EFFECT OF ORIENTATION MISALIGNMENTS BETWEEN ARRAY ELEMENTS ON INTERFERENCE MITIGATION PERFORMANCE OF MVDR BEAMFORMER

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Abstract: Many studies on achieving robust performance MVDR beamformers have been conducted, but such research assumes that all antenna elements of arrays are perfectly aligned and only the phases of the signals received by the antenna elements differ. However, in practice, no array is perfectly aligned, and the orientations of antenna elements can be misaligned for various reasons. Therefore, in the case of the MVDR beamformer, which assumes perfect alignments, received signals undergo attenuations owing to orientation misalignments. In this paper, the effect of orientation misalignment between array elements on the interference mitigation performance of the MVDR beamformer is described using polarization concepts. The mathematical expressions for the received signal and array gains in the case of misalignments are derived and compared to the typical signal model and array gain without misalignments. The simulation result confirms the validity of the proposed approach.

Keywords: MVDR beamformer, robustness, orientation misalignment, polarization, interference mitigation.

1. INTRODUCTION

Array-based adaptive beamforming is the most widely used techniques in fields such as wireless communication, radar, acoustic signal processing, and sonar [1-11], because the technique has the capability to enhance the desired signals and suppress undesired interferences. The minimum variance distortionless response (MVDR) beamformer [12] is a commonly used beamforming method and has been studied intensively due to its effective interference mitigation capability and simple implementation [13-19].

The MVDR beamformer maintains unit gain in the direction of the desired signal using the corresponding steering vector. Hence, the interference mitigation performance of the MVDR beamformer depends on the perfectness of the steering vector for the desired signal. It is known that an MVDR beamformer with an imperfect steering vector for the desired signal undergoes substantial degradation of interference rejection performance.

Although many studies have been proposed to achieve robust MVDR beamformer performance in the presence of steering vector imperfection [20-27], these studies assume that all the antenna elements of the array have the same orientation, implying that the signals received by respective antenna elements are different only in terms of their phases.

However, in practice, the orientations of the antenna elements are different due to unexpected factors, resulting in differences in both the magnitudes and phases of the received signals. As the typical steering vector of a MVDR beamformer involves only the phase differences between the received signals into account, the performance of the MVDR beamformer is adversely affected owing to orientation misalignments.

In this work, the effect of orientation misalignments between antenna elements of the array on the interference mitigation performance of the MVDR beamformer is studied. The received signal of the array with misalignments of elements is modeled using the concepts of polarization vectors and, based on the model, an expression for the modified array pattern is presented. For comparison, a typical model and expressions for the received signal and the array pattern without misalignments of antenna elements are also given. The result of numerical simulations is illustrated to confirm the performance degradation of the MVDR beamformer due to the orientation misalignment of array elements.

2. PROBLEM FORMULATION

Let us consider an N-element uniform linear dipole array, as depicted in Fig. 1, where θ_n ($-90° \leq \theta_n \leq 90°$, $n = 1, 2, \cdots, N$) and θ_s ($-90° \leq \theta_s$ θ $90°$) are the orientations of the *n-th* dipole element and the angular direction of the incoming signal with respect to the y-axis; $\hat{\mathbf{x}}$ and $\hat{\mathbf{y}}$ are unit vectors of Cartesian coordinates; and d is the distance between adjacent elements. We assume that the incoming signal is linearly polarized and the direction of field oscillation is parallel to the xy-plane.

In Cartesian coordinates, the polarization vector of the *n-th* dipole element, which is the polarization vector of the wave radiated by the antenna [28], and the incoming signal from θ_s can be expressed as follows [29]:

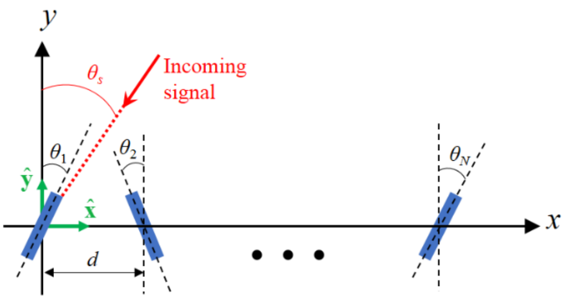

Fig. 1. A uniform linear dipole array with orientation misalignments.

$$\vec{\mathbf{p}}_n(\theta_n) = \sin\theta_n \hat{\mathbf{x}} + \cos\theta_n \hat{\mathbf{y}}$$
$$\vec{\mathbf{p}}_s(\theta_s) = -\cos\theta_s \hat{\mathbf{x}} + \sin\theta_s \hat{\mathbf{y}} \tag{1}$$

If the polarization of the incoming signal is not aligned with the antenna orientation, antenna response is reduced by the inner product of the polarization vectors of the incoming signal and the antenna [30] as follows:

$$\vec{\mathbf{p}}_s(\theta_s)\cdot \ldots \sin\theta_s \cos\theta_n - \cos\theta_s \sin\theta_n = \sin(\theta_s - \theta_n) \tag{2}$$

As shown in (2), for example, the inner product in (2) is zero when θ_s = θ_n (i.e., two vectors are orthogonal), and the signal is totally rejected. Similarly, the inner product in (2) equals one when θ_s = θ_n + 90° (i.e., two vectors are aligned), indicating that the antenna totally receives the signal. If we define $\Delta\theta_{1,n}$ = θ_n – θ_1, the equation (2) can be rewritten as follows:

$$\vec{\mathbf{p}}_s(\theta_s)\cdot \ldots {}_{1,n}) = \sin(\theta_s - (\theta_1 + \Delta\theta_{1,n})) \ . \tag{3}$$

Equation (3) will be used to describe the received signal model in the next section.

3. RECEIVED SIGNAL MODEL

Based on the polarization vector concepts described in the previous section, the complex received signal vector of an N-element dipole array can be written as follows when there are one desired signal and K interference signals.

$$\mathbf{r}[k] = P(\theta_D)\boldsymbol{\alpha}(\theta_D)s[k] + Q(\theta_{J,1},\cdots \ \circ \ \ldots k] \tag{4}$$

where $\mathbf{r}[k]$ is the N-by-1 received signal vector at the k-th sampling epoch, $\boldsymbol{\alpha}(\theta_D)$ is the N-by-1 steering vector of the desired signal impinging from θ_D, $\mathbf{J}$ is an N-by-K matrix whose m-th column (m = 1, 2, ⋯, K) indicates the steering vector of the m-th interference from $\theta_{J,m}$, $s[k]$ is the desired signal, $\mathbf{v}[k]$ is the K-by-1 interference signal vector, and $\mathbf{n}[k]$ is the N-by-1 complex additive white Gaussian noise vector, and ∘ means the Hadamard product, which is the element-wise product of two matrices, respectively. The N-dimensional diagonal matrix $P(\theta_D)$ and the N-by-K matrix $Q(\theta_{J,1},\cdots$ are given by

$$P(\theta_D) = \begin{bmatrix} \sin(\theta_D - (\theta_1 + \Delta\theta_{1,1})) & & \mathbf{0} \\ & \ddots & \\ \mathbf{0} & & \sin(\theta_D - (\theta_1 + \Delta\theta_{1,N})) \end{bmatrix} \tag{5}$$

$$Q(\theta_{J,1},\cdots = \begin{bmatrix} \sin(\theta_{J,1} - (\theta_1 + \Delta\theta_{1,1})) & \cdots & \theta_{J,K} - (\theta_1 + \Delta\theta_{1,1})) \\ \vdots & \ddots & \vdots \\ \sin(\theta_{J,1} - (\theta_1 + \Delta\theta_{1,N})) & \cdots & \theta_{J,K} - (\theta_1 + \Delta\theta_{1,N})) \end{bmatrix} \tag{6}$$

For comparison, the typical received signal model of the antenna array without considerations of antenna misalignment is given by

$$\mathbf{r}[k] = \boldsymbol{\alpha}(\theta_D)s[k] + \mathbf{J}\mathbf{v}[k] + \mathbf{n}[k] \tag{7}$$

On comparing (4) and (7), we find that the received array signals have differences both in magnitudes and phases in the case of misalignments, whereas only phases differ from each other in the case of ideal arrays. As typical MVDR algorithms assume ideal arrays with no orientation misalignments between array elements and use the received signal model given in (7), the performance can be adversely affected when misalignments occur.

4. MVDR BEAMFORMER

The MVDR beamformer is one of the most widely used approaches for interference suppression in array applications. The mathematical expression of the typical MVDR beamformer can be written as follows:

$$\min \ \mathbf{w}^H \mathbf{R}\mathbf{w} \ \text{subject to} \ \mathbf{w}^H \boldsymbol{\alpha}(\theta_D) = 1 \ , \tag{8}$$

where **w** is the weight vector for the array and **R** is the covariance matrix of the received array signals. The constraint equation $\mathbf{w}^H\boldsymbol{\alpha}(\theta_D) = 1$ in (8) stands for a unit array gain toward the direction of the desired signal and $\mathbf{w}^H\boldsymbol{\alpha}(\theta)$ is referred to as the array gain for a signal from θ in the case of ideal arrays. However, when antenna misalignments are present, the array gain needs to be modified as follows:

$$G(\theta) = \mathbf{w}^H P(\theta)\boldsymbol{\alpha}(\theta) \quad . \tag{9}$$

Therefore, when the misalignments occur, the MVDR beamformer given in (8) is not able to maintain a unit gain to the desired signal and the weight vector is computed incorrectly, as the array gain in the presence of misalignments is given by (9) rather than $\mathbf{w}^H\boldsymbol{\alpha}(\theta)$. Thus, the signal to interference-plus-noise ratio (SINR) performance of the MVDR beamformer deteriorates.

5. SIMULATION RESULT

To illustrate the effect of antenna orientation misalignment on the performance of the MVDR beamformer, numerical simulations were performed. The simulations consider a uniformly linear 15-element dipole array and each misalignment $\Delta\theta_{1,n}$ is regarded as a random variable uniformly distributed in the range of $-\delta \le \Delta\theta_{1,n} \le \delta$. It is assumed that there are one desired signal from 30° and one interference from −50°, and the interference-to-signal power ratio is 20 dB. Fig. 2 depicts the resultant SINR of the MVDR beamformer for each δ.

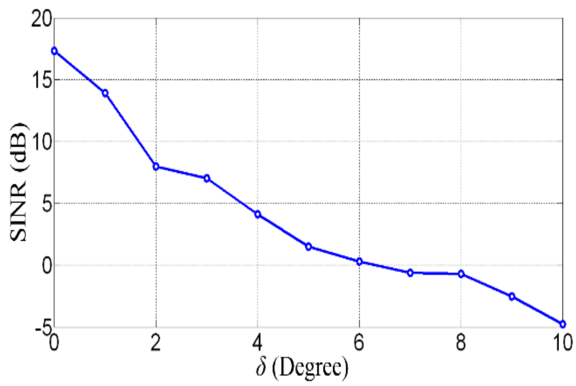

Fig. 2. SINR performance deterioration of the MVDR beamformer due to orientation misalignment.

As expected, the SINR performance of the MVDR beamformer continuously deteriorates as the orientation misalignment of each element increases. This is because, as δ increases, the deviation between the two signal models given in (4) and (7) increases. Therefore, the interference mitigation performances of the MVDR beamformer undergoes significant deterioration.

CONCLUSIONS

In this paper, the effect of orientation misalignment between array elements on the interference mitigation performance of the MVDR beamformer is described. The received signal is modeled by using polarization concepts; based on the signal model, array gain in the case of orientation misalignments is also derived. As the performance of the MVDR beamformer depends on the precision of the steering vector, the MVDR beamformer's SINR performance undergoes substantial deterioration. The simulation result is provided to verify the present study.

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