Fundamental Study on Synthetic Aperture Imaging by using Millimeter Wave Automotive Radar

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Abstract

We challenged to realize a high accuracy of millimeter wave automotive radar by means of a synthetic aperture radar (hereafter, referred to as SAR) with virtually synthesized large-aperture antenna, which was a method to obtain the high accuracy. Assuming millimeter wave automotive radar, we performed simulations with three kinds of method, and compared those results. Also we processed actual measurement data for several targets in the same manner of simulation, and compared those results. Under present circumstances, we consider Backprojection method effective, because it is highly accurate and shorter in calculation time than current method. However, it doesn't reach real time processing required for millimeter wave automotive radar, then it is difficult to apply to millimeter wave automotive radar right now. If we can solve this problem with data compression technology etc. this method is considered to be promising one of realizing a high accuracy of millimeter wave radar. In this paper, we perform a basic experiment of millimeter wave automotive radar by means of SAR, and introduce the result.

1. Introduction

Recently, millimeter wave automotive radar has been attracting attention as an advanced driving assistance system to prevent traffic accident. Millimeter wave automotive radar is already in practical use as an on-vehicle application due to capability of detecting the relative speed between vehicles by measuring Doppler frequency. In contrast to other driving assistance system such as an optical camera, an infrared radar and others, millimeter wave automotive radar is expected for higher performance to prevent traffic accident because of high resistance to environment for rain, fog and snow etc. and having long detecting distance. Millimeter wave automotive radar is mainly used to detect front vehicles and surrounding obstacles. However, detecting of targets not only forward but also front-lateral is needed to prevent "bumping into each other as they enter the intersection" and "traffic accident due to run-out of pedestrians". In order to detect targets with great accuracy, high accuracy of the sensor system is necessary to be equipped, such as a radar with large-aperture antenna which can sharpen antenna beam, but mounting space for millimeter wave automotive radar in vehicle is limited. There are some methods to satisfy the requirement to realize highly accurate sensor system in limited space such as electronic scan method and virtual array method using statistical processing etc. Among them, the simplest hardware structure is SAR (Synthetic Aperture Radar) imaging.

SAR imaging is a method to realize high accuracy by synthesizing virtual large-aperture antenna by the result of detecting targets by moving radar as shown in **Fig. 1**. It is important method when there isn't enough space for large-aperture antenna for a radar. [1]
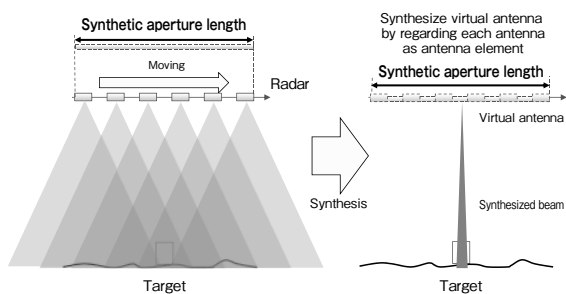
Fig. 1 Principle of SAR

Travelling direction of radar is called azimuth direction and perpendicular direction to travelling direction is called range direction in **Fig. 1**. Highly accurate detecting in the azimuth direction is possible by SAR imaging processing of the data obtained from radar. On the other hand, highly accurate detecting in the range direction cannot be realized by SAR imaging, which is made possible by applying pulse compression technology and the like on the transmitter pulse. Applying SAR imaging to millimeter wave automotive radar, travelling direction of vehicle is the azimuth direction and perpendicular direction to travelling direction is the range direction.

SAR imaging is mainly applied to surface measurement by a satellite and an aircraft, which performs highly accurate detection. If SAR imaging can be applied to millimeter wave automotive radar, it is considered that great accurate detection is possible like the surface measurement.

In this paper, we introduce the result of a basic study of millimeter wave automotive radar by means of SAR imaging.

2. Application to millimeter wave automotive radar

The aim of applying SAR imaging to millimeter wave automotive radar is mainly detecting target existing in front-lateral. **Fig. 2** shows an image figure of millimeter wave automotive radar turned to front-lateral of the vehicle.
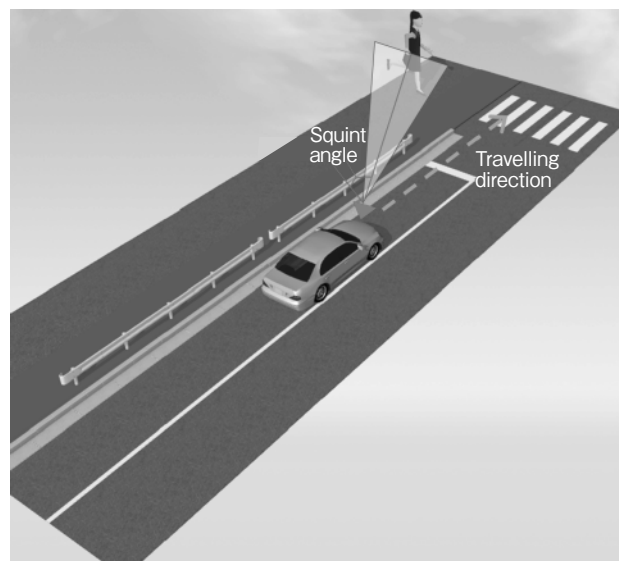

Fig. 2 Image of Millimeter Wave Automotive Radar

In actual operation, as shown in **Fig. 2**, If detection object such as a crossing pedestrian exists in front of the vehicle, synthetic aperture is synthesized in the position before the object. Synthetic aperture length is limited by distance to pedestrian according to vehicle travelling speed and acceptable observation time, and excellent imaging area is limited in the angle range centered on squint angle that refers to the direction where the radar points. Therefore, the result of imaging includes detecting error at the place away from squint angle.

In contrast to creating topographical map by SAR imaging processing of data obtained from satellite and aircraft, millimeter wave automotive radar needs imaging processing in real time.

As described above, there are following issues to apply SAR to millimeter wave automotive radar and operate it for actual use.

① Minimization of detecting error
② Imaging in real time

3. SAR imaging methods

There are BeamFormer method, Range-Doppler method, and Backprojection method as main SAR imaging methods under study now.

As for BeamFormer method, as shown in **Fig. 3**, it is a method to identify the target position

by searching the position where output power is maximum among the results scanned on all combination of both coordinates of azimuth direction and range direction in imaging range. As advantage of this method is to be able to set any imaging area and coordinate system, there is disadvantage that calculation time exponentially increases when the number of pixels for imaging increases, because of double-loop imaging. [2] To apply this method to millimeter wave automotive radar, reduction of calculation time is an issue.

Range-Doppler method is a method to identify the target position by using approximate calculation when obtained data is processed as shown in **Fig. 4**. Compared to BeamFormer method, its advantage is overwhelmingly short calculation time, but there is a disadvantage that the error becomes larger at the place near radar area and away from squint angle.

Backprojection method is a method to which BeamFormer method was improved. As shown in **Fig. 5**, this method identifies the target position by allocating the beat signal to the pixels located at the same distance away after deploying beat signal, which represents distance from target, to two-dimension plane. With this method, calculation time is shorter than one of BeamFormer method because of one-loop calculation, but it takes 8 to 9 times of calculation time compared to Range-Doppler method. [3]
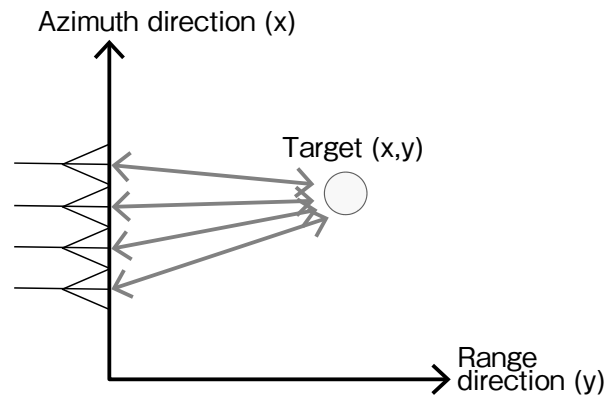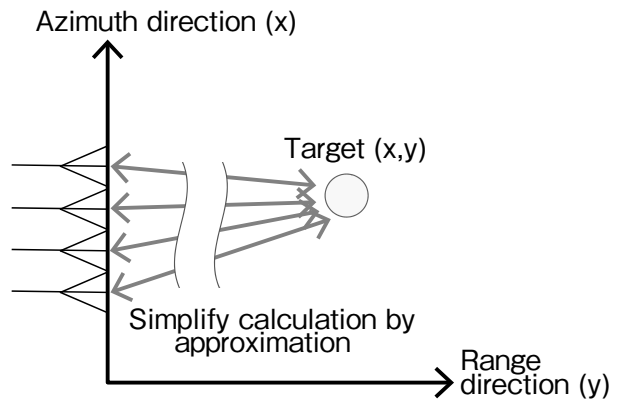

Fig. 3 Image of BeamFormer Method

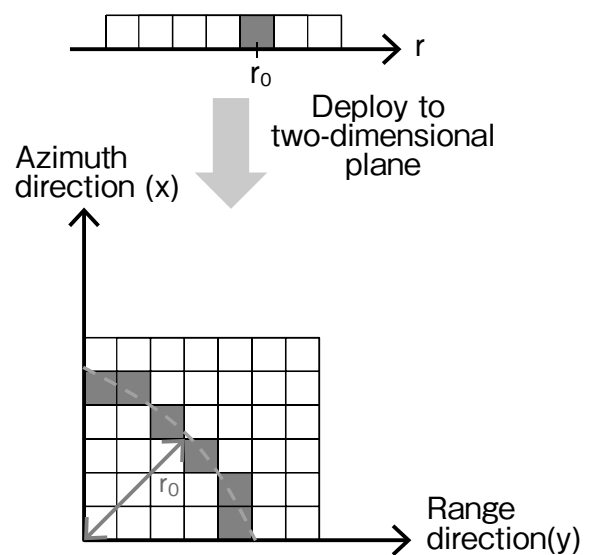Fig. 4 Image of Range-Doppler Method

Fig. 5 Image of Backprojection Method

4. Simulation Result and Experimental Result

Fig. 6 shows simulation image, and **Table 1** shows simulation parameters. Radar that we assume is 77GHz band FMCW system. A squint angle is set to 55° toward the target that is arranged tilted forward as shown in **Fig. 3**. Then, we simulated SAR imaging when the target moved 0.5m forward. We assumed that there are 9 targets, 3 of them are arranged at a distance of 5m, 10m, and 15m from the center of synthetic aperture, and the rest were arranged on the left and the right of each target with 2.5m distance.
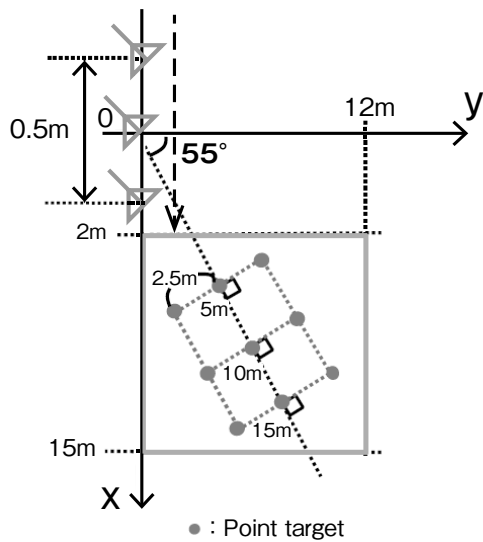
Fig. 6 Simulation Image

Table 1 Simulation Parameters

Radar system	FM-CW
Center frequency	76.5GHz
Sweep frequency bandwidth	0.9GHz
Sweep time	0.5msec
Synthetic aperture length	0.5m
Squint angle	55°

Simulation result is shown in **Fig. 7** to **Fig. 10**. **Fig. 7** shows an imaging by actual aperture before synthesis. **Fig. 8** to **Fig. 10** shows SAR imaging. **Fig. 8** is an imaging by BeamFormer method, **Fig. 9** is an imaging by Range-Doppler method, and **Fig. 10** is an imaging by

Backprojection method. As strong power area appears as a line in **Fig. 7**, it appears as a spot due to effect of synthetic aperture in **Fig. 8** to **Fig. 10**. Also, strong power areas are on the coordinates where targets exist in **Fig. 8** and **Fig. 10**, but the result of Range-Doppler method in **Fig. 9** shows error for the targets away from squint angle direction, and some targets were detected as a bar. These problems are caused by influence of approximation error which is generated on processing.
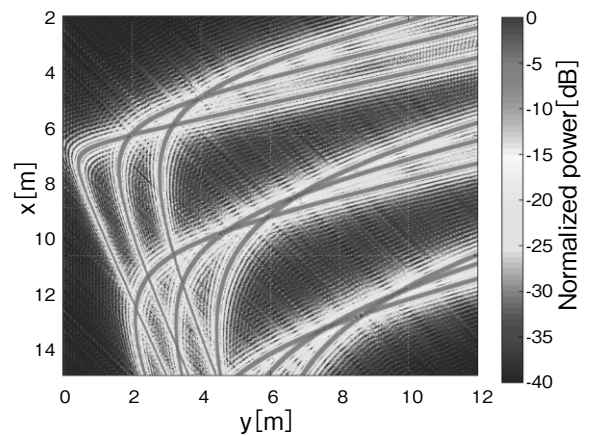
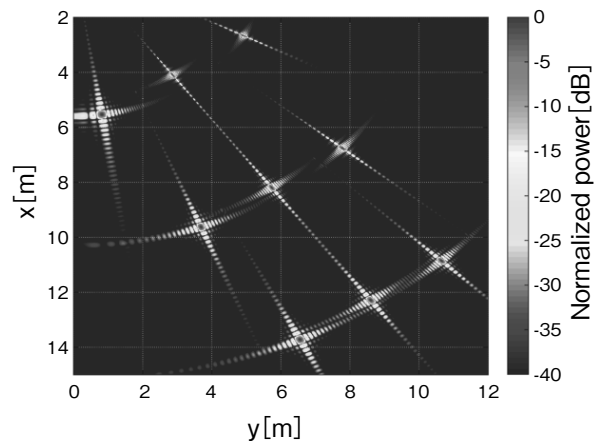Fig. 7 Simulation Result (Actual synthetic aperture)

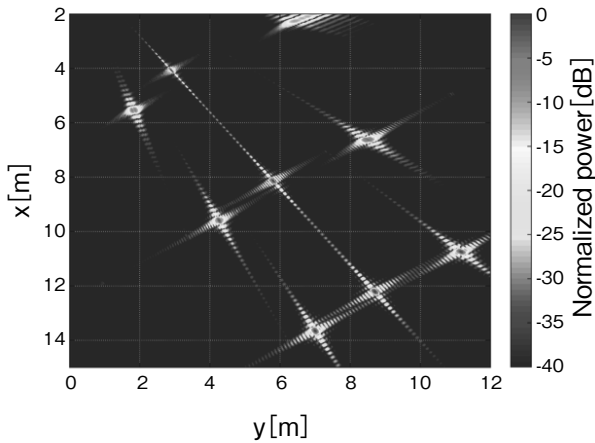Fig. 8 Simulation Result (BeamFormer Method)

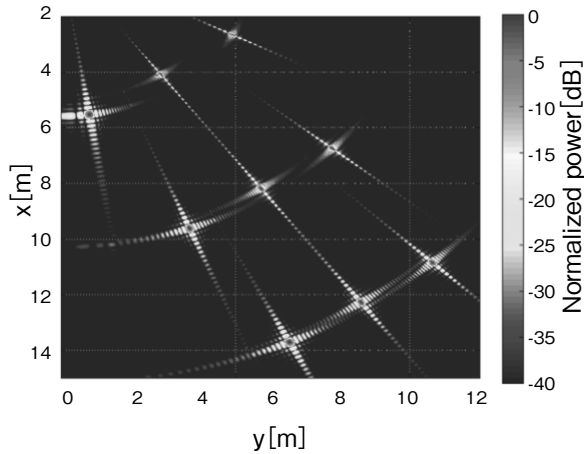Fig. 9 Simulation Result (Range-Doppler Method)

Fig. 10 Simulation Result (Backprojection Method)

The following figures show experimental result. In the experimental environment as shown in **Fig. 11**, We mounted the radar on vehicle and detected several kinds of targets, which were arranged three-sided corner reflector, guardrail, rubber ball, traffic sign, and crash test dummy. Also, as described experimental parameters in **Table 2**, parameters of radar used in experiment are the same as simulation parameters except synthetic aperture length.
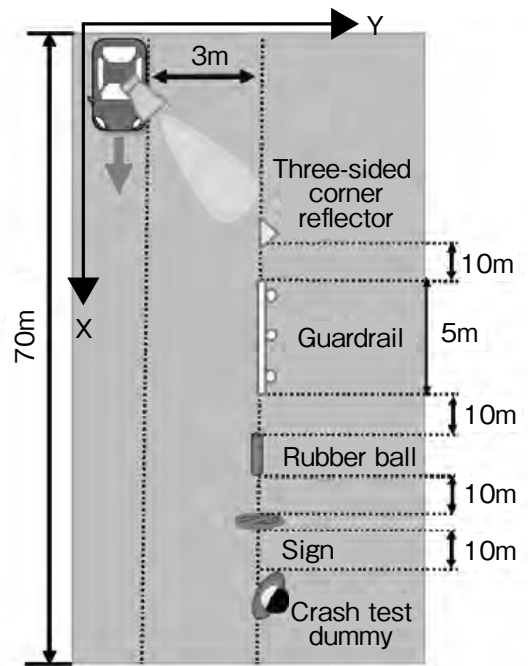

Fig. 11 Experimental Environment (Top view)

Table 2 Experimental Parameters

Rader system	FM-CW
Center frequency	76.5GHz
Sweep frequency bandwidth	0.9GHz
Sweep time	0.5msec
Synthetic aperture length	1m
Squint angle	55°

Experimental result is shown in **Fig. 12** to **Fig. 15**. These results show that the radar detects the target 5m away from the radar in the azimuth direction (x-coordinate) and 3m away from the radar in the range direction (y-coordinate) and detected target is three-sided corner reflector. **Fig. 12** shows an imaging by actual aperture before synthesis. **Fig. 13** to **Fig. 15** show SAR imaging. **Fig. 13** is an imaging by BeamFormer method, **Fig. 14** is an imaging by RangeDoppler method and **Fig. 15** shows an imaging by Backprojection method. In the same manner as simulation, strong power area appears as the line in **Fig. 12**. However, it appears as the spot due to effect of synthetic aperture in **Fig. 13** to **Fig. 15**. As for these SAR imaging results, calculation error is observed, because vehicle velocity is not exactly constant, we

considered. As for Range-Doppler method, there was calculation error by approximation observed in simulation, but in case of the experiment, the result of Range-Doppler method was the same as other method because of focusing on the target only in squint angle direction.
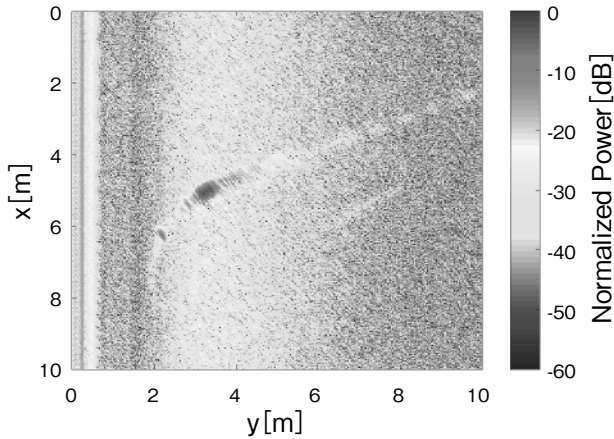

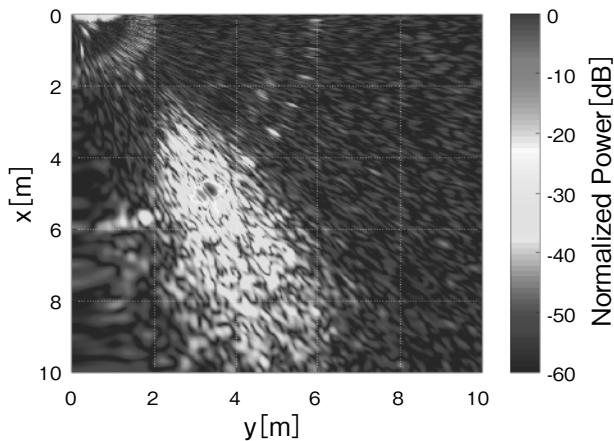Fig. 12 Experimental Result (Actual synthetic aperture)
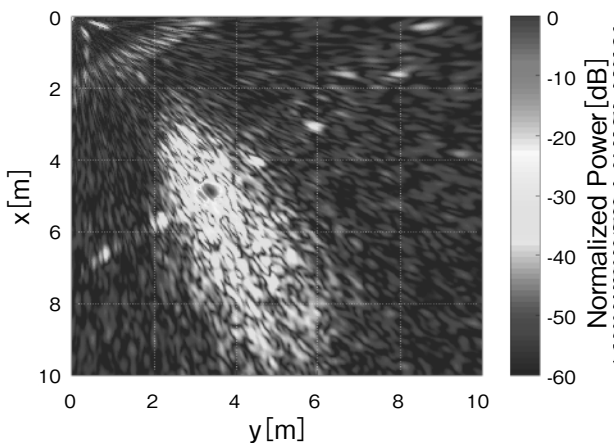

Fig. 13 Experimental Result (BeamFormer Method)
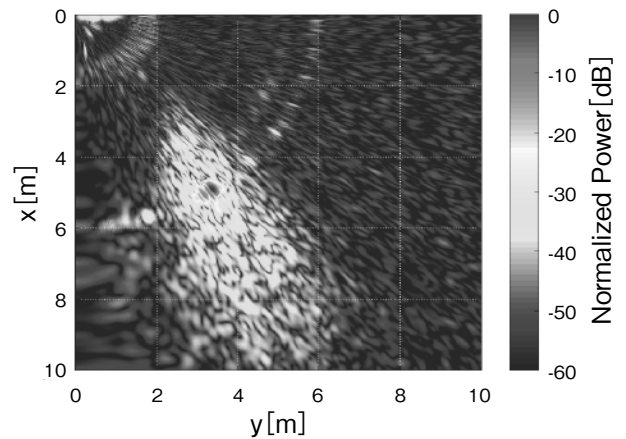

Fig. 14 Experimental Result (Range-Doppler Method)

Fig. 15 Experimental Result (Backprojection Method)

5. Conclusion

This paper described the fundamental study on synthetic aperture imaging by using millimeter wave automotive radar. As for the simulation result, RangeDoppler method is currently less accurate than other method, because calculation error increases for the target away from squint angle direction. As highly accurate results are obtained in both BeamFormer method and Backprojection method, we consider that Backprojection method is the best right now, because it is short in calculation time compared to BeamFormer method as shown in **Table 3**.

Table 3 Summary of SAR Imaging Method
(Simulation Result)

	Beam Former method	Range -Doppler method	Back projection method
Accuracy	Almost no error	Max error About 1m	Almost no error
Calculation time	About 2H&20min.	About 5sec.	About 41sec.

Future issue is firstly to reduce further calculation time. As Backprojection method has been improved in calculation speed compared to BeamFormer method, imaging in real time requires further shortening calculation time. Also, considering actual operation, as shown in the experimental result in chapter 4, calculation error arises because vehicle velocity is not necessarily constant. Therefore, we

must find the measures to reduce error, and maintain and improve the accuracy. If we can overcome these issues, current millimeter wave automotive radar is expected to be improved for further accuracy.

Reference
1) Institute of Electronics, Information and Communication Engineers : Fundamental Study on Synthetic Aperture Radar Imaging by Using Millimeter Wave Automotive Radar [2015]
2) Institute of Electronics, Information and Communication Engineers：Fundamental Study on SAR with Millimeter Wave Automotive Radar by Using Compressed Sensing [2016]
3) Institute of Electronics, Information and Communication Engineers : Study on Simple Imaging by Squint-mode SAR with Millimeter Wave Automotive Radar [2017]

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