International Journal of Internet, Broadcasting and Communication Vol.15 No.3 8-13 (2023)
http://dx.doi.org/10.7236/IJIBC.2023.15.3.8

IJIBC 23-3-2

A Signal Detection of Minimum Variance Algorithm on Linear Constraints

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Abstract

We propose a method for removing interference and noise to estimate target information. In wireless channels, information signals are subject to interference and noise, making it is difficult to accurately estimate the desired signal. To estimate the desired information signal, it is essential to remove the noise and interference from the received signal, extracting only the desired signal. If the received signal noise and interference are not removed, the estimated information signal will have a large error in distance and direction, and the exact location of the target cannot be estimated. This study aims to accurately estimate the desired target in space. The objective is to achieve more presice target estimation than existing methods and enhance target resolution.An estimation method is proposed to improve the accuracy of target estimation. The proposed target estimation method obtains optimal weights using linear constraints and the minimum variance method. Through simulation, the performance of the proposed method and the existing method is analyzed. The proposed method successfully estimated all four targets, while the existing method only estimated two targets. The results show that the proposed method has better resolutiopn and superior estimation capability than the existing method.

Keywords: *Linear Constraints, Minimum Variance Algorithm, Beamformer, Weight, Array Antenna, Correlation Matrix.*

1. Introduction

Detecting information about threat targets is an crucial technology for countering enemy threats. Threat target detection technology involves transmitting radio waves from an antenna and analyzing the received signals from the object to estimate information about the threat targets. Methods for detecting, identifying and tracking obstacles have been extensively studied to mitigate risks. Obstacle detection is achieved through signal processing of reflected signals. To accurately estimate the information of the obstacle, noise and interference in the received signal must be removed [1]. Adaptive array signal processing methods to remove interfering signals have been applied in the field of obstacle detection [2]. In radar systems, interference signals are a mixture of multipath received signals reflected from the target and radiated signals from other systems [3].

In addition, the information signal is received with the presence of noise and interference, making it

Manuscript Received: July. 24, 2023 / Revised: August. 4, 2023 / Accepted: August. 07, 2023
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important to have techniques for removing such interference and noise in the receiving system. The method of eliminating interference and noise to obtain the desired information signal is called signal processing technology, which finds application in radar, sonar, science and technology, and mobile communication fields. Numerous researchers are working on antenna polarization techniques, array antenna structures, adaptive array algorithms, and beamforming algorithms [4]. Particular, Frost proposed a linear constrained signal processing technique that maintains unit gain or has a constant response to the target signal to eliminate strong interfering signals originating from a specific direction [5]. Griffith and Jum implemented a linear constrained minimum variance algorithm as an unconstrained side-lobe canceller using adaptive noise cancelling techniques [6-7].

This study proposes a minimum variance algorithm technique for removing multiple interfering signals under linear constraints. Adaptive noise cancellation and optimal weighting of the beam pattern are achived by applying a minimum variance algorithm to the received signal, and the desired information is estimated by forming a zero point in the direction of the interfering signal. The study is organized as follows: Section 2 describes the system model, and Section 3 proposes a minimum variance algorithm for interference cancellation. In Section 4, the performance of the proposed algorithm is simulated, and finally, Section 5 presents the conclusion.

2. System Model

The basic principle of the minimum variance algorithm is to minimize the output power or variance of the system while maintaining the desired response for the desired signal and signal components in a particular direction. The minimum variance algorithm with linear constraints is used in the beamforming method and the receiving system has N receive taps on M array antennas. The received signal vector is represented as follows [8-9].

$$\mathrm{x} = \mathrm{s} + \mathrm{i} + \mathrm{n} \tag{1}$$

Where x is the source signal, i is the interference signal, and n is the noise signal.

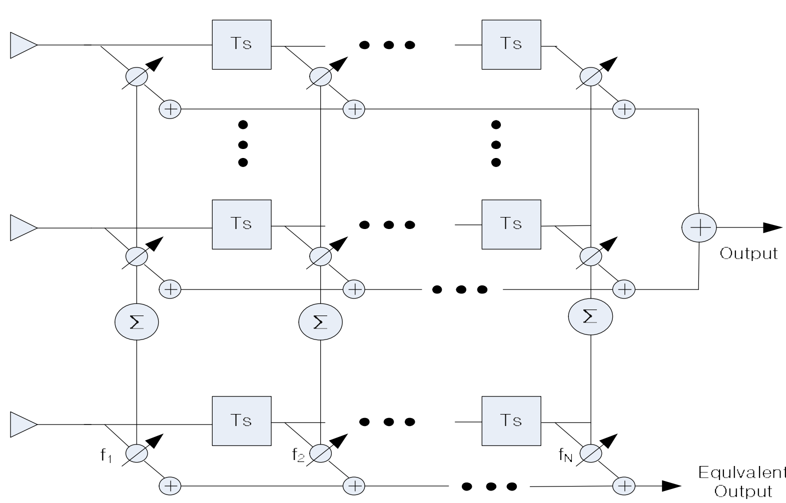


Figure 1. Beamformer System

Figure 1 shows the beamforming system at the receiver, where W is the weight, and T_S is the delay sampling period. If the beamformer is pre-oriented in the direction of the desired information signal, there is no time delay in the target signal component entering the array. The array antenna is assumed to be an omnidirectional sensor, and the information, interference, and noise signals are uncorrelated. The noise signal has a Gaussian distribution with mean 0 and variance σ_n^2. The coefficient vector of the beamformer is defined as follows.

$$\mathrm{W} = [w_1, w_2, \cdots, w_M]^T \tag{2}$$

The output of the beamformer is as follow.

$$\mathrm{Y(k)} = \sum_{m=1}^{M} W_m^* \, X_m(k) = W^H X(k) \tag{3}$$

Were the superscript H denotes the complex conjugate transpose and the output variance is as follows.

$$\mathrm{Var[Y(k)]} = W^H \, E[\mathrm{x}(k)\mathrm{x}(k)^H] W = W^H R \, W \tag{4}$$

Since the information, interference, and noise signals are uncorrelated, the signal correlation matrix is represented by the sum of each signal.

3. Minimum Variance Algorithm on Linear Constraints

If the desired optimum condition is to have the minimum variance output from the beamformer, the optimum coefficient vector is as follows [10-11].

$$W_{op} = \underset{W}{minimize} \; W^H R \, W = R^{-1} R_{\mathrm{xs}} \tag{5}$$

Then $\mathrm{R}_{xs} = \sum_{m=1}^{M} E[\mathrm{x}_1 \mathrm{s}_m]^T$. To maintain constant frequency filtering for signals incident in the directed direction, we assume that there are N constraints. The problem of minimizing the output variance with these linear constraints can be represented by

$$\underset{W}{minimize} \; W^H R \, W \quad subject\ to\ C^H \, W = \mathrm{f} \tag{6}$$

Where R is the covariance matrix and C is the constraint matrix of dimension MX x N.

$$\mathrm{C} = [C_1, C_2, \cdots, C_N] \tag{7}$$

Where C is a column vector with MN x 1 dimensions consisting of the following zeros and ones.

$$C_i = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \\ 0 \end{bmatrix}_{MN \times 1} \tag{8}$$

The beam output for a signal component can be represented as follows.

$$\mathrm{Y}_s(\mathrm{k}) = \sum_{n=1}^{N} W_n^H \, s(k-n) \, \xi \tag{9}$$

Where ξ is a column vector of size M x 1 with each element equal to 1. If $\mathrm{f(n)} = W_n^H \, \xi$, then $Y_s(k)$ can be represented by a FIR filter output that has the form of a single tapped delay line. The $\mathrm{f(n)}$ can also be represented as the sum of the coefficients at each tap, representing the beamformer as single-tapped delay line processor. The vector f is a constraint vector of dimension Nx1 that can be represented as the frequency response to the directed direction.

$$\mathrm{f}=\begin{bmatrix} \mathrm{f}_1 \\ \mathrm{f}_1 \\ \vdots \\ \mathrm{f}_{N-1} \\ \mathrm{f}_N \end{bmatrix}_{N\,\mathrm{x}\,1} \tag{10}$$

The adaptive coefficient vector has N degrees of freedom to maintain the constraints and the remaining NM-N degrees of freedom to minimize the output power. The optimal coefficients behave adaptively in the spatial domain but are fixed by f in the frequency domain. If only white noise is introduced to the signal processor, the input covariance matrix is a unit matrix. In this case, the optimal weighting factor can be represented as follows.

$$\mathrm{W}_c = \mathrm{C}\,(C^H\,C)^{-1}\,\mathrm{f} \tag{11}$$

The constraint matrix C represents the unit gain for the directional signal component and rejects N interfering signals. In the constraint case, it has a gain of 0 dB in the signal direction and forms a null in the direction of the interfering signal. The size of the constraint matrix to handle such a signal can be expressed as follows.

$$\mathrm{C} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 1 & e^{jw\tau_1} & \cdots & e^{jw\tau_N} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & e^{jw(M-1)\tau_1} & \cdots & e^{jw(M-1)\tau_N} \end{bmatrix} \tag{12}$$

Where $\tau_n = 2\pi d cos\theta_n / c$, $\theta_n$is the incidence angle of the n$^{\text{th}}$ interfering signal and c is the propagation speed. The response vector f is given by

$$\mathrm{f}= [1\ 0\ 0\ \cdots 0]^T \tag{13}$$

The optimal weighting coefficients using the minimum variance of the linear constraints can be expressed as follows.

$$\begin{aligned} W_{opt} &= \mathrm{W}_{op} + W_c \\ &= R^{-1}\,C\,(C^H\,R^{-1}\,C)^{-1}\,\mathrm{f} \end{aligned} \tag{15}$$

4. Simulation

This chapter analyzes the performance of the methods proposed in this paper. The antenna array has 64 elements, and the signal-to-noise ratio is set to 23dB. Under these experimental conditions, the interference and noise in the received signal are removed, and the desired target is estimated.

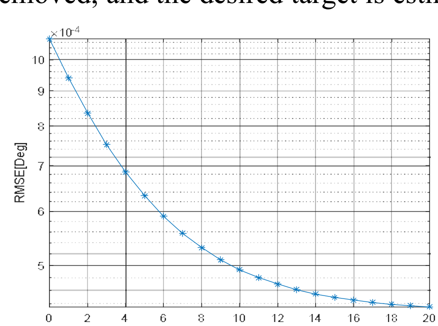
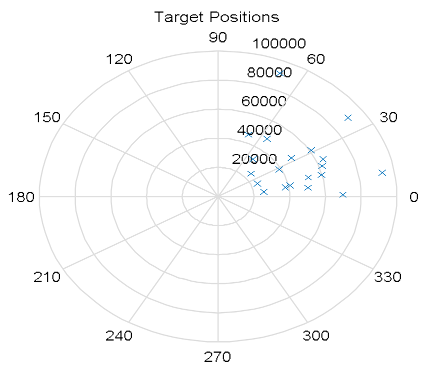
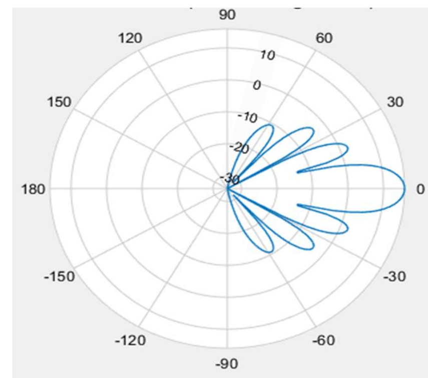


Figure 2. Signal Error by SNR

Figure 2 shows the average received signal analysis error as a function of signal-to-noise ratio. It can be seen that as the signal-to-noise ratio increases, the performance error of the signal decreases. The method of improving the received signal performance by increasing the signal-to-noise ratio is not efficient due to the increase in power.



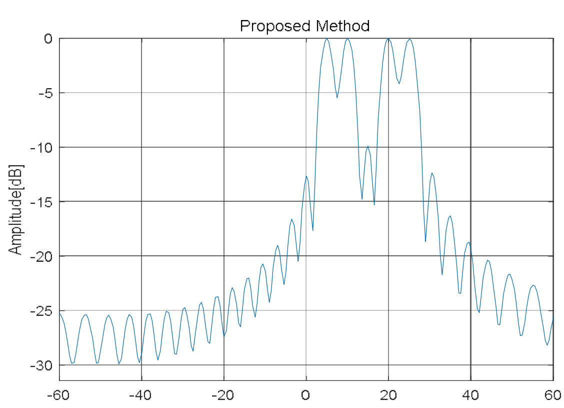
(a) Target Position



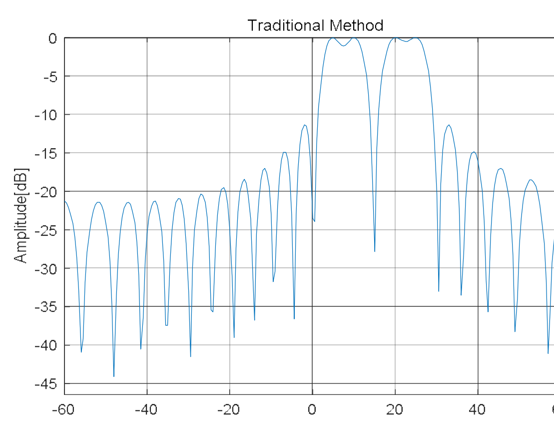
b) Target Beampattern

Figure 3. Target Signal performance

Figure 3(a) shows the distribution of targets from 0 to 30 degrees. Figure 3 shows the distribution of targets from 0 to 30 degrees. The signals to the targets were acquired at a sample rate of 20 MHz with 20k samples per signal. Figure 3(b) shows the beam formation for the targets. It shows the beam pattern after beamforming to a concentrated area of targets. It shows the radiation pattern oriented in the direction of the targets after removing interference, noise, and spurious targets.



(a) Proposed Method



b) Traditional Method

Figure 4. Targets Estimation

Figure 4 shows the target estimation performance of the proposed method and the existing methods in this paper. Figure 4(a) shows that the proposed method correctly estimates all four targets. However, the conventional method in Figure 4(b) fails to estimate four targets due to a significant reduction in target resolution.

5. Conclusion

We conducted a study to accurately estimate the desired target in a wireless channel. Since the information signal is received by adding noise and interference signals, it is important to have a technique to remove the interference and noise in the receiving system. As the transmit power increases and the signal-to-noise ratio improves, the desired target can be accurately estimated. However, these methods have the disadvantage of reducing receiver`s efficiency and incurring costs. Obtaining optimal weights to eliminate non-informative is of utmost importance. In this study, a linear constraint and minimum variance method are proposed to obtain the optimal weights and remove the noise and interference signals. The proposed method eliminates the interference and noise of the received signal to obtain an optimal weighting method that estimates the target more accurately than the existing method. To verify the performance of the proposed method, simulations are conducted, and the results are compared with the existing methods. The simulation results show that the proposed method estimates all targets, while the existing method fails to estimate all targets. It can be seen that the proposed method has better target estimation performance and resolution than the existing method.

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