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Research paper

RCS Analysis of Target and Clutter in FMCW Radar

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Abstract

The radar cross section (RCS) of a target is used to identify it and to glean its characteristics, by measuring the size of reflected radar signal. In this study, we used a 77 GHz triangular frequency modulated continuous wave (FMCW) array radar to detect pedestrians, automobiles, and clutter. It is possible to classify target and clutter by analyzing the characteristic of the measured RCS. In this study, suitable target RCS characteristics (mean, variance and probability distribution) were analyzed based on measured data.

Keywords: *FMCW radar, RCS, target classification*

1. Introduction

The automobile industry has developed various types of collision avoidance systems (CAS) devices including laser sensors, rear and front detection sensor utilizing ultrasonic sensors, and radar sensors. These sensors considerably increase the safety of both drivers and pedestrians in traffic situations. Among these, radar is target-detection system to determine the range, angle and velocity of objects by using radio waves. Because of its safety and convenience, many of drivers pay attention to automotive radar. The most important aspect of automotive radar is to identify objects [1]. If automotive radar system can detect and classify other automobiles, pedestrians, and obstacles in advance, drivers can avoid facing dangerous situations.

Several methods of target classification via the radar system have been studied [1-5]. FMCW radar is able to acquire an object location information in real time, which makes it possible to precisely detect moving objects at high speed. Recently, much research has been carried on the application of FMCW radar to CAS, because its resolution is superior to that of pulse radar and in particular, it shows high resolution at short range [3-6].

The target RCS refers to the effective area defined by the ratio of the backscattered power to the incident power density. The larger the RCS is, the higher is the amount of power scattered to the rear side of the radar [6]. The RCS characteristics are determined by the reflective properties of the target, and the material and shape of the target are important factors affecting the reflective properties [7]. In this study, we used 77 GHz triangular FMCW radar to classify targets (pedestrians, automobiles, and so on) and clutter by their RCS characteristics.
This paper is organized as follows. In Section 2, the conventional detection method is introduced. Then, the RCS measurement of FMCW radar is proposed in Section 3. The RCS measurement results and the statistical modeling based on the RCS are presented in Section 4. Finally, we conclude this paper in Section 5.

2. Conventional Detection Method

2.1 RCS

Generally, the RCS is expressed by the following equation:

$$\sigma = \frac{(4\pi)^3 R^4}{G^2\lambda_0^2}\left(\frac{P_r}{P_t}\right) \tag{1}$$

where R is distance, G is the antenna gain, λ_0 is the wavelength P_r is the received power, and P_t is the transmitted power. Therefore, the RCS can be expressed simply as the ratio between the received power and the transmitted power.

In the literature on the probabilistic model of RCS, there is a probabilistic reflection model proposed by Swerling. However, most studies including the model proposed by Swerling, have been performed with pulse radar, and in order to analyze the RCS characteristics of an FMCW radar signal, it is necessary to conduct an experiment [8].

2.2 FMCW Radar

In general, pulse radar can be computed using the signal strength in the time domain. FMCW radar, however, utilizes a signal with a beat frequency of sinusoidal form, which is generated by the difference between the chirp frequencies linearly increasing and decreasing in the frequency domain. It is difficult to obtain the RCS by operations in the time domain. The transmitted signal, received signal, and beat frequency signal of the target generated by FMCW radar are given by:

$$s(t) = A\cos\left(2\pi\left(f_c - \frac{BW}{2} + \frac{BW\cdot t}{2\Delta t}\right)t\right) \tag{2}$$

$$r(t) = B\cos\left(2\pi\left(f_c - \frac{BW}{2} + f_d + \frac{BW\cdot(t-t_d)}{2\Delta t}\right)(t-t_d)\right) \quad (3)$$

$$b(t) = s(t)r(t) = AB\cos\left(2\pi\left(\frac{BW\cdot t_d}{2\Delta t} - f_d\right)t + \emptyset\right) \quad (4)$$

where A and B are the amplitudes of the transmitted and received signals, respectively, f_c is the carrier frequency, f_d is the Doppler frequency, t_d is the delay due to the distance, and $\frac{1}{\Delta t}$ is the chirp rate, which is the ratio of the bandwidth BW.

3. RCS Measurement from FMCW Radar

As you can see in equation (4), the magnitude of the beat frequency signal is expressed by the product of the transmitted and received signals. It is possible to extract the RCS component using the magnitude of the beat frequency. In other words, based on Parseval's theorem, the magnitude of beat frequency signal can be used as an index of the RCS.

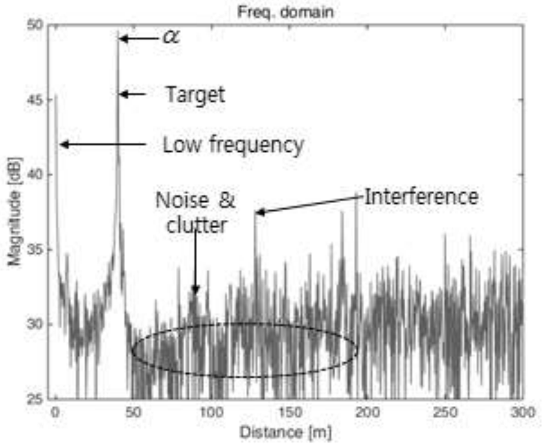


Figure 1: RCS configuration: received signal in the frequency domain.

Figure 1 shows a plot of the RCS generated in the frequency domain of the received signal. As you can see in the figure, there is a beat frequency component of the target, and by using the magnitude of beat frequency, it is possible to analyze the RCS characteristics.

$$\text{RCS}[dB] = 10log_{10}(\alpha) = 10log_{10}\left(\frac{AB}{2}\right) \quad (5)$$

Using the measurement results, we analyzed the RCS characteristics of various targets and clutter in terms of the definition in equation (5).

4. Properties Analysis of RCS Using Measured Data

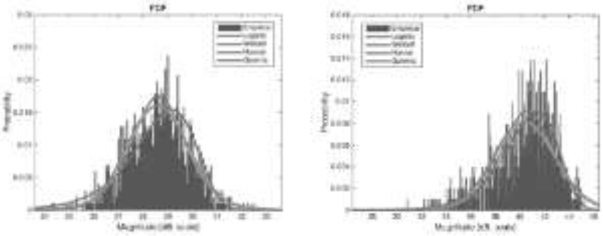
Scenarios: In this study, the RCS of a pedestrian, an automobile, and clutter were measured by using a 77 GHz triangular FMCW radar in order to detect optimized RCS from measurements. In this regard, experiment was conducted in two cases, at distances from the radar to the target of 20 and 40 m.

(a) (b) (c)

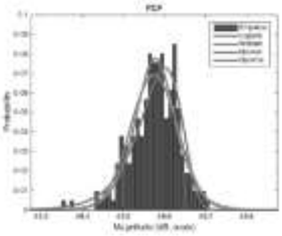
Figure 2: Distance 20m (a) clutter, (b) pedestrian, (c) automobile

(a) (b) (c)

Figure 3: Distance 40m (a) clutter, (b) pedestrian, (c) automobile

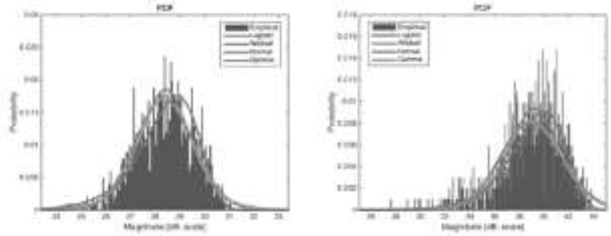


Clutter(19.89m) Pedestrian(18.43m)

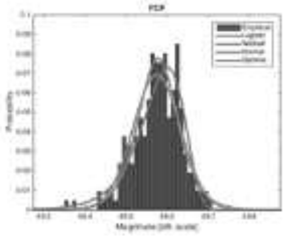


Automobile(17.84m)

Figure 4: Probability distribution for the measured RCS of targets and clutter(near 20m)



Clutter(40.07m) Pedestrian(39.49m)



Automobile(39.20m)

Figure 5: Probability distribution for the measured RCS of targets and clutter(near 40m)

Table 1: Properties of target RCS and clutter

Target	Clutter		Pedestrian		Automobile	
Distance (m)	19.89	40.07	18.43	39.49	17.84	39.2

Total average	Mean (dB)	28.62	28.39	40.4	38.92	48.7	49.59
	Variance (dB)	1.56	1.28	6.36	6.29	0.009	0.002
Distribution	Single antenna	Weibull		Weibull		Normal	
	Average of array antennas	Normal					

As shown in Fig. 4, Fig. 5, and Table 1, we were able to confirm mean, variance, and probability distribution of the RCS of target and clutter. The mean RCS was 10 dB higher for the pedestrian than the clutter, and that of the automobile was 10 dB higher than the pedestrian. In other words, it was shown that RCS mean of ground clutter was lower than that of the pedestrian and automobile, by more than 10 dB. As a result, it is possible to identify the difference in the mean RCS values among different targets and/or clutter.

The RCS variance was also different. In the case of the automobile, the RCS variance was low, owing to the highly reflective material and planar characteristics of the automobile. However, the clothes of the pedestrian were made of low-reflectivity materials and the body shape was cylindrical, which caused a higher RCS variance than observed for the automobile. As for the clutter, the RCS variance was measured as close to 1 dB, which was higher than for the automobile and lower than for the pedestrian. The RCS variance can also be used as an index to classify clutter, pedestrians, and automobiles.

The probability distributions were examined in two ways: The probability distribution of the received signal by a single antenna within the array and the probability distribution of the average antenna signal value over the entire array were respectively confirmed. The results showed that probability distribution of the automobile was a normal distribution and that of the pedestrian was a Weibull distribution. In the case of the pedestrian and automobile, probability distribution of each antenna's signal and that of average value of array antenna's signals were identical. On the contrary, in case of clutter, probability distribution from each antenna's signal was a Weibull distribution, and the probability distribution of the average value of the array antenna signal was not the a normal distribution. When the target was a pedestrian or automobile, the received signals of each antenna showed characteristics related to the target, but in case of a reflected signal from a random surface such as ground clutter, the received signals of each antenna had independent characteristics. Therefore, when using the average value of the array antenna signal, the probability distribution was a normal distribution, such as white noise.

5. Conclusion

In this study, the RCS characteristics of a pedestrian, an automobile, and ground clutter were measured with a 77 GHz triangular FMCW array radar system. Because conventional RCS research is difficult to apply to this system, we have analyzed the RCS characteristics using a new method. We proved that it was possible to classify targets and distinguish them from clutter by analyzing their characteristics based on mean, variance, and probability distribution of the measured RCS. The magnitudes of the mean RCS increased in the order of automobile, pedestrian, and clutter, whereas the magnitudes of RCS variance increased in the order of pedestrian, clutter, and automobile. Additionally, it is appropriate to classify the probability distribution models by using the average value of the received signals for all array antennas. When calculating the average of the signals received by antennas and confirming the probability distributions, the pedestrian shows a Weibull distribution, the automobile shows a normal distribution, and the clutter shows a normal distribution. Therefore, in order to classify the target and clutter, it is required to consider the mean, variance, and probability distribution of the adequately measured RCS for each object..

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