Interference Cancellation and DOA Estimation by Generalized Receiver Applying LMS and MUSIC Algorithms

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Abstract— Under implementation of the generalized receiver (GR) constructed based on the generalized approach to signal processing (GASP) in noise there is a need to cancel an interference to improve the GR performance. In this paper, we discuss an interference cancellation technique based on the non-blind beamfroming algorithm, namely, the least mean square (LMS) algorithm employed by GR. The direction of arrival (DOA) estimation is also used by LMS algorithm to provide a priori knowledge about the desired signal in GR. The simulation results demonstrate a superiority of GR performance in comparison with the Neyman-Pearson (NP) receiver.

1. INTRODUCTION

The generalized receiver (GR) is constructed based on the generalized approach to signal processing (GASP) in noise discussed in [1–5]. The GR is a combination of Neyman-Pearson (NP) detector that is optimal for detection of signals with known parameters and the energy detector that is optimal for detection of signals with unknown parameters. With the purpose to improve the GR performance under noise and interference conditions, the least mean square (LMS) algorithm is proposed for interference cancellation [6]. LMS beamforming algorithm is a non-blind beamforming algorithm that needs a reference signal to update the weight vectors of array antenna with the purpose to form a desired direction vector and generate nulls towards an interference direction [7].

Employment of GR with LMS algorithm requires a prior knowledge about the desired signal. The direction of arrival (DOA) estimation is used to provide the GR with the required information about arrival angles of the received signals. For the past few decades, a wide variety of techniques have been proposed for the DOA estimation. The subspace algorithms such as the multiple signal classification (MUSIC) and estimation of signal parameter via rotational invariance technique (ESPRIT) algorithms are widely used owing to their high resolution [8]. In this paper, the MUSIC algorithm for DOA is employed with LMS algorithm with the purpose to cancel interference. The simulation results demonstrate a good performance at the output of GR with LMS algorithm and MUSIC DOA estimation under the interference cancellation. The rest of this paper is organized as follows: Section 2 presents the simple GR flowchart and main functioning principles. Section 3 discusses the LMS beamformer employed by GR. Implementation of DOA estimation algorithm is introduced in Section 4. The simulation results are discussed in Section 5. The conclusion remarks are given in Section 6.

2. GR STRUCTURE

GR flowchart is presented in Fig. 1. Here, AF is the additional filter used to generate the reference noise and PF is the preliminary filter that can be considered as a band pass filter matched by bandwidth with the desired signal. The AF resonance frequency is detuned relative to the PF resonant frequency on such a value that both the signal and noise can be appeared at the PF output, whereas only the noise is appeared at the AF output. The detuning value must be more than $4 \sim 5$ signal bandwidth. In this case, the correlation coefficient between the processes forming at the PF and AF outputs is not more than 0.05. MSG is the model signal generator generating the reference signal or model signal a_i^M. The stochastic process at the GR output takes the following form:

$$Z_g = \sum_{i=1}^{N} \left(2X_i a_i^M - X_i^2 + \eta_i^2 \right), \tag{1}$$

where

$$a_i^M = \gamma a_i, \tag{2}$$
$$X_i = a_i + \xi_i, \tag{3}$$

a_i is the sample of desired received signal at the PF output, γ is the coefficient of proportionality, X_i is the sample of observed stochastic process at the PF output. η_i and ξ_i are the samples of

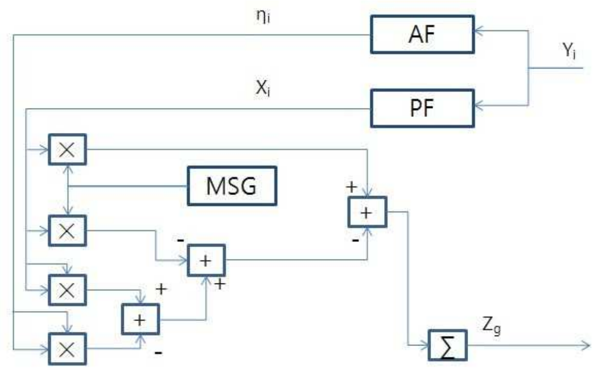

Figure 1: The main structure of GR.

the observed noise at the AF and PF outputs respectively, and $i = 1, 2, \ldots, N$, where N is the sample size. If the reference signal or model signal is identical to the desired signal, i.e., $\gamma = 1$, Equation (1) can be written as

$$Z_g = \sum_{i=1}^{N} (a_i^2 + \eta_i^2 - \xi_i^2). \tag{4}$$

It is well known that $\sum_{i=1}^{N} a_i^2$ is the received signal energy, and $\sum_{i=1}^{N} (\eta_i^2 - \xi_i^2)$ is the background noise formed by AF and PF.

3. GR WITH LMS BEAMFORMER

LMS algorithm is a basic non-blind beamforming algorithm used to reject the interfering signals based on the minimum mean square error (MMSE) criterion and the steepest descent method. Updating the coefficients in weight vector W_i adjusts the phase and amplitude of the input signal, respectively, and the output signal (beamformer output) will be closed to the desired signal. LMS algorithm can be defined by the following equations:

$$M_i = W_{i-1}^T S_i, \tag{5}$$
$$e_i^* = M_i - d_i, \tag{6}$$
$$W_i = W_{i-1} + \mu e_i^* S_i, \tag{7}$$

where M_i is the beamformer output, S_i is the received signal or the beamformer input, d_i is the reference signal in the beamformer, e_i^* is the error between the beamformer output and reference signal, μ is the step size that is called the adaptation rate and must be chosen based on the correlation matrix of S_i, and $*$ denotes the complex conjugate.

In the case when there are interfering signals, the LMS algorithm can be applied at the output of GR to cancel them. The structure of GR with LMS beamformer is shown in Fig. 2. Statistics forming at the GR output when the interference signals are present takes the following form:

$$Z_g = \sum_{i=1}^{N} \left(a_i^2 - 2I_i\xi_i - I_i^2 + \eta_i^2 - \xi_i^2\right), \tag{8}$$

where I_i is the sample of the observed interference signal. In (8), the term $-2I_i\xi_i - I_i^2$ is caused by interaction between the interference and noise that deteriorates the GR performance.

In GR with LMS beamformer, the model signal of LMS beamforming algorithm should be the square of the signal a_i^M due to the fact that the output of the GR is presented as the energy of the signal. According to (5)–(7), we can obtain the following equations:

$$d_i = \left(a_i^M\right)^2, \tag{9}$$
$$M_i = W_{i-1}^T Z_{g_i}, \tag{10}$$

$$e_i^* = W_{i-1}^T Z_{g_i} - \left(a_i^M\right)^2, \tag{11}$$
$$W_i = W_{i-1} + \mu e_i^* Z_{g_i}. \tag{12}$$

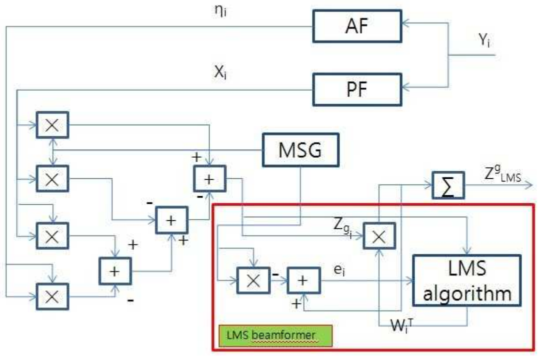

Figure 2: GR with LMS beamformer.

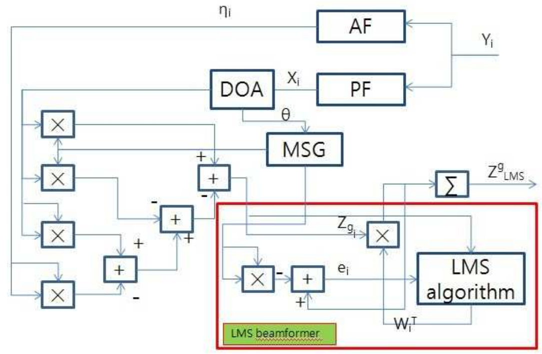

Figure 3: GR with LMS beamformer appling MUSIC algorithm.

Updating the weight vector W_i, the component $-2I_i\xi_i - I_i^2$ in (8) caused by interaction between the interference and noise can be cancelled, and the final output of GR with LMS beamformer can be approximated by (4).

4. UNKNOWN DOA

Both GR and LMS beamformer need a prior knowledge about the desired signal, namely, the DOA to process the received signal. However, the DOA of signals is usually unknown in practical situation, e.g., mobile communication systems. Therefore, it's necessary to apply the DOA estimation technique that estimates the DOA of signals based on array response in the received signal.

The MUSIC algorithm is one of subspace DOA estimation algorithms and has a high resolution technique based on exploiting the eigenstructure of input covariance matrix. MUSIC algorithm assumes that the noise in each channel is uncorrelated and the correlation matrix is diagonal. The incident signals are to be correlated and generate the nondiagonal correlation matrix. The number of incident signals should be less than the number of array elements. If D is the number of signals, M is the number of array elements, the number of signal eigenvalues and eigenvectors is D, and the number of noise eigenvalues and eigenvectors is $M - D$. The array correlation matrix with uncorrelated noise and equal variance is given by

$$\mathbf{R}_{xx} = \mathbf{A}\mathbf{R}_{ss}\mathbf{A}^H + \sigma_n^2\mathbf{I}, \tag{13}$$

where $\mathbf{A} = [a(\theta_1)\, a(\theta_2)\, \dots\, a(\theta_D)]$ is the $M \times D$ array steering matrix, $\mathbf{R}_{ss} = [s_1(t)\, s_2(t)\, \dots\, s_D(t)]^T$ is the $D \times D$ signal correlation matrix, σ_n^2 is the noise variance, and $\mathbf{I}$ is means the identity matrix. $\mathbf{R}_{xx}$ has D eigenvectors associated with signals and $M - D$ eigenvectors associated with the noise. Thus, it is possible to construct the $M \times (M - D)$ noise subspace spanned by the noise eigenvectors using eigenvalue decomposition such that $\mathbf{V}_N = [V_1\, V_2\, \dots\, V_{M-D}]$. The noise subspace eigenvectors are orthogonal to array steering vectors at the angles of arrivals θ_D, and the MUSIC pseudospectrum is given as

$$P_{MUSIC}(\theta) = 1/abs\left\{\mathbf{a}^H(\theta)\mathbf{V}_N\mathbf{V}_N^H a(\theta)\right\}. \tag{14}$$

where $abs\{\cdot\}$ means to take the absolute value. By this way, the DOA can be estimated by searching the spectrum peak.

Figure 3 shows the GR with MUSIC algorithm and LMS beamformer. Here, the MUSIC algorithm is applied at the GR PF output. The estimated DOA is transmitted to MSG to generate the reference signal or model signal. The reference signal or model signal has some error compared with the true value. However, we can neglect this error owing to the high resolution of MUSIC algorithm.

5. SIMULATION RESULTS

The simulation results are persented to evaluate the performance of GR with LMS beamformer when DOA of signals is unknown. Four element uniform linear array (ULA) antenna with half wavelength distance is used to receive signals, and there are three incident signals. The first signal is the desired signal arriving at 10°, the second and third signals are interference arriving at $-60°$ and 60° respectively. These angles are assumed to be unknown and should be estimated by MUSIC

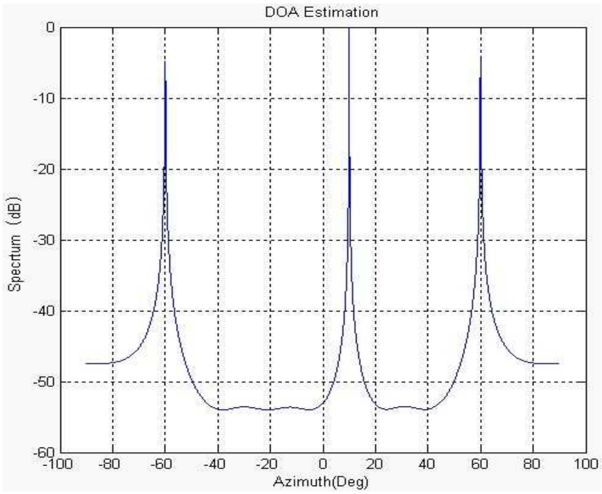

Figure 4: DOA estimation by MUSIC algorithm.

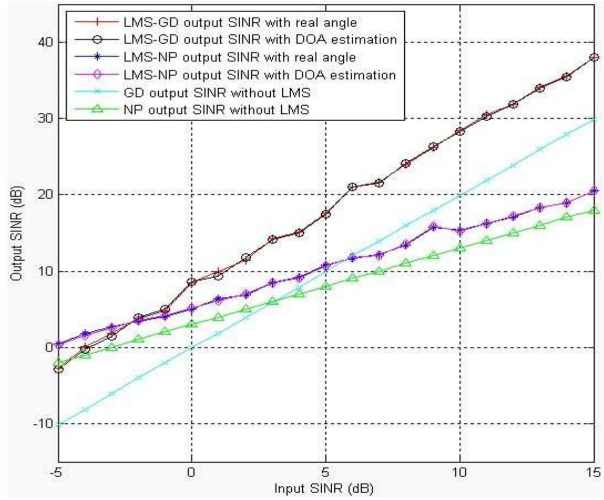

Figure 5: Peformance comparison between GR and NP.

algorithm. All signals are set as Gaussian random sequences with the mean equal to 0. We compare the NP receiver and GR by performance under identical input conditions.

Figure 4 presents the DOA estimation results of MUSIC algorithm. After DOA estimation process, the MSG gets the DOA information about the desired signal and generates the reference signal. The simulation results comparing the NP receiver and GR performances are presented in Fig. 5 in the form of the relation between the input signal-to-interference-noise ratio (SINR) and the output SINR for both receivers. In general case, the output SINR increases when the input SINR increases and the DOA estimation error decrease. We can see from Fig. 5 that GR with LMS beamformer has a good performance for interference cancellation in both cases when LMS beamformer is used. In practice, the GR overcomes NP by detection performance applying the LMS algorithm with and without DOA estimation.

6. CONCLUSION

The GR with LMS beamformer has a good ability for interference cancellation, and MUSIC algorithm is a high resolution technique for DOA estimation. This paper deals with the employment of DOA estimation algorithm (MUSIC) and GR with LMS beamformer when the DOA is unknown. The simulation results show a promising performance that for a practical SINR values, GR overcomes the NP receiver under the same conditions using MUSIC algorithm and LMS beamformer.

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