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Suppression of Scattering Waves from the Outside of a Search Area Using a Gating Technique in Compressed Sensing Based Scatterer Detection

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***Abstract*—A compressed sensing technique can be used for scatterer detection with less antenna elements. The detection accuracy, however, degrades when scatterers exist also in the outside of a search area. In this paper, we propose a preprocessing scheme for compressed sensing based scatterer detection. The scheme uses a gating technique in a cross range, and suppresses scattering waves from the outside of a search area. Also, we introduce a wide area detection scheme dealing with scatterers located very close to the search area that the gating technique cannot suppress. We show the performance of scatterer detection with the proposed method.**

***Index Terms*—MIMO radar, compressed sensing, scatterer detection, gating technique.**

1. Introduction

Scatterer detection using a radar system has many applications, and the demand of it is increasing. Recently, a compressed sensing technique has been studied for accurate scatterer detection [1], [2]. In a case where scatterers are located also in the outside of a search area, the technique cannot detect scatterers accurately. This paper presents compressed sensing based scatterer detection with gating preprocessing that suppresses scattering waves from the outside of a search area. As for scatterers that are located very close to the search area and cannot be suppressed by the gating technique, we propose a wide area detection scheme. The performance of the technique will be numerically evaluated.

2. Scatterer Detection and Modified OIHT Algorithm

In this paper, we assume a linear array with L antenna elements as shown in Fig.1, and we divide a search area into N small cells. We assume that L is even in this paper. Note that Fig.1 shows a case of $L = 16$. Each antenna transmits sinusoidal waves with different P frequencies $f_p (p = 1, 2, \ldots, P)$. All the antennas receive scattered signals. We express an N-dimensional unknown original vector, an M-dimensional received signal vector, and an $M \times N$ observation matrix as $\boldsymbol{x}$, $\boldsymbol{y}$ and $\boldsymbol{A}$, respectively. Here, $M = L^2 P$ holds. Each element in $\boldsymbol{x}$ denotes a scattering coefficient at a cell in the search area. Then, we have

$$\boldsymbol{y} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{n}, \tag{1}$$

where $\boldsymbol{n}$ is an M-dimensional noise vector. In this paper, we assume a K-sparse scenario where there are at most K dominant scatterers in a search area ($K \ll N$), and we can use compressed sensing techniques to obtain $\boldsymbol{x}$. The orthogonal iterative hard thresholding (OIHT) algorithm has been proposed to solve sparse problems [3]. We slightly modified the algorithm as shown in Table I. $\mathbf{A}^{\dagger}_{\boldsymbol{\Gamma}_{n+1}}$ denotes the Moore-Penrose pseudo-inverse of $\mathbf{A}_{\boldsymbol{\Gamma}_{n+1}}$ in the table. We call it the modified OIHT algorithm. In this paper, we employ the algorithm for scatterer detection.

TABLE I
Modified OIHT Algorithm

Algorithm
Require: $\boldsymbol{y}, \boldsymbol{A}$ and K
$n = 0,\ \hat{\mathbf{x}}_0 = \mathbf{0}$
while $n \neq K$ and $\|\|\mathbf{y} - \mathbf{A}\hat{\mathbf{x}}_n\|\|_2 \neq 0$ **do**
$1 : \boldsymbol{\alpha}_{n+1} = H_{n+1}(\hat{\mathbf{x}}_n + \mathbf{A}^{\mathrm{H}}(\mathbf{y} - \mathbf{A}\hat{\mathbf{x}}_n))$
$2 : \boldsymbol{\Gamma}_{n+1} = \mathrm{supp}(\boldsymbol{\alpha}_{n+1})$
$3 : \hat{\boldsymbol{\alpha}}_{n+1} = \mathbf{A}^{\dagger}_{\boldsymbol{\Gamma}_{n+1}}\mathbf{y}$
$4 : \hat{\mathbf{x}}_{n+1} = H'_{n+1}(\hat{\boldsymbol{\alpha}}_{n+1})$
$5 : n = n + 1$
end while
Ensure: signal approximation $\hat{\mathbf{x}} = \hat{\mathbf{x}}_{n+1}$

3. Gating Technique and Wide Area Detection

In a case where we have scatterers also in the outside of a search area, the scattering waves from them are included in $\boldsymbol{y}$. This leads to erroneous results. As for a range direction, we can suppress unwanted waves by switching control at each receiver input. We propose an angle-domain gating technique for elimination of unwanted waves from a cross range direction below. The basic concept of the gating technique is the same as that stated in reference [4].

From the elements of $\boldsymbol{y}$, we obtain P $L \times L$ matrices $\boldsymbol{K}(f_p)(p = 1, 2, \cdots, P)$ whose (i, j) element is the signal received by the ith antenna when the transmit antenna is $\#j$ at frequency f_p. Note that we have $i, j = 1, 2, \ldots, L$. Then, we express an $L \times L$ beamforming matrix based on the spatial FFT as $\boldsymbol{W}(f_p)$. The L-dimensional row vector $\boldsymbol{w}_m(f_p)$ given by the mth row of the matrix $\boldsymbol{W}(f_p)$ forms the main beam toward

$$\theta_m = \sin^{-1}\left(\frac{2m}{L}\right) \quad m = -\frac{L}{2}+1, -\frac{L}{2}+2, \ldots, \frac{L}{2}. \tag{2}$$

To reduce the sidelobe levels of patterns given by $\boldsymbol{W}(f_p)$, we utilize a Gaussian window function, and introduce a beamforming matrix with low sidelobes $\boldsymbol{W}'(f_p) = \boldsymbol{W}(f_p)\boldsymbol{Z}$, where $\boldsymbol{Z}$ is an $L \times L$ diagonal matrix whose diagonal elements are given by a Gaussian function. Using these matrices, we obtain an $L \times L$ angle-domain matrix $\boldsymbol{K}_\theta(f_p) = \boldsymbol{W}'(f_p)\boldsymbol{K}(f_p)$. The (m, j) element of $\boldsymbol{K}_\theta(f_p)$ is an angle-domain signal weighted by the mth row of $\boldsymbol{W}'(f_p)$

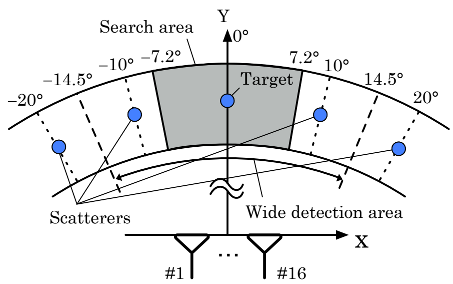

Fig. 1. Simulation environment.

when the transmit antenna is $\#j$ at frequency f_p. Note that we have $m = -\frac{L}{2}+1, -\frac{L}{2}+2, \ldots, \frac{L}{2}$ and $j = 1, 2, \cdots, L$.

We pad 0s to all the row elements in $\boldsymbol{K}_\theta(f_p)$ corresponding to the outside of the search area, and we express the zero-padded matrix as $\boldsymbol{K}'_\theta(f_p)$. By the zero padding, we can reduce scattering waves from the outside of the search area. From $\boldsymbol{K}'_\theta(f_p)$, we calculate $\boldsymbol{K}'(f_p)$ as follows:

$$\boldsymbol{K}'(f_p) = \boldsymbol{W}'^{-1}(f_p)\boldsymbol{K}'_\theta(f_p) \quad p = 1, 2, \ldots, P \qquad (3)$$

Using these P $L \times L$ matrices $\boldsymbol{K}'(f_p)$, we obtain the M-dimensional received signal vector $\boldsymbol{y}'$. This process is a reverse of that we obtained $\boldsymbol{K}(f_p)$ from $\boldsymbol{y}$. This is the angle-domain gating preprocessing, and we can reduce scattering waves from the outside of the search area.

Unfortunately, we cannot eliminate the scattering waves from objects located very close to the search area, and they remain in the vector $\boldsymbol{y}'$. To avoid the effect of these scatterers, we apply the modified OIHT algorithm to a slightly wider area than the original search area. In the wider area, all the scatterers that cannot be eliminated by the gating exist. We obtain only the scatterers in the search area. We call this the wide area detection scheme. Using the preprocessing of the angle-domain gating and the wide area detection, we can reduce the effects of the scatterers located in the outside of the search area.

We evaluated the performance of the proposed scheme by computer simulations. Figure 1 and Table II show the simulation environment and the simulation parameters. λ_c in Table II represents the wavelength (0.03 m) corresponding to the center frequency (10 GHz).

Figure 2 shows the detection result when we do not use the gating technique. The wide area detection is applied. Although a single target exists at the center of the search area, many erroneous peaks appear. We see that the compressed sensing technique does not work due to the scatterers located in the outside of the search area.

Figure 3 shows the case where we apply the gating preprocessing and the wide area detection. The gate region ranges from $-14.5°$ to $14.5°$. Since we have 16 antenna elements, $\boldsymbol{K}_\theta(f_p)$ is a 16×16 matrix. We padded 0s to the mth rows where $m = -7, -6, \cdots, -3, 3, 4, \cdots, 8$, and we obtained $\boldsymbol{K}'_\theta(f_p)$. The scattering waves form $-20°$ and $20°$ were suppressed by the gating. In Fig.3, we see a dominant response of the target at the center of the search area. This is a much more accurate result.

Figure 4 shows average error versus target position. We changed the target position from $-3.5°$ to $3.5°$. It has been shown from another simulation that the cross-range

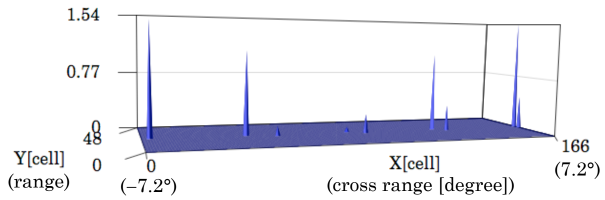

Fig. 2. Detection result (1). Without gating.

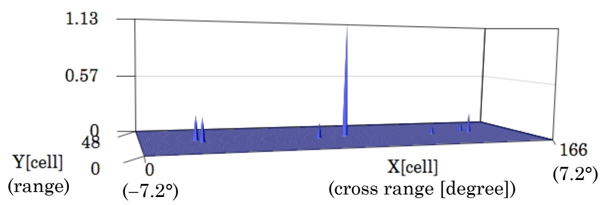

Fig. 3. Detection result (2). With gating from $-14.5°$ to $14.5°$.

TABLE II
Simulation Parameters

Frequency band	$8.75 \sim 11.25$ [GHz]
No. of utilized frequencies P	11
Frequency interval	250 MHz
No. of antennas L	16
Antenna spacing	$\lambda_c/2$ (0.015 m)
Distance between antennas and search area	10 m
SNR	20 dB
Cross range of search area	$-7.2° \sim 7.2°$
No. of cells in search area	49 (Range)×167 (Cross range)
Cross range of wide area detection	$-14.5° \sim 14.5°$
No. of cells in wide area	49 (Range)×337 (Cross range)
Cell width	$\lambda_c/2$ (0.015 m)
No. of targets in search area	1
Position of target in search area	Middle of search area (Range) Cross-range coordinate depends on the situation.
Scattering coefficient of target in search area	1
Positions of scatterers in the outside of search area	Middle of area (Range) $\pm 10°$ and $\pm 20°$ (Cross range)
Scattering coefficient of scatterers in the outside of search area	1
No. of algorithm iterations K	20
Gaussian window function	Average 0.5, Standard deviation 5

resolution of the algorithm in this case is about $6.5°$. When the target is located in the outside of the above region, the detection fails because it is close to the scatterer located at $-10°$ or $10°$. This is the reason why we determined the target position from $-3.5°$ to $3.5°$. At each position, we obtained 100 target position errors changing noise waveforms, and averaged them. It is seen that the average error increases due to the target at $-10°$ or $10°$ when the target position is close to $-3.5°$ or $3.5°$. The average errors are, however, within 15 cells.

4. Conclusion

In this paper, we have proposed the gating preprocessing and the wide area detection for scatterer detection with a compressed sensing technique. From computer simulation results, it has been shown that although we have limitations due to resolution, the proposed scheme realizes accurate detection.

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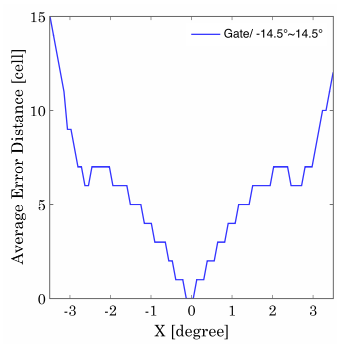

Fig. 4. Average error versus target position.