Radar cross section measurement of road debris in 79 GHz-band

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Abstract: Many automotive accidents are reported every year, some of which are attributed to fallen debris on road. For road debris detection, it would be difficult to find with imaging sensor while driving, especially in case of bad weather conditions such as rain and fog. The use of 79 GHz-band ultra-wideband automotive radar is hence expected for road debris detection because of the high range-resolution and good weather resistance. The detection performance basically depends on the radar cross section (RCS) of road debris. For example, the maximum detection range is proportional to one quarter of the RCS. However, there is no report regarding to the RCS as far as the authors know. This paper presents the RCS characteristics of 11 typical road debris for 79 GHz-band radar available in automotive radar which is also compared with 24 GHz-band.

Keywords: automotive radar, millimeter-wave, RCS, road debris

Classification: Sensing

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1 Introduction

Many automotive accidents are reported every year, some of which are attributed to road debris, therefore the demand for road debris detection has increased [1]. In bad weather conditions such as rain and fog, it will be not easy to detect small road debris several dozens of meters ahead of the vehicle even if using high-sensitivity image sensor. It may also be difficult to use existing 24 GHz-band (24-24.25 GHz) and 76 GHz-band (76-77 GHz) band automotive radar because the radar echo from road debris would be considered to be embedded in road clutter within the range-resolution cell [2]. It is noted that road debris is generally detected by comparing the radar cross section (RCS) value with a threshold level defined in terms of a prescribed receiver sensitivity. Although the debris detection is a challenging task, it may be feasible with 79 GHz-band automotive radar. This is because a huge bandwidth of up to 4 GHz has become available for the new 79 GHz automotive radar band. The radar system actually provides higher range-resolution as well as weather resistance, thereby resulting in better clutter suppression performance relative to the 24 GHz and 76 GHz-band radar [3, 4, 5]. For road debris detection, therefore, it is important to know the RCS characteristics. However, it is not easy to estimate the RCS of complex shaped debris since the RCS is influenced by many physical parameters such as size, shape, material and so on. There is no report regarding to the RCS of road debris with 79 GHz-band radar as far as the authors know [6]. This paper presents the RCS characteristics of 11 typical road debris with 79 GHz-band automotive radar, which is also compared with 24 GHz-band radar. Section 2 shows the measurement procedure and Section 3 presents the measured RCS. Finally, Section 4 concludes this work.

2 RCS measurements

79 GHz-band automotive radar system would offer precise debris detection capability because of the bandwidth up to 4 GHz available (corresponding to approximately 4 cm range-resolution). Radar cross section (RCS, denoted by $\sigma$) is generally represented by radar equation [2]:

$$\sigma = \frac{P_r (4\pi)^2 R^4}{P_t G^2 \lambda^2}$$  \hspace{1cm} (1)

where $P_t$ is transmitted power, $P_r$ received power, $R$ range, $G$ transmit and receive antenna gain, and $\lambda$ the wavelength.

Maximum detectable range is proportional to the fourth root of $\sigma$ and so the RCS information of debris is indispensable in order to develop debris detection radar system. In this study, the measurements were carried out with use of a vector network analyzer (VNA) by sweeping the frequency from 79 to 80 GHz in an anechoic chamber where the floor of the chamber was also covered with radio absorbers. Please note that RCS measurements in 24 GHz-band were also conducted.
as a reference [6]. Transmit and receive antennas were connected to the ports 1 and 2 of the VNA, respectively, and transmission coefficient \( S_{21} \) data was measured. The measurement system with RF cables and antennas was calibrated for the 1 GHz bandwidth from 78 to 79 GHz in advance and then characterized using a standard trihedral corner reflector [7]. Each debris was placed on the center of the rotatable table at an average distance of 5 meters away from the antennas and then was rotated 360° azimuthally in an interval of 0.1°. The height of the antennas was almost the same as that of each debris because the vehicular radar are supposed to be mounted behind the front bumpers.

3 RCS of road debris

The RCS of a debris depends on the size relative to the radar wavelength, geometrical shape, incident angle (also known as aspect angles), surface roughness, and materials. Polar plot of RCS data in decibels is often used to visualize the RCS behavior [6]. Fig. 1 shows the polar plots of 11 road debris at vertical-vertical (V-V) and horizontal-horizontal (H-H) polarizations. Please note that the red arrows (front direction) of each illustration correspond to the 0° and 180° of polar plots, respectively. For simple shaped debris with smooth surface (e.g., plastic container box and aluminum can), there is no significant difference for RCS behaviors in the 79 and 24 GHz-band. However, that of complex surface shaped debris (e.g., automotive tire, tire burst piece and plastic hammer) depends on frequency and polarization. For example, the automotive tire may look like rotationally symmetric, but the RCS behaviors differ by the frequency bands and polarizations because of the complex tread groove patterns (radar wavelength will be comparable to the size of tread groove width and depth). Although the RCS in 79 GHz-band is smaller relative to the 24 GHz-band for vertical polarization, that is found to be larger for horizontal polarization. The tire burst is also similar.

Table I summarizes the RCS variation for aspect angle in the 79 GHz-band. It is noted that the variation can be accounted for the effect due to the radar transmitted signal reflecting off various parts of the debris and the resultant signal interfering with each other. The variation, which is 20~40 dBsm for most of the debris, is generally small for simple shaped object and is large for complex surface shaped object relative to the wavelength. Smaller variation seen for the tire is caused by the asymmetric tread groove patterns. It may be important to investigate angular dependence of each RCS for the debris detection. The RCS distribution would be approximated by some probability distributions [2, 8], but it can’t be discussed here due to space limitations. Table I shows the statistical parameters instead. It is noted that the mean and median values are very small and roughly agree. It is seen from Table I that each complex shaped debris exhibits wide RCS variation regardless of the physical 3-dimensional shape and there would be some correlation between the physical size and mean RCS. It may be hence interesting to estimate the mean RCS from the mean projected area which is defined as the mean of maximum and minimum projected areas of debris. This is because the mean projected area can be more easily measured as compared with the total surface area and irradiation area. Fig. 2 depicts the measured mean RCS of 11 road debris versus the mean projected area.
Fig. 1. RCS polar plot of 11 debris for V-V and H-H polarization. The left is the illustration of each debris (red arrow direction represents line-of-sight from radar), the middle and right are for V-V and H-H polarization respectively.
(f) Timber block

(g) Metal shovel

(h) PET bottle

(i) Aluminum can

(j) Plastic hammer

(k) Metal screw

Fig. 1. Continued
Table I. Variation in RCS for 11 debris in 79 GHz-band

| Object                | Radar cross section in dBsm | mean | median |
|-----------------------|----------------------------|------|--------|
| Automotive tire       | -7.5                       | -5.35|        |
| Plastic container box | 2.6                        | 2.12 |        |
| 18-liter oil can      | -0.12                      | 0.44 |        |
| Tire burst piece      | -9.0                       | -9.87|        |
| Cardboard (small)     | -5.89                      | -5.78|        |
| Timber block          | -14.9                      | -15.9|        |
| Metal shovel          | -17.9                      | -17.9|        |
| PET bottle            | -14.2                      | -14.9|        |
| Aluminum can          | -17.4                      | -17.8|        |
| Plastic hammer        | -18.8                      | -19.6|        |

Fig. 2. Scattered mean RCS plots as mean project area in 79 GHz-band. The horizontal axis is defined as the mean of max and min projected areas of debris.

area where the regression line applied to the measured plots is also overlaid. The mean RCS is likely to be in rough proportion with the mean projected area and there is no significant difference for both polarizations.

4 Conclusions

In this paper, we conducted RCS measurement of road debris in 79 GHz-band because the knowledge of RCS measure is of great importance to prevent the traffic accident caused by road debris. The main contributions are as follows:

- RCS behaviors of simple shaped debris shows similar regardless of the polarizations and frequency-bands. However, that of complex shaped debris such as automotive tire show polarization and frequency-band dependencies.
- Variation in 79 GHz-band RCS is approximately 30 dBsm or more for a considerable number of road debris.
- The mean RCS is found to be in rough proportion with the mean projected area of object and the V-V polarized RCS is a little larger as compared with the H-H.

Finally, our future research will be directed towards the empirical study on road debris detection with 79 GHz high range-resolution radar.

Our efforts will be directed toward the empirical study of road debris detection.