Contribution to the achievement of SDGs
by Furukawa Electric Group

77 GHz Band Radar Technology Supporting the Future of Japanese Agriculture

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ABSTRACT In recent years, there has been a demand for automation and efficiency in agricultural activities in response to the serious decline in the number of farmers in Japanese agriculture. In the agricultural environment, fog during pesticide application and sand dust generated during driving have become challenges for sensing vegetation and obstacles. We have developed the sensing technology through our business of in-vehicle peripheral monitoring radar equipment. We have developed a new 77 GHz band radar application, by applying this technology. In addition to the detection performance and the environmental resistance evaluated by applying the 77 GHz band radar to an agricultural environment, we will present the evaluation of autonomous driving by integrating a software for autonomous driving as well as this radar.

1. INTRODUCTION

1.1 Background and Challenges

In recent years, the decline in the number of farmers in Japan has become a serious problem, and challenges are autonomous driving agricultural machinery and automating agricultural activities, as well as increasing efficiency[1]. In order to solve these problems, a sensor capable of accurately detecting vegetation and obstacles during farming is required. However, a technical challenge is the false detection of sensors caused by environmental factors unique to agriculture, such as fog during pesticide application and sand dust during farm machinery driving (Figure 1).

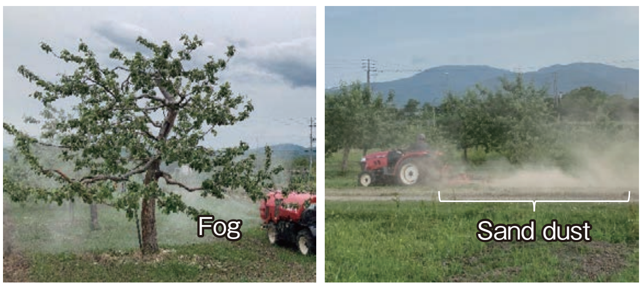

Figure 1 Targeted agricultural environment.

Simultaneous Localization And Mapping (SLAM), which is a technology that simultaneously estimates the self-position of a moving object and creates an environment map, has been attracting attention as a means of realizing the autonomous driving of agricultural machinery. Generally, Global Navigation Satellite System (GNSS) is used for the self-position estimation. However, in agricultural environments, GNSS signals from satellites are often blocked by trees and buildings. To establish the self-position estimation method by combining sensors and SLAM technology, which does not depend on GNSS, is also an important challenge.

1.2 77 GHz Band Radar for Agricultural Machinery

We are developing a 77 GHz band radar for agricultural machinery[2]. We have developed our technology in the business of in-vehicle peripheral monitoring radar[3), 4)]. and we aim to solve the aforementioned problems by applying this technology to the agricultural field. Here, radar is a sensor device that can detect the position and the relative velocity of objects using radio waves. As shown in Table 1, compared to other sensors such as Light Detection And Ranging (LiDAR) and Sound Navigation And Ranging (Sonar), the radar offers a higher degree of transparency, because of its resistance to rain, fog, sand dust, and other environmental conditions. Also, generally, the wider the frequency bandwidth used, the higher the distance resolution of the radar[5]. The radar in the 77 GHz

Table 1 Comparison of distance sensors.

	Radar	LiDAR	Sonar
Distance resolution	△	○	△
Detection distance	○	○	△
Transparency	○	×	×
Relative velocity detection	○	×	×

○ : Best fit △ : Alternative × : Not fit

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band has a relatively wide frequency bandwidth of 4 GHz (77 to 81 GHz) that can be used, and can achieve a resolution of a few centimeters.

Based on the above features, the radar is expected to be an effective sensing method in agricultural environments where environmental resistance to fog and sand dust is required. In addition, in combination with the SLAM technology, it is also expected to be used as a sensor for autonomous driving of agricultural machinery. In this paper, we introduce the performance of our 77 GHz band radar in detecting vegetation, its environmental resistance to fog and sand dust, and the evaluation of autonomous driving by integrating the radar with a software for autonomous driving.

2. MAJOR SPECIFICATIONS OF THE 77 GHZ BAND RADAR UNDER DEVELOPMENT

Figure 2 shows the picture of the radar under development. This radar uses Fast-Chirp Modulation as its modulation method and operates in the 77 GHz band (77 to 81 GHz). The default maximum detection distance is approximately 20 meters, although it can be adjusted based on specific usage requirements and environmental conditions. Additionally, the detection angle covers a range of ±60° in the horizontal direction and ±10° in the vertical direction. The measurement cycle is every 100 microseconds.

Figure 2 Picture of the radar under development.

3. RADAR EVALUATION IN AGRICULTURAL ENVIRONMENT

3.1 Selection of Evaluation Environment

The Ministry of Agriculture, Forestry and Fisheries has designated apples, grapes, peaches, citrus fruits, persimmons, and strawberries as priority export commodities[6]. Among these, apples are the most important commodity in terms of sales scale and production volume. Therefore, an apple orchard was selected as the evaluation environment for this study.

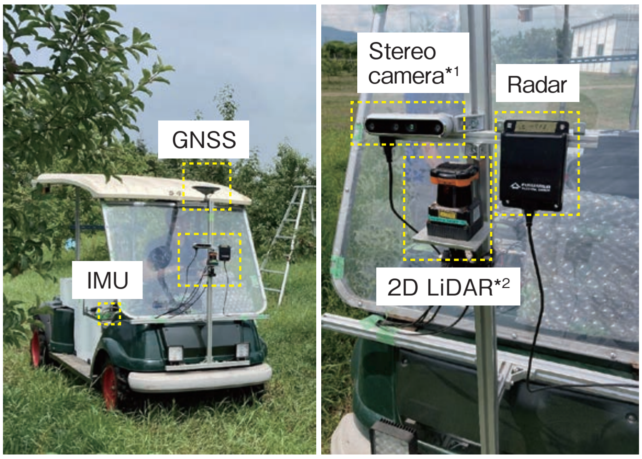
The evaluation facility was the Yoichi Orchard of the Field Science Center for Northern Biosphere with the cooperation of Hokkaido University (Figure 3).

3.2 Evaluation Systems

Figure 4 shows the evaluation vehicle and sensors, and Figure 5 shows the configuration of the evaluation system. An evaluation vehicle owned by Hokkaido University was equipped with various sensors, and the driving evaluation was conducted in an orchard. In this system, vehicle information (position and attitude) was acquired using GNSS (Septentrio, AsteRx SB3 CLAS) and Inertia Measurement Unit (IMU) (Vectornav, VN-100 IMU/AHRS*3). Also, in addition to the radar, a 2D LiDAR (Hokuyo, UTM-30LX) and a stereo camera (Intel, Realsense d455) were installed as reference sensors. Note that the LiDAR has a ranging accuracy of ±30 mm in a measurement range of 0.1 to 10 m[7]. The above vehicle and sensor information is integrated with Robot Operation System (ROS)[8] on a PC.

*3 Attitude Heading Reference System (AHRS)

Figure 3 Photo of the Evaluation environment.



*1 Intel, Realsensed455 *2 Hokuyo, UTM-30LX

Figure 4 Evaluation vehicle and sensors.

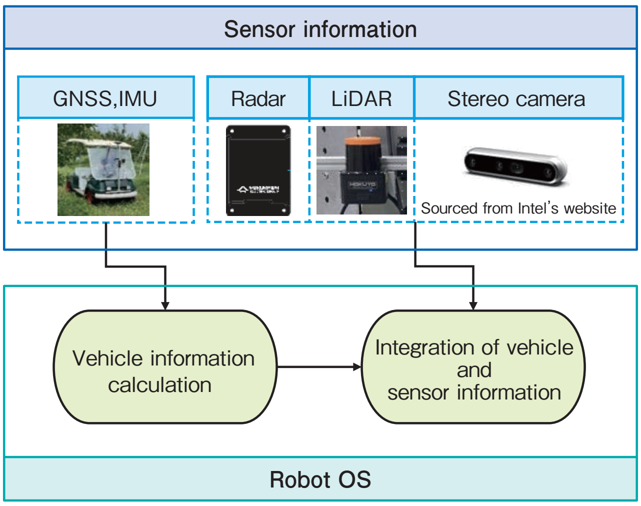


Figure 5 Evaluation system.

3.3 Evaluation of Ranging Performance

In this experiment, the ranging performance of the radar was evaluated in an apple orchard. As shown in Figure 6, evaluation targets were vegetation and person, and results were compared with those of the high-precision LiDAR.

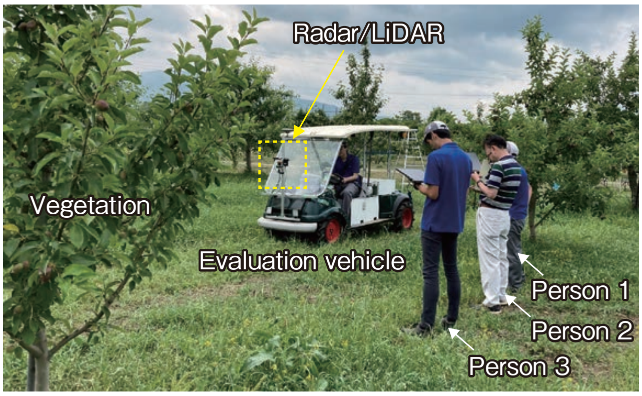


Figure 6 Evaluation view of radar and LiDAR ranging performance.

Figure 7 shows the results. In Figure 7, the LiDAR was installed at the positions marked with a black X (horizontal, depth direction) = (0.00 m, 0.00 m) and the radar was installed at the positions marked with a black • (horizontal, depth direction) = (-0.15 m, 0.00 m). Points where a person 1 to 3 and vegetation were detected from these locations are plotted. Detection points of the LiDAR indicated by the gray X and the radar indicated by the colored • overlap, indicating that they were detected at the same locations. Note that the color of the radar detection point indicates the reflection intensity. In addition, in Figure 7, the results of the radar detection position error are shown next to the dotted lines surrounding each evaluation target (vegetation and person). The error is the difference between the average values of radar and LiDAR detection positions within each box. As a result, the error in the detection positions of a person 1 to 3 was 0.15 m to 0.34 m, and the error in the detection position of vegetation was 0.17 m. These errors are thought to be due to the fact that the radar is a 3D detection system while the LiDAR is a 2D detection system, and that the LiDAR detects only the surface of an object while the radar detects parts other than the surface of the object.

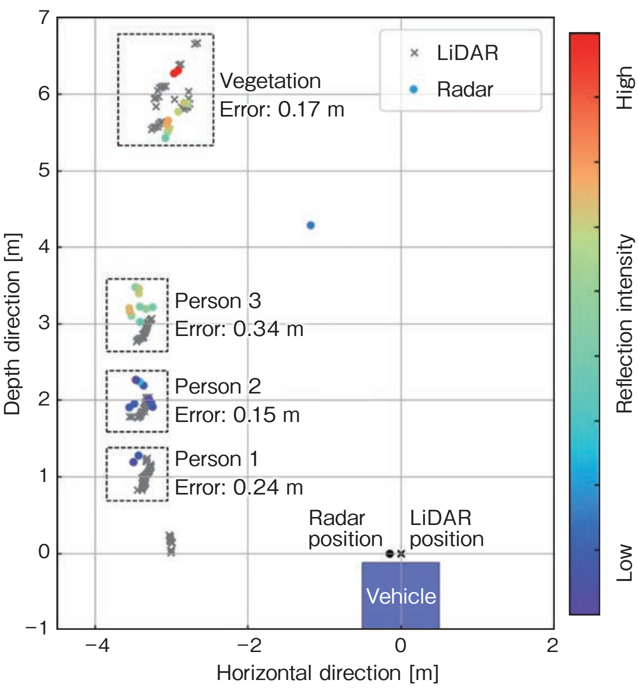


Figure 7 Comparison results of radar and LiDAR ranging performances.

3.4 3D Detection Performance

In orchards, branches that affect the travel of agricultural vehicles may extend high above the ground. Avoidance of such obstacles requires a 3D detection capability. Figure 8 is a 3D plot of radar point cloud results from a different viewpoint to give a 3D view from diagonally above. As can be seen in Figure 8, although the spatial resolution in the elevation angle direction is inferior to that of the horizontal direction, it was confirmed that 3D detection of branches located above the vehicle is possible. Based on this result, we expect that this method can be applied to the determination of the travel route of agricultural machinery. Note that the 2D LiDAR is limited to detecting branches located above the vehicle only at the installation height, making it difficult to detect branches located above the vehicle.

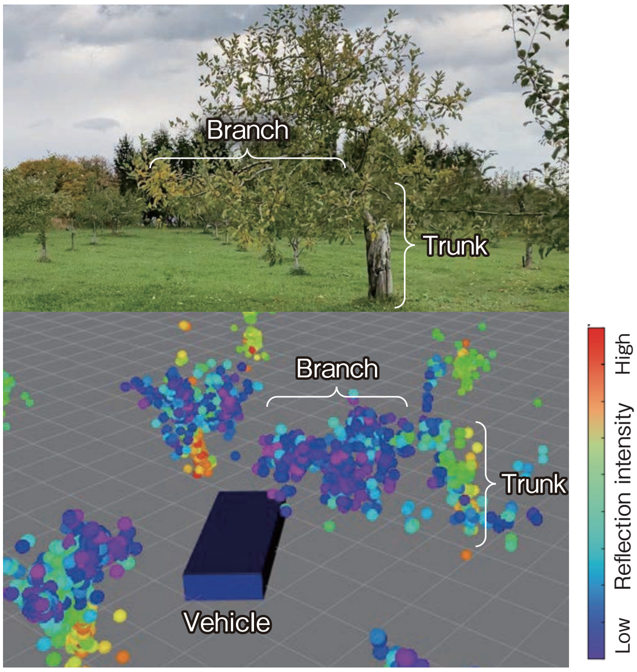


Figure 8 3D detection performance of radar.

4. EVALUATION OF RADAR'S ENVIRONMENTAL PERFORMANCE AGAINST FOG AND SAND DUST

In this experiment, a comparative evaluation was conducted to see if the radar and the LiDAR could detect a person behind fog (Figure 9) and sand dust (Figure 10).

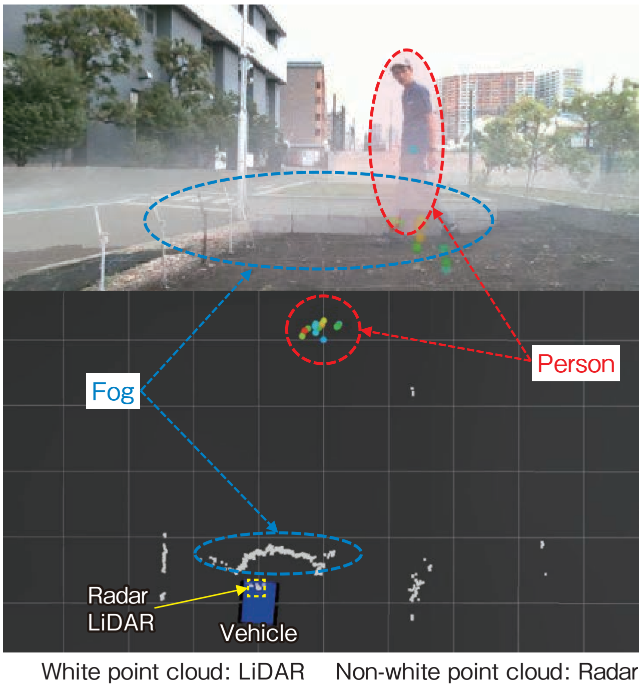


Figure 9 **Comparison results of radar and LiDAR detection performance in a foggy environment.**

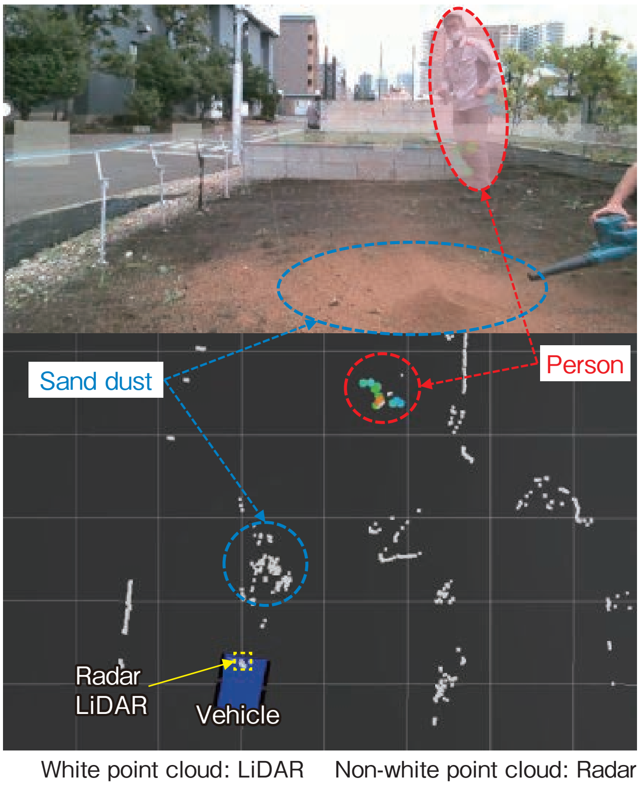


Figure 10 **Comparison results of radar and LiDAR detection performance in sand dust environment.**

In order to simulate a foggy environment, we used an agricultural sprayer to artificially generate fog. Note that the sprayer used (HG-KBS20L) has a maximum spray rate of 3.1 L/min and a maximum spray force of 0.55 MPa. A 2D LiDAR sensor was used to compare to the radar sensor. Note that both sensors were installed at the same height. The sand dust environment was reproduced by blowing wind on the sand using a blower.

Figures 9 and 10 compare the detection performance of radar and LiDAR in fog and sand dust environments, respectively. White point cloud indicate the detection results from the LiDAR and non-white point cloud indicate the detection results from the radar. The lower panel of Figure 9 shows that the white point cloud indicating the LiDAR detection exist in the fog area surrounded by the blue dotted line in front of the vehicle, but no white point cloud exists at the position of the person surrounded by the red dotted line. This indicates that the LiDAR is not able to detect the person behind the fog due to the effect of detecting the fog. On the other hand, the radar does not detect the fog itself, but detects the person behind the fog, indicating that it has a certain level of transparency. Figure 10 similarly shows that the LiDAR detects sand dust and fails to detect a person, while the radar detects a person without detecting sand dust. This is because the radar wavelength is sufficiently long compared to fog particles and sand dust. Although this was a simulated evaluation, we believe that the radar can maintain good sensing even in an actual agricultural environment where fog and sand dust are generated. In particular, we believe that our radar can demonstrate a stable detection performance during plowing and harvesting operations where there is a lot of sand dust.

5. EFFORTS TOWARD AUTONOMOUS DRIVING OF AGRICULTURAL MACHINERY

5.1 Advantages of Radar SLAM

The SLAM technology is an important technology in the application of autonomous driving systems in the agricultural sector. In particular, the radar SLAM has the potential to solve the problems faced by conventional cameras and LiDAR-based SLAM. As mentioned earlier, cameras and LiDAR have had problems with reduced detection accuracy due to fog and sand dust, but the radar can demonstrate a stable performance in rainy weather, at night, and in sand dust environments. This characteristic of the radar SLAM is expected to contribute to improving the reliability of autonomous driving systems in the agricultural field, where environmental resistance is required.

In this paper, as a preliminary step to verify the effectiveness of radar in SLAM, we report the results of an autonomous driving evaluation integrating radar in the existing autonomous driving software in ROS.

5.2 Evaluation of Autonomous Driving Between Trees

The sensor configuration for an autonomous driving application is shown in Figure 11. The evaluation system in this experiment was equipped with the radar as the primary sensor and used for obstacle detection applications in the vicinity. In the autonomous driving control system, an odometry function that calculates the length and the direction of a vehicle movement from the number and direction of wheel rotations, and a ROS Navigation Stack[9], which provide a route planning and obstacle avoidance function, are used. This evaluation system was used to evaluate whether the vehicle could automatically travel to its destination while avoiding obstacles based on radar data.

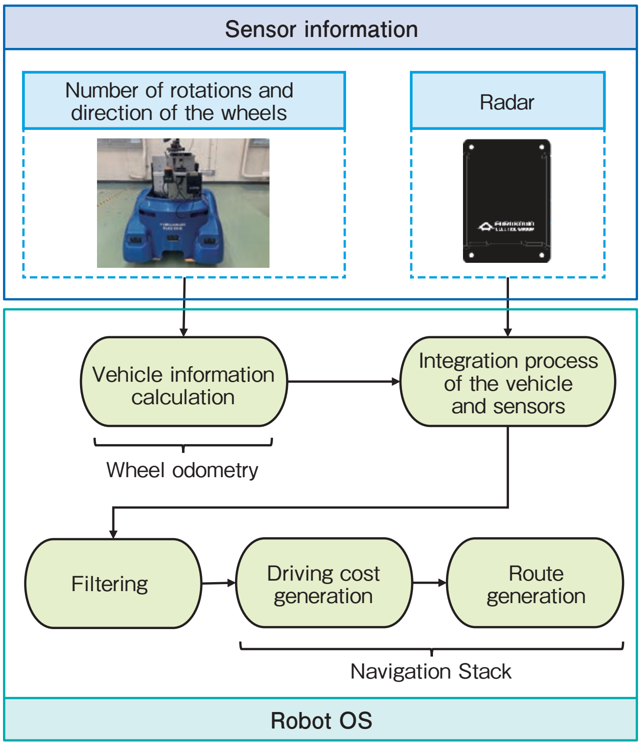


Figure 11 Sensor configuration to an autonomous driving application.

In this experiment, two radars were mounted on the left and right corners in front of the vehicle as shown in the lower left of Figure 12 to evaluate the autonomous driving between trees. The colors of the point cloud data in Figure 12 represent the height from the ground surface (red: high, blue: low). The goal was set at approximately 12 m from the origin point, and there were trees between origin and destination points that served as obstacles. Heading toward the destination, the area judged to have obstacles based on the point cloud data detected by the radar is shown in black. The gray area linearly connected between the location of this black obstacle and the vehicle is determined to be the area that can be traveled, and the vehicle travels in the gray area during automatic driving. In Figure 12, the vehicle is traveling in a narrow space between trees, and there is a risk of the vehicle coming into contact with an obstacle. To avoid contact with such obstacles, a certain safety margin is set between the vehicle and the obstacle to avoid getting too close to the obstacle. The distance between the vehicle and the obstacle is set at two levels. The light blue area indicates an impenetrable area, and the purple area indicates a safety margin to reduce the risk of collision. The radar system determines whether or not the vehicle can travel between narrow trees, taking into account this area information and the size of the vehicle. As a result of the evaluation, the radar detects the surrounding vegetation appropriately and succeeds in automatically reaching the destination point while avoiding collisions with obstacles.

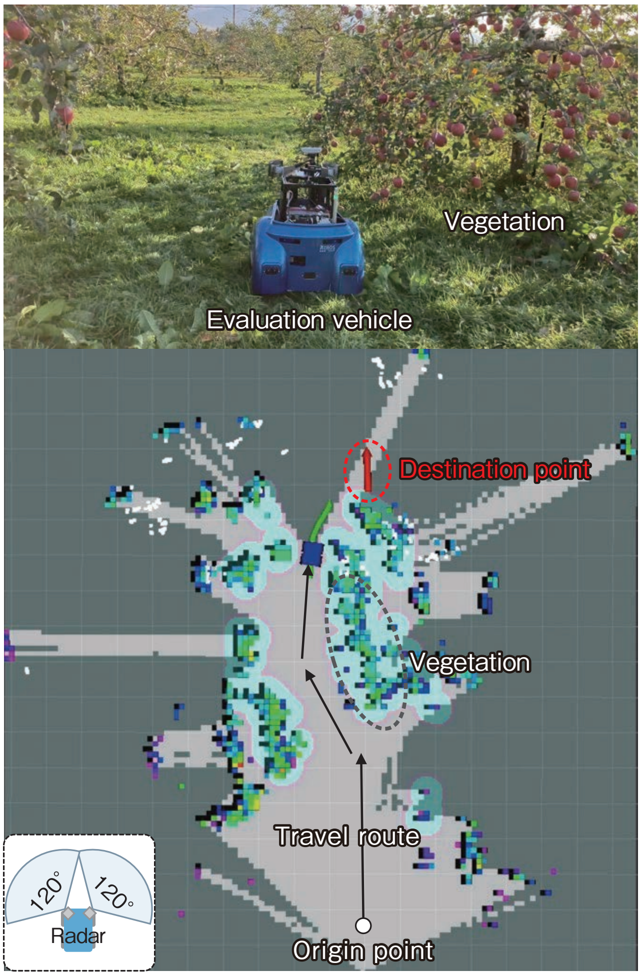


Figure 12 Evaluation results of autonomous driving evaluation using radar.

6. CONCLUSION

In this paper, we introduce the detection performance of our 77 GHz band radar for vegetation, its environmental resistance to fog and sand dust, and the evaluation of autonomous driving by integrating the radar with a software for autonomous driving. We showed that our radar has the same detection performance of a conventional 2D LiDAR and has better environmental performance than the 2D LiDAR. Furthermore, by integrating the radar with an autonomous driving software, we showed that the radar can avoid vegetation and reach the destination point automatically based on the radar information. Further development of the self-position estimation technology, one of the components of radar SLAM, is expected to contribute to automation and efficiency in agricultural operations such as transportation in environments where GNSS signals are difficult to reach, etc.

In summary, we have shown that our radar is a useful sensor that contributes to a precision in agriculture activities and improves its efficiency.

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