Detection of Position of Trackside Workers Using 90 GHz Band Millimeter-wave Radar

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In Japan, automatic train operation has been introduced on a restricted number of lines, such as those with no level crossings. More recently there have been plans to expand the introduction of automatic train operation to conventional lines which have level crossings, which increases the importance of having methods for automatically detecting humans and obstacles on railway lines. This paper introduces a test system using 90 GHz band millimeter-wave radar and reports the results of tests conducted to confirm its performance specifically for detecting the position of humans on railway tracks. The paper also presents future plans for building a comprehensive railway track monitoring system using 90 GHz band millimeter-wave radar.

Keywords: 90 GHz band, millimeter-wave, radar, detection of humans, railway track

1. Introduction

The safety of train operation is achieved by means of signalling systems, which secure the route of a train to prevent collisions with other trains, or derailments, and provide various functions and mechanisms to ensure the safety of platforms and railway tracks. Currently in Japan, it is train drivers who watch out for and detect people and obstacles on railway tracks. If a driver sees someone or an obstacle on the tracks, the driver will attempt to stop the train or decelerate for safety. Recent years however, have seen other methods being introduced to detect humans or obstacles on the tracks, using, for example, cameras, lasers, infrared rays, tension on wires, pressure mats to help drivers in this task, and alleviate their burden [1]. However, each of these methods have limitations in terms of what they can detect and across what area, which shows that it is difficult to detect all human presence and obstacles on railway tracks using just one method. Yet, given automatic railway operation is already being developed, it is essential to establish a method for automatically detecting humans and obstacles on tracks rather than relying on driver vision.

Radars are used in various fields as one method for detecting obstacles in a given monitored area. A radar detects the presence and the distance of a target object based on the time and intensity of radio wave reflected by the objects, which is transmitted from the radar equipment. Currently, the Railway Technical Research Institute is developing a track monitoring system using 90 GHz band millimeter-wave radar [2], which is currently little used for other applications and offers a wide frequency band [3], and radio over fiber technology. This system detects humans and obstacles on the railway track to a high degree of accuracy. Until now, it has been confirmed that a person entering a railway track and non-metallic concrete pieces placed on the rails can be detected about 200 meters away [4].

Furthermore, by using the ability of millimeter-wave band radar that can detect position with high accuracy, it is expected that it is possible to detect the position of workers in the railway track. And it is also expected to be used for systems that transmit necessary information only to workers in the specific railway track.

This paper describes the outline and results of field tests that were conducted on a number of railway lines, where it was assumed there were many workers. Then having confirmed the feasibility of the system for detecting the position of workers using the 90 GHz band millimeter-wave radar, the paper then outlines the future direction of further research.

2. 90 GHz band millimeter-wave radar

2.1 90 GHz band millimeter-wave

Radio waves with a frequency of 30 GHz to 300 GHz are called millimeter waves because their wavelength is 1 mm to 10 mm. One characteristic of millimeter-waves is their strong straightness in radio wave propagation. This characteristic is suitable for use in a system, where radio waves should propagate across long distances along the railway tracks. Since the 90 GHz band millimeter-wave has less attenuation in the atmosphere than millimeter-waves in other frequency bands [5], it is considered that the 90 GHz band millimeter-wave can cover a wider service area with the same transmission power. Currently, although some frequency ranges in the 90 GHz band are used for radio astronomy, the rest of them are not used for other purposes. When transmitting radio waves parallel
to the ground, such as in railway applications, there is little concern about interference with other wireless systems using the same frequency band so it is possible to build a system that uses a wide frequency band. On the other hand, when using the 90 GHz band, it is necessary to consider the effects of rainfall and snowfall. So, RTRI conducted a verification test to confirm the attenuation characteristics of 90 GHz band millimeter-waves caused by rainfall, and snow on the antenna surface. It has been confirmed that the amount of attenuation due to rainfall is approximately proportional to the amount of rainfall [6], and that it was necessary to consider about 20 to 25 dB of attenuation when antennas were covered with wet snow [7].

2.2 Radar using 90 GHz band millimeter-wave

As a radar using the millimeter-wave band, the 60 GHz band, the 76 GHz band, and the 79 GHz band are used as means for detecting obstacles ahead in order to assist in preventing car collisions [3].

As one of radar methods, there is an FM-CW (Continuous Wave) method that detects a target by continuous transmission radio waves which are FM-modulated. In this FM-CW method, the distance resolution \( X \) [m] can be expressed by (1).

\[
X = \frac{c}{2 \cdot \Delta f}
\]

where \( \Delta f \) [Hz] is frequency bandwidth of the radar equipment and \( c \) [m / s] is speed of light.

As shown in (1), this method can detect an object with a higher distance resolution as the usable frequency bandwidth is wider. For example, when the frequency bandwidth is 1 GHz, the distance resolution is about 0.15 m. When the frequency bandwidth is 8 GHz, the distance resolution is about 0.02 m. As shown in the previous section, there is a possibility that the millimeter-wave in the 90 GHz band can use a wide frequency band. The use of this frequency band for FM-CW radar enables highly accurate detection of targets.

3. Results of experiments

This study investigated the detection of the position of track workers, assuming that workers are working on railway tracks. Figure 1 shows an overview of the installation of the radar equipment in consideration of worker position detection during track work.

3.1 Radiation method of radio wave

There are two methods for radiating radio waves to detect humans and obstacles in the monitoring area using radar. One method is to fix the antenna of the radar equipment and monitor only a fixed direction. And another method is to rotate the antenna horizontally for monitoring, like in a plane. For example, if the purpose is only to detect if someone has passed a railway site boundary, the former method can be used: but this will not provide information to know whether or not the person who passed through the area being monitored is still there. To detect the presence of an individual in such a case and establish whether or not they are still on the tracks, the latter method must be used.

The purpose of this study is to detect the location of workers where there are multiple railway tracks, regardless of their working posture, and to identify the exact railway track where they are located. For this reason, the study is conducted on the assumption that the antenna is rotated in the horizontal direction and a wide area is monitored. Figure 2 shows the outline of the detection method used in this study.

If the antenna height is too high, the radiated radio wave will not hit any human. If the height of the antenna is too low, the radiated radio waves will be blocked by rails or existing facilities installed on the ground. Therefore, the height of the antenna was set in consideration of the height of a human being.

3.2 Separation of existing equipment and target to be detected

There are many existing facilities on railway tracks other than the targets to be detected. When a radar equipment monitors something in railway track, existing facilities are also detected as objects, and it is not possible to distinguish them from a human presence or obstacle that needs to be detected. As described in section 3.1, the radar used in this study has an antenna rotated in the horizontal direction. For this reason, the radar periodically detects objects. For a certain point, the detection result at the point in the immediately preceding cycle is compared with the latest detection result. Then, if an object that was
not previously detected is picked up, it is considered that a target for detection has appeared at that point. In addition, workers need to be recognized not only at one point but also at different places on the track depending on their movement. Therefore, when a worker walks on the track (about 1 to 2 m/s), the goal of this system is to detect the worker and to follow their movements.

4. Verification of position detection performance by radar

Tests are performed to verify the performance of worker location detection using the 90 GHz band millimeter-wave radar equipment where multiple railway tracks are present [8].

4.1 Implementation environment of detection test

The detection tests are carried out in a railway tracks with multiple tracks and electricity poles. Figure 3 shows the picture of the location of the detection test.

4.2 Configuration of 90 GHz band millimeter-wave radar equipment

This test is performed using the 90 GHz band millimeter-wave radar equipment of the FM-CW method [1]. Figure 4 shows the configuration of the 90 GHz band millimeter-wave radar equipment, and Table 1 shows the specifications of the 90 GHz band millimeter-wave radar equipment.

The radar equipment used in this test employs an offset parabolic antenna that collects radio waves radiated upward from the focal point and transmits radio waves tilted at 90 deg. Therefore, the beam is rotated in the horizontal direction by rotating the antenna. As shown in Table 1, the half-value angle of the antenna is 1 deg., and the relationship of the distance from the radar equipment and the width of the monitoring area is as shown in Fig. 5 and Fig. 6. Furthermore, since the frequency bandwidth is 1 GHz, the theoretical distance resolution that does not consider the influence of ambient noise is about 0.15 m from (1) shown in section 2.2. The radar equipment used in this test is designed to output detection results with a distance resolution of about 0.4 m, taking into account FFT processing of the inspection results.

4.3 Implementation conditions for the detection test

In the detection test, as an example of a scene in which humans are present on the railway tracks, it was assumed that a worker worked in the railway track. The test was performed under the following two conditions.

| Table 1 Specifications of the 90 GHz band millimeter-wave radar equipment |
|-----------------------------------------------|
| Transmission power | 50 mW (+17 dBm) |
| Center Frequency | 96 GHz |
| Frequency bandwidth | 1 GHz |
| Antenna gain | 41 dBi |
| Antenna half-value angle | 1 deg. |
| Antenna rotation period | 4 sec. |
4.3.1 Verification of angular resolution (Condition 1)

When working in railway tracks, it is assumed that workers may work close to each other. The detection performance of the radar equipment in the angular direction affects the ability to separately detect each of workers nearby and to detect their positions. Therefore, under the condition that there is multiple human presence on the same track at intervals that can be detected in theory, a test was conducted to verify whether each human can be detected separately. Specifically, the test was conducted with 5 humans lined up horizontally at about 0.2 m intervals along the railway track, at about 8 m away from the 90 GHz band millimeter-wave radar equipment. The antenna height was set at 1.5 m above the rail level, so that the radio wave transmitted horizontally from the radar equipment would hit the upper body of a human. Figure 7 shows the placement during the test, and Fig. 8 shows the test situation.

4.3.2 Verification of distance resolution (Condition 2)

When working in places where multiple railway tracks are close to or parallel to each other, workers may be working on separate tracks. The detection performance in the angular direction and the detection performance in the distance direction of the radar equipment affect the ability to detect the detailed positions of workers distributed across the tracks. Therefore, a test was conducted to verify the detection performance of workers when multiple workers are spread across multiple railway tracks.

Specifically, the location had 4 railway tracks in parallel, 4 individuals (person A, B, C, D) were arranged to stand in a straight line at a certain angle. Person A was positioned on a railway track at a distance of 2.3 m from the radar equipment to the center of the railway track, person B stood on a railway track at a distance of 4.4 m, person C stood on a railway track at a distance of 9.2 m, and person D stood on a railway track at a distance of 14.5 m. The antenna height was then set to 1.5 m under condition 1, but to confirm the detection performance when the antenna height is set lower, the antenna height was set to 1.25 m above rail level. Figure 9 shows the positions of the individuals during the test, and Fig. 10 shows the test situation.

4.4 Detection test results and consideration

As described in section 3.2, in order to determine whether or not the 90 GHz band millimeter-wave radar can detect a human, the detection results with and without human presence were compared.

4.4.1 Results of angular resolution verification test (Condition 1)

Figure 11 shows the detection results in a situation where 5 humans were lined up at approximately 0.2 m intervals on the railway track. The results show that 5 objects were detected at a position about 8 m from the radar equipment, confirming that the 5 individuals on the track were detected separately along with their positions.

The width of the monitoring area using the radar equipment was determined by the half-value angle of the antenna and the distance from the radar equipment. The half-value angle of the antenna of the radar equipment used in the detection test was 1 deg. As shown in Fig. 6, the theoretical monitoring area of the radar equipment
at a distance of 8 m from the radar equipment was about 0.14 m. It is considered that the distance between humans (0.2 m) was recognized as space (a place where there is no detection target) and the 5 individuals could theoretically be separated and detected based on the equipment specifications.

4.4.2 Results of distance resolution verification test (Condition 2)

The test was conducted in a situation where there was one individual on each of the 4 railway tracks with different distances from the radar equipment to the center of the railway track, and as a result, it was possible to detect the position of each by separating them. On the other hand, as shown in Fig. 12, when 4 individuals were lined up at a certain angle from the radar equipment, person A, person C, and person D could also be detected, but person B was not. This is because person B was in the shadow of person A and the radio wave transmitted from the radar equipment was blocked. This cannot be avoided on the radar principle. In order to avoid this, it is necessary to cover the detection area with multiple radar equipment as shown in Fig. 1. Also, for person C and person D, who were located along the line extending from person A, in the same way as with person B, they were detected at positions with different angles of 2 to 3 degrees from the radar equipment. As shown in Fig. 6, the monitoring width at an angle of 1 degree was about 0.16 m at 9.2 m and about 0.25 m at 14.5 m. It is estimated that person C and person D were detected because person C was about 0.4 m away and person D was about 0.6 m away from the straight line connecting the radar equipment and person A.

As shown in Fig. 12, person A was detected at a 2.4 m linear distance, person C was detected at a 9.3 m linear distance, and person D was detected at a 14.9 m linear distance from the radar equipment. Compared to the test conditions in Fig. 9, the difference in detection distance of person D was about 0.5 m. However, radar equipment acquires data at intervals of about 0.4 m. In consideration of this data acquisition interval, the difference in the distance direction was approximately one data difference.

5. Subject for the realization of a railway track monitoring system

The test results show the prospect that multiple 90 GHz band millimeter-wave radars can be used to separate and detect multiple individuals in an environment with multiple railway tracks. On the other hand, it also clarified the problems to be considered for the system to be put
into practical use. This chapter describes what needs to be considered in future to realize a railway track monitoring system using 90 GHz band millimeter-wave radar.

5.1 Detection time and detection cycle

When radar equipment is used in a railway environment, existing equipment is also detected. The results from the detection tests in Chapter 4 determined human presence through comparison with results where there was no human presence. When using radar equipment as a monitoring system on railway tracks, freshly detected objects are extracted as targets for detection based on comparisons with the previous cycle. Then, movement of the target is detected when the presence of the target decreases in comparison with the previous cycle.

When using this method to detect workers in the railway track, the radar detection cycle must be set up to take movement into account. In addition, it is necessary to consider the processing time for extracting newly detected points in successive cycles. In future, it will be necessary to examine the detection cycles of the radar equipment and the processing time to extraction of an obstacle producing a detection result. Since the walking speed of humans is about 1 to 2 m/s, it is estimated that it is possible to detect and follow the movement of humans if the detection cycle is set to 1 s.

5.2 Composition and Comparison of Scanning Results

The verification tests of position detection described in chapter 4 were conducted with one piece of radar equipment. As shown in Fig.1, the in-track monitoring system should consider the positions of radars to overlap the monitoring area, install multiple radar equipment along track, to reduce the risk of missing detection. It is expected that the accuracy and reliability of position detection can be improved by synthesizing the inspection results from multiple radar devices.

5.3 Antenna of radar equipment

The radar equipment used in the verification test made the beam mechanically rotate horizontally. However, the mechanically rotating part is a source of new problems such as maintenance of the movable part. It is suggested that one solution to this problem would be to use an antenna that controls the directivity by electronic scanning, which has been used in practice in automobile radars.

6. Conclusions

This paper describes the outline of field tests conducted to detect the positions of multiple workers working on multiple tracks using a 90 GHz band millimeter-wave radar, and presents the results of these tests.

In the field test, it was confirmed that the 90 GHz millimeter-wave radar equipment was able to detect the presence of multiple individuals standing side by side at intervals of about 0.2 m or the position of multiple individuals on multiple tracks. These results confirmed the principle of being able to detect the position of human presence using 90 GHz band millimeter-wave radar. This paper also revealed a number of remaining problems, such as the processing time until detection, the length of the detection cycle, the method for synthesizing and comparing results, and the processing time of inspection results from multiple radar devices.

In the future, we will work on realizing a railway track monitoring system and verifying radar detection accuracy. In addition, a study will be carried out with a view to realizing a monitoring system which combines a forward monitoring method using images from on-board cameras [9] with the ground-based 90 GHz band millimeter-wave radar.

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