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Development of Radar-enabled AI Convergence Transportation Entities Detection System for Lv.4 Connected Autonomous Driving in Adverse Weather

[1]*Myoungho Oh, [2]Mun-Yong Park, [3]Kwang-Hyun Lim

[1]Senior Executive Director, NOVACOS Inc.*
[2]Executive Manager, NOVACOS Inc.
[3]Associate Director, NOVACOS Inc.
[1]mhoh3966@novacos.co.kr,*
[2]pmy@novacos.co.kr
[3]khlim0928@novacos.co.kr

Abstract

Securing transportation safety infrastructure technology for Lv.4 connected autonomous driving is very important for the spread of autonomous vehicles, and the safe operation of level 4 autonomous vehicles in adverse weather has limitations due to the development of vehicle-only technology. We developed the radar-enabled AI convergence transportation entities detection system. This system is mounted on fixed and mobile supports on the road, and provides excellent autonomous driving situation recognition/determination results by converging transportation entities information collected from various monitoring sensors such as 60GHz radar and EO/IR based on artificial intelligence. By installing such a radar-enabled AI convergence transportation entities detection system on an autonomous road, it is possible to increase driving efficiency and ensure safety in adverse weather. To secure competitive technologies in the global market, the development of four key technologies such as ① AI-enabled transportation situation recognition/determination algorithm, ② 60GHz radar development technology, ③ multi-sensor data convergence technology, and ④ AI data framework technology is required.

Keywords: *AI data framework, AI-enabled transportation situation recognition/determination algorithm, Lv.4 connected autonomous driving, Multi-sensor data convergence, 60GHz radar*

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Corresponding Author: mhoh3966@ novacos.co.kr
Tel: +82-31-423-2300, Fax: +82-31-423-2308
Senior Executive Director (AI Specialist, Ph.D.), NOVACOS Inc., Korea

1. Introduction

Adverse weather environments may degrade performance of autonomous driving sensors, resulting in unstable driving. This can create anxiety for users who will use autonomous vehicles as passengers and make it difficult to trust autonomous driving technology [1].

There are five levels of autonomous driving technology, with Level 4 representing advanced autonomous driving, where the autonomous system takes control of all situations, and Level 5 representing full autonomous driving, where the driver is not required. The government is actively developing related technologies and building infrastructure with the goal of commercializing full autonomous driving in 2027. Autonomous vehicles are equipped with various sensors such as radar, lidar, optical cameras, thermal imaging cameras, and ultrasonic sensors as core components, and R&D is being conducted by the Korean National Police Agency to overcome the limitations of perception range, recognition errors, poor visibility due to weather conditions, and lack of cooperation among autonomous driving infrastructure.

Securing transportation safety infrastructure technology for autonomous driving is crucial for the spread of autonomous vehicles, and in the case of adverse weather and transportation obstacles, the safe operation of Lv.4 autonomous vehicles is limited by vehicle-only technology development. In particular, the detection capabilities of EO/IR (Electro-Optical/Infrared) and lidar are severely limited in adverse weather conditions, and close collaboration between autonomous vehicles and transportation infrastructure is required in sections that require not only detection and identification but also complex situational determination, such as merges, unsignalized intersections, blind spots, and school zones.

We developed the radar-enabled AI (Artificial Intelligent) convergence transportation entities detection system. This system is mounted on fixed and mobile supports on the road, and provides excellent autonomous driving situation recognition and determination results by converging and processing transportation object information collected from various surveillance sensors such as 60GHz radar and EO/IR based on artificial intelligence.

By installing such a radar-enabled AI convergence transportation entities detection system on autonomous driving roads, it will be possible to improve driving efficiency and ensure safety during adverse weather. In order to secure competitive technologies in the global market, four core technologies are required: (1) AI-based transportation situation recognition/determination algorithm, (2) 60GHz radar development technology, (3) multi-sensor data convergence technology, and (4) AI data framework technology.

In the case of 60 GHz radar, it is an alternative to the existing 24 GHz radar sensor, which has a small detection range and a narrow frequency band and is likely to be interfered with other radars, and it has a large FOV (Field of View) area, miniaturization, light weight, and high detection range such as distance and resolution angle, enabling multi-angle detection without any restrictions on development and use.

Adverse weather performance evaluation of the 60 GHz radar and EO/IR cameras was conducted at SOC (Social Overhead Capital) Demonstration Research Center. Both EO/IR cameras showed limited performance in pedestrian detection, while the 60 GHz radar demonstrated its efficiency for autonomous driving in adverse weather.

2. System Development

2.1 AI Convergence Transportation Object Detection System

The AI convergence transportation entities detection system is developed based on AI-STUDIO, an AI data framework developed by INFINIQ, and develops deep learning-based transportation entities detection/identification and transportation situation detectors, and applies deep learning AI and Handcraft Knowledge AI for AI application model development and quality control.

2.1.1 System Development Technical Structure

There are five technology layers applied to the development of AI convergence transportation entities detection system: ① service, ② AI learning, ③ platform, ④ operating system, and ⑤ computing power. AI algorithms refer to AI-enabled methods and procedures for solving specific problems, and utilize both deep learning AI for intelligent detection/identification and handcrafted knowledge AI for intelligent tracking/decision. AI learning model refers to a sw equipped with an algorithm that creates a detector based on deep learning, and uses YOLOv4 for real-time detection and identification. Technology architecture for system development is shown in Table1.

Table 1. Technology architecture for system development

Technical class		Implementation plan and development goals
Service	Solutions to provide and utilization plan	* AI convergence transportation entities detection syste m 1) AI- enabled detection / identification solution 2) AI- enabled tracking solution 3) Autonomous driving situation awareness / determinati on solution
AI learning	AI data category	* EO/IR, radar data 1) Target: people, vehicles, etc. 2) Form: image, video, RF signal, etc.
	How to learn AI data	1) Supervised learning and reinforcement learning 2) Fine tuning method
Platform	AI algorithm	* AI detection / determination algorithm implementation plan 1) Deep learning AI: Intelligent detection / identification 2) Handcrafted Knowledge AI: Intelligent tracking / decis ion
	Deep learning model	YOLOv4, YOLOv5, etc.
	deep learning framework	1) PyTorch 2) TensorFlow
	Data framework	AI STUDIO
Operating system		1) Windows 11 pro 2) Linux
Computing Power	Development server	IBM LinuxONE Emperor 4
	AI semiconductor	AI Accelerator (Accelerator) : GPU (Graphics), TPU (Tensor), etc.

A deep learning framework is an AI learning library that specializes in parallel processing of vector and matrix operations, and uses PyTorch and Tensorflow as deep learning frameworks.

2.1.2 AI System Production and Algorithm Concept Diagram

To the existing Radar & EO/IR datasets, we add new datasets that are built by acquiring real data and synthetic data. Synthetic data is obtained by implementing various objects in 3D simulation and converting the data into Radar and EO/IR data. We also utilize data convergence technology to converge radar and EO/IR data. AI system production and algorithm concept diagram is shown in Figure 1.

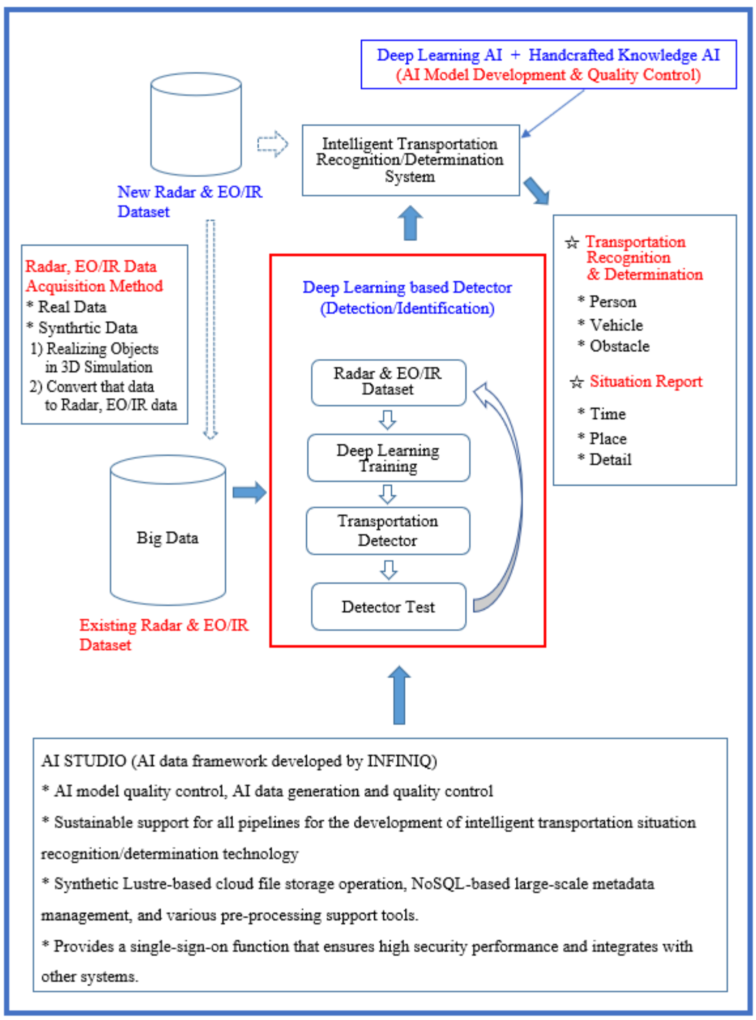


Figure 1. AI system production and algorithm concept diagram

We produce an intelligent transportation situation recognition/determination system based on deep learning-based transportation entities detector (detection/identification/transportation situation). Transportation situation recognition/determination targets include people, vehicles, equipment, and obstacles.

2.1.3 System Configuration

System configuration and Edge system configuration plan are shown in Figure 2 and Figure 3 respectively.

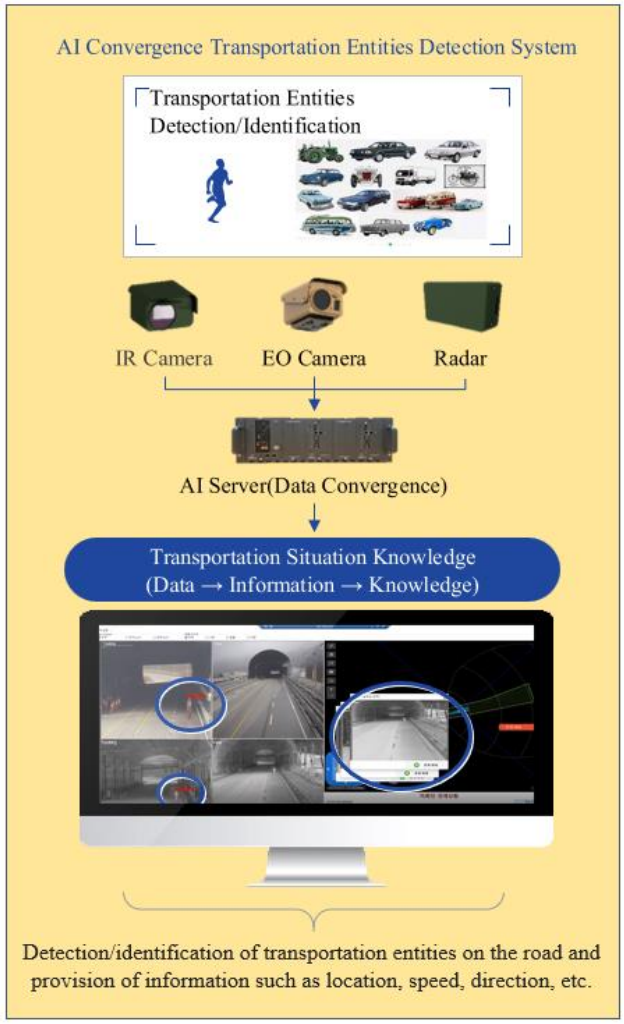


Figure 2. System configuration

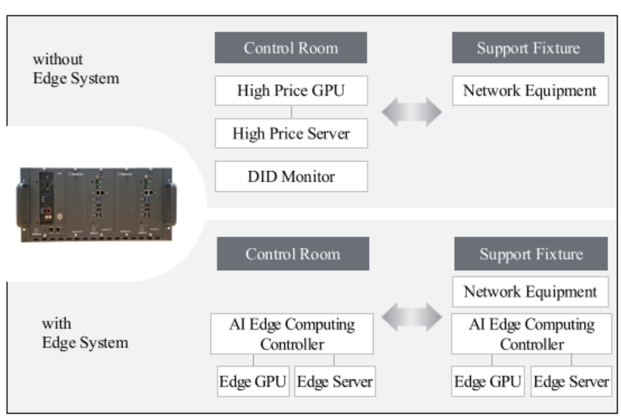


Figure 3. Edge system configuration plan

When considering efficiency and weight reduction, the application of Edge System is required, and information transmission equipment, AI edge computing controller, edge GPU (Graphic Processing Unit), edge server, etc. are installed on the support (fixed / mobile). Support shape is shown in Figure 4.

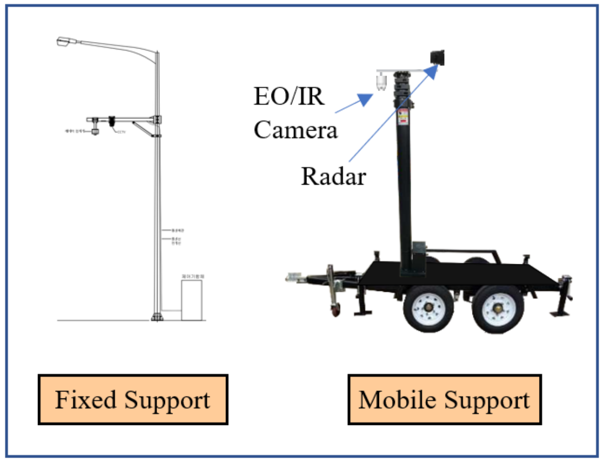


Figure 4. Support shape

2.1.4 User Interface

User interface of the system is shown in Figure 5.

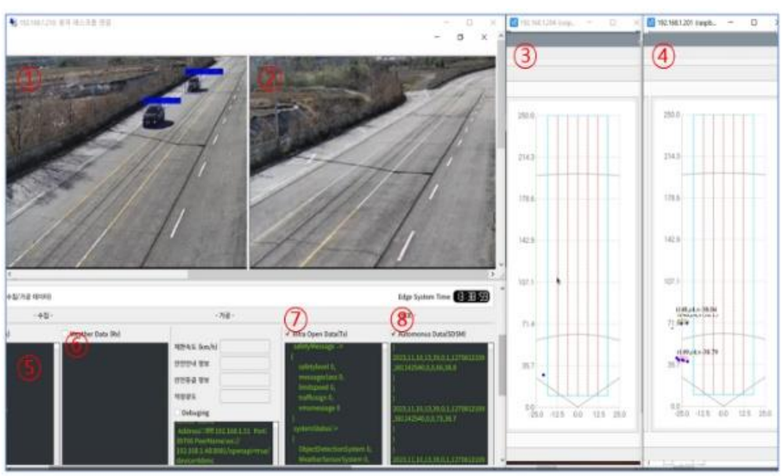


Figure 5. User Interface

[Radar and video information]

① Video screen detected by camera 1 (short range)

② Video screen detected by camera 2 (long range)

③ Video screen detected by radar number 2 (long range)

④ Video screen detected by radar 1 (short range)

[Edge system server information]

⑤ Object data: Moving object detection information reception data

⑥ Weather data: Weather information data provided by safety information system

⑦ Infra Open Data(Tx): Infrastructure open data information distributed through linked systems such as integrated control center / safety information provision system / control service

⑧ AutonomusData (SDSM): V2X (Vehicle to Everything) data distributed to autonomous vehicles (including moving object (position, direction, speed) information)

2.2 60GHz Radar

EO/IR cameras show physical limitations in the object recognition performance of autonomous vehicles in adverse weather conditions, a 60GHz radar is required for advanced detection / tracking of moving objects in rain and fog situations.

2 4GHz radar is used as a short-range radar for vehicles and a radar frequency for road transportation, but due to its narrow bandwidth, there is a possibility of performance degradation due to mutual interference when the number of vehicles equipped with radar increases in the future. On the other hand, the 60GHz radar can be used freely and allows for increased detection distance and high resolution due to its wide bandwidth and high effective radiation power compared to the 24GHz radar. The reasons for developing 60GHz radar is shown in Table 5.

Table 2. Reasons for developing 60GHz radar

Item	24GHz radar	60GHz radar
Radar signal interference	Mutual interference, performance degradation	Favorable to mutual interference
Object recognition accuracy	Good	Up to 20 times higher than 24GHz
Effective radiated power	Good	Up to 200 times higher than 24GHz

The radar chip selected for the development of the 60GHz radar is TI 's IWR6843, an all-in-one chip with a built-in radar transceiver, DSP (Digital Signal Processor), MCU (Micro Controller Unit), and H/W logic. The advantage of this chip is that 60 ~ 64 GHz is recognized as an unlicensed frequency band around the world, so it can be used freely, and as an all-in-one product, products can be developed at 1/4 the size of existing products, which is advantageous for miniaturization, and recently, factory automation has been introduced. and is rapidly emerging for autonomous driving. The shape of the 60GHz radar under development is as shown in Figure 6.

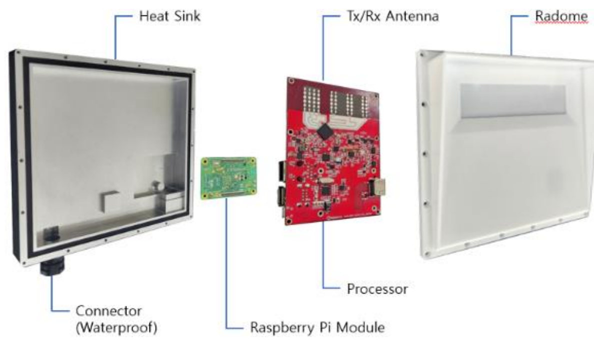


Figure 6. 60GHz radar configuration

As part of the improvement of 60 GHz radar detection performance, an integrated PCB (Printed Circuit Board) design is applied to improve the signal matching (maximum power transfer) problem between the antenna and transceiver. Simulations show that the integrated antenna improves the gain by 10% compared to the separate antenna. 60GHz radar antenna (integrated) is shown in Figure 7.

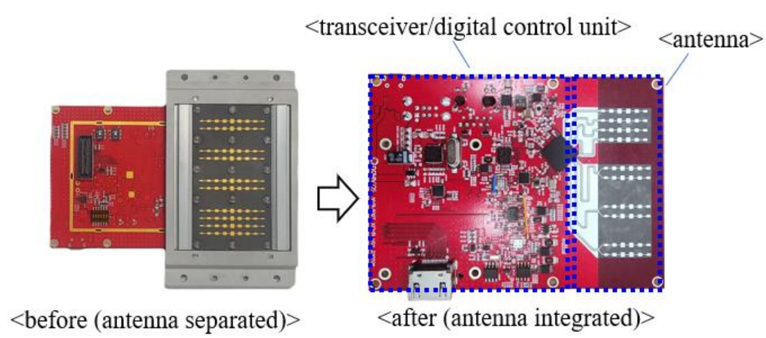
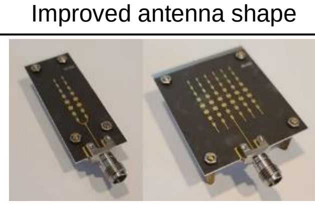
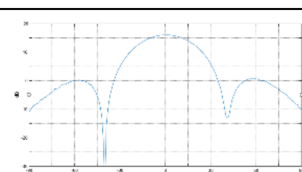


Figure 7. 60GHz radar antenna (integrated)

After further improving the antenna structure and gain, the measurement results and network diagram are shown in Table 3.

Table 3. Configuration improvement of 60GHz radar antenna

Improved antenna shape	Measurement results
	
• Antenna structure - Transmit 2x8, Receive 1x8 • Antenna gain - Transmit 17.2dBi, Receive 14.2dBi	• Improved antenna measurement results - Transmit 16dBi - Receive 12.6dBi

The network configuration diagram of the system is shown in Figure 8.

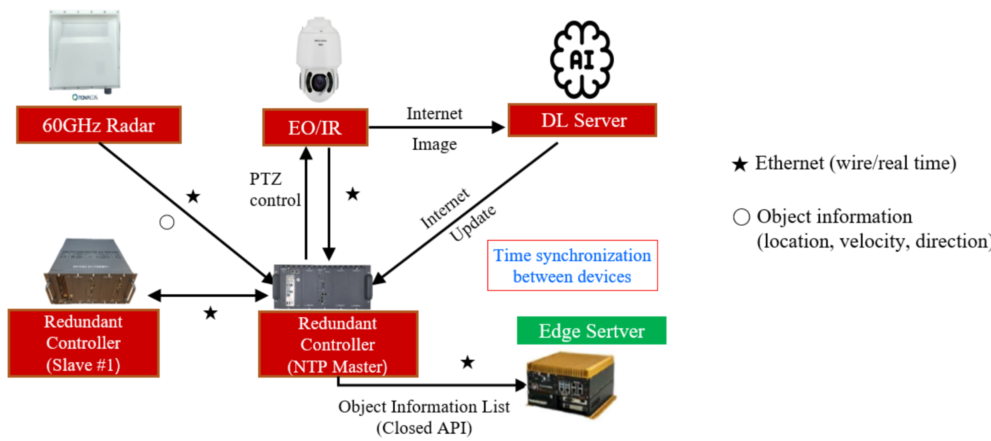


Figure 8. Network configuration diagram

3. Evaluation Results and Discussion

The adverse weather performance evaluation of the 60GHz radar and EO/IR camera was conducted at the SOC Demonstration Research Center of the Korea Institute of Civil Engineering and Building Technology in Yeoncheon, Gyeonggi-do, and the key specifications of the surveillance equipment used in the adverse weather performance evaluation are listed in the Table 4.

Table 4. 60GHz radar & EO/IR key specifications

Item	Key specifications	
60GHz radar	• Frequency band: 60GHz • Target detection range: 350m • Number of detection targets: Up to 255	• Azimuth range: 120° / 30° • Dust and water proof: IP 67 • Operating temperature: -32 ~ 43 °C
Real image / thermal image (EO/IR) camera	• Real video Resolution: 3048×2160 • Thermal imaging Resolution: 640×480 • Zoom (Digital): 4 times	• Zoom (Optical): 36 times or more • Dust and water proof: IP 66 • Operating temperature: -32 ~ 43 °C

The Road Infrastructure National Performance Testing Station, installed and operated within the Korea Institute of Civil Engineering and Building Technology's Yeoncheon SOC Demonstration Research Center, is Korea's highest-level road transportation research and development comprehensive testing facility. The adverse weather reproduction facility is the first in Korea to reproduce severe weather conditions at the actual weather level (rainfall intensity of 50 to 100 mm/h and fog visibility of 30m).

Test center view and test preparation scenes such as (a) panoramic view of weather reproduction tunnel, (b) artificial rain scene, and (c) preparation for evaluation are shown in Figure 9.

(a) Panoramic view of weather reproduction tunnel

(b) Artificial rain scene

(c) Preparation for evaluation

Figure 9. Test center views and preparation scenes

As a result of evaluating pedestrian detection performance in adverse weather situations, it was impossible to detect pedestrians in both 10mm/h rainfall (distance over 80m) and 30mm/h rainfall (distance over 40m) in the case of real image (EO) cameras. Meanwhile, the thermal imaging (IR) camera was able to detect pedestrians up to 90m in 10mm/h rainfall and up to 40m in 30mm/h rainfall. The adverse weather performance evaluation results for EO/IR are shown in Table 5.

Table 5. EO/IR camera adverse weather performance evaluation results

Pedestrian detection probability (rainfall of 10mm/h)					
item	80m	90m	100m	130m	150m
EO	0%	0%	0%	0%	0%
IR	83%	83%	0%	0%	0%
Pedestrian detection probability (rainfall of 30mm/h)					
item	40m	50m	60m	70m	80m
EO	0%	0%	0%	0%	0%
IR	83%	0%	0%	0%	0%

The 60GHz radar performance evaluation in adverse weather conditions, the detectable distance for medium-sized vehicles was measured to be 114m under normal conditions, 111m under low-visibility fog, 100m under high-visibility fog, 103m under 50mm/h rain, and 114m under 30mm/h rain. Meanwhile, as a result of performance evaluation for pedestrians, the detectable distance was measured to be 85m in normal conditions, 82m in low-visibility fog, 70m in high-visibility fog, 51m in 50mm/h rain, and 60m in 30mm/h rain. The sensing data measurement speed between the object detection sensor and the object recognition system was 50ms. The adverse weather performance evaluation results for 60GHz radar are shown in Table 6.

Table 6. 60GHz radar adverse weather performance evaluation results

Vehicle (medium) detection distance (m)					
item	normal	Fog (low visibility)	Fog (high visibility)	rainfall (50mm/h)	rainfall (30mm/h)
result	114m	111m	100m	103m	114m
Pedestrian detection distance (m)					
item	normal	Fog (low visibility)	Fog (high visibility)	rainfall (50mm/h)	rainfall (30mm/h)
result	85m	82m	70m	51m	60m
Sensing data transfer rate (object detection sensor → object recognition system)					
50ms					

4. Conclusion

We developed the radar-enabled AI convergence transportation entities detection system. This system collects transportation entity information from newly developed 60GHz radar and EO/IR surveillance sensors, then provides autonomous driving situation recognition / determination results to autonomous vehicles through data convergence and AI processing.

In adverse weather situations, the detection performance of EO/IR cameras is significantly reduced, and close collaboration between autonomous vehicles and transportation infrastructure is necessary in sections that require complex transportation situation determination.

The adverse weather performance evaluation of the 60GHz radar and EO/IR camera was conducted at the SOC Demonstration Research Center of the Korea Institute of Civil Engineering and Building Technology in Yeoncheon, Gyeonggi-do. As a result of the pedestrian detection performance evaluation, both EO/IR cameras showed limited performance. The 60GHz radar was shown to be capable of detecting mid-sized vehicles from 100m to 114m and pedestrians from 51m to 85m, proving the efficiency for 60GHz radar in autonomous driving in adverse weather.

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