INVESTIGATION ON THE CONDITIONS FOR DISTURBANCES IN THE SAFETY PERFORMANCE ASSESSMENT ON THE PERCEPTION FUNCTION OF AUTOMATED DRIVING VEHICLES

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ABSTRACT

This study focuses on perception as a fundamental part of the function chain of automated driving systems. The dynamic control of automated driving vehicles will be operated based on the perception function resulting from processing information gathered by sensors. Factors influencing perception should be identified and determined for the safety performance assessment because such factors consequence the behavior of automated driving vehicle. Especially, the characteristics of radar on perception function in ADS was investigated, and conditions for disturbances to developing safety performance assessments was discussed.

1. INTRODUCTION

The vehicle regulation for Automated Lane Keeping Systems (ALKS) under the framework of the 1958 agreement in UNECE came into force in January 2021[1]. This regulation will promote the mass production of automated driving vehicles (ADVs) in markets. At the same time, evaluation methods for ADVs respecting technology neutrality will be desired to ensure vehicles' (including ADVs) safety on roads.

The regulation defines technical requirements for the vehicles with ALKS. However, test methods, including such testing conditions and criteria, are not clarified to produce sufficient reproducibility between testers yet.

This study focuses on perception as a fundamental part of the function chain of automated driving systems (ADSs). The dynamic control of ADVs will be operated based on the perception function resulting from processing information gathered by sensors. Factors influencing perception should be identified and determined for the safety performance assessment because such factors consequence the behavior of ADV.

Various types of sensors such as cameras, LiDAR, radar, and GNSS are involved in the perception function in ADS. As the first step, the characteristics of radar on perception function in ADS was investigated. A radar unit was installed in the test vehicle, and the distance to the target truck forward was detected in the proving ground. The distance was tuned as the test condition beforehand. The error between the actual and radar detected distances was evaluated. Furthermore, in the rainfall facility, the influence of rain as a natural disturbance is investigated.

2. FIELD OF VIEW TEST FOR EVALUATION ON SENSOR PERFORMANCE

The ALKS United Nations Regulation (UNR 157) describes requirements for the recognition performance of automated vehicles and their test methods.

Chapter 7 of the Regulation contains provisions on object and event detection and response, which defines the detection range for forward and side detection. As shown in Fig.1, this regulation specifies a frontal detection range of 46 m or more and a side detection range up to the outer edge of both adjacent lanes. In addition, the test requires detection of other road users within a range equal to or greater than this range.
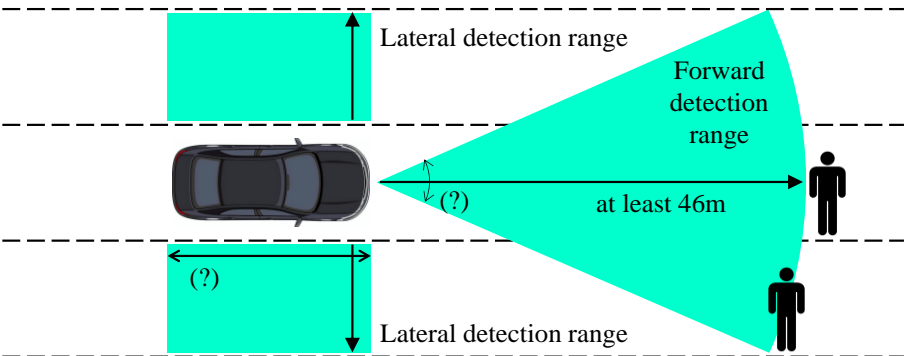

Fig.1 Range of recognition as defined in the ALKS UN Regulations

Chapter 5 of the appendix to the regulations describes the test method, which includes a field of view test, which describes the test requirements for recognition performance. Although these requirements include descriptions of recognition performance for stationary pedestrians at the outside edge of adjacent lanes and stationary motorcycles in their ego lane, they do not specify specific measurement conditions or evaluation criteria.

In a typical driving environment, such as road types, static or dynamic conditions, kinds of objectives and weather, etc. are considered to affect recognition performance, and depending on the combination of these items, there is a possibility that the object may not be recognized.

3. EXPERIMENTAL SETUP

For the experiment, a 79 GHz band stand-alone radar (RAD98, manufactured by Keycom) were used for verification. Figure 2 shows the appearance of the radar for verification, and Table 1 shows the specifications of the radar for verification. Although these parameters are design values, we also confirmed that the parameters were met by the measurement results.

In the experiment, the distance to the recognition target (hereinafter referred to as "preceding vehicle") was obtained by setting the origin at the radar for verification. The verification radar was attached to the leading edge of the vehicle, and the radar control software was used to acquire the radar recognition results. Medium-duty truck with manual transmission, as shown in Fig.3 were used as the preceding vehicles.

Experiments were measured under the evaluation conditions shown in Table 2 in a straight road geometry, referring to the conditions of the ALKS UN rules among the typical driving environment noted above.

Fig.2 The verification radar

Fig.3 Medium-duty truck as preceding vehicle

Table 1 Specifications of the verification radar

Frequency range	Short: 76~77GHz Middle and Long: 77~81GHz
Distance range/ accuracy	Short: 3~20m / ±0.24m Middle: 20~83m / ±0.40m Long: 83~250m / +1.00~-3.00m
Distance resolution	Short: 0.345m Middle: 1.055m Long: 5.751m
Velocity range/ accuracy	Short: ±10.8km/h / ±1.0km/h Middle: ±55.0km/h / ±2.0km/h Long: ±153.4km/h / ±2.7km/h
Horizonal angle range/ accuracy	Short: ±50° / ±2.790°~±3.789° Middle: ±50° / ±4.581°~±6.571° Long: ±40° / ±4.581°~±5.675°
Horizonal angle resolution	35°
Sampling frequency	10Hz

Table 2 Experimental conditions

	Conditions	
	Static	Dynamic
Status	Stationary in front	Moves at given speed
Lanes	Ego or adjacent lane	Ego or adjacent lane
Distance from ego vehicle	・3~20m (every 1m) ・20~80m (every 5m) ・80~200m (every 10m) (Total 42 conditions)	300m towards origin
Speed		Forward: Constant velocity at idling 1st gear: 7km/h 2nd gear: 12km/h 3rd gear: 18km/h Backward: Constant velocity at idling Back gear: 6km/h

4. RESULTS AND DISCUSSIONS

After describing recognition results under basic radar evaluation conditions, the effects of disturbances such as rainfall and structures on recognition performance are discussed as test condition.

4.1 Measurement results under static conditions

The measurement results for the static condition, in which the preceding vehicle is stationary in front of the ego vehicle, are shown. In the static condition, accurate distance (true value of distance) was obtained by placing the preceding vehicle at each landmark position actually measured from the origin. Figs.4 and 5 show the measured distance and measurement error against the true value of the distance measured by the verification radar.

Figure 4 shows the distance recognized by the radar relative to the true value (average value measured for 10 seconds at a frame rate of 10fps), and ideally, the measurement points should line up on a straight line where Y=X. While the radar was able to measure up to 100m in the condition where the vehicle ahead was in its ego lane, it was unable to measure in the range of 50m to 60m and in the range of 90m or more in the condition where the vehicle ahead was in the adjacent lane.
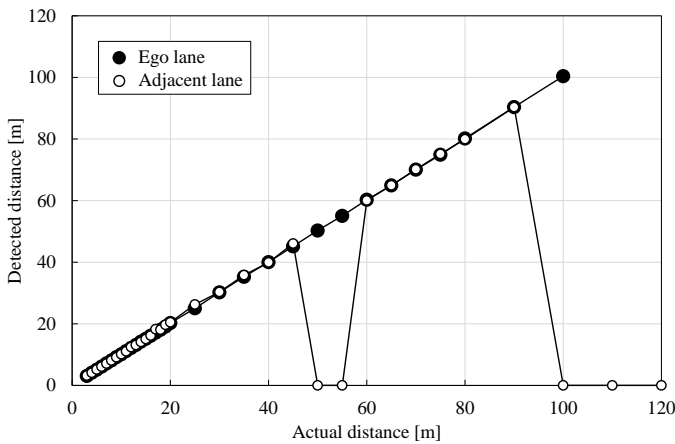

Fig.4 Detected distance at static conditions

Figure 5 shows the measurement error (mean and ±3σ) relative to the actual distance between vehicles. The error is acceptable if it is within the accuracy of the radar parameters listed in Table 2 (single dotted line in Fig.5). Under the condition that the vehicle ahead is in its ego lane, the error is within the accuracy. On the other hand, when the preceding vehicle is in the adjacent lane, the error is out of the range of accuracy for distances up to 50m.

The above results indicate that, under static conditions, the system can recognize a vehicle with a small error up to 100 m when the preceding vehicle is in its ego lane, but when the preceding vehicle is in a adjacent lane, the error becomes large at distances up to 50 m, resulting in poor recognition performance. When the preceding vehicle is in the adjacent lane, the measurement error may become larger due to the influence of radar reflected from the side of the preceding vehicle.
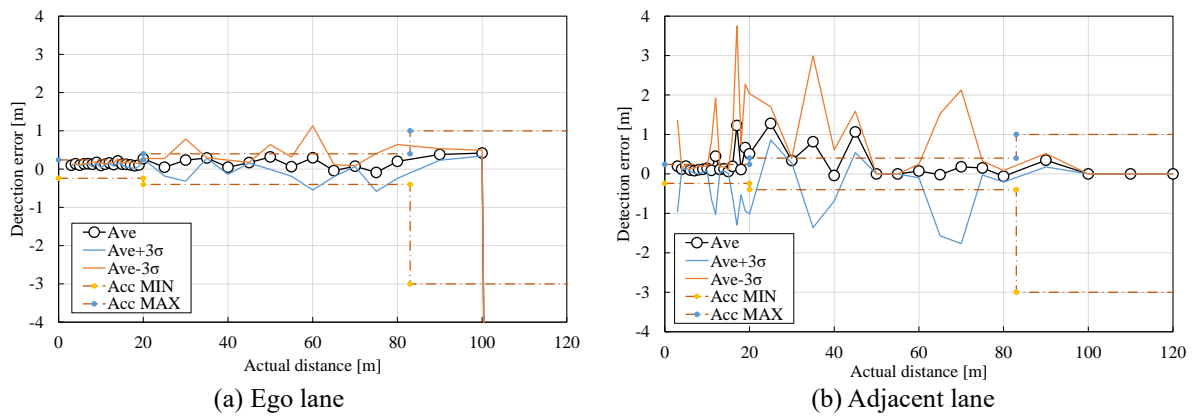
(a) Ego lane

(b) Adjacent lane

Fig.5 Detection errors on static conditions

4.2 Measurement results under dynamic conditions

The measurement results are shown for dynamic conditions in which the vehicle ahead moves at a given relative speed. The RCS (radar cross section [dBsm][2]) is a value that expresses the size of the reflective surface and the ability of the radar to reflect the radio waves emitted by the radar and return the reflected waves to the radar detector. A large RCS value indicates that the radar can easily detect the target.

Figure 6 shows how the figure is viewed. The colors of the plots in the figure indicate the order of RCS, with blue, green, and red indicating higher RCS. Here, the color of the plot is only a rank order and does not correspond to the RCS value. The origin is the front end of the radar, and the blue line is the travel path of preceding vehicle (if it is in its ego lane, it is on the Y-axis origin; if it is outside its ego lane (adjacent lane), it is offset in the X-axis direction by that amount). The points around the trajectory are the preceding vehicle, and other objects in the vicinity, such as buildings and guardrails, are detected.
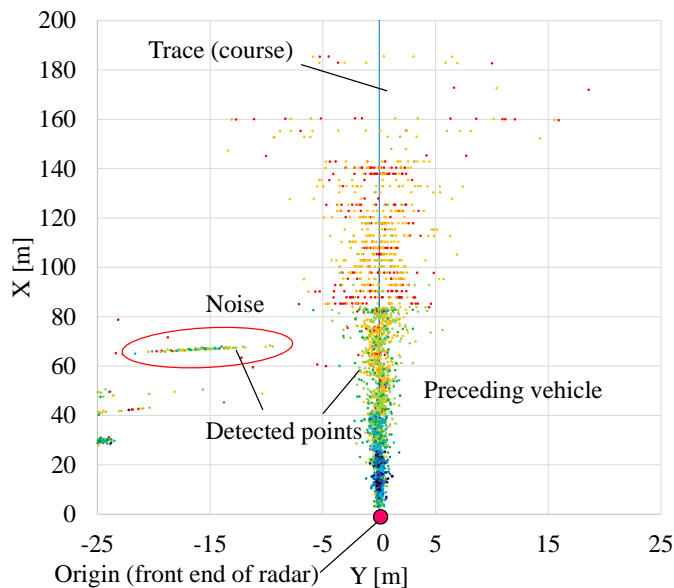

Fig.6 How to read the figure of detected points

Figure 7 shows a comparison of static and dynamic conditions. In the static condition, the measurable range is about 100m when preceding vehicle is in the ego lane (as also shown in Fig.4). However, when there is a preceding vehicle in the adjacent lane, the distance that can be measured with good sensitivity becomes shorter, and the measurement stability in the middle part is significantly impaired. In addition, under the condition where the preceding vehicle was in the adjacent lane, the effective measurement points varied in the Y-direction due to the influence of lane position. Next, comparing the results with those of the dynamic condition, clear differences were observed between the dynamic condition and the static condition. The maximum measurable distance was about 100m in the static condition, whereas it was about 200m in the dynamic condition. It is also clear that the static condition has a larger variation in the Y-direction and noise in areas where no recognition target exists compared to the dynamic condition. On the other hand, there is less difference among the velocities of the preceding vehicle. In general, radar detects the phase difference caused by the RCS and the relative speeds of the ego vehicle and the

preceding vehicle, and the combination of RCS and phase difference is used to identify the target. Under static conditions, the phase difference information is not available and noise sources such as guardrails are stationary, making it impossible to discriminate between the preceding vehicle and the noise based on the phase difference. Hence, under static conditions, the RCS of the preceding vehicle is easily buried in the noise and is considered to be difficult to recognize. On the other hand, under dynamic conditions, the preceding vehicle is considered easier to identify because it has a different phase difference from the noise component. The horizontal variation decreased as the relative speed increased, but there was no significant difference among the speeds.

For these reasons, it is considered that vehicle-mounted radar can recognize a moving preceding vehicle more favorably than a stationary preceding vehicle.
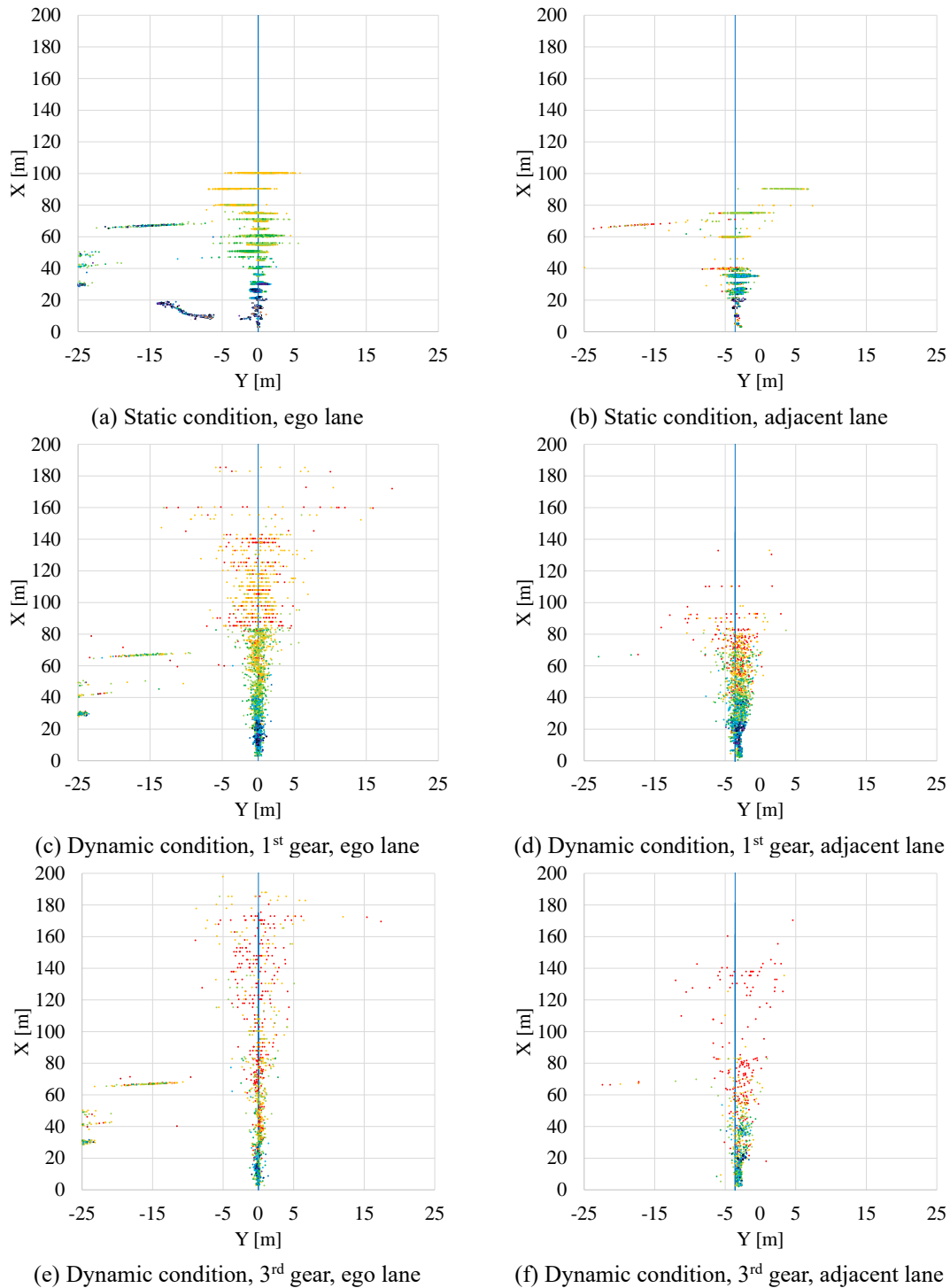

(a) Static condition, ego lane

(b) Static condition, adjacent lane

(c) Dynamic condition, 1st gear, ego lane

(d) Dynamic condition, 1st gear, adjacent lane

(e) Dynamic condition, 3rd gear, ego lane

(f) Dynamic condition, 3rd gear, adjacent lane

Fig.7 Comparison between static condition and dynamic condition

4.3 Effects of Disturbances from Buildings and Other Artificial Objects on Recognition Performance

The effect of disturbance from buildings and structures on recognition performance is evaluated. Comparison of the maximum measurable distance, etc. in the area lined with buildings (No.3 post location), the area with few buildings (No.6 post location) at the Kumagaya 1st proving ground of the National Traffic Safety and Environment Laboratory (NTSEL), and the specific environment test facility of the Japan Automobile Research Institute (JARI) is performed. Each evaluation environment is shown in Fig.8. Measurements were taken at the center of the second lane from the left edge of each environment.

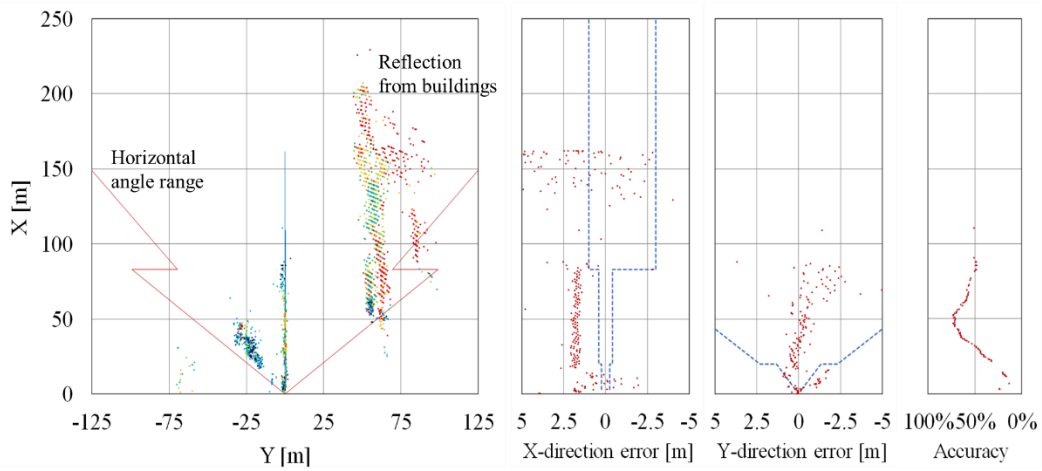(a) No.3 post location

(b) No.6 post location

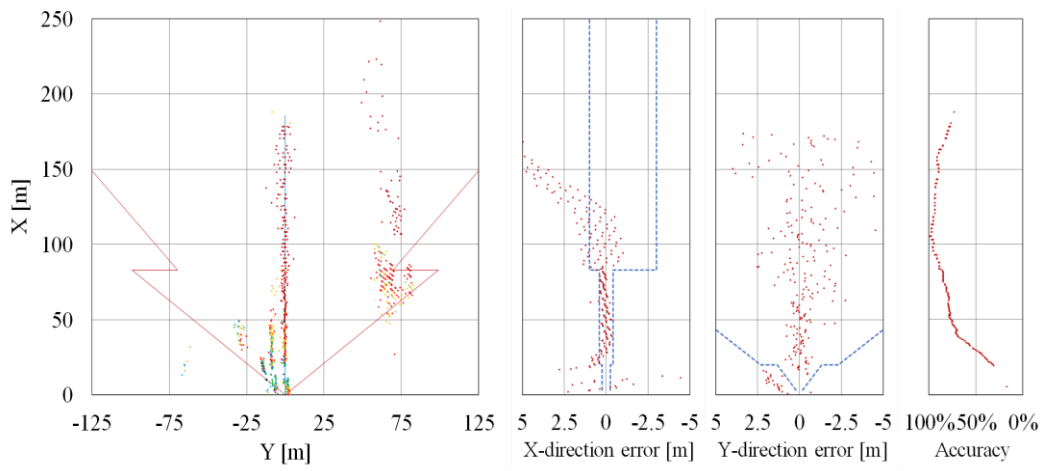(c) Specific environment test facility
Fig.8 Test environments

At the No.3 post location, buildings and steel walls are considered to be disturbances that affect recognition performance, while at the No. 6 post location, there are relatively few buildings, and recognition performance is considered to be less disturbed. In the specific environment test facility, the steel frame of the building is considered to affect recognition performance. Here, based on the results of Section 4.2, we verified the dynamic condition in which preceding vehicle travels ahead of its ego lane. The measurement results for each evaluation environment are shown in Fig.9. Figure 9 shows not only the error between the actual position and the position detected by the radar, but also the accuracy of recognition.

From Fig.9, comparing the No.3 and No.6 post locations, it can be seen that the group of points around Y=75m at the No. 3 post position is darker than that at the No. 6 post position. This is due to the influence of reflected waves from buildings, and is considered to be a clear difference in the evaluation environment. The maximum measurable distance at the No.3 post was about 160m, which was shorter than the distance at the No.6 post, about 180m. Furthermore, the maximum measurable distance at the No.3 post was about 60m, which was shorter than the distance at the No.6 post. The error in the X- and Y-directions at the No.3 post position was larger than that at the No.6 post position, suggesting that disturbance from buildings and other objects may cause a larger error.

Furthermore, although the maximum measurable distance of the specific environment test facility was approximately 200m, the errors in the X and Y directions were large. The specific environment test facility is surrounded by a steel frame and is narrower in the horizontal direction than the Kumagaya No.1 proving ground, which is thought to make it easier for reflected waves from recognition targets to be buried by reflected waves from the walls of the facility. Therefore, it was found that artificial objects such as buildings affect the recognition performance such as the maximum measurable distance of the radar.

(a) No.3 post location

(b) No.6 post location
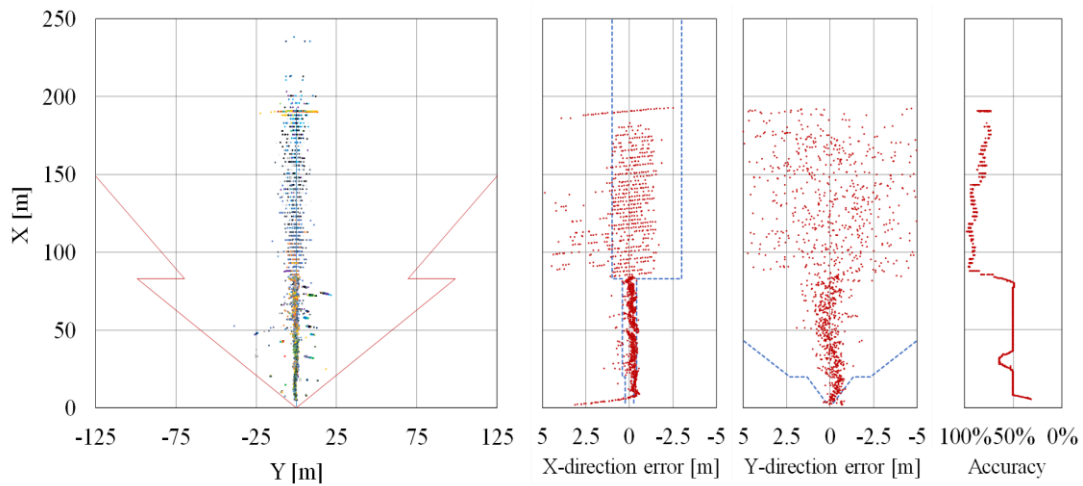
(c) Specific environment test facility
Fig.9 Detection results in each test environments

4.4 Effects of natural disturbances such as rainfall on recognition performance

To evaluate the effect of rainfall on radar recognition performance, measurements were conducted under artificially rainy conditions at the specific environment test facility. Figure 10 shows the rainfall in the facility.

Fig.10 Rainfall in specific environment test facility

This facility can reproduce precipitation amounts of 30mm/h, 50mm/h, and 80mm/h. At each precipitation level, measurements were taken under dynamic conditions. Figure 11 shows the relationship between precipitation and RCS. With increasing precipitation, the RCS, which represents the energy of the reflected wave, attenuated and the maximum measurable distance became shorter. Therefore, it was found that rainfall degrades radar recognition performance, and the effect increases with increasing precipitation.
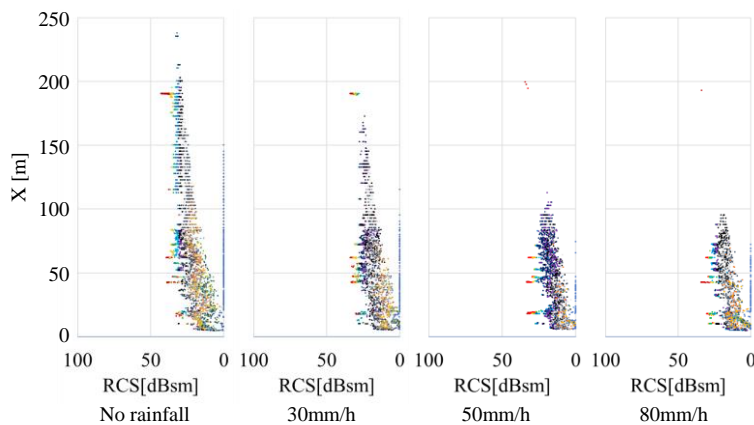

Fig.11 Precipitations and radar cross section

5. CONCLUSIONS

The perception performance of the radar differs among static and dynamic conditions. The error depended on test environments and conditions, especially safety walls and rain were significantly influenced. Under the test condition, without any roadworthy objects such as safety fences, walls, or poles of traffic lights, the radar detected the preceding vehicle and derived the distance with low errors. On the other hand, when the preceding vehicle was located close to the safety wall made of steel, the radar could not detect the preceding vehicle and derived the distance with many errors. In addition, rainfall was found to degrade radar detection performance.

From the perspective of ensuring the safety of ADVs, it is important to determine the static, dynamic, and disturbance conditions to ensure technological neutrality in evaluating the suitability of ADVs for the required performance. In particular, in the recent dynamometer system [3] for validating perception performance, the conditions above under which the vehicle is in driving condition but the surroundings are static will be important.

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