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Transmission Error Correction Using Overlapping Elements in Virtual Array of MIMO Radar

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Abstract – In the MIMO radar using the transmission antenna switching, the phase and amplitude errors in the transmission signals may yield deterioration of the estimation accuracy of target directions. In this paper, we introduce overlapping elements in the virtual array of MIMO radar, and we improve the estimation accuracy by correcting transmission signal errors with the overlapping elements.

Index Terms — MIMO radar, virtual array, transmission antenna switching, transmission signal errors, overlapping elements.

1. Introduction

In recent years, development of high-performance radar is an urgent issue in order to realize collision avoidance systems and autonomous cars. Especially, MIMO (Multiple-Input and Multiple-Output) radar has attracted much attention because it has higher accuracy and higher resolution than conventional radar [1], [2]. However, in the MIMO radar using the transmission antenna switching, the phase and amplitude errors may occur in the transmission signals, which degrade seriously the estimation accuracy of target directions. In this paper, we improve the estimation accuracy of target directions by correcting the transmission signal errors with overlapping elements in the virtual array. The estimation performance is evaluated by computer simulation.

2. MIMO Radar and Virtual Array

As shown in Fig. 1, we consider that the MIMO radar is composed of M-element transmitting array and N-element receiving array. The element spacings of transmitting and receiving arrays are \(d_t\) and \(d_r\), respectively. It is assumed that there are L targets in the same range. Signals transmitted from the M-element transmitting array, are reflected by the targets and received by the N-element receiving array. The received signal vector from mth transmitting antenna, \(x_m(t) \in \mathbb{C}^{N \times 1}\), is expressed as [1], [2]

\[
x_m(t) = A_r B A_t^T s_m(t) + n_m(t) \quad (m = 1, 2, \ldots, M)
\]

where \(s_m(t)\) is the transmitted signal from mth transmitting antenna, \(A_r \in \mathbb{C}^{M \times L}\) is the transmission mode matrix, \(A_t \in \mathbb{C}^{N \times L}\) is the reception mode matrix, \(B \in \mathbb{C}^{L \times L}\) is the diagonal matrix consisting of reflection coefficients of the targets, and \(n_m(t)\) is the internal noise vector when receiving \(s_m(t)\).

In this paper, we employ the transmission antenna switching, and so we normally have \(s_m(t)\) equal to a common signal \(s(t)\). On the condition that radio environment is unchanged during the switching operation, we can have an \(MN\)-element virtual receiving array as shown in Fig. 1, and the received signal vector of the virtual array is represented by

\[
\bar{x}(t) = [x_1^T(t) \cdots x_M^T(t)]^T \in \mathbb{C}^{MN \times 1}
\]

It is advantage that we can make the \(MN\)-element virtual receiving array from \(M + N\) real elements.

3. Transmission Error Correction Using Overlapping Elements

In the MIMO radar using the transmission antenna switching, phase and amplitude errors of the transmitting signals generally occur in switching the transmitting antennas. For the error correction, we set up the overlapping elements in the virtual array [3]. Fig. 2 shows the example with \(M = 2\) and \(N = 4\) in which we have the following received vectors.

\[
x_1(t) = [x_{11}(t), \ldots, x_{14}(t)]^T = [x_1(t), \ldots, x_4(t)]^T
\]

\[
x_2(t) = [x_{21}(t), \ldots, x_{24}(t)]^T = [x_5(t), \ldots, x_8(t)]^T
\]
Since $s_2(t)$ has a transmission error for $s_1(t) = s(t)$, the received signals of the 5th to 8th elements has phase and amplitude errors for the 1st to 4th elements in the virtual array. In this case, $x_2(t)$ and $s_3(t)$, which are the 4th element of $x_1(t)$ and the 1st element of $x_2(t)$, respectively, are overlapping elements in the virtual array. Therefore, when we have $N_s$ snapshots of the received vectors, we can obtain the following error correction factors.

$$\alpha_n = \frac{x_n(n)}{s_n(n)} \quad (n = 1, 2, \cdots, N_s)$$  \hspace{1cm} (5)

Using $\alpha_n$, the received signal snapshot vectors are corrected every snapshot as follows:

$$\tilde{x}(n) = [x_1(n), \cdots, x_4(n), \alpha_n x_3(n), \alpha_n x_5(n), \alpha_n x_9(n)]^T \in \mathbb{C}^{7 \times 1}$$  \hspace{1cm} (6)

This correction method is called the instantaneous correction method.

On the other hand, we take the average of the correction factors for $N_s$ snapshots as follows:

$$\alpha = \frac{1}{N_s} \sum_{n=1}^{N_s} \alpha_n$$  \hspace{1cm} (7)

Hence, we can also have the following corrected snapshot vectors using $\alpha$.

$$\tilde{x}(n) = [x_1(n), \cdots, x_4(n), \alpha x_3(n), \alpha x_5(n), \alpha x_9(n)]^T \in \mathbb{C}^{7 \times 1}$$  \hspace{1cm} (8)

The method is called the average correction method.

### 4. Performance Analysis by Computer Simulation

In order to evaluate the performance of correction methods for transmission signal errors in MIMO radar, the computer simulation is carried out under the conditions of Table I. As the estimation algorithm, MUSIC algorithm is used [4], [5].

Fig. 3 shows the RMSE (Root Mean Square Error) of the target direction estimation as a function of the input SNR from 0 dB to 30 dB when the target directions are (a) 30° and (b) 60°. For comparison, this figure includes the results for the case of no signal error, the case before the error correction, and the cases where the errors are corrected by the instantaneous and average correction methods. From Fig. 3, it can be seen that both correction methods can improve the estimation accuracy for the high SNR beyond 10 dB. Furthermore, the instantaneous correction method shows better performance than the average correction method for SNR beyond 10 dB.

### Table I Simulation Conditions

<table>
<thead>
<tr>
<th>Number of transmitting elements</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of receiving elements</td>
<td>4</td>
</tr>
<tr>
<td>Element spacing of transmitter</td>
<td>1.5</td>
</tr>
<tr>
<td>Element spacing of receiver</td>
<td>0.5</td>
</tr>
<tr>
<td>Target direction [deg]</td>
<td>30 or 60</td>
</tr>
<tr>
<td>Reflection coefficient</td>
<td>1.0</td>
</tr>
<tr>
<td>Transmitting amplitude error [dB]</td>
<td>1.5</td>
</tr>
<tr>
<td>Number of snapshots</td>
<td>128</td>
</tr>
<tr>
<td>SNR [dB]</td>
<td>0~30</td>
</tr>
<tr>
<td>Number of trials</td>
<td>500</td>
</tr>
</tbody>
</table>

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**Fig. 3.** RMSE of target direction estimate vs. SNR.

**5. Conclusion**

In the MIMO radar using the transmission antenna switching, we have examined the performance of transmission error correction methods. The methods characterize the use of overlapping elements in virtual array. From simulation results, it is demonstrated that the target direction estimation accuracy for high SNR can be improved by the proposed correction methods. In the future, we will enhance further the estimation accuracy by devising overlapping elements.

**References**


