

# Fundamental Study on Data Volume Reduction for Squint Mode SAR with Millimeter Wave Automotive Radar by Using Compressed Sensing

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**Abstract** – Automatic operating system for vehicles has been widely studied. Especially millimeter wave (MW) automotive radar has been attracting attentions. Although synthetic aperture radar (SAR) by using MW radar can obtain a high-resolution 2-dimensional image, an amount of observation data become huge. Compressed sensing (CS) is a method of solving this problem. In this paper, we provide some simulation and experimental results applying the CS by using orthogonal iterative hard thresholding algorithm to SAR image reconstruction, and show that the scatterer can be detected by compressed data.

**Index Terms** — Compressed sensing, Millimeter wave automotive radar, Synthetic aperture radar.

## 1. Introduction

Automatic driving systems, such as advanced driver assistance systems, have become in practical use recently. To overcome bad weather condition such as a dense fog and a snow fall, millimeter wave (MW) automotive radar has been attracting attentions. Although there are several researches on 2-dimensional (2-D) imaging by the MW radar, their performance is limited because of the array size on the car. However, when we exploit the movement of the car, we can realize high-resolution side-looking imaging radar based on the concept of the synthetic aperture radar (SAR) [1].

Squint mode SAR imaging by using the radar loaded on the car allows us to obtain high-resolution 2-D images [1]. MW SAR image require a huge amount of observation data. Compressed sensing (CS) [2], [3] is a method of solving this problem. It can recover an image from fewer samples than those required by conventional method.

In this paper, we show that CS by using orthogonal iterative hard thresholding (OIHT) algorithm [4] can reconstruct the SAR image from a few data observed by 76 GHz band MW radar. Simulation results show that OIHT can detect the scatterer from the reduced samples. In addition, validity of OIHT is shown by the result of field experiment.

## 2. Linear Model for SAR Signal

In this study we assume that the radar is mounted on the left-corner of the car, whose main beam is squinted to observe the side of the car. The observed data is collected every position as the car move. The number of observation

points is  $L$ . At each points the radar transmits a short up-chirp pulse to estimated target distance as the FM-CW radar. This type of the radar often called bust-FM or Linear-MF radar. The received beat signal is sampled by  $Nt$  points.

In this study, we adopt the CS technique to detect targets. In the CS, the observed 2-D area is divided into  $N$  domains with assuming  $K$  targets ( $K \ll N$ ). The linear model for the SAR signal can be described by

$$\mathbf{r} = \mathbf{A}\mathbf{s} + \mathbf{n}, \quad (1)$$

where  $\mathbf{r}$  is the  $(Nt \cdot L) \times 1$  received signal vector,  $\mathbf{A}$  is the  $(Nt \cdot L) \times N$  measurement matrix,  $\mathbf{s}$  is the  $(Nt \cdot L) \times 1$   $K$  sparse vector composed of scattering coefficient, and  $\mathbf{n}$  is the  $(Nt \cdot L) \times 1$  white Gaussian noise vector.

## 3. Reconstruction SAR Image by Using CS

CS is the technique to reconstruct the sparse vector by extracting rows from received signal vector and measurement matrix randomly. This method allows us to recover the image by a few data. The compressed data can be given by

$$\begin{aligned} \mathbf{r}' &= \mathbf{E}'\mathbf{r} \\ &= \mathbf{E}'\mathbf{A}\mathbf{s} + \mathbf{E}'\mathbf{n} \\ &= \mathbf{A}'\mathbf{s} + \mathbf{n}', \end{aligned} \quad (2)$$

where  $\mathbf{E}'$  is the  $M \times N$  submatrix constructed by selected  $M$  rows of  $(Nt \cdot L) \times (Nt \cdot L)$  identity matrix  $\mathbf{E}$  randomly. If  $M$  is smaller than  $N$ , eq. (2) is an ill-posed problem and it is impossible to calculate  $\mathbf{s}$  in general. If  $\mathbf{s}$  is a  $K$  sparse vector,  $\mathbf{s}$  can be estimated by using sparse reconstruction in constraint condition of norm. In this report, we use the OIHT. This algorithm estimates  $\mathbf{s}$  by solving the optimization problem under condition that Frobenius norm of  $\mathbf{A}'$  is less than 1:

$$\min_{\hat{\mathbf{s}}} \|\mathbf{r}' - \mathbf{A}'\hat{\mathbf{s}}\|_2^2 \text{ such that } \|\hat{\mathbf{s}}\|_0 \leq K, \quad (3)$$

where  $\|\hat{\mathbf{s}}\|_p$  is a  $p$ -norm and  $\hat{\mathbf{s}}$  is the signal approximation.

#### 4. Simulation Result

The SAR simulation uses four point targets. Its environment is shown in Fig. 1 and its parameters are listed in TABLE I. In the original SAR data, we have 251251 signal samples ( $L = 1001$ ,  $Nt = 251$ ). The result using 0.05% signal samples (126 samples) is shown in Fig. 2 and the data volume required by traditional method and the CS is shown in Fig. 3. As can be seen in Fig. 2 and Fig. 3, OIHT can detect positions of scatterer using only a few data and estimate power of received signals from each scatterers correctly.

#### 5. Experimental Result

The SAR imaging was created by OIHT from the received data whose squint angle is 60 degrees. Experimental parameters are the same as listed in TABLE I and the experimental environment is also shown in Fig. 4. The target was a corner reflector. The result using 0.05% signal samples is shown in Fig. 5. As can be seen in Fig. 5, the OIHT can recover the locations of the scatterer using only 0.05% data of the experimental data. Therefore, CS is a valid method to reconstruct the image by reduced amount of data for squint mode SAR.

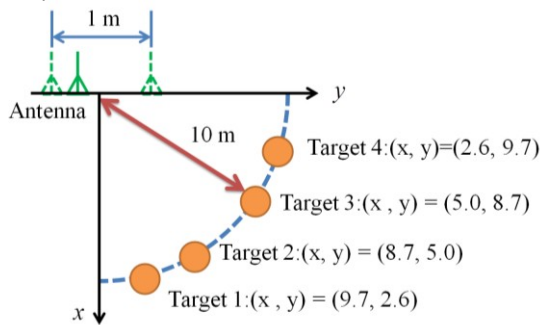


Fig. 1. Simulation environment.

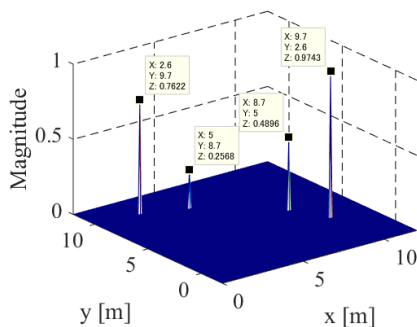


Fig. 2. Simulation result.

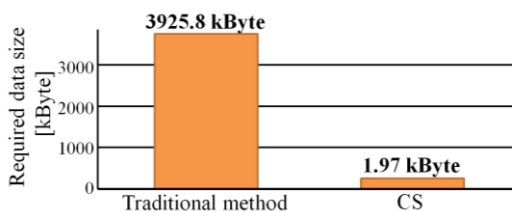


Fig. 3. Data size required by traditional method and the CS.

TABLE I  
Simulation Parameters

Center frequency / Bandwidth	76.5 GHz / 1GHz
Sweep time / Sampling frequency	1.0 msec. / 250 kHz
Sampling frequency	250 kHz
Synthetic aperture length	1.0 m
Observation interval	1.0 mm
SNR	20 dB
Received powers	Target 1 : 1.0, Target 2 : 0.5 Target 3 : 0.25, Target 4 : 0.75
Maximum number of iterations	5

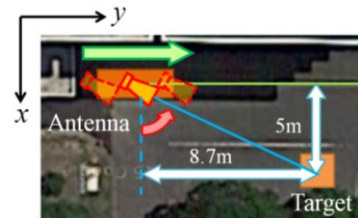


Fig. 4. Experimental environment.

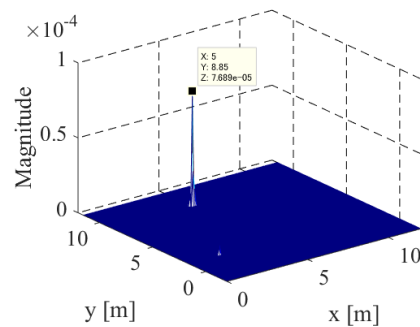


Fig. 5. Experimental result.

#### 6. Conclusion

In this paper, to reduce amount of the data for squint mode SAR in MW automotive radar, we propose to apply the CS using OIHT for the SAR imaging. The experimental result shows that the CS is valid in actual environment. More practical experiments on road environment will be carried out in near future. In this study we omit Doppler frequency effect. It will be also considered in the next study. We will carry out experiment on a road in near future, and we will create the SAR imaging for various targets and extract feature quantity, and consider compensation for Doppler frequency of platform movement.

#### References

- [1] J. Minotani, H. Yamada, Y. Yoshio, "Experimental study on MW-SAR imaging in outdoor environment", in Proc. 2015. *International Workshop on Electromagnetics and R&S Student Competition (iWEM2015)*, pp. 1-2, Nov, 2015.
- [2] S.-J. Wei, X.-L. Zhang, J. Shi, and G. Xiang, "Sparse reconstruction for SAR imaging based on compressed sensing," *Progress In Electromagnetics Research*, Vol. 109, pp.63-81, 2010.
- [3] D. L. Donoho, "Compressed sensing," *IEEE Trans. Inf. Theory*, vol. 52, No. 4, pp. 1289-1306, Apr. 2006.
- [4] J. Li, Y. Shen, and Q. Wang, "Stepwise suboptimal iterative hard thresholding algorithm for compressive sensing," in Proc. 2012. *International Instrumentation and Measurement Technology Conference (I2MTC)*, pp. 1332-1336, May, 2012.