Development of an Automotive Active Safety System Using a 24 GHz-band High Resolution Multi-Mode Radar

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ABSTRACT In recent years, Advanced Driver Assistance System (ADAS), which has sensor devices mounted and avoids vehicle accidents by detecting objects in surroundings, started to be popular. Here, we introduce the examples of the development of integrated performances as an automotive system, using the high resolution multi-mode radar, which we have developed, that can be switched automatically for various applications in the 24 GHz band.

1. INTRODUCTION

For the requirements of the sensor that is applied to ADAS, the functions of relative velocity detecting to foresee a crash risk in advance and of associated poor visibility such as with rain, fog and darkness, are required.

The functional comparison of each sensor is shown in Table 1.

It is important to meet the regulations in using the radar (radio wave). The 24 GHz band had been provided by the relevant laws in Japan, U.S., Europe and other countries of the world, is easier to use and has a higher adaptability to the market compared to the millimeter-wave band (76 GHz band, 79 GHz band) for which relevant laws have ongoing adjustments. Moreover, various applications of the radar can be considered, thus the multi-mode performances that can switch the state of its performance are also important.

Table 1 The functional comparison of the sensors.

Types	Radar	Laser	Ultrasonic	Camera
Relative velocity direct detecting	○	×	×	×
Withstand to weather (fog, rain)	○	×	△	×
Adequacy to night time (darkness)	○	○	○	△

○: suitable, △: available, ×: not available

The trend in making preventive safety technologies compulsory[1)], which is promoted mainly in Europe, is shown in Table 2. The expansions into the general vehicles and into pedestrian protection application further in the future are also considered.

Table 2 The trend in making preventive safety systems compulsory.

Europe	November, 2013	Making installation of the AEB (Autonomous Emergency Braking) on the new large type vehicles is compulsory.
	In the year 2014	The AEB for passenger vehicles will become an evaluation item (for five-star ratings) by Euro NCAP (European New Car Assessment Programme).
	In the year 2015	The AEB will be applied to large continuous production vehicles.
Japan	November, 2014	Making installation of a crash damage reduction brake on new large type trucks and buses is compulsory.
	In the year 2014	The addition of AEB to the evaluation standard will be planed to consider in JNCAP (Japan New Car Assessment Program).
	November, 2017	The AEB will be applied to large continuous production vehicles.

These are the sensing mainly intended to forward long distance. The importance of the all-around monitoring in short distance are lively discussed in international conferences, such as IWPC, on which the manufactures of vehicles or sensors meet, and there is a possibility of applications for insurance rate discounts and for the evaluation standard in the assessments mentioned above with the goals of accident reduction.

Here, we introduce the applications for the all-around monitoring and the examples of the development of inte-

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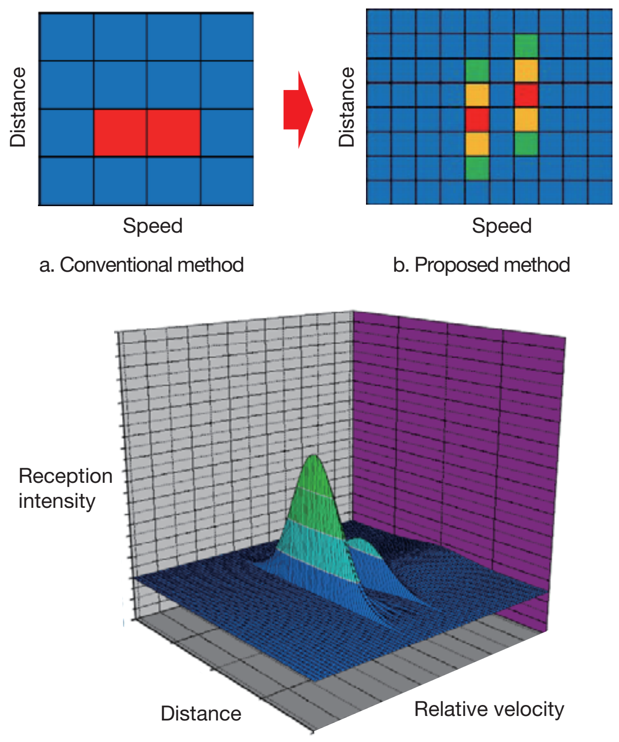
grated performances defined as the automotive system, using the high resolution multi-mode radar at the 24 GHz band which we have developed and which can be suitable to various applications.

2. THE 24 GHz BAND HIGH RESOLUTION MULTI-MODE RADAR

In this chapter, we will introduce the outline of the multi-mode radar (B0 sample) that is being considered. Comparing to the narrowband radar of the conventional method (Figure 1-a), it becomes possible to segregate high density objects and to detect substantially the angles and the distances of each object with the signal processing and the circuit technologies developed on the basis of the Ultra Wide-Band (UWB) radar technology[2] which had been reached so far (Figure 1-b, c).



c. Example of a multi-target separation

Figure 1 The realization image of a high resolution.

Specifications of the 24 GHz band high resolution multi-mode radar are shown in Table 3. The Control Area Network (CAN) is used as the interface, and the radar selects autonomously operational modes while using the vehicle information data (vehicle speed, ON / OFF of winker, gear) which can be obtained by connecting to the CAN of the vehicle body. According to each operational mode, the danger toward a driver is assessed and alarmed.

Figure 2 shows examples of the autonomous changes of the operational modes.

Table 3 Specifications of the 24 GHz band high resolution multi-mode radar.

Item	Value	Unit
Modulation method	Pulse	—
Frequency band	24.05 – 24.25	GHz
Minimum detection distance	0	m
Maximum detection distance	72	m
Horizontal angle range	120	deg.
Minimum detection target	Pedestrian	
Shape	100 × 100 × 30 	mm

Data of the vehicle state	Gear state	Reverse	Forward	
	Vehicle speed	Low speed		High speed
Application		R-CTA	LCDAS	
		The radar detects vehicle state and change the operational mode.		

Figure 2 Examples of the autonomous changes of the operational modes.

3. THE PREVENTIVE SAFETY SYSTEM USING THE RADAR

The preventive safety system which consists of the radar itself can alarm to a driver through the Human Machine Interface (HMI) when the crash with a detected object is predicted. The name of the applications is specified depending on what types of dangers are alarmed.

Figure 3 shows various perimeter monitoring applications and examples for the placement of each application and beam[3]. One application is shown for each beam, therefore the placements of the beams with the same functions are assumed to be on the right and the left or in the front and the back.

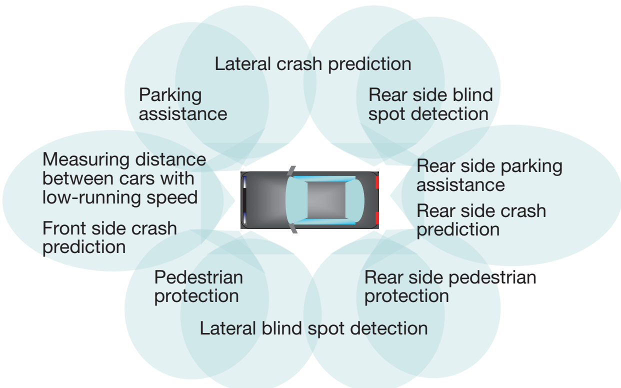


Figure 3 Examples of the various perimeter monitoring applications using the radar.

3.1. The Posterolateral Application (LCDAS: Lane Change Decision Aid System)[4)]

With respect to assisting safety in lane change, which detects the existence of another vehicle diagonally behind and alarm to the driver, LCDAS is getting gradually popular since 2005 mainly in the Euro-American markets to be installed on the luxury or top-of the line cars as an optional equipment. There are three types for the LCDAS.

a. LCDAS Type-I: The Blind Spot Detection, which detects other cars entering the blind area around own car (adjacent lanes on the right/left and back area within 3m or so)
b. LCDAS Type-II: The Closing Vehicle Warning, which detects other cars which rapidly approach on the adjacent lanes, in addition to the blind area.
c. LCDAS Type-III: The type which combines Type-I and Type-II.

With respect to warning to drivers, there are systems that only light a warning lamp and that make stronger caution such as adding torque on a steering wheel when the car is about to change the lane in the dangerous situation.

Also, Rear-Cross Traffic Alert (R-CTA)[5)] is the application that detects the vehicles or the pedestrians that exist in the blind area and prevent serious accidents such as bodily injury when unloading backward from a parking space, and often uses the same sensor the LCDAS does. It makes alarms to the driver with sound and LED and performs an automatic break control if the dangers, such as crash, are expected.

The operation image of R-CTA is shown in Figure 4.

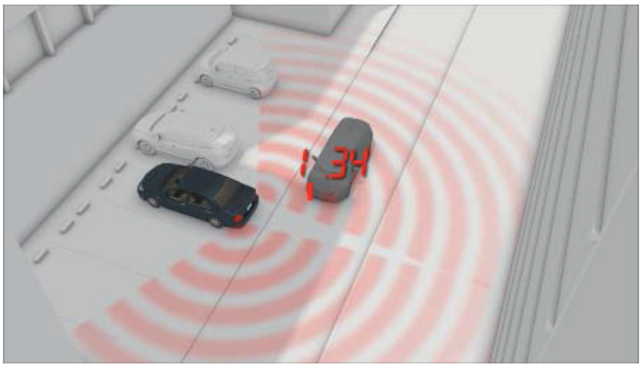


Figure 4 Image of R-CTA performances.

3.2. The Anterolateral Application (Front-Cross Traffic Alert: F-CTA)

The operation image of F-CTA is shown in Figure 5.

F-CTA is the application that detects the vehicles and the pedestrians in left and right forwards to avoid accidents having them bumped into each other at blind intersections and others. As same as R-CTA, F-CTA makes alarms to the driver and performs an automatic break control if the dangers, such as crash, are expected. However, since the speed of the intended vehicle is faster, with respect the time until it crashes, F-CTA requires a longer detecting distance than R-CTA.

In addition to this, the preventive safety technologies, such as the application developed with respect to a monitoring in 360-degree view, are being actively developed.

Figure 5 Image of F-CTA performances.

4. THE SYSTEMS MOUNTED ON VEHICLES

4.1 The Recording System of Measuring Data

Since the preventive safety system can be consisting of the radar itself, to confirm the validity of measurement on the development process, it needs indicating and recording not only the detecting results of the target on a real-time basis but also the detecting results of the referential sensors being synchronized. As the referential sensors, we used LIght Detection And Ranging (LIDAR); (Laser scanner, Detected data for distance and orientation) and a camera (confirming the scenes which are assessed). The measuring data flow is shown in Figure 6. The detecting results and assessed results are indicated on the PC display on a real-time basis and the data is recorded at the same time.

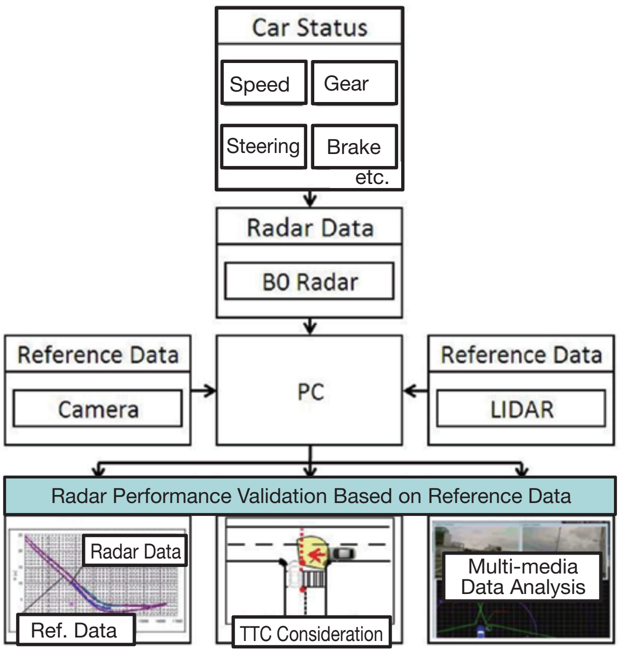


Figure 6 The measuring data flow.

In the application decision, it is possible to assess each mode by stabilizing the operational mode, and also to assess the validity of the mode transition by obtaining the vehicle information data as shown in Figure2.

4.2 Mounting on the Vehicles

Figure 7 shows the schematic for mounting the radar and the measuring systems on the vehicles.

To accommodate a driving test and others, the measuring system is mounted on the vehicle for evaluation. The radars are mounted, in the bumpers, in the four corners of the vehicle and collect the vehicle information data from the CAN of the body. If the amount of data is large at measurement, it may set up another gateway separately to avoid the radar data flowing into the vehicle body.

On the other hand, for the method of alarm, we select the method, where the packet, which shows the alarm status that is sent from the radar, is displayed on the PC display or is received by the specific Electronic Control Unit (ECU), and that controls lighting a LED and honking a buzzer which are mounted in the Human Machine Interface (HMI) installed on the dashboard.

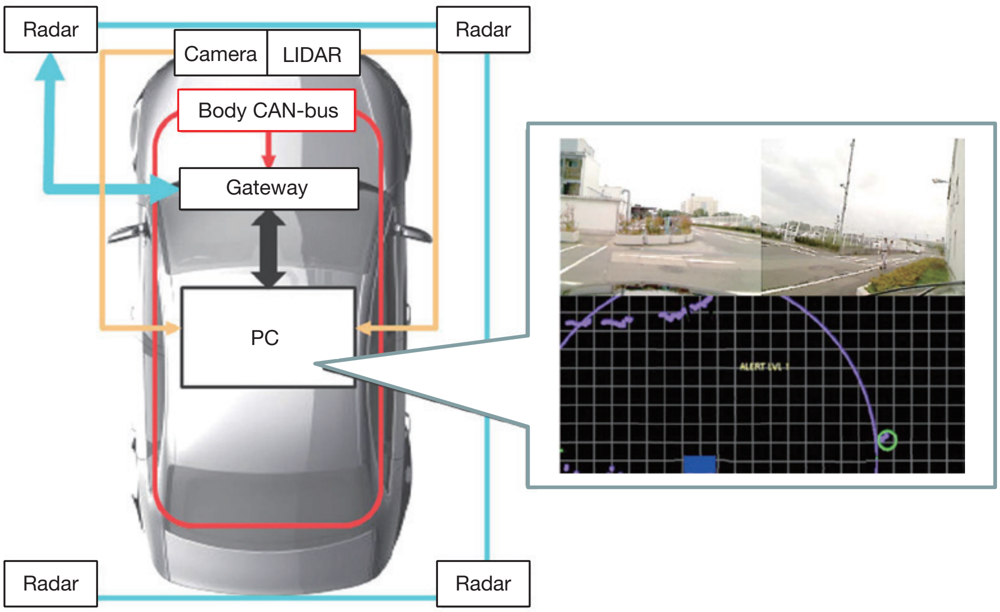
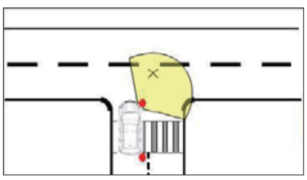


Figure 7 Mounting the radar and the measuring systems on the vehicles.

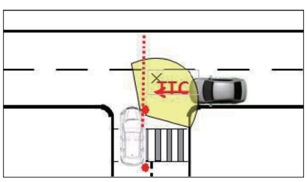
4.3 Examples of the Alarm Performance

Examples of the performance of this vehicle mounting system are shown for F-CTA.

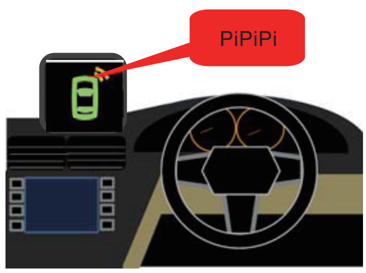
(1) According to the vehicle information data, the appropriate application is activated.



(2) Time To Cross line (TTC) is computed toward a vehicle coming closer, and an alarm packet is sent if the result of the computing is assessed as smaller than the specified TTC value.



(3) The upper-level system such as the PC or the HMI-ECU receives the alarm packet and warns to the driver.



Moreover, it is possible to alarm as the radar lights directly the LED for the condition (3) above.

5. ON BOARD EVALUATION

5.1 Contents of the Evaluation

Based on the results from the previous chapters, using the vehicle for evaluation with the radar mounted, we confirm that the alarm alerts when a pedestrian is approaching the vehicle.

In this evaluation, the performance of the F-CTA is confirmed for the alarm application toward the front of the vehicle. This alarm has alerted when TTC, which is the time from when pedestrians or vehicles of coming closer from the front are detected to when they cross the specified threshold line, becomes shorter than the specified time. Small TTC value means that the time is short until the pedestrian has a crash with the vehicle and that the degree of the risk is high.

This alarm can be set the specified time for TTC on any value according to the degree of the risk. In this evaluation, we set the alarm warning time as followings.

a. The degree of the risk: Low (Level 1) = 6 sec.
b. The degree of the risk: Middle (Level 2) = 4 sec.
c. The degree of the risk: High (Level 3) = 2 sec.

Considering the detected data from the LIDAR and the image data from the camera as real values, the validity for the results of the radar measurement is examined comparing the measured value by the radar with the real values.

5.2 The Evaluation Results

Figure 8–10 shows the continuous representations of the movement locus of the pedestrian who is detected by the radar. The upper section of each of the figures shows the camera footage and it can be seen that the pedestrian is approaching on foot from the right side. The lower section of each of the figures shows a detected object by the radar and its alarm levels. The blue square shows the place of the evaluated vehicle. The green circle shows the detected information data by the radar on a real-time basis. The pedestrian detected by the LIDAR measurement system is shown by the blue-violet dots in the figures. The radar is set to detect only moving objects and the evaluated vehicle is stopped, therefore only the pedestrian is detected.

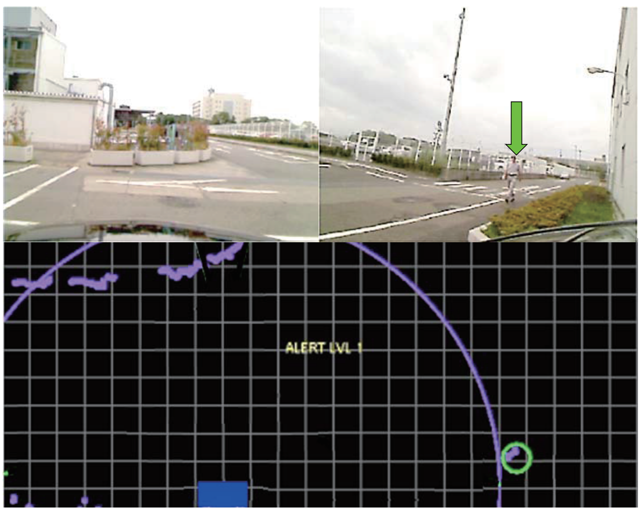


Figure 8 The detection of a pedestrian in the alarm level 1.

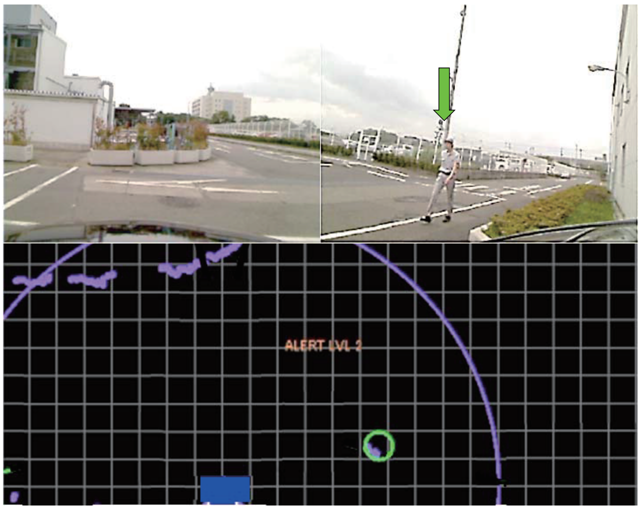


Figure 9 The detection of a pedestrian in the alarm level 2.

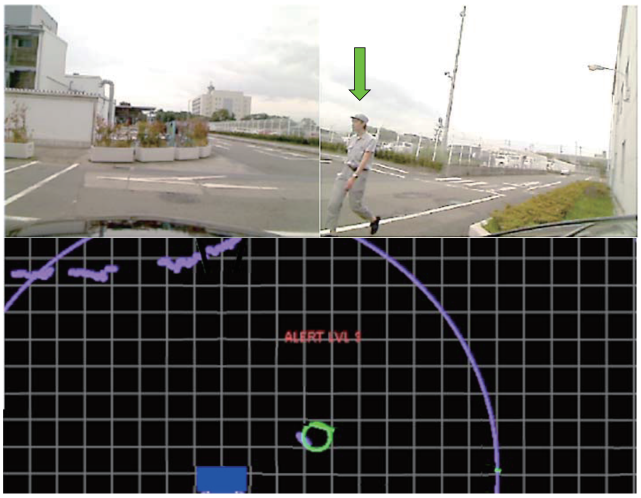


Figure 10 The detection of a pedestrian in the alarm level 3.

From the result of the evaluation, it can be confirmed that the detection of a pedestrian by the radar and the true value are in the same position, by comparing them.

Figure 11 shows the detected position of a pedestrian and the alarm level. It can be confirmed that the pedestrian is approaching toward the vehicle as time advances and can be detected almost without errors, comparing with the detection by the LIDAR measurement system.

In addition, going back from the TTC=0 (sec.) where the distance to the vehicle becomes zero, the alarm level progresses from Level 1 to Level 3 at the points of 6, 4, and 2sec. In this evaluation, it is confirmed that the alarm is warning at the specified alarm time.

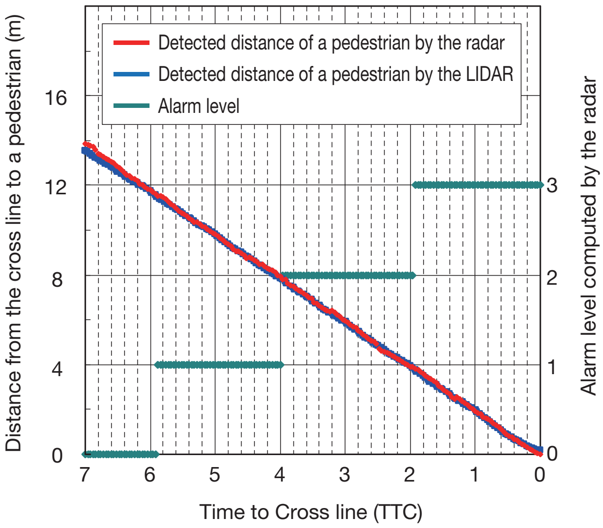


Figure 11 The detected position of a pedestrian and the alarm level.

6. CONCLUSION

Here we introduce the applications which target the panoramic monitoring of surround of the vehicle and the examples of the construction of the automotive system which can correspond to each application using the 24 GHz band high resolution multi-mode radar which we have developed. Moreover, it is confirmed that the alarm levels according to the degree of the risk can be activated and the accuracy of the calculated TTC has no large difference when comparing with the real value from using the developed radar. Even if the vehicle is running, with constructing the system that can make quantitative evaluations, it becomes possible to assess the timing of the alarm, the detecting and the un-detecting at the actual running evaluations on general roads and highways.

We will improve the accuracy and expand the range of the application in the future.

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