Millimeter-Wave Radar with Wide Viewing Angle for Improved Installation Flexibility

Yusuke YAHATA*, Hideaki SHIRANAGA, Nobuo HIGASHIDA, Masaki KISHI, Atsushi HIGASHI, and Hideki HAWAKA

The global need for pedestrian detectors is increasing to improve traffic safety and efficiency. In order to achieve accurate detection at intersections, the detectors need to be placed in the right locations. However, constructing new poles requires much effort and cost, making it essential to utilize existing poles for widespread deployment of the detectors. Meanwhile, achieving effective pedestrian detection on both far and near sides presents challenges due to the limited sensor viewing angles. Additionally, many sensors are unable to detect pedestrians directly beneath them, thereby restricting the possible installation locations. To overcome these challenges, we have developed a cost-effective radar system with a wide vertical coverage angle, offering improved installation flexibility. This paper introduces the innovative radar and presents experimental results demonstrating its expanded detection area.

Keywords: safety, road traffic, pedestrian detection, radar, viewing angle

1. Introduction

In the United States, accidental pedestrian deaths have increased by approximately 53% over the past 10 years and this has become a grave social issue. To protect pedestrians, the United States government has taken the lead in implementing various measures, including geometrical improvements made to roads and optimization of traffic signal timing. One of the challenges is that pedestrian pushbuttons abundantly used in the United States are unable to aid those who have difficulty in pressing the button. As a solution to this challenge, the use of detectors that eliminate the need for the pedestrian to manually push a button is greatly anticipated. In Europe and Asia, testing of systems incorporating pedestrian detectors is under way. However, for widespread use of pedestrian detectors, where to install them becomes a major issue. Erecting a new pole for installing a detector involves significant cost. Moreover, at many intersections, it is impossible to erect another pole for various reasons. Therefore, when installing a pedestrian detector at an intersection, it is essential to use an existing pole.

Meanwhile, many existing sensors (Image sensor,[*1] LiDAR,[*2] Radar[*3]) fail to provide an adequate vertical coverage angle. Accordingly, it is difficult for them to detect pedestrians on both far and near sides. One possible solution to this challenge is to install more than one pedestrian detector. However, this solution would increase the cost according to the necessary number of detectors and require software designed for data integration. To address this issue, the authors have succeeded in expanding the vertical coverage angle by installing a small reflector within the radar case. The reflector may be made of metal such as steel or aluminum. According to the results we have obtained, the additional installation of the reflector does not require a software update.

We have developed a radar unit that is capable of detecting pedestrians both on far and near sides by simply adding a small reflector in the case and installing the unit on an existing pole. Furthermore, radar helps ensure safety in all situations because it functions stably without being affected by the brightness of the day, the darkness of the night, or changes in weather. Additionally, unlike cameras, radar does not require regular cleaning because it has no lens; this is a great advantage of radar as a sensor installed at a high elevation. This paper reports on the details of the development and the results of experimental verification of a prototype conducted on a playing field.

2. Radar Specifications and Application

A radar unit is often installed on one corner of an intersection to detect pedestrians on the crosswalk and in the waiting areas, as illustrated in Fig. 1. (Figure 1 also presents the exterior of the prototype radar unit constructed by the authors.)

The antennas installed in the radar unit periodically emit a radio signal in the 60 GHz band and receive the reflected signal. The distance between the antennas and the reflecting object is calculated from the round trip time of the signal. The angle between the front direction and the reflecting object is calculated based on the phase difference between signals received by multiple receiving antennas.

(a) Prototype radar unit

(b) Rendered image of radar installation

Fig. 1. Exterior of the prototype radar unit and a rendered image of radar installation

Additionally, the velocity of the reflecting object is calculated from the Doppler shift of the signal.

The specifications for the prototype that we developed are given in Table 1. The pedestrian detection area was set at 60 m (front) by 30 m (side to side) based on the sizes of typical crosswalks and waiting areas.

Table 1. Specifications for prototype

Modulation system	FMCW
Power source	12-15 VDC
Power dissipation	25 W max
Frequency range	61.0-61.5 GHz
Occupied bandwidth	500 MHz
Transmit power	10 mW
Number of antennas	Tx : 2, Rx : 4
Range of pedestrian detection	In front of radar: 1-60 m Side to side of radar: 30 m
Operating temperature	-40 to 75°C
Size	130 × 120 × 40 (mm)
Weight	1.0 kg max. (include mounting attachment)

This paper focuses on the minimum detection distance directly beneath the radar unit as a measure of evaluating the viewing angle of the radar unit. When installing a radar unit on a pole, the distance between the pole and the nearest position in the detection area should be greater than the minimum detection distance. Consequently, in enhancing the usability of existing poles, the greatest challenge is to reduce the minimum detection distance. For example, given a vertical viewing angle of 30 degrees with an image sensor or other sensors, for a radar unit installed at an elevation of 3 m to detect 1.5 m tall pedestrians up to 60 m away, the minimum detection distance would be 3 m. To reduce this minimum detection distance, the authors built and evaluated a prototype by mounting a reflector in a radar unit.

3. Radar Unit Structure and Software

Figure 2 shows the internal structure of the radar unit. Two transmitting antennas and four receiving antennas are provided as patch antennas mounted on a substrate. Using radio wave propagation simulations, the authors determined several combinations of reflector size and reflector mounting angle which enable the radar to detect pedestrians directly beneath it while maintaining the far side of the detection area. Of these combinations, the one that allowed the reflector to be smallest was adopted to reduce the case size.

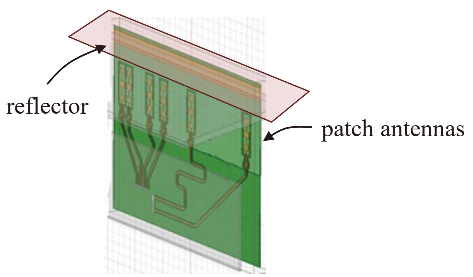

Fig. 2. Configuration of reflector and antennas

Figure 3 shows the antenna directivity simulation results. The results reveal considerable increases in gain between elevation angles of -70 degrees and -30 degrees (equivalent to between 70 degrees and 30 degrees below the front direction of the antennas).

The simulation results indicate that when the radar unit is installed at an elevation of 3 m, as shown in Fig. 4, the minimum detection distance decreases to 1 m (when the pedestrian is 1.5 m tall).

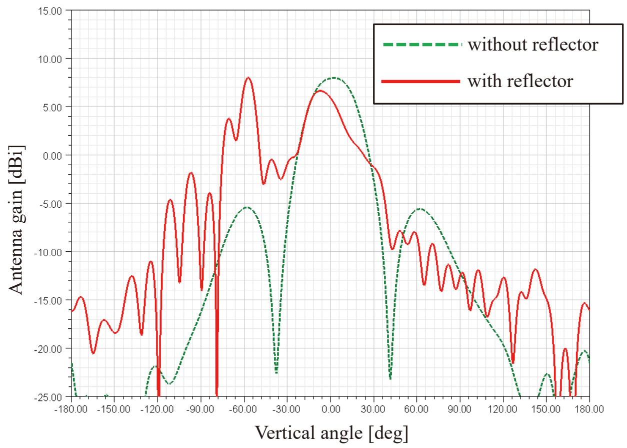

Fig. 3. Antenna directivity simulation results

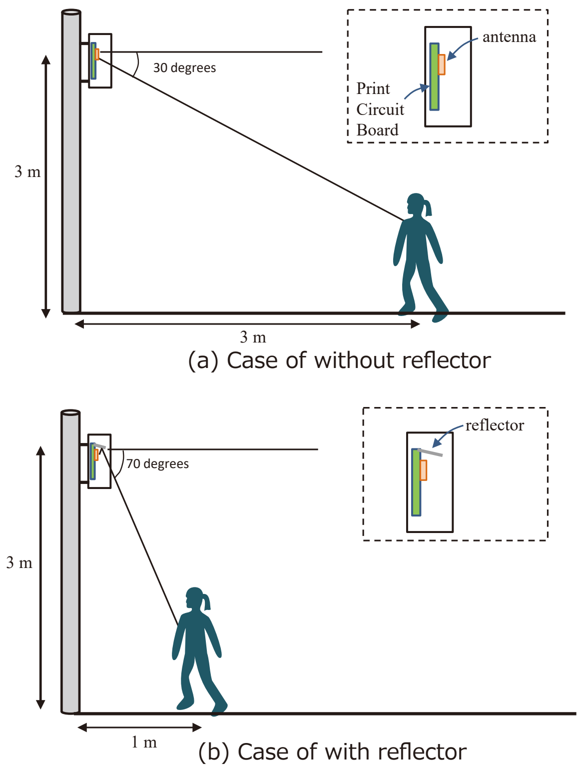

Fig. 4. Minimum detection distance reduced by reflector

The installed reflector causes the radio signal to take four paths when reaching the receiver antennas, as illustrated in Fig. 5. The round trip time of the radio signal differs by path due to different path lengths; however, the differences in path length are minimal. Accordingly, the differences in round trip time varying with path are far smaller than those arising from the complexity of the shape of a pedestrian. Incidentally, in some cases, the signals received through four paths may interfere with each other, resulting in a low signal level; however, the impact of the interference does not last long. The software developed by the authors, with the function of calculating the time-based moving average of the received signals, proved that the impact of the interference is negligible by calculating the moving average. Moreover, the reflector can be installed at such an angle as to maintain the phase difference between the signals received by the four receiving antennas. Thus, the software is able to handle the signals received through the four paths whether the reflector is present or not, so no software update is required.

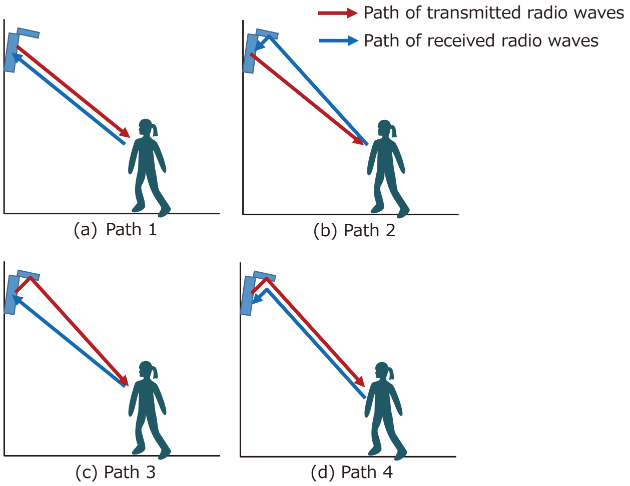

Fig. 5. Four paths taken by radio signals

4. Experimental Results

We built a prototype radar unit containing a reflector and tested it outdoors, as shown in Photo 1. The radar unit was installed on a tripod. The radar emitted a radio signal and received its reflection from pedestrians. The received signals were accumulated on a personal computer.

Figure 6 presents the experimental results. The blue dots indicate the successful detection of pedestrians in the corresponding locations. In other words, in those locations, received reflected signals had sufficient signal strength, and the software detected the presence of the pedestrian. These experimental results reveal that the addition of the reflector was effective in considerably expanding the detection area directly beneath the radar unit at all installation elevations. For example, when the radar unit, without a reflector, was installed at an elevation of 6 m, it could not detect the pedestrian closer than 4.7 m from the radar unit, whereas by adding a reflector, it became able to detect the pedestrian as close as 1.7 m away.

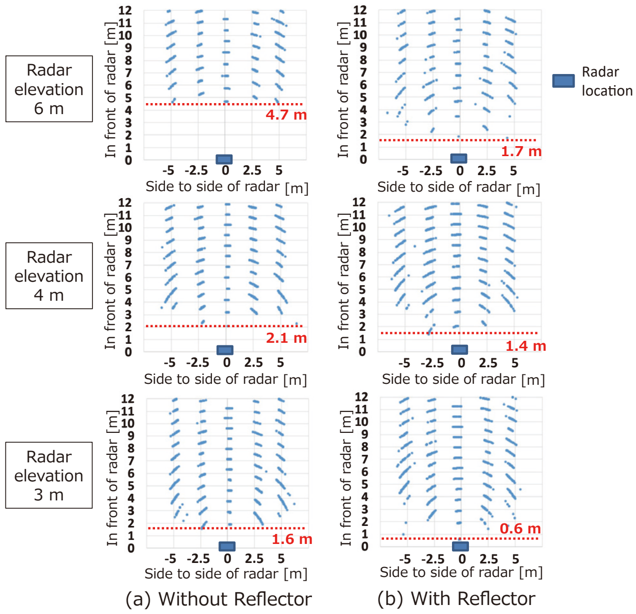

Fig. 6. Pedestrian detection results, in proximity to radar

Photo 1. Experiment in a playing field

We also took measurements from the far side of the detection area. The results revealed that the radar unit maintained its detection area on the far side despite the installation of the reflector, as shown in Table 2. These experimental results are consistent with the simulation results.

Table 2. Summary of Experimental Results for Detection Area

Installation elevation	Reflector	Detection area: Near side	Detection area: Far side
6 m	Not available	4.7 m	70 m
	Available	1.7 m	70 m
4 m	Not available	2.1 m	70 m
	Available	1.4 m	70 m
3 m	Not available	1.6 m	70 m
	Available	0.6 m	70 m

5. Effectiveness in Reducing Setback

When actually installing a radar unit on a road, it is necessary to place it away from the detection area by the minimum detection distance, as illustrated in Fig. 7. This distance is known as the setback. With a radar unit that can detect pedestrians close to the area directly beneath it, the setback can be reduced, which means that the radar unit may be installed on a pole near the detection area. In cases where a pedestrian signal is provided close to the detection area, that is, a crosswalk, a radar unit viable with a small setback may be installed on the pole provided for the pedestrian signal. Since many such intersections exist, the aforementioned radar unit can use many existing poles. As a consequence, the cost incurred for radar installation can be considerably reduced.

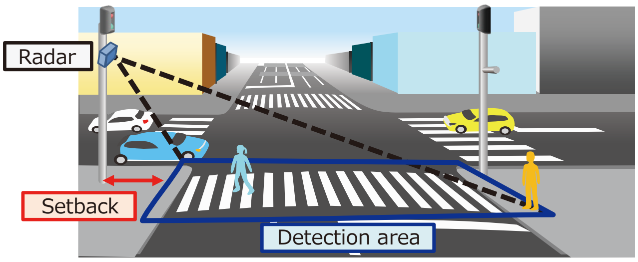

Fig. 7. Rendered image of radar installation

6. Conclusion

We have developed a radar unit that has a wide coverage angle for detection both on the far side and in the area close to directly beneath the radar, owing to a small reflector mounted in it. The radar unit will open a broad possibility for existing poles, such as those for traffic signals, being used to install radar. It has been verified that the change to the radar unit does not require a software update. We anticipate that the new technique will be utilized to accelerate the widespread use of pedestrian detection radar units installed at intersections and to contribute to enhanced pedestrian safety.

Technical Terms

*1 Image sensor: A sensor that uses images taken with a digital camera to detect the presence of objects and determine the type of the object.

*2 LiDAR: An acronym for light detection and ranging; LiDAR is a sensor that casts light upon objects and measures the distance between it and the object and the shape of the object based on information acquired from the reflected light.

*3 Radar: A sensor that emits radio waves and measures the distance between it and the object, the direction in which the object is present, and the velocity of the object based on information acquired from the reflected radio waves.

Reference

(1) Atsushi Higashi, A Pedestrian Detection Method based on 24-GHz Band Radar for Driving Safety Support Systems, in ITS world congress (Singapore, 2019)

Contributors

The lead author is indicated by an asterisk (*).

Y. YAHATA*
• Assistant Manager, Information Network R&D Center

H. SHIRANAGA
• Group Manager, Systems & Electronics Division

N. HIGASHIDA
• Assistant General Manager, Systems & Electronics Division

M. KISHI
• Assistant Manager, Systems & Electronics Division

A. HIGASHI
• Assistant Manager, Systems & Electronics Division

H. HAWAKA
• R&D Planning & Administration Division