Contribution to the achievement of SDGs
by Furukawa Electric Group

3 GOOD HEALTH AND WELL-BEING

Development of Automotive Application Using Peripheral Monitoring Radar MMR2

Yasushi Aoyagi[*1], *Yoshihiro Nagare*[*1], *Yoshiyuki Ishida*[*1]
Shigeru Hosoda[*1], *Zsolt Selmeczi*[*2], *Robert Hajdu*[*2]

ABSTRACT The Advanced Driver Assistance Systems (ADAS) are becoming increasingly popular. It is specifically important to develop applications that utilize a peripheral monitoring radar that is installed at the four corners of the vehicle. In addition to the conventional blind spot detection and the advanced backward approach warning, a support for other various applications (e.g., lane change decision aid, free space detection, approaching collision warning, Emergency Lane Keeping (ELK), etc.) using the radar-acquired object location information is required. In order to enable these functions, a software structure that adapts to the evolution of vehicle networks is necessary, and the dummy evaluation that emphasizes the reproducibility and the support for simulation-based virtual experiments is also important in order to verify these functions. In this paper, we introduce the case study of an application development using the MMR2, which is a peripheral monitoring radar developed by us.

1. INTRODUCTION

The Radio Detection And Ranging (RADAR) is a type of sensor device that can detect the position and the relative speed of objects using radio waves (Table 1). In recent years, a widespread adoption of the ADAS to prevent vehicle accidents by installing such sensor devices and to detect surrounding objects has begun. The sensor requirement for the ADAS includes its adequacy to a relative speed detection function to detect the risk of collision and to poor visibility conditions such as rain, fog, nighttime, etc.

Table 1 Comparison of environment perception sensors capabilities.

Method	RADAR	LiDAR	Ultra-sonic	Camera
Relative speed detection	○	×	×	×
Weather resistance (fog, rain)	○	×	×	△
Night (darkness)	○	○	○	△

○: Suitable △: Possible ×: Impossible

We have focused our attention on the superiority of radars and have developed a peripheral monitoring radar[1), 2)]. This paper introduces the development of applications for the second-generation radar MMR2. Figure 1 shows the shape view of the MMR2, and Table 2 shows its specifications.

Figure 1 Shape of the MMR2.

Table 2 Specification.

Item	Specification value (reference)
Modulation method	Pulse Doppler
Angle measurement method	Digital Beam Forming
Operating frequency	24.05–24.25 GHz
External dimensions	W131 × D129 × H23 mm
External Communication I/F	CAN-FD, HS-CAN

Currently, bands for automotive radars are in the quasi-millimeter wave band (24.05–24.25 GHz) and in the millimeter wave band (76–77 GHz and 77–81 GHz). Table 3 shows characteristics of each frequency band. The radio waves in the quasi-millimeter wave band have a wavelength about three times longer than those in the millimeter wave band, so they are less affected by rainfall, etc. and have less spatial propagation loss. Furthermore, the number of paint coatings and the effect of bumpers at each frequency also cause larger differences in the char-

[*1] Engineering Div. 3, Furukawa Automotive Systems Inc.
[*2] Furukawa Electric Institute of Technology Ltd.

acteristics at higher frequencies. In particular, the reflectivity is involved in the multipath generated between bumper, vehicle body, and radar, which increases the detection angle error of objects. Thus, a robust sensing is possible in the quasi-millimeter wave band because the effects of the paint and the material of the bumper are small. The disadvantage is that the distance resolution is poor due to the narrow-allocated bandwidth of 200 MHz. The greatest advantage of the millimeter wave band is its wide allocated bandwidth, which enables a high-resolution ranging. Furthermore, when the wide bandwidth is shared amongst radars, the mutual interference can be reduced[3].

Table 3 Comparison of frequency band characteristics in the radar.

Frequency		Quasi-millimeter wave band	millimeter wave band
		24.05–24.25 GHz	76–77 GHz
Rainfall attenuation coefficient[4] γ (dB/km)	Heavy rain 10 mm/h	1.42	5.65
	Weak rain 3 mm/h	0.40	2.23
Bumper permeability (triple coating, round trip)[5]		1 dB	7 dB
Bumper reflection characteristics (triple coating)[5]		−10 dB	−3 dB

In this development, the quasi-millimeter-wave band was selected because of its weather immunity and its ease of installation.

In this paper, we describe the application installed with the MMR2, explain the software design and the actual verification to achieve it, and furthermore, introduce our efforts for the virtual verification, which is an important future step.

2. APPLICATION STUDIES ADAPTED TO THE MARKET

The application development is the process of selecting an application extracting the vehicle information (vehicle speed, steering, yaw rate, brake, gear, blinker status, etc.) that is adapted, and built in the in-vehicle system and displaying the requested information (presence of danger, object position and speed information, road geometry, etc.) from the sensing results under each condition.

Figure 2 shows an example of the operation of lane change decision support, which is a radar-only warning application, and Figure 3 shows the installation position and the system configuration. The radar is located at left and right rear ends of the vehicle, and the application is consisting of the following operations (1) to (3), while addressing left and right radars.

(1) The radar feeds with vehicle information, and the application is activated when it is determined that the vehicle is traveling at or above a predetermined speed and that the curve radius of the traveled road is larger than a predetermined radius.

(2) The system monitors the adjacent lane behind the vehicle from directly beside the vehicle and deter-

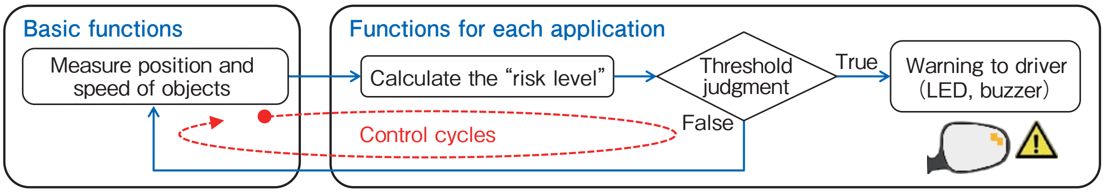

Figure 2 Basic operation in radar-based preventive safety systems.

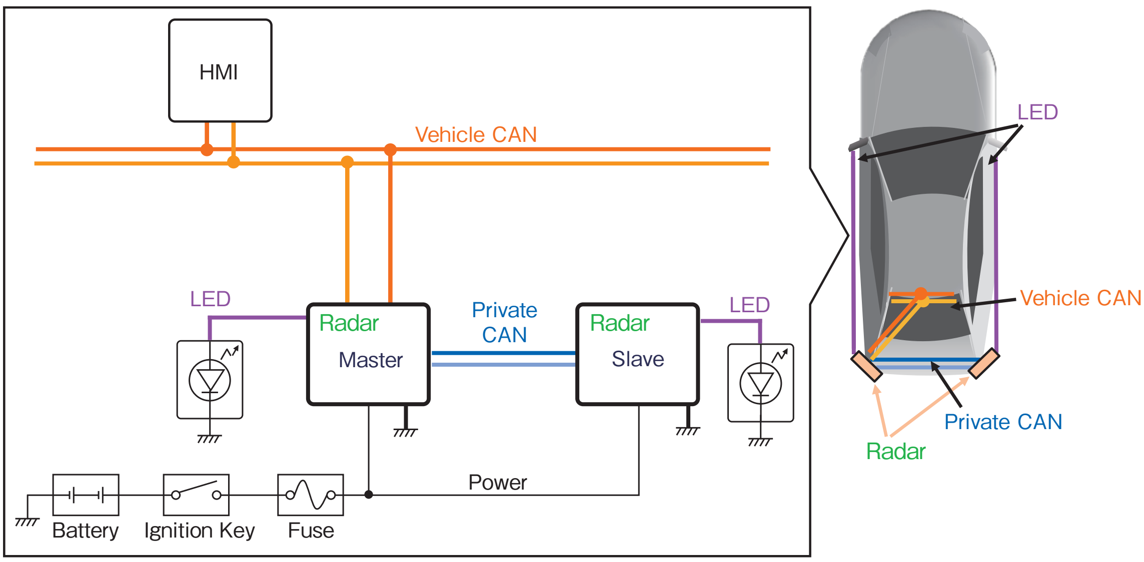

Figure 3 Configuration of radar system[1].

mines the degree of danger if the vehicle changes lanes.

(3) When the predetermined danger level is exceeded, the system judges the vehicle to be dangerous and notifies of the danger through the Human Machine Interface (HMI) to the driver. HMI includes LEDs in door mirrors and in the instrument panel display.

In complex environments such as highways, urban areas, parking lots, etc., structures and various targets must be separated and detected accurately and simultaneously, and in the MMR2, these are achieved with its high resolution using the pulse method in addition to its high-speed resolution.

2.1 Applications to be Achieved With the Peripheral Monitoring Radar

Here, we introduce some examples of applications to which the MMR2 can be applied.

2.1.1 Rear side application

The Lane Change Decision Aid System (LCDAS)[6] warns the possibility of collision when changing lanes to the driver (Figure 4 (a)). It has two functions: Blind Spot Warning (BSW), which detects the location of the target vehicle in the adjacent area, and Closing Vehicle Warning (CVW), which detects the proximity of the target vehicle in the rear area.

The Rear Cross Traffic Alert (RCTA) is a function that detects vehicles approaching from the rear on left and right when backing up in a parking lot (Figure 4 (b)).

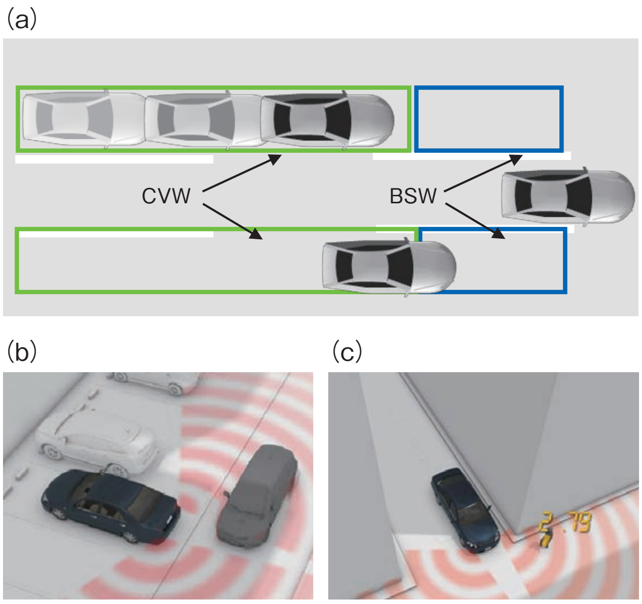

Figure 4 **Adopted application of the peripheral monitoring radar.**

2.1.2 Front side application

The Front Cross Traffic Alert (FCTA) is a function that detects approaching objects such as vehicles, bicycles, pedestrians, etc. in poor visibility conditions, such as crossing collision (Figure 4 (c)).

2.1.3 Front and rear application

The Free Space Detection (Figure 5) is a function that recognizes the shape of guardrails and other objects around the vehicle. The free space information is used as an auxiliary information to safely evacuate the vehicle to the shoulder in the event of an abnormality that makes it difficult for the driver to continue driving, such as a heart attack or stroke, while driving on an expressway or in other situations where an emergency stop is difficult.

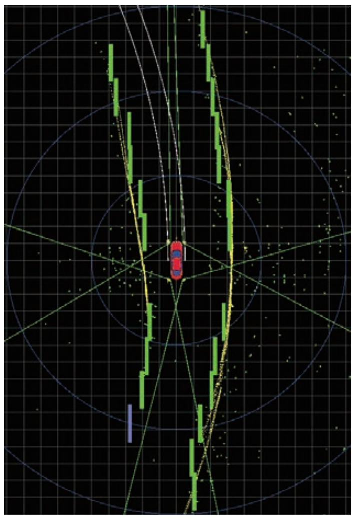

Figure 5 **Free Space Detection.**

2.2 Linked Operation With Other Sensors

There are applications that are not based on the peripheral monitoring radar information alone, but are adapted in conjunction with other sensors such as cameras.

The ELK is a function that automatically returns to the original lane when a vehicle veers out of its lane and the following dangers are anticipated (Figure 6 is for a lane change).

(1) The vehicle drifts across the center line and collides with an oncoming vehicle.

(2) The vehicle changes lanes while being overtaken and collides with another vehicle.

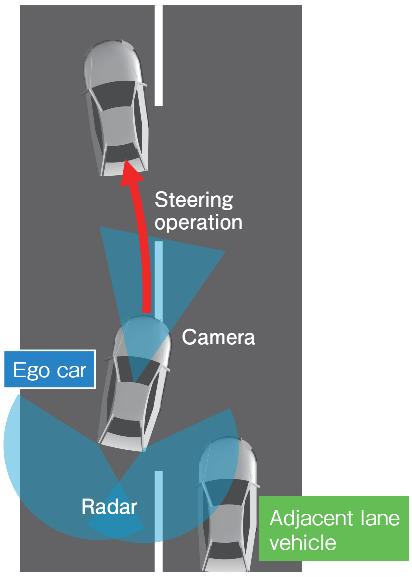

Figure 6 **An example of the ELK function.**

As shown in Figure 7, in addition to the radar, the MMR2 even includes a module that operates the steering wheel using the lane information detected by the camera. The MMR2 contributes as a sensor to detect whether a vehicle is approaching or is existing at a predetermined position in the adjacent lane, i.e., auxiliary information for the danger prediction of (2) in the rear lateral side.

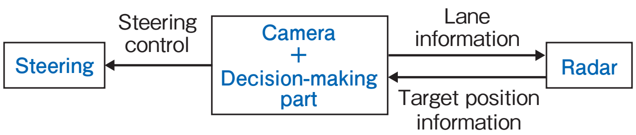

Figure 7 System configuration of the ELK.

3. SOFTWARE STRUCTURE ADAPTED TO THE APPLICATION DEVELOPMENT

For the accurate operation of applications introduced so far, it is important to adapt the communication function to receive vehicle body information such as vehicle speed, yaw rate, and gear information, and to transmit information on objects captured by the radar. On the other hand, the amount of data from Electronic Control Units (ECUs) has been increasing year by year as vehicles are becoming more sophisticated. The MMR2 also needed to change the in-vehicle network standard to the Controller Area Network Flexible Data rate (CAN-FD), which has a higher maximum transmission speed and an increasing transmission data length size change, due to the increase in the amount of data used.

Table 4 shows a comparison of communication specifications between CAN-FD and the conventional mainstream High-Speed Controller Area Network (HS-CAN).

Table 4 Comparison of the in-vehicle network communication specifications.

Protocol	HS CAN	CAN FD
Max. communication speed	1 Mbps	5 Mbps
Transmitted data length	8 bytes	64 bytes

Figure 8 shows the conventional software structure, and Figure 9 shows the structure of the MMR2. Specifically,

(1) The AUTomotive Open System ARchitecture (AUTOSAR)[7] that was introduced,
(2) The application was divided into data processing and functional parts and was allocated to software components (SW-C),
(3) A driver was created as a basic software Complex Device Driver (CDD) for the hardware-dependent part of the MMR2,
(4) The application was designed in a manner that make the software modular and easier to reuse.

The introduction of the AUTOSAR has made it possible to respond to changes in in-vehicle network standards with a minimum of effort. The detailed configuration of the AUTOSAR is shown in Figure 10. In addition, a vulnerability diagnosis was conducted during the verification in order to ensure a high level of safety. These supports allow to provide secure products to OEMs.

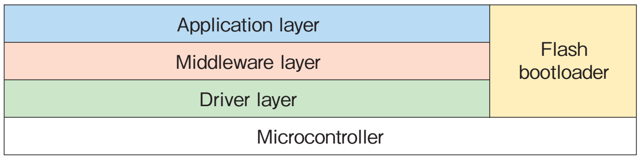

Figure 8 Structure of the conventional software.

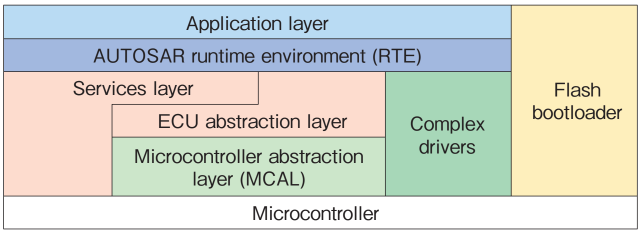

Figure 9 AUTOSAR software structure adapted to the MMR2.

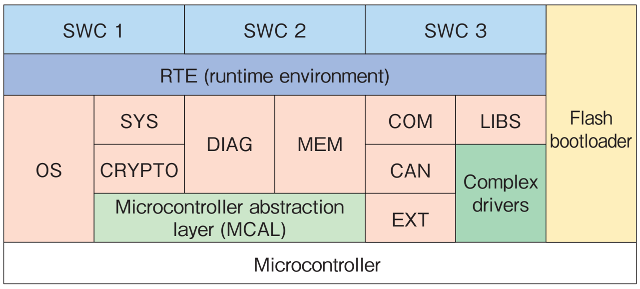

Figure 10 Details of the AUTOSAR software structure.

4. VERIFICATION AND PERFORMANCE DEVELOPMENT

In the radar development, the most important element is the evaluation of the actual driving to confirm the feasibility of applications. The performance development should be conducted based on evaluation criteria such as undetected alarms, false positives, and timing (delay, fluctuation), taking into consideration of their impacts on drivers and targets which are the objects to be detected. Figure 11 shows the performance development flow that we implemented.

(1) Formulate various running scenarios based on application specifications.
(2) Analyze data obtained from field tests, determine whether there are any issues, and if so, list them and register them in a database.
(3) Based on issues, study countermeasures, formulate an operation model, and predict effects and side-effects.
(4) Firmware and parameters are determined by incorporating countermeasures.
(5) Conduct the driving evaluation again, and continue the process from (2) until the issue is resolved.

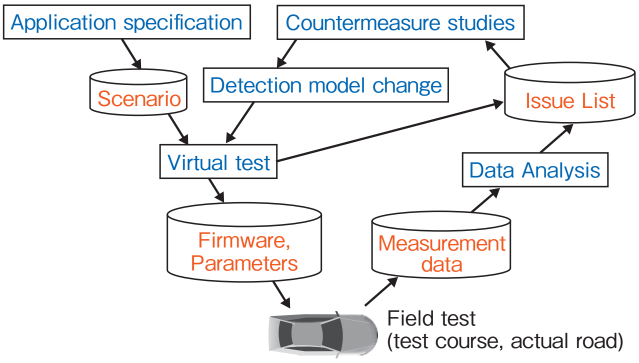

Figure 11 Flow of the application performance development.

In this performance development flow, there are several ways of handling the tests, depending on the location and target specifications. Table 5 shows the classification of actual tests.

The following is a description of the test course driving and virtual test activities.

Table 5 Test type for the performance development.

Classification	Explanation
Static tests	Evaluate under the condition of the static vehicle.
Test course driving	Evaluate using a test course that can occupy dedicated lanes.
Field tests	Evaluate by driving on actual public roads and highways.
Virtual tests	Set up a virtual space, reproduce the radar operation model and the radio wave reflection characteristics from simulations, and evaluate the feasibility of applications in virtual reality.

4.1 Example of Test Course Driving Performance Development

The verification using a test course is being conducted at the ZalaZONE (AVL ZalaZONE, area: 250 hectares)[8] (Figure 12). The test course was newly established in western Hungary. It has a test course exclusively for the ADAS. Since the evaluation tools such as a steering operation robot to ensure the driving reproducibility, a pedal robot to control the accelerator and brake including the Global Vehicle Target (GVT: Vehicle dummy target), the Guided Soft Target (GST: a robotic platform for GVT dummy transfer) and other various dummies are available, reproducible evaluations can be performed (Figure 13).

Figures 14 and 15 show examples of actual test results. The test under reproducible conditions has been achieved by using the vehicle installed with the radar and controlling the GVT with a robot.

Figure 12 ADAS test area in ZalaZONE.

Figure 13 An example of the evaluation equipment.

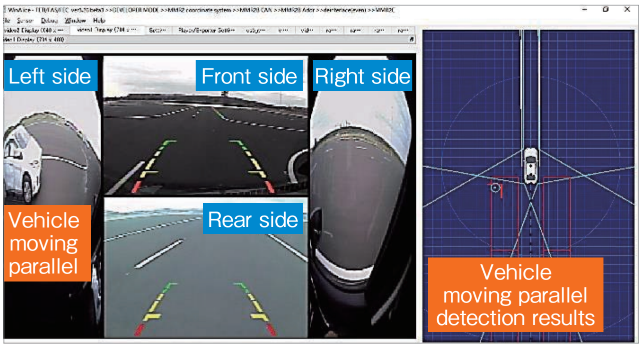

Figure 14 When the target is a dummy car + GST (parallel running).

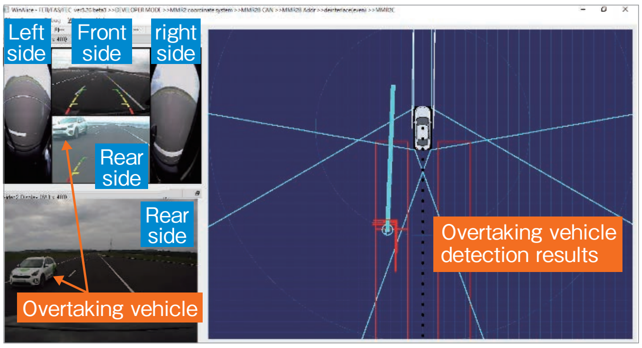

Figure 15 Overtaking test with an actual vehicle as the target.

4.2 Virtual Testing Approach

In order to investigate the reproducibility of scenarios and the effects of subtle positional relationships, not only actual evaluations but also virtual tests utilizing simulations are important. In the MMR2, a radar model that can operate in this simulation environment has been developed (Figure 16).

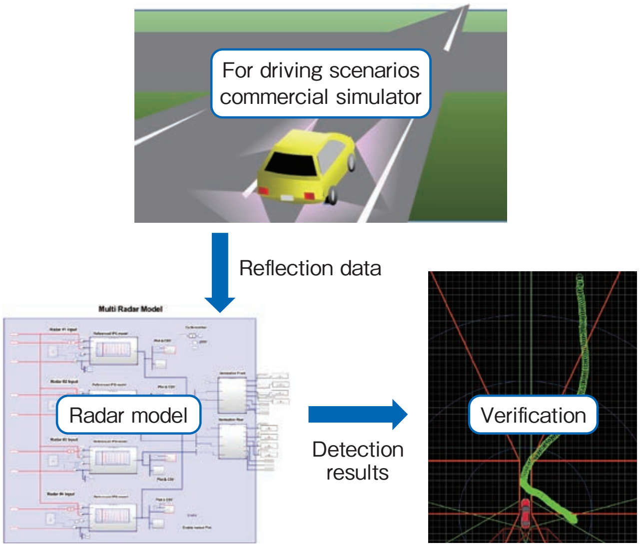

Figure 16 Flow of the simulation development.

The radar model (Figure 17) is designed to work in combination with a commercial simulator, and simulation results can be obtained in the same data format as actual vehicle measurement data (point data, object markers, and warning output). Therefore, the accumulated data and the simulation results can be subjected to a common data analysis, so that this structure allows an easy understanding of correlations, etc.

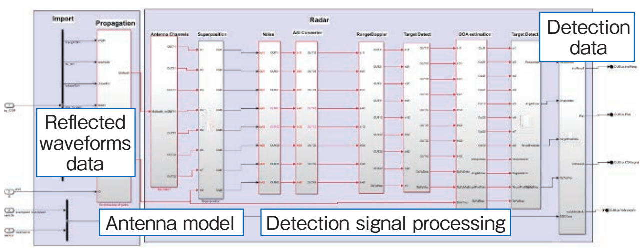

Figure 17 Configuration of the radar model.

By configuring the firmware and parameters including antenna characteristics incorporated in the embedded version, the components of the radar model are designed to operate in the same manner as the one in the actual vehicle.

Figure 18 shows the verification flow using this radar model. In addition to the radar reflection information, the vehicle information such as vehicle speed and yaw rate can be input to the model, and the radar model uses this information to run warning applications and make warning decisions in the same way as the actual radar. The output of the model can output the same data as that sent over the CAN in the actual radar. Furthermore, the model can be used for the sensor fusion simulation by connecting it to a model of a host ECU used for the radar performance verification.

The model is available in two versions, which are adapted to either MATLAB/Simulink or C/C++, and adaptations to a variety of simulation platforms are being considered.

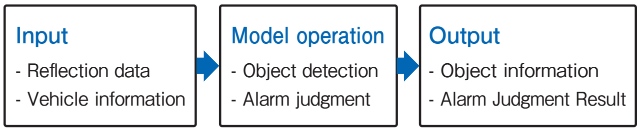

Figure 18 Flow of verification using the radar model.

Figure 19 is a comparison of the virtual test using the road data from the Metropolitan highway C1 and the actual evaluation data in detection results performed using these models. The results are in good agreement, indicating that the radar model and the map data are efficiently utilized.

Currently, in addition to the scenario evaluation using dummies as stipulated in the New Car Assessment Program (NCAP)[9], etc., a simulator that can simulate

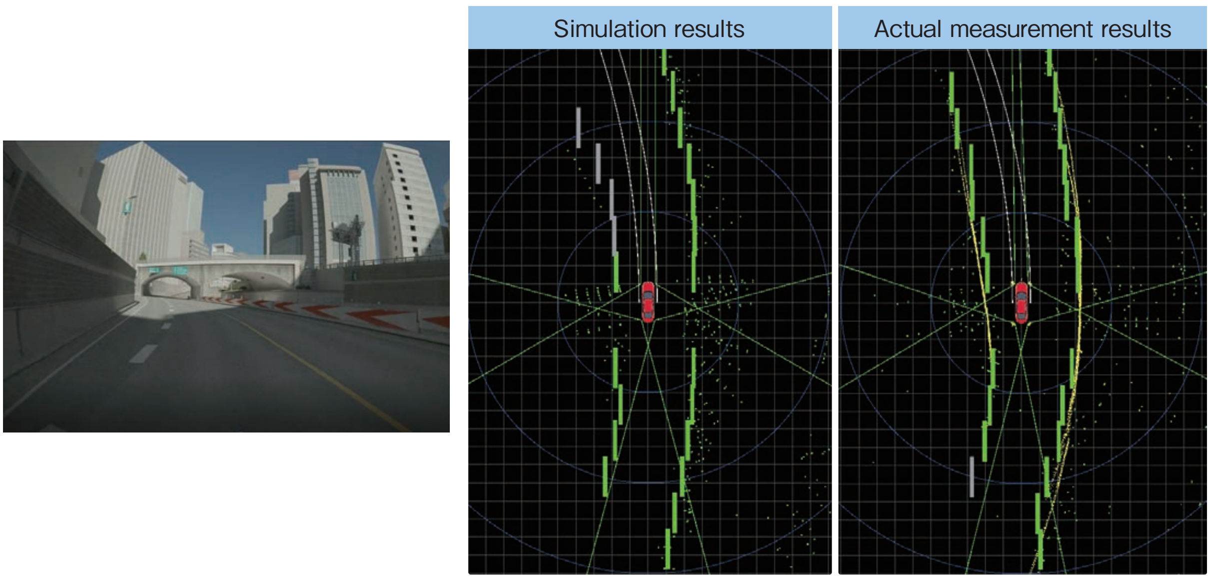

Figure 19 Free space simulation results for the Metropolitan Highway C1.

driving on public roads is being tested, and the application range of simulations is explored.

Since the field verification of radars needs to be conducted under many conditions, including complex environments such as urban areas and special environments such as snowy areas, etc. the amount of acquired data is enormous when using only actual radar data. Therefore, in order to take advantage of the simulations, as shown in Figure 20, it is essential to understand the correlation between the measurement results of actual radar and the simulation results according to the verification items, to build a database based on statistical data such as scenario search, detection result analysis, and errors, and to manage data including automation of data analysis, etc.[10]. In the future, we aim to utilize the database integrating both data for the verification planning, and to complement the verification using the actual vehicles with the simulation.

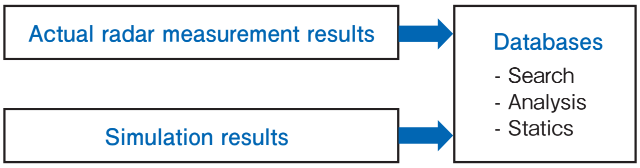

Figure 20 Database using the actual devices and simulation.

5. CONCLUSION

This paper introduced an overview of application developments using a peripheral monitoring radar. In the future, we will continue to improve the reliability of the radar and expand its functions in order to support the next-generation ADAS and automated driving.

REFERENCE

1) Yasushi Aoyagi: "Development of 24GHz Peripheral Monitoring Radar", Furukawa Electric Review, No. 137 (2018), 3.
2) Yasushi Aoyagi: "Development of a 24-GHz Band Vehicle Peripheral Monitoring Radar", IEICE Society Conference, Sensing and Device Technologies for Automatic Driving, No. CI-3-5, 2019.
3) A. Bourdoux et al.: "Phenomenology of mutual interference of FMCW and PMCW automotive radars", 2017 IEEE Radar Conference (RadarConf), 2017.
4) Takada: "Basic theory of radio propagation", MWE 2005, (Referred on Dec.19, 2022).
http://www.apmc-mwe.org/mwe2005/src/TL/TL05-01.pdf
(in Japanese)
5) R. Lachner: "Development Status of Next Generation Automotive Radar in the EU", ITS Forum 2009, (Referred on Dec.19, 2022).
http://www.itsforum.gr.jp/Public/J3Schedule/P22/ lachner090226.pdf
6) ISO: "ISO17387: Intelligent transport systems – Lane change decision aid systems (LCDAS) – Performance requirements and test procedures performance requirements and test procedures", 2008.
7) AUTOSAR organization, (Referred on Dec. 19, 2022).
https://www.autosar.org/
8) Automotive Proving Ground Zala Ltd, (Referred on Dec.19, 2022).
https://zalazone.hu/
9) National Agency for Automotive Society and Victims' Aid, (Referred on Dec. 19, 2022).
https://www.nasva.go.jp/mamoru/ (in Japanese)
10) Cabinet Office, "Recruitment of Monitor Participants for DIVP (R)", (Nov.22, 2021), (Referred on Dec.19,2022).
https://www8.cao.go.jp/cstp/stmain/20211122sip. html
(In Japanese)