided by V2N.

Fig.2(a) shows the comparison of traffic recognition distance between V2I, V2N and camera based recognition. The results show that the distance at which the traffic light can be recognized (the recognition distance) is approximately 150m when the autonomous recognition technology using the on-board camera is used. At the same time, the traffic light information transmitted by wireless communication based on V2I and V2N makes it possible to recognize the traffic light state from a greater distance. However, in the examination in this project, it was assumed that the traffic light recognition distance required to pass through an intersection is approximately 120m, and it was found that both methods have sufficient recognition distance. On the other hand, in situations where traffic lights are not physically visible, recognition using an on-board camera becomes difficult, and V2I/V2N are considered effective in such situations.



(a) Comparison of traffic light recognition distance betwe
V2I/V2N and camera



(b) Effectiveness of deceleration suppression in the dilemma zone using V2I with remaining time information

Fig.2: Results of evaluation of V2I/V2N traffic light information

In this project, we also developed a technology to facilitate intersection entry by utilizing information on the remaining time at traffic lights transmitted from V2I, and verified the effectiveness of this technology. Specifically, as shown in Fig.2(b), in the so-called "dilemma zone" where the traffic light color changes from green to yellow/red just before entering an intersection and sudden deceleration is unavoidable, we confirmed that the system can start deceleration before the actual traffic light color changes, enabling smooth deceleration and stopping before the intersection. Since sudden deceleration in a dilemma zone always occurs regardless of whether driving in automated or manual modes when the decision to enter an intersection is based solely on the current traffic light information, the number of remaining seconds via wireless communication is considered to be a useful piece of information for safe entry into an intersection.

Next, we show the results of an evaluation of the emergency vehicle location information provided by V2N. In this evaluation, simulated emergency vehicle locations were distributed by V2N via a server, and their usefulness was evaluated based on the information received by the vehicle. Fig.3 shows an example of receiving the location of a simulated emergency vehicle in the Tokyo waterfront area. The results show that the location of the simulated emergency vehicle can be determined smoothly at the most cases. At the same time, we observed that an error of about 20m occurs in some environments, making it difficult to determine the location of the simulated emergency vehicle in detail. Therefore, if we assume that an automated vehicle must autonomously take evasive action when approached by a simulated emergency vehicle, it may be necessary to combine autonomous recognition technology with on-board sensors to determine the detailed location of the emergency vehicle. On the other hand, when using on-board sensors, we can assume that it is difficult to confirm the approach of an emergency vehicle at a distance or outside the visible range, and therefore, V2N simulated emergency vehicle location information may be particularly useful in such situations.

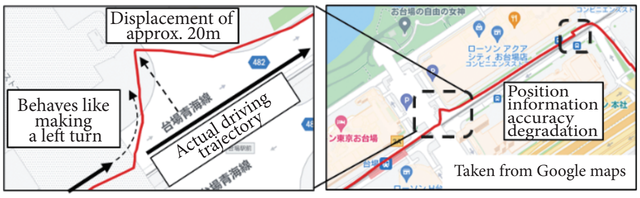


Fig.3: Example of V2N simulated emergency vehicle location information acquisition data

3 Evaluation of Recognition Technologies

In the development of automated driving systems and the evaluation of their safety, it is important to confirm whether automated driving functions operate correctly under actual traffic conditions by driving automated vehicles on actual roads, as was done in this project. On the other hand, evaluations in actual road environments have limitations in terms of time, cost, and efficiency. In addition, it is difficult to evaluate the marginal performance of automated driving functions in real environments. For this reason, this project also evaluated recognition technologies using virtual environments such as DIVP® (Driving Intelligence Validation Platform), which was implemented as another project. In this section, we present an overview of the various recognition technologies developed in this project, as well as the results of the marginal performance evaluation using the virtual environments.

3.1. Development of Traffic Light Recognition Technologies and Examination of Conditions That Make Recognition Difficult

Accurate recognition of traffic light state is important for smooth intersection crossing in automated driving. In this project, we developed a state-of-the-art recognition algorithm that maximizes the performance of traffic light recognition by conducting technological development combining conventional pattern recognition technology and the latest AI technology in utilizing the latest cameras developed for on-board applications. In addition, we also evaluated marginal performance in failure scenarios as found in the FOTs using the virtual environment developed in the DIVP project to look at situations where recognition proved difficult in the FOTs.

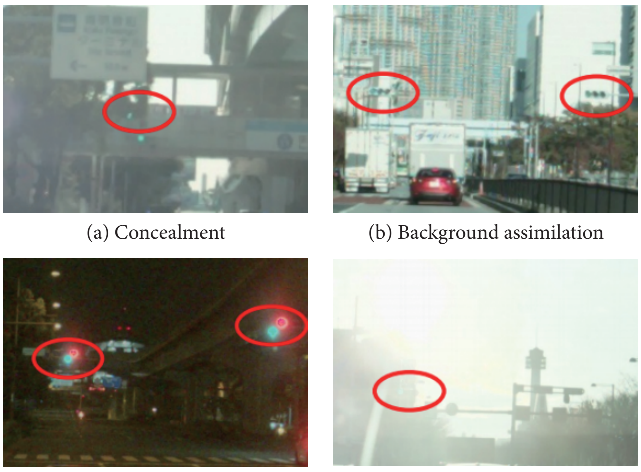
(1) Development of Traffic Light Recognition Technologies

The development of an algorithm for recognizing traffic lights by image recognition using an on-board camera was conducted from the viewpoint of the use of digital maps and the development of several types of image recognition algorithms. When a digital map is used, it is possible to limit the recognition range in the image, and thus false positives can be suppressed and high-speed processing can be expected. For the multiple image recognition algorithm, we considered a method of pattern recognition that focuses on features such as brightness and the circular shape of lighted areas in the input image, and a method of semantic segmentation that uses deep learning. The AI technology is expected to enable recognition that takes into account not only the local brightness information but also the surrounding objects. We evaluated the performance of the algorithm developed in this way on driving data from the Tokyo waterfront area. Fig.4 shows an example of recognition results of traffic lights using the developed algorithm.

Fig.4: Example of traffic light recognition results

(2) Issues Identified in the Tokyo Waterfront FOTs

Next, given the results of the FOTs in the Tokyo waterfront area, we analyzed the technical issues in the recognition of traffic lights, which are mainly caused by environmental factors, and evaluated the algorithm. As a result, as shown in Fig.5, we confirmed that the recognition performance temporarily degraded under the following environmental conditions: backlighting, forward lighting, concealment, background assimilation, and nighttime. On the other hand, in many situations, the influence on the decision of whether to enter an intersection is considered to be limited because the effects are mainly temporary when approaching an intersection. At the same time, due to the effects of backlighting, there are moments when objects cannot be seen due to image saturation, which may prevent appropriate decisions on whether to enter when an event occurs at the start of an intersection. However, it was also verified that the effects of such failures are limited in the image when using an on-board grade camera, and therefore, it is desirable to use information from other traffic lights when there are multiple traffic lights at the intersection, or to use V2I/V2N information when there is only a single traffic light at the intersection to assist in the decision. In the evaluation of recognition performance through FOTs, we demonstrated that the system can recognize green, red, and arrow traffic lights within 120m, which is the target performance, more than 99% of the time by introducing a strategy of determining intersection entry based on the status of multiple traffic lights.(2)



(a) Concealment (b) Background assimilation

(c) Nighttime (c) Backlight

Fig.5: Examples of scenarios in which traffic light recognition becomes difficult, as confirmed by field operational tests in the Tokyo waterfront area

(a) Actual environment (b) Virtual environment

Fig.6: Example of reproduction of reflected light from a building in a virtual environment

(a) Actual environment (light rain) (b) Virtual environment (heavy rain)

Fig.7: Evaluation of marginal performance in wet weather using a virtual environment

(3) Evaluation of Marginal Performance in a Virtual Environment

We worked to reproduce in a virtual environment the problems that we have encountered in our FOTs. We reproduced in a virtual environment situations such as the aforementioned failure caused by backlighting and the rare situation shown in Fig.6, in which sunlight reflecting off a building makes it difficult to recognize a traffic light, and evaluated the consistency of the reproduced images as well as the marginal performance of the system. As a result, it was confirmed from the evaluation results in the virtual environment that traffic light recognition in rainy conditions, which did not cause recognition failures in the actual FOTs due to only light rain, can fail under heavy rainfall of several tens of mm/h (so-called downpour) (Fig.7).

3.2. Development of AI Technology Necessary for Long-Distance Object Detection

For safe and smooth automated driving, it is important to reliably detect vehicles, motorcycles, pedestrians, and other objects in the vicinity of the vehicle. For this reason, in this project we examined ways to improve the detection performance of distant moving objects, which is an issue in moving object detection.

(1) Development of Long-Distance Object Recognition Technology

Based on the experience of the FOTs conducted to date, it is necessary to recognize automobiles within 200m and pedestrians within 70m in urban traffic environments, depending on the situation. Therefore, we developed a recognition algorithm to satisfy these requirements. First, since the blurring of distant objects due to the on-board camera being out of focus is a problem in image recognition using an on-board camera, we developed an object recognition algorithm that can deal with blurring, enabling more accurate detection of distant objects with small pixel counts. In addition, since the situations where long-distance recognition is required are limited, such as at intersections to be passed, we also verified that stable recognition is possible by using a digital map to limit the recognition area in the image.

In LiDAR recognition, an object must be detected as a 3D rectangular BOX from a group of observed points, but it is not easy to stably recognize an object from a sparse group of distant points. Therefore, we verified that sensor fusion with the recognition results of camera images is effective in compensating for the sparse groups of points in the distance. Using such sensor fusion, we created a recognition algorithm that achieved the target performance of 90% detection of automobiles within 200m and pedestrians within 70m in a normal environment.

(2) Issues identified in the Tokyo Waterfront Area FOTs

Because object recognition by LiDAR and cameras recognizes objects based on the overall image features of the object based on the observed sensor information, recognition can be difficult due to changes in environmental conditions such as the arrangement of surrounding objects, degree of concealment, and weather conditions. Other issues include background assimilation when an object is near a median strip or a pole, and in the case of a camera, the effects of sunlight conditions. In the case of causes of failures specific to certain sensors, we can deal with them with the aforementioned sensor fusion strategy, but in concealment scenarios, which are an issue for both sensor types, recognition is inherently difficult with on-board sensors. In the FOTs, we confirmed that the failure scenarios in which concealment is a major factor occurred during the judgment of approaching oncoming traffic at right-turns at intersections. It is important to evaluate the marginal performance of the system in such situations because the system must recognize vehicles farther away when passing through intersections with many lanes.

(3) Results of Blind Spot Evaluation in a Virtual Environment

In the FOTs, object recognition under the influence of concealment has been identified as an issue. However, because such scenarios are encountered only momentarily while driving, it is difficult to create a large amount of driving data under different conditions. Therefore, an evaluation of marginal performance affected by blind spots was conducted using the virtual environment being developed in the DIVP project. As shown in Fig.8, the data generated is of a scenario in which the vehicle is turning right at an intersection and an oncoming vehicle is approaching straight ahead in an environment in which there is also an oncoming truck waiting to turn right. LiDAR and image data with different shielding rates were generated by changing the relative position of each vehicle.

The detection results of objects from the LiDAR and camera sensor data for the intersection scenario generated in this way were confirmed, and the marginal performance of each sensor and sensor fusion was evaluated for different shielding rates as shown in Fig.9(a), (b), and (d). Fig.9(c) shows the distribution of the shielding rates of LiDAR and camera in the same frames. From these results, we verified that the recognition performance by sensor fusion will likely improve with different installation

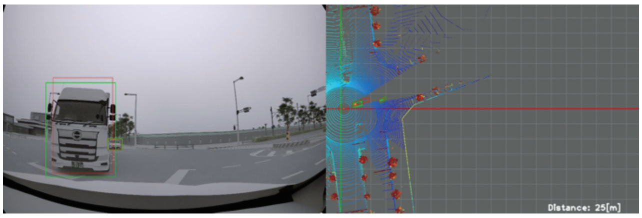
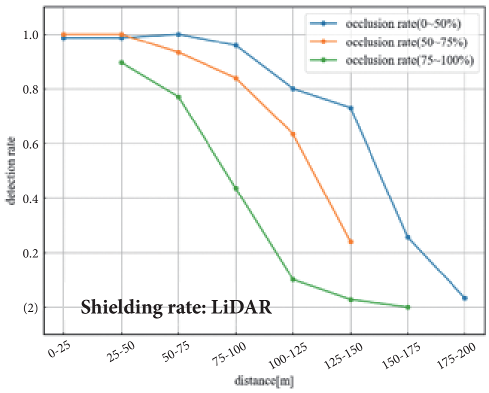
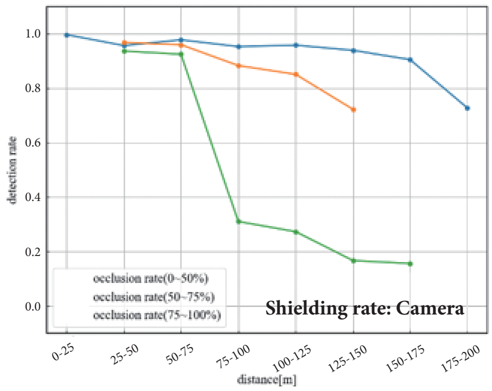


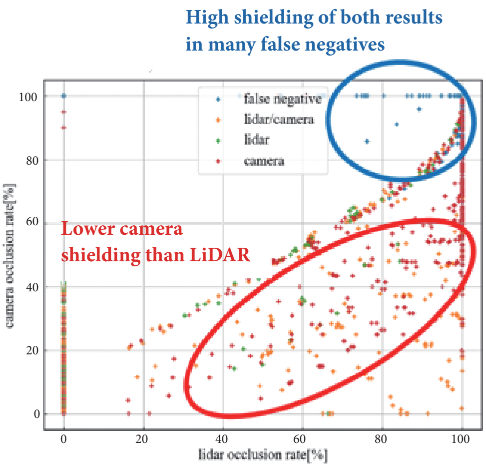
Fig.8: Recognition of oncoming vehicles at intersections in a blind spot environment



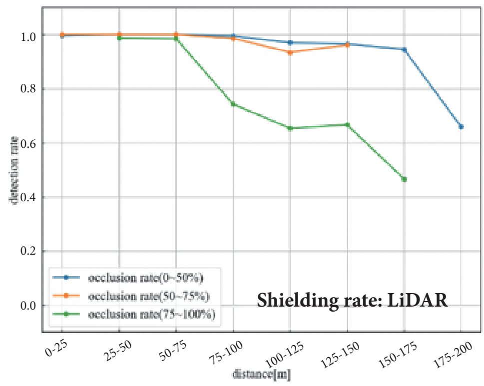
(a) Detection rate by LiDAR



(b) Detection rate by camera



(c) LiDAR/camera shielding rate distribution in the evaluation data



(d) Detection rate by LiDAR/camera sensor fusion

Fig.9: Object detection results by sensor fusion in a blind spot environment

positions and observation methods for the sensors.

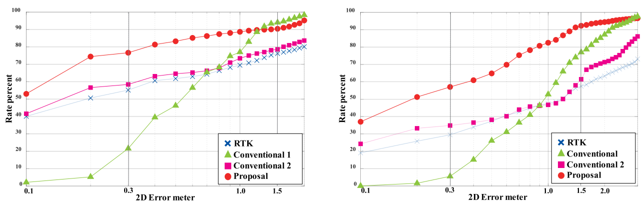
3.3. Development of Localization Technology Using MICHIBIKI

In this project, while we used signals from GNSS (Global Navigation Satellite System) satellites such as MICHIBIKI and INS (Inertial Navigation System), we also developed GNSS/INS technology that can estimate positions applicable to automated driving systems. In actual environments where automated driving is used, there is a high possibility that the accuracy of GNSS/INS will deteriorate because signals from GNSS cannot be received. Therefore, we also examined the conditions under which automated driving systems using GNSS/INS can operate stably.

(1) Study and Evaluation of GNSS/INS Applied to Automated Driving

In the development of GNSS/INS, we set two targets for the absolute positioning accuracy required for automated driving: a position estimation accuracy of 1.5m, which enables the determination of the travel lane, and a position estimation accuracy of 0.3m, which makes possible the operation of an automated driving system using only GNSS/INS. We also aimed to achieve these goals by utilizing the quasi-zenith satellite MICHIBIKI. First, to achieve a positioning accuracy of 1.5m, as a stable estimation method while still using a general-purpose GNSS, we studied a method that maximizes the effectiveness of GNSS Doppler. In addition, we developed a technique to determine the achievement of 0.3m accuracy by utilizing vehicle motion with a particular focus on the height direction. In addition, to maintain highly accurate position estimation even at locations where GNSS cannot be received, we conducted a study to improve the accuracy of dead reckoning (DR).

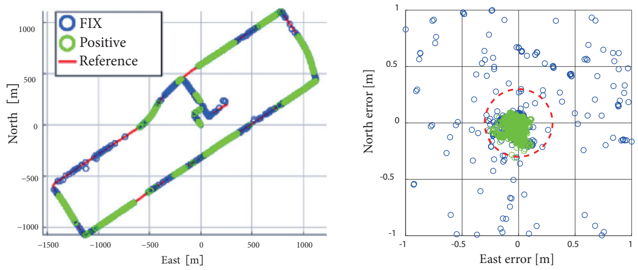
First, in the absolute positioning evaluation test using multi-GNSS, it was confirmed that a range of 30 cm@77%/1.5m@90% and 30 cm@57%/1.5m@92% could be achieved in Odaiba and Shinjuku, Tokyo, respectively. A summary of the results is shown in Fig.10, which shows the positioning method using vehicle trajectories as Conventional 1, and the method using Doppler to predict the initial RTK search position as Conventional 2.



(a) Odaiba (b) Shinjuku

Fig.10: GNSS/INS absolute position evaluation results

Next, we focused on determining locations that have achieved a positioning accuracy of 0.3m or less, and confirmed the possibility of achieving a positioning accuracy of 0.3m or less at 99% in the same evaluation locations. At the same time, we examined the possibility of determining a positioning accuracy of 0.3m, which is sufficient for automated driving, by utilizing the Centimeter Level Augmentation Service (CLAS), which provides correction information broadcast from the quasi-zenith satellite MICHIBIKI. As a result, we were able to confirm a positioning accuracy of 0.3m in 99% of the cases on a course set in Odaiba, Tokyo.[3] A summary of the results is shown in Fig.11.



(a) Results of reliability determination. (b) Accuracy of positioning solution

Fig.11: Results of Reliability Determination in Odaiba

In addition, we improved the accuracy of DR, which is important for interpolating between points where highly accurate position estimation is possible. First, we looked at the errors in the DR sections and the factors causing them, and confirmed that the initial azimuth angle has an effect in the case of a 10-second DR. Next, to improve the performance of the initial azimuth angle, we proposed a method to optimize the angle by using the FIX solutions for the past several tens of seconds. In the evaluation test, we confirmed the effectiveness of the proposed method by achieving an error rate of 0.3m or less 87.7% of the time after 10 seconds of DR on an evaluation course in an urban area (Fig.12).

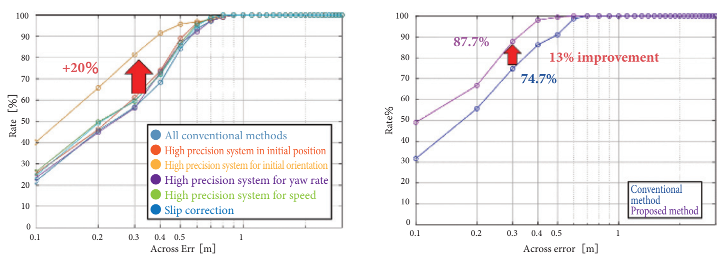


Fig.12: DR error factor analysis and performance improvement

(2) GNSS/INS Issues and Responses to Them

The results of this project showed that absolute positioning performance required for automated driving can be obtained in environments where GNSS such as MICHIBIKI can be received, and that a reliability determination of 30 cm can be made at 95% or better in Tokyo waterfront areas such as Odaiba. However, even if CLAS could be received during the evaluation, the positioning performance degraded at locations where the number of satellites decreases. For such locations, it is expected that complementary technologies such as map-matching using road infrastructure will be required to maintain positioning accuracy.

In this project, we investigated a technology that can predict positioning errors at arbitrary points using a virtual environment by collecting high precision 3D map data and GNSS signal errors as double differences. The developed technology is expected to make it possible to predict where positioning performance will deteriorate. Based on the above results, we believe that safer operations of automated driving will be possible by prioritizing the building of road infrastructure necessary for location estimation in locations where positioning performance is expected to deteriorate.

3.4. Development of Map-Matching Technology

Automated driving systems that use high precision maps must be able to continuously estimate their own location with high accuracy. For this reason, we have developed a localization technology based on map matching.

(1) Outline of the Developed Technology

As shown in Fig.13 , the localization technology developed in this project is realized by continuously estimating the position by DR and map matching.(4) DR is capable of calculating self-position at a high frequency by integrating velocity vectors obtained from sensors, but it is not suitable for long-term localization due to cumulative errors. To solve this problem, we developed a method for robustly estimating accurate self-positions by compensating for the cumulative errors in DR through image matching (template matching) using road surface pattern images obtained in real time from LiDAR and reference map images created by acquiring road surface patterns in advance.

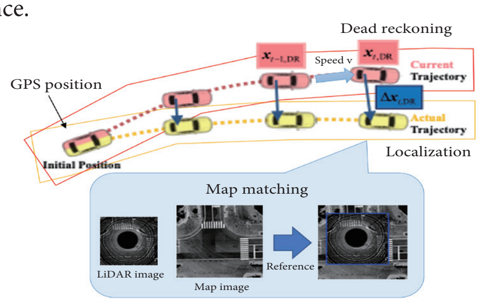


Fig.13: Overview of Localization technology

(2) Issues Identified in the Tokyo Waterfront FOTs

At the same time, the FOTs in the Tokyo waterfront area revealed that the contrast between the white lines and the asphalt deteriorates on thermal shielding-coated road surfaces and during rainfall, resulting in a loss of accuracy in matching. As a countermeasure, we developed a method to correct the reflectance from the angle of incidence of the laser using the Lambert model, which is a model of diffuse reflection of light (Fig.14). We have also confirmed that localization accuracy of 0.1m can be achieved by introducing a contrast correction process that matches the entire LiDAR image to the contrast of the map image.

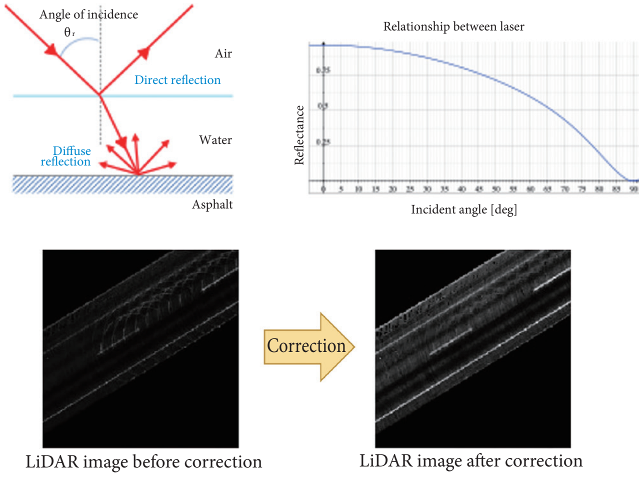


Fig.14: Correction of reflectance using Lambert reflection model

(3) Evaluation of Marginal Performance in a Virtual Environment

On the other hand, depending on the road surface material and the wetness of the road surface, the contrast between the white lines and the asphalt may be significantly reduced, resulting in incorrect localization. For this reason, we evaluated the marginal performance of self-localization by reproducing scenarios that caused localization problems identified in the FOTs using the virtual environment being developed in the DIVP project.

In this evaluation, as shown in Fig.15, we changed the wetness of a normal asphalt road surface and a thermal shielding-coated road surface, and compared the matching results to obtain performance limits. In the DIVP virtual environment, the wetness of the road surfaces was defined in five levels: Level 0 is a dry road, Level 1 is a road where raindrops have begun to seep in, Level 2 is a road where water has fully seeped in and saturated the road surface, and Levels 3 and 4 are a thin water film of 1-2 mm and a thick water film of several mm or more, respectively. The results of the evaluation confirmed that localization is possible even at the maximum wetness of Level 4 for a normal asphalt road surface. On the other hand, for a road surface with a thermal shielding coating, a wetness level of 1.9 was confirmed to be the performance limit.

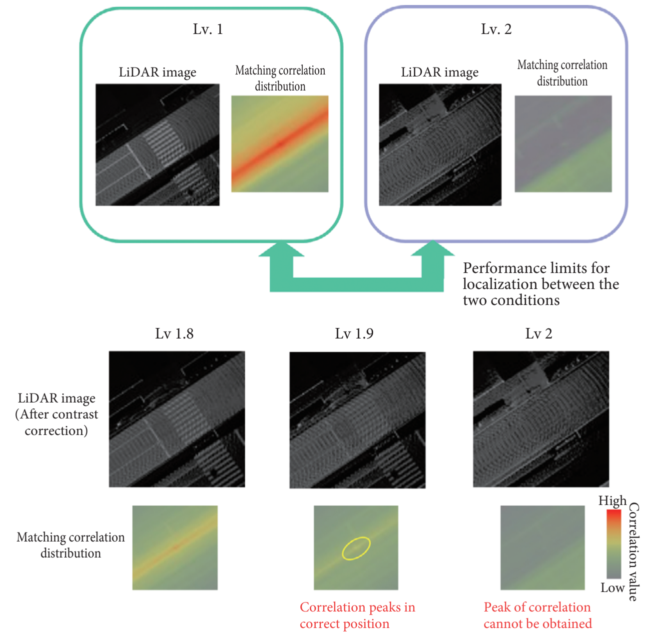


Fig.15: Map-matching results near the performance limit during rainfall on a thermal shielding-coated road surface

3.5. Development of Emergency Vehicle Recognition Technology

As stipulated in Article 40 of the Road Traffic Act, when an emergency vehicle approaches, it is necessary to take evasive action so as not to obstruct its path. For this reason, we developed a technology for recognizing emergency vehicles using on-board sensors.

(1) Recognition of Emergency Vehicles by Camera

For the image-based recognition of emergency vehicles, we recognized the vehicles themselves, such as police cars and ambulances, and detected the flashing of their emergency lights. In this project, YOLO v4 was used as the recognition algorithm for emergency vehicles. First, YOLO v4 was trained using a dataset for object detection collected in the Tokyo waterfront area. The Tokyo waterfront area dataset contains seven classes of objects for detection, including general vehicles, pedestrians, bicycles, and different states of traffic lights. After training on the Tokyo waterfront dataset, we added classes for emergency vehicles, and conducted additional training nine classes. In training the first seven classes, the system acquires features suitable for object detection using video acquired from a camera mounted on the vehicle as input. Then, by training additional classes, features suitable for emergency vehicles can be additionally acquired. Fig.16 shows an example of emergency vehicle detection results. At the same time, it may be difficult to detect an approaching emergency vehicle using only image recognition based methods when the vehicle is far away or in an environment where it is physically difficult to see the vehicle due to blind spots or other reasons. For this reason, a method to

(a) Ambulance (b) Patrol car

Fig.16: Example of emergency vehicle detection

detect the siren sound of an emergency vehicle using microphones mounted on the test vehicle shown in Fig.1 was also studied.

(2) Recognition of Emergency Vehicles by Microphone

For emergency vehicle recognition by microphone, in addition to determining the presence or absence of an emergency vehicle, it is necessary to determine the location of the vehicle. For this reason, in this project we developed a siren sound recognition technology and a sound source localization technology. For siren sound recognition, features were extracted from the sound data of the on-board microphones, and the siren sound is identified by machine learning. In this project, SVM (Support Vector Machine) was used as the recognition algorithm, and in addition to the test vehicle driving data, data from ESC-50, which is a publicly available environmental sound dataset, and voice data scraped online were also used as the training dataset. Table 1 shows the evaluation results of the ambulance siren sound detection technology developed in this project. The Precision index indicates a value closer to 1 when there are fewer false positives, and the Recall index indicates a value closer to 1 when there are fewer false negatives. Table 1 shows that the sirens were identified with an accuracy of more than 90%.

Table 1: Recognition rate of ambulance siren sound

	Precision	Recall
Recognition rate	0.964	0.965

In addition, we studied the phenomenon of the recognition rate decreasing due to attenuation of the siren sound, increase in noise, and the Doppler effect depending on the distance to the emergency vehicle and the vehicle's speed. Fig.17 shows a graph of the recognition accuracy as a function of vehicle speed and distance to the emergency vehicle. The figure shows that

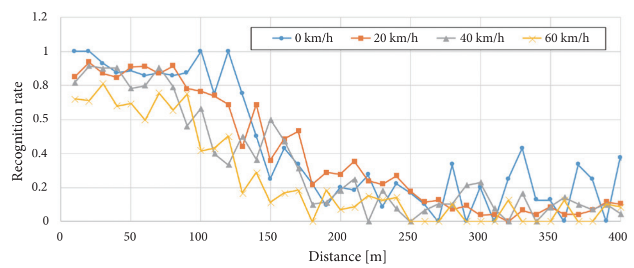


Fig.17: Recognition accuracy based on own vehicle speed and distance

the recognition accuracy is 90% when the distance to the emergency vehicle is within 120m, but the recognition accuracy decreases significantly when the distance to the emergency vehicle is farther away. It can also be confirmed that the recognition accuracy generally decreases as the speed increases.

The test vehicle was equipped with four microphones for sound source localization (Fig.1). Using these on-board microphones, we developed a technique for estimating the direction and distance of a sound source by calculating the time difference of sound arrival between the microphones.

To confirm the principle, the distance to the emergency vehicle was fixed at 100m, the azimuth angle was varied while both vehicles were stationary, and the accuracy of the source azimuth estimation by the two microphones was evaluated. As shown in Table 2, it was confirmed that an azimuth estimation with an error of about 10 degrees was possible under each condition.

Table 2: Accuracy of sound source azimuth estimation with two microphones

True value [deg]	Estimated position [deg]	Error [deg]
−36.2	−45.7	−9.5
9.4	1.9	−7.5
48.6	37.7	−10.9

4 Postscript

In this project, through universities as neutral research institutes, we developed the recognition technologies required for a Level 4-equivalent automated driving system in complex urban traffic environments with a mixture of ordinary traffic participants and other automated vehicles. We also evaluated the effectiveness of infrastructure-cooperative driving using wireless infrastructure such as V2I/V2N through FOTs in the Tokyo waterfront area. In addition, we reproduced in a virtual environment the problems of autonomous recognition technologies based on on-board sensors that emerged in the FOTs in the Tokyo waterfront area, and evaluated the marginal performance of these recognition technologies.

In the future, for the introduction of automated driving technology to society in various environments, including prefectural and municipal roads, it will be important to evaluate not only advancements in recognition and decision-making technologies in automated driving systems, such as those developed in this project, but also their safety. At the same time, evaluations in actual road environments are limited in terms of time, cost, and efficiency. For this reason, it will be important to construct frameworks for efficient and comprehensive safety assurances using virtual environments, as was done in this project.

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3) Research of New Cyberattack Techniques and Countermeasure Technologies

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(Abstract) As connected cars and automated driving systems develop and spread, a lot of information of advanced maps and the vehicles, people, and infrastructure facilities mapped onto them is transmitted to vehicles via external networks. This situation causes cybersecurity issues. Furthermore, since the introduction of UN-R155/R156 to the safety standards for road vehicles—agreed-upon regulations for cybersecurity and software updates—it is also necessary to take countermeasures against cyberattacks from a legal perspective. To solve these issues, this study focused on intrusion detection systems (IDS) as a new countermeasure technology against cyberattacks after shipment, and developed IDS evaluation guidelines to serve as a baseline for evaluation and testing when introducing IDS. During the current fiscal year, we are studying methods of collecting and accumulating threat information on connected cars and conducting collection experiments using methods such as honeypots, seeking to create a mechanism to support an initial response when an incident actually occurs.

Keywords: IDS (Intrusion Detection System), Honeypot, Threat Information, STIX/TAXII, S-BOM

1 Purpose of this research study and overview of activities

In accordance with the research and development plan, objectives and goals of the second phase of SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services): Research of New Cyberattack Techniques and Countermeasure Technologies, the "Formulation of IDS Evaluation Methodology and Guidelines" and "Research study on Threat Information and Initial Response Support for Connected Cars" are being conducted from August 2020 to February 2023.

2 Formulation of IDS Evaluation Methodology and Guidelines

As shown in Fig.1, our objective with this topic is to contribute to post-shipment cybersecurity measures. We hope to achieve this by creating IDS evaluation guidelines and then providing them to industry organizations as a baseline for OEMs when selecting, verifying, and operating IDS. The main target audience is OEMs that have just started considering the introduction of on-board IDS with the intent of raising the level of post-shipment cybersecurity of their vehicles.

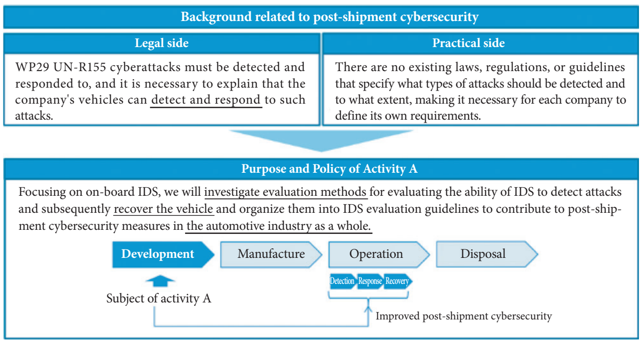

Fig.1: Purpose and Policy for Formulation of IDS Evaluation Methodology and Guidelines

2.1. Derivation of basic test cases

In order to organize the points to be evaluated in the selection and testing phases of on-board IDS, we analyzed previous published cases of attacks and derived the cybersecurity events from them. Among the cybersecurity events, we selected

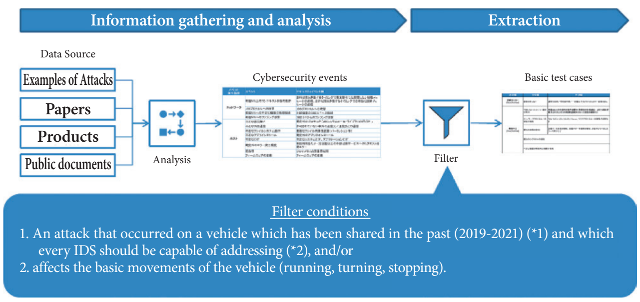

Fig.2: Derivation of basic test cases

those that an IDS should detect at a minimum, and summarized them as basic test cases. (Fig.2)

2.2. Basic test case testing environment

Based on the basic test cases, three types of testing environment were considered, as shown in Fig.3. In light of the incurred costs, this study examined a test procedure based on the assumption that testing would be conducted in either a simulation environment (Fig.4) or a testbed environment. (Fig.5)

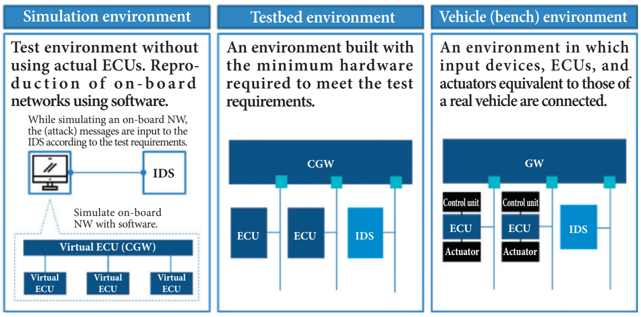

Fig.3: Types of IDS testing environments

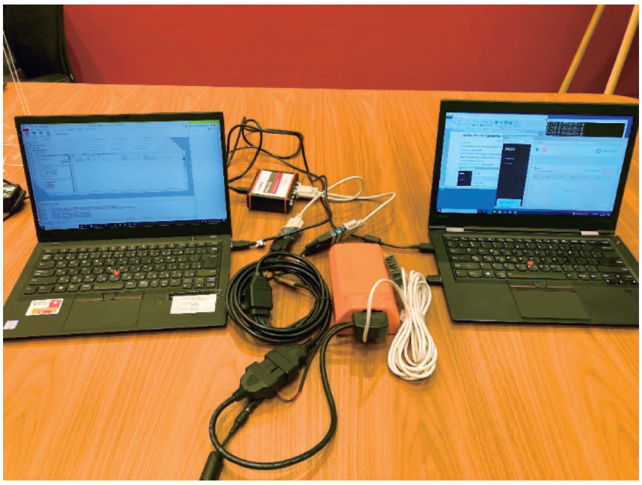

Fig.4: Simulation environment

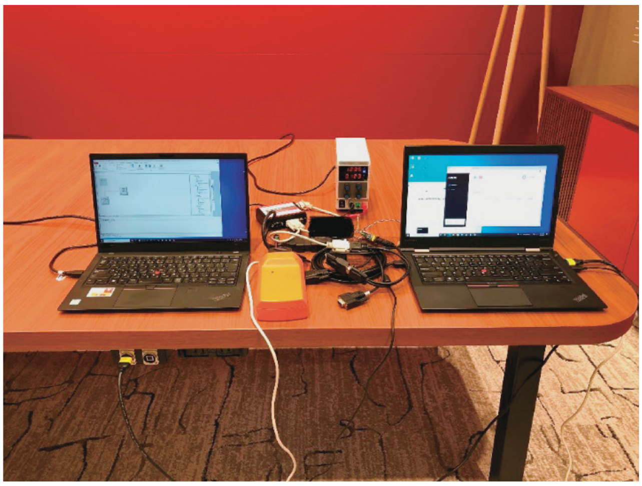

Fig.5: Testbed environment

2.3. Testing of test cases using actual IDS equipment

The purpose of actual IDS equipment testing is to verify the validity of the test method of the basic test case (whether the test can be performed using the predefined test method).

For this purpose, one OEM (hereinafter referred to as "OEM A") provided the communication data and ECU for the on-board network necessary for testing a basic test case. In addition, we asked ETAS Corporation and Arilou Information Security Technologies Ltd. to provide IDS adapted from their respective companies for the specific vehicle model of OEM A. We conducted testing according to the test procedures of the basic test cases, and confirmed whether the test results matched the expected values.

2.4. Results of testing

The procedures shown in the test method for all test perspectives tested were performed for the IDS of the two companies under the simulation and testbed environments. It was confirmed that there were no errors in the procedures and that the IDS performed as expected.

2.5. Activities for social implementation

A technical review meeting was held with JASPAR (Japan Automotive Software Platform and Architecture), the future recipient of the IDS evaluation guidelines, in preparation for the transfer of the IDS evaluation guidelines. The IDS evaluation guidelines were finalized by responding to feedback from the recipient right up until the transfer, which—including administrative procedures—was then completed in August 2022.

3 Research Study on Threat Information and Initial Response Support for Connected Cars

Our goals with this topic have been to define basic specifications for methods of collecting and accumulating threat information on connected cars and for initial response support using threat intelligence, and to transfer our outputs to industry organizations in 2023. "Threat intelligence" is information collected, analyzed, and accumulated to support responses to cyberattacks and other threat. In some industries, there are threat intelligence sharing activities.[(1)]

Sharing threat intelligence is expected to be effective in preventing chain-reaction damage caused by similar cyberattacks, but the currently shared threat intelligence comes mainly from the IT domain.

3.1. Examination of basic specifications for information collection and storage

In order for organizations in the automotive industry to obtain threat information more efficiently and proactively, we conducted PoC (Proof of Concept) on collection methods other than public information collection, referring to examples of implementation in the IT domain. During this activity, we focused on honeypots[*1] and playgrounds (one format of CTF[*2]), and examined whether these methods can be applied to the automotive domain.

3.1.1. Honeypot PoC

We created an automotive version of a honeypot used in the IT field and conducted PoC. Specifically, we investigated aftermarket products that can be detected via wide-area scanning, developed a honeypot prototype using the corresponding products, and began cyberattack observation experiments in late January 2021. Fig.6 shows an overview of the automotive honeypot.

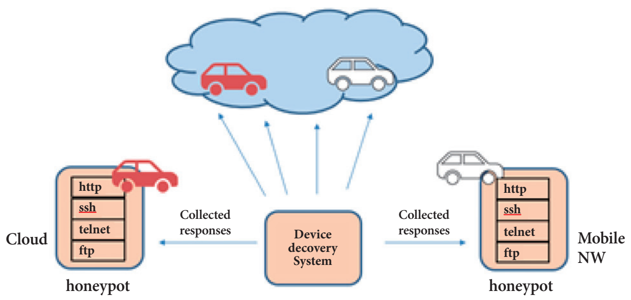

Fig.6: Overview of automotive honeypots

As a result of the current observation, we observed many activities that match the characteristics of IoT malware (Mirai etc.) as seen in IoT products, sending IDs and weak passwords to telnet. This is considered an automated attack from a device infected with malware and not an attack based on recognizing the honeypot as an on-board device.

As part of the honeypot PoC, we have also been concurrently studying efficient equipment search methodologies, and have proposed two approaches: keyword search using an Internet search engine to search websites for on-board unit products, and a direct search using Censys[*3] for keywords related to on-board unit.

The scope of the honeypot PoC up to FY2021 was honeypots that imitated aftermarket products among on-board unit, but in FY2022, we are also studying the methodology for collecting threat information using honeypots that imitate connected systems as a whole.

3.1.2. Playground experiments

Playground experiments were conducted to investigate cyberattack methods targeting vehicles in connected systems, as well as attacker's behavior and logs to determine if an attack was targeted at a vehicle. These playgrounds were conducted as hacking contests in which participants report vulnerabilities with the goal of exploiting the system, without the setting of any specific flags.

For the playgrounds, we prepared an environment that imitates a general connected system as shown in Fig.7. Although there are various attack surfaces in a connected system, the attack surface in this playground is a user application or a web portal site open to the public.

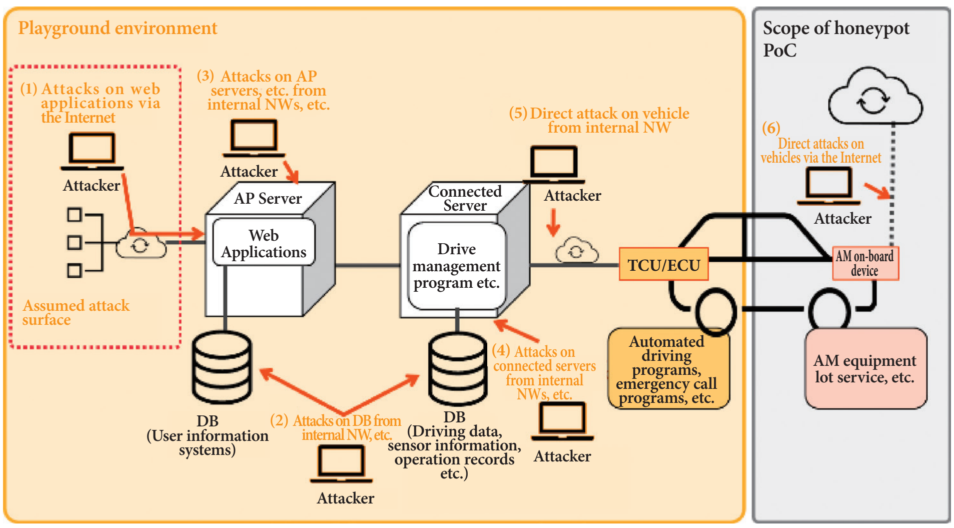

Fig.7: Playground environment

*1 Equipment for observing attacks. A method to collect and observe access information and attack methods of attackers by disclosing a system on the Internet with the intention of it being attacked.

*2 A method in which white hat hackers intentionally launch attacks against an environment that simulates a system to collect information on the availability of attacks and their methods. A widely known method is to set a target (flag) for the attack and compete for points.

*3 Censys is an IoT search engine. It can search for devices that are open to the public on the Internet.

3.2. Methods of describing and sharing threat information

In order to collect and share threat information efficiently, the threat information must have a certain level of structure and a method for sharing it must be formulated. As shown in Fig.8, as vehicles become more connected and automated, there will be more opportunities to adopt technologies used in IT domain. We are conducting research focusing on STIX/TAXII,*4 which is the most popular protocol in the IT field and is capable of describing many types of information.

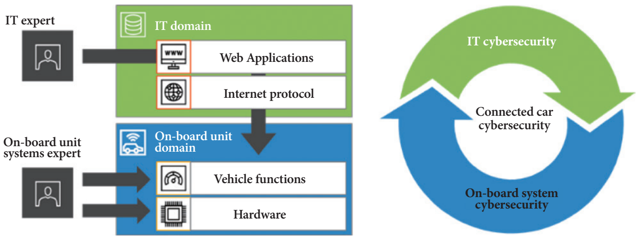

Fig.8: Integration of automotive and IT domains

3.3. Utilization of threat information for initial response

In order to manage threat information and utilize it for an initial response, it is necessary to determine whether the data discovered and reported daily is relevant to the vehicles or systems that will be managed. In particular, when open source software (hereinafter referred to as "OSS") is used, a large amount of vulnerability data is reported and frequent updates are performed. In turn, this makes it necessary to constantly update the relevant information and keep track of the version, increasing the difficulty in determining the relevance. Using Software Bill of Material (S-BOM) to manage the components included in software has been attracting attention as a solution to these issues. Although the S-BOM can be created in-house and used for vulnerability management, it can be used throughout the supply chain for a more comprehensive and efficient initial response. By creating an S-BOM and linking it to other information sources, such as information sharing systems, it is possible not only to determine whether or not the company's vehicles and systems are vulnerable, but also to smoothly access the relevant vulnerabilities and information necessary for an initial response in the event of an incident. (Fig.9)

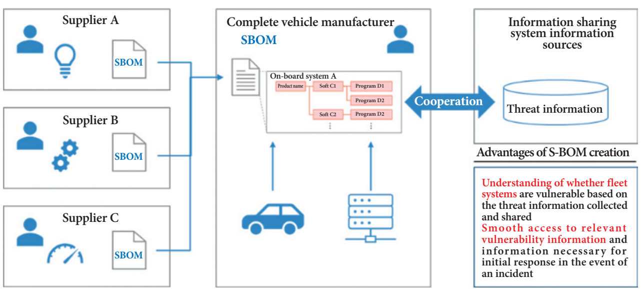

Fig.9: Use of S-BOM for initial response

3.4. Activities for social implementation

Our goals for this topic consist of two deliverables: basic specifications for an information sharing system that accumulates threat information in the automotive domain and can be used to support initial response to cybersecurity incidents, and an information collection guide that compiles knowledge on attack methods and technologies for connected systems as obtained from the honeypot and playground. Technical review meetings with J-Automotive-ISAC, to which the deliverables will be transferred, are being held on an ongoing basis and approval has been received for the transfer of the deliverables.

In order to cope with cyberattacks in the automotive domain, it is important to take cybersecurity measures not only for individual companies but also for the entire supply chain. In order to make the deliverables easier to deploy in practice, meetings were held as necessary with J-Auto-ISAC, the final recipient, in order to exchange opinions with the teams conducting testing and research at the field level.

After the transfer, which is scheduled for December 2022, we will continue discussions with J-Auto-ISAC for practical deployment and additional activities.

4 Outcomes of the Project

4.1. Development of IDS evaluation guidelines

For this topic, IDS evaluation guidelines were developed mainly to contribute to accelerating the start-up of on-board IDS development by OEMs/suppliers who are facing difficulties.

Regarding the basic test cases, test case procedures and expected values were confirmed using actual equipment through the collaboration of two companies, one OEM and one IDS vendor, validating their suitability. The transfer of the test cases to JASPAR has also been completed.

IDS for on-board units will be a typical technology and product that provides detection functions to cope with new cyberattacks in the future, but we found through interviews with some OEMs that this technology is not being studied at the same level in the automotive industry as a whole. The target of our evaluation was an off-the-shelf network monitoring IDS using CAN communication as the target protocol. The main content of this project is testing and evaluation methods focusing on detection functions, which is the main function of

*4 STIX is a standardized language developed to describe threat information, while TAXII is a specified procedure for sharing threat information.

IDS. It is expected that OEMs/suppliers will introduce appropriate IDS by referring to these IDS evaluation guidelines.

4.2. Research study on threat information and initial response support for connected cars

This topic aims to prevent cybersecurity incidents and minimize damage in the event of an attack on connected cars and automated driving systems, which are technology that have seen remarkable development in recent years. The basic specifications for an information sharing system and an information gathering guide for proactive threat information gathering are being prepared.

The deliverables for this topic will promote information sharing activities in the automotive industry, where connected cars are widely used and new cyberattack methods are continuously reported, and will contribute to enhancing first response capabilities. We hope that the proposed specifications will be used to develop and implement information sharing systems, and that the guidance will be used as a reference for proactive information gathering in addition to publicly available information. We also expect that these sharing systems and information collection efforts will continue to be improved and adapted to the automotive industry through continuous operation and review.

4.3. Conclusion

Since ensuring automotive cybersecurity may have an impact on automotive safety, it is appropriate to ensure that minimum cybersecurity standards are met and that the common threats faced as a whole must be made a cooperative area for the entire Japanese industry, or at least actively shared, in order to improve the development and operational efficiency of connected services and help Japanese companies to maintain their international competitiveness. It is also important to strategically approach standardization organizations so that the cybersecurity measures and information sharing mechanisms that have been established can be used to the advantage of Japanese companies, allowing Japan to make recommendations for future international standards and the development of automotive cybersecurity.

The final results of this project also lead into our further research and areas of focus. For the IDS evaluation guidelines, it will be possible to create guidelines for the evaluation of IDS other than off-the-shelf products, other protocols such as Ethernet, testing and evaluation methods for non-functional requirements such as performance that cannot be generalized at this time, and guidelines relating to IPSs (Intrusion Prevention Systems).

With regard to the basic specifications for information sharing systems and the information collection guidelines, it is necessary to catch up with and utilize methodologies and new technologies from overseas and other industries, and to continue research not only on information gathering, but also on methods of analyzing collected information and improving its accuracy and precision. In addition, cybersecurity on the side of connected services (such as servers and platforms), which has been investigated and handled independently by OEMs/suppliers, may become a new area of cooperative area, and is therefore considered to be an area of future research and focus.

Based on the above, data cybersecurity activities have an important role in the development of automated driving systems, and are expected to contribute to the development of cybersecurity activities in the industry.

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4) Research of Education Methods for Advanced Automated Driving Systems

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(Abstract) This paper outlines the activities of "Research and Development of Knowledge that Drivers and Pedestrians Should Acquire and Effective Educational Methods (Task C)" of the second phase of SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services). In Task C, based on the main research objectives, we have set three research themes for further developing educational methods: (1) proposal of an educational method based on individual characteristics, (2) proposal of a motivational method, and (3) development of complete educational materials that can be modularized with partial education in mind. In addition, using prototype teaching materials, we verified the effectiveness of providing general knowledge about automated driving in advance using a driving simulator.

Keywords: education, training, motivation, knowledge, experience

1 Introduction

In order for the user to safely utilize an automated driving system, the user must be able to make appropriate judgments and take appropriate actions according to the system functions, the role of the user (driver), and the situation in which he or she is placed. The human-machine interface (HMI) installed in the vehicle should support the user's judgment, and ideally, the HMI should support the user in making appropriate judgments intuitively, regardless of the user's knowledge. However, unfortunately, an ideal HMI that can guarantee the user's appropriate judgment and execution of actions has not yet been realized, and even if it were technically feasible, it may not be possible to use an ideal HMI due to cost constraints.

Therefore, it is necessary to consider how education and training should be conducted to provide users with the necessary knowledge and skills. This research and development is an effort to educate users on the safe use of automated driving.

2 Proposal of educational methods based on individual characteristics

In order to conduct education efficiently, it is necessary to appropriately take into account the characteristics of the recipient of education, such as learning styles. In this research and development, in addition to learning styles, we focused on resilience characteristics, one of the individual difference variables of personality characteristics, and examined the effects on knowledge acquisition when transitioning from Level 3 automated driving to manual driving, taking into account the fact that automated driving is a new learning experience.

Specifically, we analyzed the results of a survey of 3,240 participants conducted via the Internet during the first phase of SIP-adus in relation to personality characteristics and knowledge acquisition. Three types of educational materials (leaflets, quizzes, and videos) were used, and the effect of knowledge acquisition after learning with each material was compared.(1) A logistic regression analysis was conducted using the binary variable of the ascending and non-ascending groups as the dependent variable, and a group of variables that were assumed to influence the dependent variable as the independent variable, using propensity score matching. As a result, it was confirmed that the absorption effect of resilience characteristics differed depending on the format of the teaching materials, and that the video teaching materials had the greatest potential to absorb resilience characteristics.

In addition, a method that can absorb individual characteristics and be effective in educating a large number of trainees was investigated, as well as a method that can easily identify characteristics. As a result, we were able to develop a shortened version of the learning style and career resilience scale.[(2) (3)] Furthermore, we found that effective teaching materials can differ depending on differences in learning styles and career resilience. These results suggest that adaptive learning is feasible if thre is enough time in a education, where learning styles and career resilience can be easily examined using a shortened version of the scale, and learners are provided with more appropriate learning materials according to the results of the examination.

3 Proposal on motivation methods

The target audience for safety education is all transportation users, and is diverse and wide-ranging in terms of age groups, backgrounds, and learning styles. Many of them are not interested in automated vehicles. Driver education may include a course at the time of license renewal, but it is necessary to devise ways to increase learning effectiveness in a limited amount of time. Therefore, in addition to teaching materials, a method to arouse interest in the learning content was studied. In this study, we developed two types of motivational videos for safety education ("Narrative" videos that focus on stories that are expected to be emotionally moving, and "Fact-based" videos that focus on objective facts), using the motivational ARCS model. The results of formative evaluation suggested that the two types of videos were able to motivate at the same level.

In addition, in order to examine motivational methods for automated driving education, we used two types of motivational videos we developed and examined the effectiveness of motivational videos considering the influence of individual characteristics from a web-based survey of 2,790 participants.[(4)] Propensity score matching results verified the possibility that motivational videos utilizing the narrative method can absorb individual resilience factors compared to fact-based videos, and that after the fact scores increase with lower levels of resilience. In addition, the use of narrative-based motivational videos may be more effective when the individual's learning style is taken into account. It was also suggested that the use of narrative-based motivation may be able to absorb differences in individual attributes such as gender, age, marital status, and whether or not they have children.

In addition, the methodology of group training to increase motivation was also examined. We designed and implemented an online training course, and found that the training improved knowledge about automated driving systems and promoted attitude change.

4 Development of complete educational materials that can be modularized with partial education

One of the objectives of this project is to develop and accumulate a variety of educational material modules that can be combined with each other so that users can learn using educational materials that match their own characteristics and learning styles. For the research, we developed four modules including two types of motivational videos as described in Section 3, and quiz materials and video materials for acquiring general knowledge about automated driving. By developing a variety of teaching materials as short, micro-learning-enabled modules, it is possible to learn each of them independently, or to combine them according to learning goals or actual objectives. In addition, a simple driving simulation system that enables users to experience a driving takeover situation was developed as a web-based remote learning material. The effectiveness of these teaching materials has been confirmed through web-based surveys and verification experiments using the simulator described in Section 5.

In addition, among the materials developed for the research, the motivational videos and general knowledge videos will be published as sample teaching materials for actual use.

5 Experiments to verify educational effectiveness for educational opportunities

5.1. Educational opportunities

In this research project, we examined educational opportunities for automated driving with a view to social implementation. There are various educational opportunities, including mass media and websites, to provide the knowledge necessary to use automated driving or to interact with automated vehicles. Since the time and resources available for each of these opportunities are limited, it is important to select the appropriate level of specificity and granularity in line with the characteristics of each opportunity.

Opportunities to convey knowledge and information about specific systems to actual users may include opportunities for explanations at dealerships and car rental offices and at the time of delivery, as well as the ability to convey knowledge through in-vehicle systems. However, according to the ongoing research conducted to date in this project,[5] it is believed that some people generally have almost no knowledge of automated driving at all, and therefore it is necessary for them to have general knowledge to be able to understand the explanations of individual systems. Therefore, in this project, we decided to verify the effectiveness of communicating general knowledge about automated driving in advance.

5.2. Simulator-based verification experiment on general knowledge

First, we decided to verify the effectiveness of the general knowledge provision as a trial before the prototype teaching materials in Section 2. (Experiment 1) Based on the instructional materials used in the knowledge provision study conducted in the first phase of SIP-adus, we organized the general knowledge about automated driving, created an explanatory video, and had the participants watch it. Approximately one month later, an experiment on the handover from automatic to manual driving was conducted using a driving simulator. To test whether general knowledge is useful for several specific systems, two types of experiments were conducted: one that provided Level 3-equivalent functions only at low-speed following, and the other that provided Level 3-equivalent functions with no speed limit (between-subjects factor). Neither of the two types provides a function for changing lanes.

Fig.1 shows an example of the experiment results.[6] This is a scene in which a broken-down car is stopped in front of the driver's lane and the driver needs to change lanes to avoid it. Since the automated driving system in this experiment does not have a lane change function, the driver must take over in order to continue driving. Fig.1 shows the ratio of the number of people involved in a collision to the number of vehicles involved in a breakdown. As shown in Fig.1, the results suggest that if general knowledge about automated driving is provided in advance, the driver may be able to perform an appropriate takeover when RtI is presented by the system in a situation where doing so is necessary.

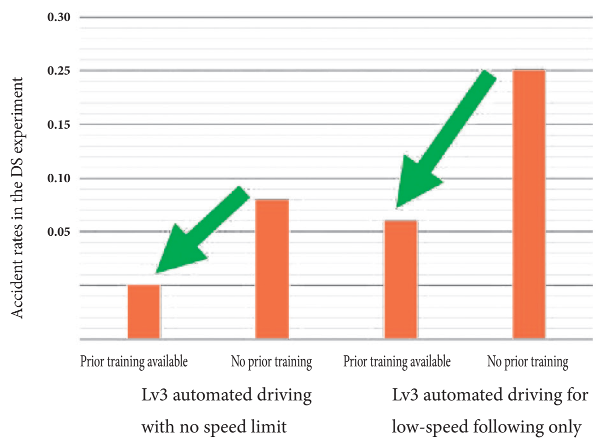

Fig.1: Example of experiment results

Next, a verification experiment was conducted using the video materials developed in Section 4, which were shortened to the time expected to be spent on actual education. (Experiment 2) In this experiment, an explanation of the system used in the experiment, along with general knowledge, was given approximately one month before the simulator experiment was conducted. As a result, many participants were observed to be unaware that they were being asked to take over driving in the first half of the experiment, even though the RtI was presented to them. The difference is that in Experiment 1, the explanation of the actual system was provided on the day of the experiment, whereas in Experiment 2, it was provided one month before the experiment. Although the usefulness of providing general knowledge was confirmed in Experiment 1, it is necessary to promote understanding of the provided knowledge in order to enable truly safe use of the system.

In order to promote understanding and retention, we reorganized the teaching materials so that necessary explanations are given in a timely manner, and we confirmed that in many cases, the participants were able to respond appropriately to driving takeover. In addition, we also examined the two points of including a specific system in the general explanation, and of providing even a simplified experience of the driving takeover, and confirmed that better results were obtained in the verification experiment when a specific system was included as a case study. The results also indicated that the effect of the experience of switching drivers may work in a more positive direction, although the effect was not statistically significant.

5.3. Verification experiment on how education and training should be conducted when actually using the system

Even if the same automated driving system is used in the sense of Level 3, the functions, their limitations, and situations in which driving takeover is required differ depending on the type of vehicle and system, such as whether there is a speed limit or not. Therefore, when actually using a particular system, it is necessary to have knowledge specific to that system and acquire the skills to respond appropriately in situations where driving takeover is required.

One of the important issues here is how effective the experience is. From the first phase of SIP-adus results,[7][8] we discovered that various experiments gradually allow the driver to respond more skillfully. On the other hand, when the driver suddenly encountered a serious situation such as loss of sensor function, there was a delay in intervention. In addition, it was confirmed that experience with functional failure, which is considered to be one of the most severe situations requiring driver handover, is effective when encountering actual situations, and that such an experience may be effective over a long period of time.[9] From the above, it is considered important to have the trainees experience specific driving takeover situations in advance. However, it is not always possible to devote enough time to the test-drive experience in the midst of complicated procedures such as contracting when buying or selling a vehicle. Rather, it would be effective to provide users with an opportunity to freely learn on their own in their spare time. Therefore, we conducted an experiment to verify the effectiveness of using the web-based system developed in Section 4 to allow users to experience a possible driving takeover situation using the same HMI as the vehicle they will actually use at a later date. As a result, it was found that the participants were able to take quicker action during the actual driving takeover by experiencing such a situation in advance.

In the web-based learning, there were some cases in which the learners skipped watching the video materials that they should have viewed, and as a result, there were some cases in which their understanding was considered insufficient.

6 Social implementation

Instead of simply summarizing the results of this research and development in this report, they should be utilized for social implementation. For those who plan education, etc., this report is a manual that summarizes the knowledge that contributes to planning and development of teaching materials. In addition, as described in Section 4, we are preparing to release motivational videos and general knowledge video materials as samples. We hope you will find the manual and other materials useful.

Since this manual was compiled, we have continued to analyze data obtained as a result of our research and development activities, and as further findings are obtained, we hope to take the opportunity to revise it as necessary.

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5) Research on Communication between Low-Speed Automated Transportation and Logistics Services Vehicles and Surrounding Traffic Participants

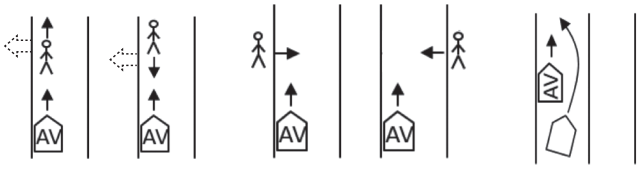
Tatsuru Daimon, Masahiro Taima, Jieun Lee, Tomoyuki Furutani (Keio University)

(Abstract) Aimed at addressing societal problems such as facilitating mobility for vulnerable road users, alleviating a lack of drivers for transportation and logistics services, and reducing costs, technologies are currently being developed for low-speed automated transportation and logistics service vehicles, and FOTs (Field Operational Tests) are being done in rural regions. In contrast to traditional driver-operated vehicles, low-speed automated service vehicles need to see a number of issues addressed, including safety, security, and traffic efficiency, through better communication with traffic participants, including pedestrians and other drivers. In order to achieve safe and reliable communication between low-speed automated service vehicles and traffic participants, we analyzed communication characteristics observed during the FOTs, and conducted experimental studies concerning communication methods (vehicle behaviour, external HMI (eHMI), etc.) for relaying to traffic participants the intent and status of automated service vehicles. Furthermore, through the field operational tests, we tested communication methods through eHMI identified based on experimental studies, and confirmed the effectiveness of design recommendations for communication methods.

Keywords: communication, expression of intent, eHMI (external human machine interface), vehicle behavior, traffic participant

1 Introduction

To ensure mobility for vulnerable road users in rural, or depopulated areas, and to alleviate a shortage of drivers for transportation and logistics services, research is being done into the deployment and usage of transportation and logistics services that make use of automated vehicles. At this early stage, research is proceeding with the expectation that these services will be used for low-speed travel in general road environments and traffic situations where there are pedestrians, drivers, and other traffic participants. In some areas, including those where FOTs are being done, human attendants who can manually intervene are needed for safety reasons in automated transportation or logistics service vehicles traveling at low speed. However, technological advances should pave the way to a means of vehicle operation capable of handling situations and limitations in areas of automated service vehicle deployment, including means of operation where no human attendants, or their intervention, are needed. On the other hand, conventional driver communication, such as gestures and eye contact, for the purpose of ensuring safety and traffic facilitation for participants in surrounding traffic, facilitates their understanding of the vehicle's intentions and status and their own judgment of their own actions, and improves their sense of security. However, there is unlikely to be any active communication from human crew member when automated service vehicles are being operated without involvement by such crew member. These research and development efforts[1] have focused on developing and proposing design recommendations to support and achieve safe and seamless communication between automated service vehicles and traffic participants. Through cooperation with "automated service vehicle FOTs in areas primarily around Michi-no-Eki (Roadside Stations) in rural regions,"[2] ("Michi-no-Eki FOTs"), we analyzed drive recorder video and identified typical unsafe and inefficient means of communication between automated service vehicles and traffic participants[3], shown in Fig.1. For these typical cases, a focus was placed on methods that included means of communication between traffic participants and automated golf carts (6-passenger capacity) traveling at up to 12 km/h along only electromagnetic induction line, especially external human machine interfaces ("eHMI"). We conducted experiments in a virtual reality environment (VR experiments) using a head mounted display, experiments using a driving simulator, and road experiments using an experimental vehicle on campus and in other locations, researching and proposing means of communication for each case. In cooperation with Michi-no-Eki FOTs, we also conducted FOTs relating to means of communication involving eHMI, and evaluated the effectiveness of these means.



(a) Approach/avoid (b) Cross (c) Overtake

Fig.1: Categories for communication with traffic participants

2 Communication methods for approach and avoidance situations

For approach and avoidance situations, we researched communication methods through VR experiments that focused on eHMI, for example, that included visually or auditorily conveying vehicles' intent to pedestrians in situations where automated service vehicles approach pedestrians from behind.

2.1. eHMI specifications

For eHMI used for approach and avoidance situations, as shown in Fig.2, we developed the phrases "now moving" to indicate vehicle intent and "please clear the way" as a request for pedestrians, adding auditory cues to the existing visual cues.

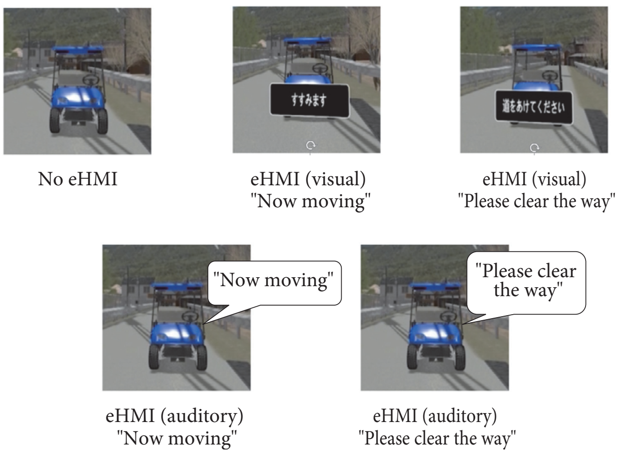


Fig.2: eHMI specifications

2.2. Experiment method

We built road environments modeled after non-intersection segments in areas surrounding Michi-no-Eki (Roadside Stations) and had experimental participants—posing as pedestrians—look back and confirm the state of an automated service vehicle approaching from or stopping behind them as the pedestrians walked down the left side of a non-intersection segment. We then studied those pedestrians' understanding, avoidance behavior, etc. when the eHMI gave them visual or auditory information about the intent of the vehicles, or requests to avoid the vehicles.

2.3. Results of the Experiment

Concerning avoidance behavior after a pedestrian notices an automated service vehicle approaching from behind, we observed numerous cases of inadequate avoidance by pedestrians, including them not getting off the roadway or moving over a little bit to the road shoulder when no eHMI was deployed. However, when the pedestrians were given information from an eHMI, many practiced proper avoidance.

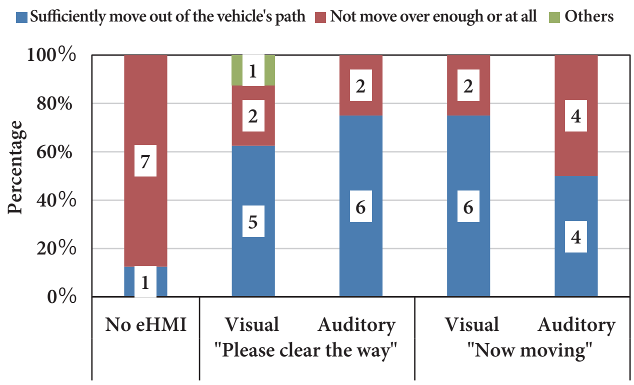


Fig.3: Pedestrian avoidance behavior upon first notice

We also analyzed how much time it took for experimental participants who conducted proper avoidance and moved completely off the roadway after noticing an automated service vehicle to complete the avoidance process. Those given any sort of auditory cues took roughly 5 seconds to complete the avoidance process, whereas those given visual cues tended to take longer, although there was considerable individual variation. In a retrospective report released after the experiment was completed, many experimental participants did not know that automated service vehicles could not drive themselves automatically separated from electromagnetic induction line.

When no eHMI was used and an automated service vehicle had stopped before the experimental participants turned around and noticed them, many said that they didn't know what they're being told about. Even when the eHMI was used, people told us, for example, that "I thought I just needed to move over to the shoulder a little and the automated service vehicle would correct a little and avoid me," "'Now moving' is not enough to prompt me to avoid vehicles," "('Please clear the way') makes me feel like I am being forced to take action, like I'm being admonished in front of others" (Visual cues) are always shown, but I'm not used to looking for them and so I don't notice them right away."

To summarize the results of the above, we expect that, in approach and avoidance situations, the recommended communication methods will convey avoidance requests to pedestrians using eHMI that provide either both auditory and visual cues or only auditory cues.

3 Communication methods for street crossing situations

For street crossing situations, regarding automated service vehicle behavior and eHMI-based communication methods identified through VR experiments focused on non-intersection segments and parking areas, we studied communication methods through on-premises road experiments that involved both the presence and absence of human crew members.

3.1. Specifications for test vehicles, deceleration behavior, and eHMI

The experimental vehicle was a golf cart capable of automated driving, as shown in Fig.4. As with the Michi-no-Eki FOTs, this vehicle was capable of automated driving along electromagnetic induction line buried under the street. For the eHMI, we installed LED panels on the dashboard under the windshield. We created three types of information communicated to pedestrians by the experimental vehicle: "After you" (request to pedestrians), "Vehicle will stop" (vehicle intent), and "Vehicle is in automated driving mode" (vehicle control state). We also established three types of deceleration behavior for street crossing situations based on experimental vehicle deceleration start point and stop point when traveling at 12 km/h (as shown in Fig.5): normal deceleration, early deceleration, and early stop.

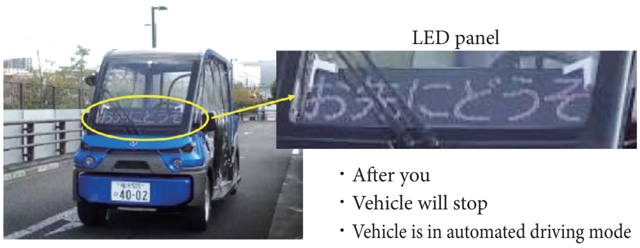


Fig.4: Experimental vehicle and eHMI specifications

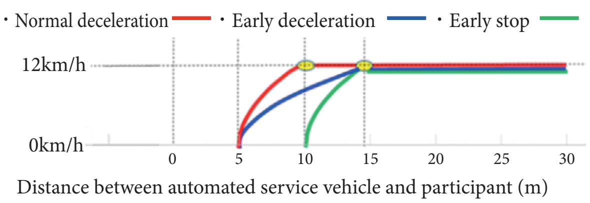


Fig.5: Deceleration behavior types

3.2. Experiment method

To simulate the residential roads with few sidewalks in areas around Michi-no-Eki (Roadside Stations), we set up comparatively narrow on-premises roads. We had experimental participants, as they waited on the road shoulder to cross the road, observe the behavior of automated service vehicles, eHMI, and the presence or absence of human crew member, as the vehicle approached at 12 km/h from up the right side of the pedestrians. We then examined whether the experimental participants perceived that the automated vehicle had given way to them or not, and also whether they could judge to cross the street safely.

3.3. Results of the Experiment

The following are the results of tests involving the presence of human crew member under the same driving condition as was present in the Michi-no-Eki FOTs. Fig.6 shows the timing with which pedestrians decided to start crossing as the experimental vehicle approached. When no eHMI was present, pedestrians made the decision to start crossing several seconds after the vehicle stopped. When an eHMI was used, pedestrians made the decision to start crossing at about the same time or even before the experimental vehicle stopped. Some participants made the decision to cross even earlier when the vehicle conducted early deceleration, and participants tended to start crossing after the vehicle started decelerating but before it stopped when given the "After you" cue.

When no eHMI was used, participants' anxiety when deciding whether to start crossing, was high when vehicles decelerated or stopped in earlier timing, and conversely was low when the vehicle conducted normal deceleration. When an eHMI was used, participants' anxiety was lessened when the vehicle performed an early stop.

To summarize the results of the above, we expect that, in street crossing situations, the recommended communication methods will be to conduct with deceleration behavior such as

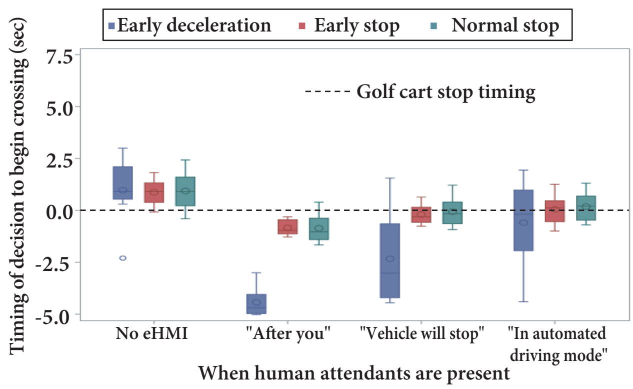


Fig.6: Deciding timing to start crossing when human crew members are present

4 Communication methods for overtaking situations

As a communication method to reduce unsafe behavior by drivers approaching from behind an automated service vehicle and overtaking it, we conducted DS experiment to study the impact that had on such drivers' understanding and overtaking behavior when they are provided with vehicle state, type, and caution information when they overtake the automated vehicle, rather than directly conveying vehicles' intent to stop or yield.

4.1. Road environment and eHMI specifications

As shown Table 1, road environments were constructed according to different types of centerlines. As shown in Fig.7, we established three types of specifications for eHMI used for overtaking situations, indicating them on the rear of the automated service vehicles. These are "Low-speed travel / Automated vehicle" (alternately displayed in one-second intervals) to indicate vehicle state and type, "Be careful when overtaking" to alert drivers when passing vehicles, and "Beware of surroundings / Please proceed" (alternately displayed in one-second intervals), which includes intent to yield as a comparison.

Table 1: Studying communication according to centerline types

Road environment	Goal of communications from golf cart to following vehicle	Golf cart vehicle state/behavior
Yellow centerline	• Restrict overtaking • Efficiently corresponding to following traffic	•Maintain travel/driving state • Stop after decelerating
White centerline	• Alert when overtaking • Efficiently corresponding to following traffic	• Maintain travel/driving state

4.2. Experiment method

After building a road environment modeled after non-intersection segments in areas around Michi-no-Eki, we had experimental participants approach and overtake automated service vehicles traveling along roads in the area. We studied the impact that was had on drivers' understanding, overtaking behavior, etc., by automated service vehicle behavior, lighting system operation (direction or hazard indicator lamp, stop lamp) and the presence or absence of eHMI. We set up contactless eye tracking systems on the DS, measured the participants' gazes as they drove, and analyzed where they looked from the time they approached the automated service vehicle to when they started and completed their overtaking.

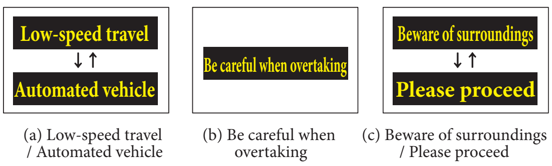


Fig.7: eHMI specifications

4.3. Results of the Experiment

The following is a summary of the results of experiment focused on white centerlines. Fig.8 shows time spent looking at surroundings, starting from when participants approached the automated service vehicle to when they started to overtake it. Participants looked at their surroundings for about five seconds when no eHMI was used, for around eight seconds when issued a "Be careful when overtaking" alert by the eHMI, and about five seconds when issued a "Low-speed travel / Automated vehicle" alert. When issued a "Beware of surroundings / Please proceed" alert, participants spent relatively less time looking at their surroundings.

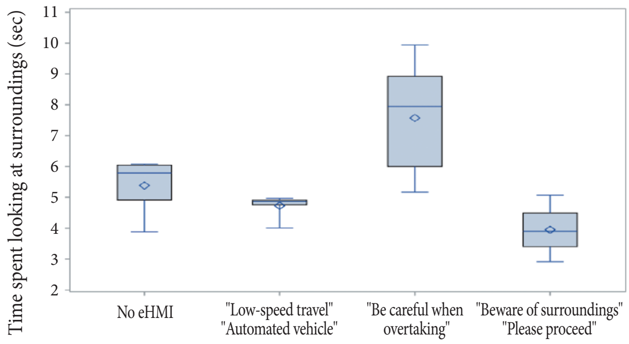


Fig.8: Time spent looking at surroundings, from start of approach to start of overtaking

Regarding participants' recognition of receiving the right-of-way from automated service vehicles, recognition was low when no eHMI was used. Recognition was highest when the eHMI issued the "Beware of surroundings / Please proceed" alert. Although "Low-speed travel / Automated vehicle" and "Be careful when overtaking" do not explicitly express vehicles' intent to yield both alerts yielded greater such recognition when compared to situations where no eHMI was used. Compared to when not using an eHMI, participants receiving eHMI alerts felt less irritation from the time they approached the automated service vehicle to when they started overtaking it.

To summarize the results of the above, we expect the recommended communication methods will use eHMI to give drivers information on vehicle state, type, when they overtake an automated service vehicle.

5 FOTs to verify communication methods using eHMI

In conjunction with Michi-no-Eki FOTs and with a focus on methods of communication between an automated service vehicle and traffic participants that were identified through VR, DS, and on premises road experiments, we used actual traffic environments to verify communication methods for crossing and overtaking situations.

5.1. Experimental vehicle and eHMI specifications

As shown in Fig.9, we installed an LED panel to serve as a rear eHMI on the rear cargo bed of an automated golf cart experimental vehicle used in the on-premises road experiments. Activation and deactivation of front and rear lighting on the eHMI were manually controlled by human crew members. We configured the front eHMI to display "After you" and "Vehicle will stop" for crossing situations, and configured the rear eHMI to display "Low-speed travel / Automated vehicle" (alternately displayed) and "Be careful when overtaking" for overtaking situations. We configured the front eHMI to display these messages roughly concurrently with deceleration start, and for the rear eHMI to display the messages constantly. We also mounted several drive recorders and cameras on the experimental vehicle to capture traffic participants' expressions and behaviors. The eHMI and messages were used in each FOT location after application was filed and approved for a relaxation of regulations.

eHMI (front)

eHMI (rear)

Fig.9: Experimental vehicle and eHMI used in the FOTs

5.2. Characteristics of the FOTs area and road traffic conditions

With support from the Road Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, Highway Industry Development Organization, local government organizations, and local transportation service providers, we conducted FOTs around Akagi-Kogen Michi-no-Eki (Iinan, Iishi District, Shimane Prefecture, hereinafter "Akagi-Kogen") and the Yamakawa region of Miyama (Miyama City, Fukuoka Prefecture, hereinafter "Miyama"). The Akagi-Kogen service route has many residential roads and little vehicle traffic. The Miyama travel route has national highways and considerable vehicle traffic, including large vehicle traffic, and there is a considerable speed difference between these vehicles and automated service vehicles. In all of the FOTs areas, parking areas existed at the start/end points and along the routes, and pedestrians could encounter situations where they crossed the path of the automated golf carts in the parking lots.

5.3. Experiment method

Under the guidance of local government organizations and service managers, the experimental vehicle was run for 10 days during daytime hours in each FOT area. To ensure traffic safety, we followed the guidance we were given and had the experimental vehicle slow down and pull over to the left when the human crew members detected the approach of following vehicles so that following drivers could overtake the experimental vehicle safely. Using drive recorders and cameras mounted on the experimental vehicles, we recorded video data of traffic participants' expressions and behavior while the vehicle was in operation. We chose eHMI message types based on the number of observations to be made and vehicle operation state, including displaying no message at all.

5.4. Results of the Experiment

To ensure that applicable instances of communication were missed, we recorded all traffic participants that were present within a certain radius from the test vehicles. In Akagi-Kogen, this was 33 pedestrians and 114 vehicles (four-wheel vehicles and large vehicles), and in Miyama this was 13 pedestrians and 525 vehicles. We established the road crossing situations as those where pedestrians noticed the test vehicle and crossed the road. For vehicle passing situations, due to the large number of incidents recorded, we selected and analyzed incidents at random.

For crossing situations, this paper analyzes observations made in Akagi-Kogen. We calculated the time it took for pedestrians to start crossing after noticing the experimental vehicle or after the experimental vehicle stopped. These results are shown in Fig.10. Although the number of observations is insufficient, when pedestrians were provided with no cues from an eHMI, they took at least five seconds to start crossing. When cues from an eHMI were provided, they took within two seconds.

For overtaking situations, this paper conducts analyses of observations made in Miyama. The analyses, which look at situations where following vehicles approach and overtake the experimental vehicle from behind, examine the traveling state of the following vehicles just before attempting to overtake the experimental vehicle. These analyses also take into account

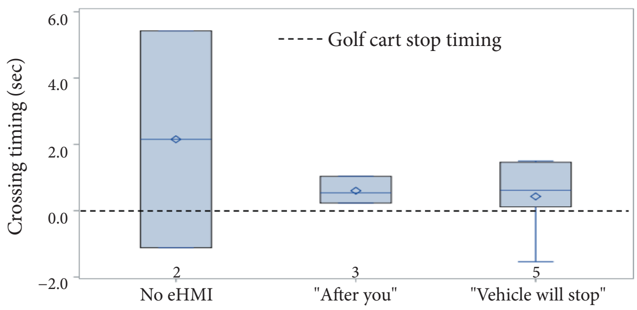


Fig.10: Pedestrian crossing timing in Akagi-Kogen

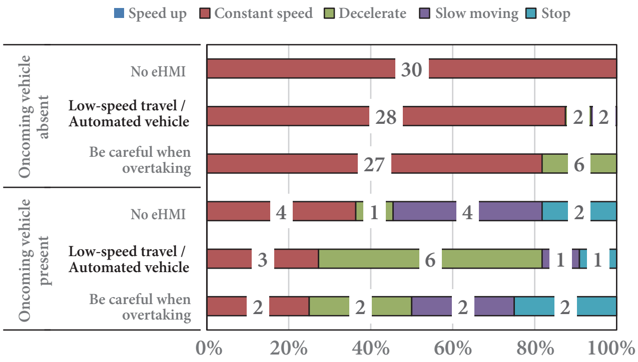


Fig.11: Travel state of following vehicles just before their start overtaking in Miyama

whether or not there were oncoming vehicles. These results are shown in Fig.11. Most of the service routes in Miyama are national highways, with vehicles traveling at speeds much higher than the 12 km/h or slower of the experimental vehicle. Although the number of observations was low when there were oncoming vehicles, we observed following cars decelerating before overtaking the experimental vehicle when provided with cues from the eHMI, suggesting these cues encourage slowing down before overtaking.

We also observed a small number of cases where, even when the eHMI provides cues, oncoming vehicles and following vehicles interfere with each other. This could be due to the road environment or to experimental vehicle stop timing or positioning when yielding to following vehicles. A more in-depth investigation is needed with regard to communication methods that take into account possible interference between traffic participants.

6 Conclusion

Aimed at achieving safe and efficient communication between an automated service vehicle traveling at low speed and traffic participants, this paper reports on the results of various experiments conducted to evaluate the effectiveness of communication methods and eHMI design recommendations, among other things, for different traffic situations. We observed instances of unsafe or inefficient communication that is difficult to collect data on through VR, DS, and on-premises road experiments and that relies on actual road environments and traffic conditions. Furthermore, we were unable to conduct an adequate number of observations due to FOT time limitations. Further FOTs and other studies will need to be done in order to observe communication situations and evaluate the effectiveness of communication methods.

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6) Research of HMI for Advanced Automated Driving Systems

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(Abstract) This paper outlines the efforts in "Development of evaluation methods of driver's OEDR (Object and Event Detection and Response) and HMI for enhancing driver' takeover in a transition from automated to manual driving (Task B)" in the second phase of SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services). In Task B, we considered evaluation indices for the driver's peripheral monitoring status before a takeover from automated to manual driving, and the effects of HMI on the driver's understanding of the system. We conducted driving simulator experiments to study a method for the quantitative evaluation of the driver's OEDR in preparation for driving in a system-initiated driver takeover from Level 3 automated driving. From the experiment results, we identified an evaluation index for the driver's OEDR and determined the time required for appropriate OEDR. In driver-initiated driver takeover situations from Level 2 automated driving, we found that eye tracking are effective in evaluating the driver's attention state during Level 2 use. We also clarified the HMI requirements so that the driver can understand the functional limits of the system appropriately and respond appropriately before the functional limits are reached.

Keywords: human factors, driver takeover,evaluation methods, HMI (human-machine interface) , driving simulator

1 Takeovers From Automated to Manual Driving

When using automated driving, the driving mode may switch from automated driving to manual driving due to causes such as reaching a system functional limit or the boundary of the system's operational design domain (ODD). Here, we addressed the human factor issue by classifying takeovers into two categories: system-initiated takeovers, in which the automated driving system announces the takeover to the driver, and driver-initiated takeovers, in which the driver takes over driving based on his/her own judgment while the automated driving system is in use.

In system-initiated driver takeovers, when the automated driving system is at Level 2, the driver needs to monitor the system's operating status as well the surrounding situation. Yet because it is not always the case that the driver maintains a state of monitoring, it is essential the system detects the state of the driver during automated driving, and knows whether it is possible to switch driving over to the driver. The first phase of SIP-adus addressed different driver states, such as looking aside (not facing forward),[(1)(2)] attention directed elsewhere (facing forward but thinking about something other than driving and not paying attention to the information necessary to drive),[(1)(3)] and dozing (decreased alertness).[(1)(4)(5)] The study was conducted for evaluation indices for each state as well as the effects of these states on driving performance during driver takeovers.[(6)] Based on these findings, we also examined methods for predicting performance after a driver takeover based on the driver's eyeball movements.[(7)] Furthermore, in addition to estimating the driver's state during automated driving and analyzing the effects on driving performance, we also studied measures to prevent the driver's alertness level from decreasing during automated driving.[(8)(9)]

Efforts in the second phase related to system-initiated driver takeovers focused on Level 3 use of an automated driving system. We investigated a method for quantitatively evaluating the state in which the driver is ready for the driving task, i.e., the state in which the driver is aware of the surrounding situation, in order to appropriately carry out driver takeovers while the driver is performing non-driving related activities (NDRA) during automated driving at Level 3.

For driver-initiated takeovers, we investigated a method to evaluate the state in which the driver can appropriately understand the system's functional limits at Level 2 automated driving and respond appropriately. In addition, we experimentally studied the requirements for HMI that enables the driver to appropriately understand the functional limits of the system and respond appropriately.

2 System-Initiated Driver Takeovers

2.1. Overview of Issues Addressed

In Level 3 automated driving, in order to properly perform a driver takeover while the driver is doing something other than driving during automated driving, it is necessary to appropriately shift the driver's attention from the non-driving related activity to the driving task. To this purpose, an effective way to prepare for the driver takeover is by having the driver recognize the surrounding situation, such as the speed of his/her own vehicle, the movement of other vehicles around him/her, and the state of the road environment, before performing the driving task manually. The key issue here is how to evaluate whether the driver is appropriately aware of the surrounding situation. Based on this awareness of issues, for this topic, we addressed the following issues. (Fig.1)

- Methods for evaluating the driver's awareness of the surroundings prior to a change of driving
- Time required for proper OEDR
- Validity of evaluation methods for OEDR by driver (comparison with standard evaluation methods for peripheral awareness)
- HMI requirements to promote proper OEDR

2.2. Experiment Scenarios

Each of the four issues above was examined in driving simulator experiments. The road traffic scenarios were the same for all experiments and were as follows

- The vehicle traveled at approximately 60 km/h in the center lane of a motorway with three lanes in each direction in automated driving mode.
- During the automated driving, participants in the experiment played a game (Tetris) using a tablet PC.
- A few minutes after the start of automated driving, we initiated a driver takeover, and a lane change was performed by manual driving within a specific section.
- We measured the driver's eye movement and head movements during automated driving. Driving behavior after switching to manual driving was also measured, and the lane change success rate was calculated.

2.3. Study of Methods for Evaluating Driver's OEDR Before a Driver Takeover

(1) Experiment conditions

In this experiment, in which 30 drivers participated, the following conditions were set: a condition in which the driver is given a one-minute warning before the takeover, a condition in which the driver stops playing Tetris and becomes aware of his/her surroundings one minute before the takeover, and a condition in which the driver changes without such a warning and without becoming aware of his/her surroundings in advance.

(2) Results of the experiments: Driving performance after driver takeover

The percentage of drivers who were able to change lanes within a specific section without colliding with other vehicles after the takeover was calculated, and the percentage was significantly higher in the condition in which the driver became aware of his/her surroundings before the takeover than in the condition in which the driver did not become aware of his/her surroundings. The results suggest that, in Level 3 automated driving, the driver can perform a takeover more appropriately when switching from a state in which the driver is doing something other than driving to manual driving by creating a preparatory state for the takeover by becoming aware of the surrounding situation.

(3) Results of the experiments: Evaluation index of driver's OEDR

An analysis of the forward fixation rate after the start of peripheral awareness based on the driver's visual behavior as detected by an eye camera showed that the forward fixation rate tended to increase for 20 seconds after the start of peripheral awareness, and stabilized at a higher value from 30 seconds after the start of peripheral recognition to

Transition from automated driving Level 3 to manual driving

-Planned driver takeover

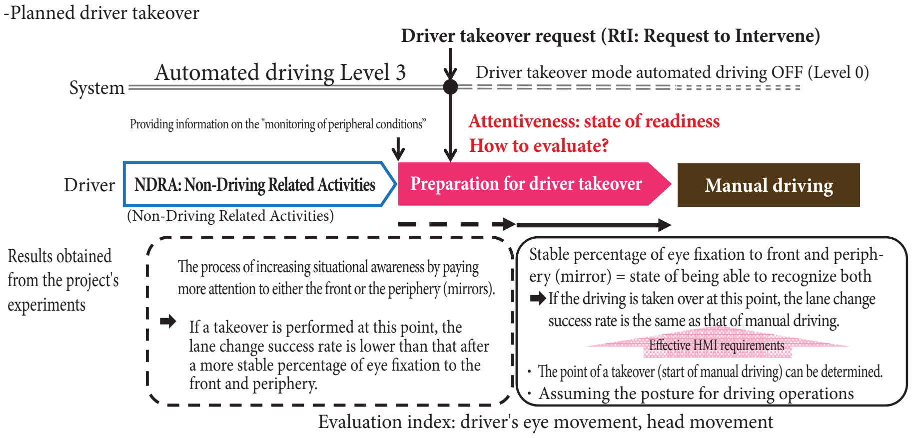

Fig.1: System-initiated driver takeover efforts and results

the point at which the driver takeover was performed. Furthermore, the forward fixation rate remained stable after the driver takeover. The eye movement other than forward fixation were directed at side mirrors, rearview mirror, and instruments.

This result suggests that the forward fixation rate after the start of OEDR can be an effective evaluation index of the driver's peripheral monitoring, and that the driver can be judged to be aware of the surrounding traffic situation when the low forward fixation rate increases immediately after the start of awareness and then remains stable.

2.4. Examination of the Time Required for Proper OEDR

(1) Experiment conditions

The experiment conditions consisted of the times taken for the driver to become aware of his/her surroundings before taking over driving. There were four experiment conditions set at 5, 10, 20, and 55 seconds, and a 0-second condition (taking over driving from the state of playing a game), plus a manual driving condition rather than an automated driving condition. There were 30 participants in the experiment.

(2) Results of the Experiment

The rates of forward and mirror gazing were calculated for the four conditions in which OEDR was studied, and the changes from the start of peripheral awareness were compared. The results showed that the changes from the start of peripheral awareness were the same in all conditions, and that the rate of forward fixation increased until 20 seconds from the start, after which it tended to stabilize. Put differently, no such stable shift was observed in the 5-, 10-, and 20-second conditions. The results of the driving performance after the takeover showed that the lane change success rate in the 55-second condition was higher than that in the 0-, 5-, 10- and 20-second conditions, and was as high as that in the manual driving condition.

This result indicates that high performance was observed in the driver takeover after the stable shift in the forward fixation rate, which supports the results in 2.3.

2.5. Study of Validity of Evaluation Methods for Driver OEDR (Comparison With Standard Evaluation Methods for OEDR)

(1) Experiment conditions

The time for the driver to become aware of his/her surroundings before the driving takeover was set to 55 seconds, and the verbal thinking method was used to obtain utterances of what the driver was thinking during that time. In the DS experiment with 20 drivers, we obtained utterances related to awareness of the surrounding situation, such as, "The flow of cars in the right lane is faster than my car."

(2) Results of the Experiment

From the obtained utterances, we tabulated the number of utterances related to the situation in front and the number of utterances related to the situation in the peripheral area. The number of forward/periphery-related utterances from the start of the driver's peripheral awareness and the change in the rate of gaze to the front/mirrors over the same time period were compared. The number of forward/periphery-related utterances and the rate of eye fixation to the front/mirrors showed nearly the same change.

This result indicates that the change in the eye fixation rate is large in the sections where the change in the number of utterances is large. Conversely, the change in the number of utterances is stable in the sections where the change in the eye fixation rate is stable. Assuming that the number of utterances indicates the degree of awareness of the situation, the result suggests that the change in eye fixation rate may correspond to the degree of awareness of the situation.

2.6. HMI Requirements to Promote Proper OEDR

(1) Experiment conditions

In order to examine HMI requirements for promoting OEDR when asking drivers to become aware of their surroundings before driver takeovers, we set the following conditions: a condition in which the driver is informed of the takeover timing by being told "Takeover after x seconds," a condition in which a countdown is given in addition to clearly stating the takeover timing, a condition in which the driver takes hold of the steering wheel and assumes the driving posture while becoming aware of his/her periphery, and a condition in which an alarm is sounded if the driver does not become aware of his/her periphery. A total of 120 drivers (20 per condition) participated in the experiment.

(2) Results of the Experiment

Comparisons of the times it took to complete lane changes and of the collision rate showed that the results of the condition in which the driver is given a countdown in addition to being informed of the takeover timing and the condition in which the driver assumes the driving posture and takes the steering wheel during OEDR were better than those of the other conditions. At the same time, the condition in which an alarm was sounded when the driver failed to become aware of his/her periphery had no effect on improving driving performance.

These results suggest that knowing the time of a driver takeover and assuming a posture for driving operations are effective in improving driving performance after the takeover.

3 Driver-Initiated Driver Takeovers

Level 2 driver assistance requires the driver to be aware of the surrounding situation and of the system status during automated driving, and to take over driving when the system reaches functional limits. In this study, we investigated a method for evaluating whether the driver understands the system status appropriately. We also studied HMIs that facilitate the driver's understanding of the system to ensure that the driver can take over driving without fail.

3.1. Method for Evaluating the Driver's Understanding of the System

We interpreted a driver state equivalent to manual driving as the state in which the driver is able to coexist with the system, i.e., he/she understands the system state. We analyzed the differences in driver behavior during manual driving and Level 2 driver assistance to investigate a method for evaluating the state of system understanding.

A driving simulator experiment was conducted with 10 experiment participants,[10] driving in the second lane of a road with three lanes in each direction by manual driving or Level 2 driver assistance. We set up potential risk situations in which the participants should pay attention to their surroundings while driving. The participants' eye movements while driving were measured using a non-contact eye camera. Significant differences were observed in the duration of eye fixation in several areas, with a tendency for the participants to spend less time looking at the front and instruments and more time looking at the periphery and mirrors during Level 2 driver assistance than during manual driving.

3.2. HMI to Facilitate System Understanding

Candidates for HMIs that would help drivers understand system detection failures and false detections were selected and operated in a driving simulator environment. An HMI that displays the recognition results of the traffic situation in real time was used in a driving experiment with 18 participants.[11] [12] The results of a questionnaire showed that, when the HMI display was present, drivers understood that the automated driving system may not be able to recognize objects other than vehicles, suggesting that the HMI may promote driver understanding of the system.

3.3. HMI for Preventing Vehicle-to-Vehicle Accidents at Signalized Intersections

The purpose of this experiment was to investigate the requirements for an HMI to prevent vehicle-to-vehicle accidents near signalized intersections through appropriate driver intervention during driving by Level 2 driver assistance. Two types of HMIs were proposed: one that presents static environmental information based on map information for the purpose of clearly indicating dangerous locations (static HMI), and one that presents object recognition information based on on-board sensor information for the purpose of confirming the Level 2 driving support mechanism (sensor HMI). We evaluated the effectiveness of these HMIs through experiments using a driving simulator. The HMIs proposed in this study display the presented information on a heads-up display fixed to the dashboard of the driving simulator.

The road environment used in the experiment simulated a Japanese national highway, with two lanes in each direction and an additional right-turn lane near intersections, resulting in three lanes. In the straight-ahead scenario, the vehicle followed another vehicle ahead of it in the second lane at 60 km/h using the Level 2 driver assistance system. The driver did not need to perform any dynamic driving tasks such as acceleration/deceleration or steering operations when the driver assistance system was in operation. In the risk scenario, another vehicle appeared in the right-turn lane of the oncoming lane at a signalized intersection, and when the driver's vehicle entered the intersection, the other vehicle suddenly started to turn right. The situation was such that if the driver did not intervene in driving, a collision would have occurred. The Level 2 driver assistance system did not request any driver intervention, and the driver had to detect the hazardous event or anomaly on his/her own and take the initiative to avoid the collision. The four experiment conditions were a combination of the presence and absence of static HMIs and sensor HMIs. An analysis of the experiment data showed that the combination of a static HMI and sensor HMI resulted in the driver intervention with the largest margin between vehicles and significantly increased the driver's sense of driving safety compared to driving without HMIs.[13] [14]

In the right-turn scenario, the vehicle makes a right turn at a signalized intersection in Level 2 driving. In the risk scenario, a motorcycle slips out from the oncoming lane while the vehicle is turning right, and the driver must intervene to avoid a collision with the motorcycle. The driver intervention time and the collision margin time upon intervention were analyzed. The driver intervention time tended to be shorter and the collision margin time tended to increase when the static HMI and the sensor HMI were used together.

3.4. HMI for Accident Prevention During Traffic Signal Changes at Signalized Intersections

During Level 2 driver assistance, in which control by signal recognition is not performed, the driver is required to perform driver-initiated intervention to stop the vehicle when the signal turns yellow on approach to a signalized intersection when engaging follow control by adaptive cruise control. The purpose of this experiment was to investigate HMI requirements to support safe travel at a signalized intersection when the signal light color changes just before the vehicle enters the intersection during Level 2 driver assistance.

We proposed a static HMI that presents static environmental information based on map information and a dynamic HMI that presents dynamic environmental information based on infrastructure information in addition to static environmental information. The dynamic HMI presented information such as the predicted color of the traffic light ahead when the vehicle reaches a signalized intersection. The information was displayed on a heads-up display fixed to the dashboard of the driving simulator, and an audible notification was made when the information was displayed. The effectiveness of the system was evaluated using a driving simulator experiment.

The road environment used in the experiment simulated a Japanese national highway, with two lanes in each direction and an additional right-turn lane near intersections, resulting in three lanes. In the straight-ahead scenario, the vehicle followed another vehicle ahead of it in the second lane at 60 km/h using a Level 2 driver assistance system. When the vehicle and the vehicle ahead of it approach the signalized intersection where the risk scenario occurs, the light changes to yellow. The vehicle ahead passes through the intersection without stopping, but if the vehicle following it continues to drive with the driver assistance system, the traffic light turns red near the stop line. We analyzed the responses under three conditions: no HMI, static HMI, and dynamic HMI. It was shown that when dynamic HMI was used, the vehicle decelerated slowly and stopped with a margin of safety.

This is thought to be because traffic prediction support information on the traffic signal enabled the vehicle to prepare for deceleration and to stop with a margin of safety. [(15) (16)]

In the left-turn scenario, the vehicle turns left at a signalized intersection by driving at Level 2. In this risk scenario, the traffic signal changes to yellow as the vehicle and the vehicle ahead of it approach the intersection. The preceding vehicle passes through the signal intersection without stopping, but before this vehicle enters the intersection, the light turns red. If the driver does not intervene, he or she will run the red light. Analysis of the stopping situation at the stop line and the driver intervention time after the signal change showed that the use of dynamic HMI increased the number of times the driver could stop in front of the stop line. In addition, the time required for the driver to intervene tended to decrease.

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