

A Study on Array Signal Estimation of Desired Target using New Method in Interference and Noise Spatial

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Abstract

In this paper, DOA estimation is an important research area in array signal processing. The performance of adaptive beamforming methods are known to degrade severely in the presence of uncertainty in the signal sight direction. We propose a novel adaptive beamforming with a Bayesian method. Bayesian method a posterior probability density DOA estimator has been shown to perform excellently. The proposed method is based on clear modeling of unknown in the desired signal array response, which provides sufficiently robustness to unknown in desired DOA, enhances the adaptive array system performance. Simulation results showed that the proposed method appear significantly better than performance as compared with general adaptive beamforming method.

Keywords: *Beamforming, Adaptive array, DOA, MUSIC, Resolution*

1. Introduction

The direction of arrival(DOA) estimation have been considered as an interest in array signal processing in radars, sonars, wireless communication, and seismology[1]. When DOA of the desired signal is known exactly, adaptive beamforming techniques provide a distortionless response to the desired signal while suppressing noise and interference [2]. However, adaptive beamformers can suffer significant performance degradation in the presence of the mismatch between the actual DOA of the signal and the look direction of the beamformers. Robust approaches to adaptive beamforming appear to be of primary importance. Direction-of-arrival (DOA) algorithm plays a crucial role in smart antenna system to ensure that the antenna array is able to estimate the direction of the incoming signal and thus, with the aid of adaptive beamforming, to point the array beam towards the estimated direction. The performance of DOA depends on several factors such as the number of element in the array, spacing between elements, number of signal samples (snapshot) and signal-to-noise ratio (SNR) [3]. The early concepts underlying beamforming were first developed for applications in sonar and radar systems. Beamforming represents a quantum step in antenna performance and complexity [4]. It is based on well establishment theoretical concepts which are now becoming practically exploitable, largely as a result of recent major advances in areas such as monolithic microwave integrated circuit technology and digital signal processing technology [5]. Beamforming technology has reached a sufficient level of maturity that it can be applied to communications for improving system performance. The application of beamforming to wireless communications is no longer only a theoretical possibility. It is fast becoming a reality. Furthermore, the demand for

increased capacity is a major driving force for incorporating beamforming into future wireless communications systems. Beamforming is a marriage between antenna technology and digital technology [7]. A generic beamforming antenna system shown in Figure 1 consists of three major components: the antenna array, the transceivers, and the digital signal processor. In a beamforming antenna system, the received signals are detected and digitized at the element level. By capturing the radio frequency information in the form of a digital stream, we open the door to a large domain of signal processing techniques and algorithms that can be used to extract information from the spatial domain data [8]. Beamforming is based on capturing the radio frequency signals at each of the antenna elements and converting them into two streams of binary baseband signals. The beamforming is carried out by weighting these digital signals, thereby adjusting their amplitudes and phases such that when added together they form the desired beam. This process can be carried out using a special purpose signal processor.

Many DOA estimation have been proposed and analyzed during the past decades including beamforming, Capon method, and subspace based methods such as Multiple Signal Classification (MUSIC) method. Many high resolution DOA estimation methods have been developed over the years. Capon method attempts to overcome the poor resolution problems associated with the delay-sum method [9]. Among these methods, MUSIC method is well known for its super resolution feature. However the performance of this method will deteriorate significantly under the low numbers of snapshots and low signal to noise ratio scenarios. More advanced approaches are high resolution methods that are root MUSIC and Estimation of Signal Parameters via Rotational Invariance Technique (ESPRIT) provident high resolution DOA estimation. Bayesian high resolution techniques apply Bayes theorem in DOA estimation become attractive for their superior performance. The Bayesian high resolution DOA estimators require multidimensional grid search which are prohibitively expensive, especially in the presence of large number of sources [10].

In this paper, we propose a new approach beamforming using a Bayesian approach, which improves robustness to uncertainty in the signal look direction. An algorithm combining the Bayesian method and the DOA estimation is proposed. The proposed method has increasing the accuracy of DOA estimation as well as reducing the computational complexity.

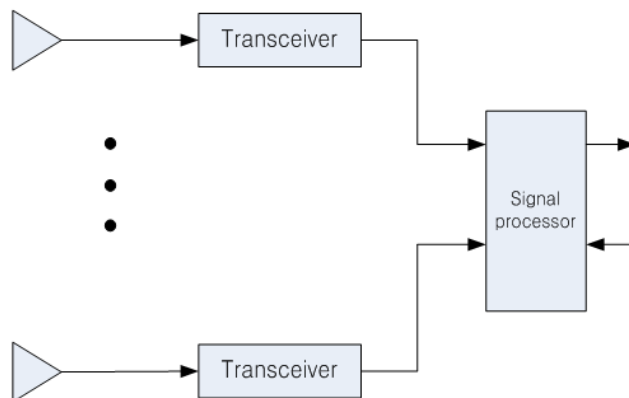


Figure 1. Beamforming antenna system

2. Signal Model Analysis

In this work, we consider array consisting a uniform linear array M narrow band far field static sources with element spacing d and consisting of L identical elements. The received signal in uniform linear array can be written as follow [11-12]

$$X(t) = A s(t) + n(t) \quad (1)$$

where $X(t) = [x_1(t), x_2(t), \dots, x_M(t)]^T$ is the received signal vector by the array at time, $s(t)$ is the signal vector, $A = [a(\theta_1), a(\theta_2), \dots, a(\theta_L)]^T$ is array manifold matrix, $a(\theta_m)$ is steering vector corresponding to the m^{th} source at direction θ_m , and $n(t)$ is additive white noise. Then, the output signal can be written as follow [13-14]

$$y(t) = W^H X(t) \quad (2)$$

Where $W = [w_1, w_2, \dots, w_M]^H$ is the Hermitian weight vector. The signal to noise ratio(SNR) is given by

$$\text{SNR} = \frac{W^H R_S W}{W^H R_N W} \quad (3)$$

Where R_S is signal covariance matrix and R_N is noise signal covariance matrix. we receive signal covariance matrix R_{SN} can be written as follow

$$R_{SN} = E[X(t)X^H(t)] = A R_{SN} A^H + \sigma^2 I \quad (4)$$

Where σ^2 is the variance of the white Gaussian. When there are coherent interferences, the signal covariance matrix is no longer full rank. Therefore all the high resolution DOA estimation methods based one eigen-decomposition and all the adaptive beamforming algorithms. The spatially smoothed covariance matrix can be written as the average of the subarray covariance.

$$\bar{R}_{SN} = \frac{1}{K} \sum_{k=1}^K R_k = A_1 \bar{R}_S A_1^H + \sigma^2 I \quad (5)$$

Where R_k is the covariance matrix with the k^{th} subarray, \bar{R}_{SN} is the modified covariance matrix of the signals. However, linear arrays have limitations in the domain of estimable DOA. \bar{R}_S can be written as follow

$$\bar{R}_S = \frac{1}{K} C C^H \quad (6)$$

Where $C = \Lambda A^T$ with $\Lambda = \text{diag}(L_1, L_2, \dots, L_M)$. Beamforming weight can be written as follow

$$W_{SN} = \frac{a(\theta) R_{SN}^{-1}}{a(\theta) a^H(\theta) R_{SN}^{-1}} \quad (7)$$

3. Proposed Estimation Method

From Bayesian method, the main entity for estimation is the posterior distribution of θ which can be as follow [15-17]

$$p(\theta|X) = \int p(X|\theta, A, \sigma)p(\theta, A, \sigma)dAd\sigma \quad (8)$$

Normalize the Bayesian posterior probability density function can be as follow

$$\bar{p}(\theta|X) = \frac{p(\theta|X)}{\int p(\theta|X)d\theta} \quad (9)$$

Where $\bar{p}(\theta|X)$ is the pdf of θ given the observations and X denotes the received data vector of K snapshots. By applying Bayes rule at Eq(10) can be as follow

$$\bar{p}(\theta|X) = \frac{\exp[\beta K a^H(\theta) R_K a(\theta)]}{\int \exp[\beta K a^H(\theta) R_K a(\theta)]} \quad (10)$$

Where R_K is the sample covariance matrix of X , and β is a monotonically increasing function of SNR. Applying cost function in proposal algorithm minimizes the mean square error while maintaining a distortionless response on the average. The beamforming problem can be formulated as follow

$$\min_W \nabla(W) = E[(d(t) - y(t))(d(t) - y(t))^H] \quad \text{subject to } \bar{a}^H W = 1 \quad (11)$$

Where $d(t)$ is desired signal, and \bar{a} is an average steering vector averaged over $\bar{p}(\theta|X)$.

$$\bar{a} = \int a(\theta) \bar{p}(\theta|X) \quad (12)$$

In order to finding an weight vector, we apply a cost function in Eq(11).

$$\nabla(W, \lambda) = \frac{1}{2} [E(d(t) - y(t))(d(t) - y(t))^H] - \lambda(\bar{a}^H W - 1) \quad (13)$$

Where λ is a Lagrange multiplier. The gradient of Eq(13) can be as follow

$$\frac{\partial}{\partial W} \nabla(W, \lambda) = \frac{\partial}{\partial W} \frac{1}{2} [r(t) r(t)^H] - \lambda \frac{\partial}{\partial W} (\bar{a}^H W - 1) = 0 \quad (14)$$

Where, $r(t) = E[d(t) - y(t)]$. Optimize covariance matrix of Eq(14) can be written as follow

$$W = \frac{E[X(t)r^H(t)] + \bar{a} \lambda}{R_{rr}} \quad (15)$$

Where, $R_{rr} = E[r(t)r(t)^H]$. Inserting Eq(15) into the constraint in Eq(11) taking into account that by definition $\lambda \geq 1$, we can be written as follow

$$\lambda = \frac{1 - \{p(\theta|X) a(\theta) R_{rr}^{-1} E[X(t)r^H(t)]\}}{p(\theta|X) a(\theta)^H p(\theta|X)^H R_{rr}^{-1} a(\theta)} \quad (16)$$

Substituting Eq(16) into Eq(15), we can obtain the optimal weight vector as follow

$$W_p = R_{rr}^{-1} E[X(t)r(t)^H] + R_{rr}^{-1} a(\theta) \frac{1 - \{p(\theta|X) a(\theta) R_{rr}^{-1} E[X(t)r^H(t)]\}}{p(\theta|X) a(\theta)^H p(\theta|X)^H R_{rr}^{-1} a(\theta)} \quad (17)$$

4. Simulation

In this section, we present some simulation to justify the performance of the adaptive beamforming with a Bayesian method. We perform a range of experiments to illustrate the performance of the proposed method. We compare the resolution performance of our method to those of MUSIC. This is followed by a comparison of the requiring sensors for correct detection of general method and the proposed method. We assume that the number of the sources is available to enhance the performance. The spatial grid is uniform in the range -90° to 90° degree with 10° separation between adjacent points. We consider uniform linear array antenna 12 sensors separated by half wavelength, zero mean narrowband Gaussian distributed and uncorrelated sources impinge on the array from far field with distinct DOA. The snapshots are fixed at 100 and sources are with equal SNR of 15dB.

We increase the number of 5 sources at $[-35^\circ -25^\circ 0^\circ 5^\circ 15^\circ]$. We show that Figure 2 correctly estimated a five direction of arrival $[-35^\circ -25^\circ 0^\circ 5^\circ 15^\circ]$ as the proposal method in this paper. It showed to correctly the five DOA estimation at 5 signals $[-35^\circ -25^\circ 0^\circ 5^\circ 15^\circ]$. Figure 3 showed a graph a DOA estimation as the MUSIC method at $[-35^\circ -25^\circ 0^\circ 5^\circ 15^\circ]$. It appeared an error about 2° when MUSIC method estimated DOA in Fig 3. The performance of DOA estimation in the case of SNR=15dB is demonstrated in Table 1. We show that Fig. 4 and Figure 5 decrease resolution. Figure 4 estimated 3 desired signals in $[-3^\circ 2^\circ 5^\circ]$ of proposed method in this paper. It showed to correctly the 3 DOA estimation at 5 signals $[-3^\circ 2^\circ 5^\circ]$. Figure 5 showed a graph a DOA estimation as the MUSIC in $[-3^\circ 2^\circ 5^\circ]$. In case of DOA estimation as MUSIC method in Figure 5, it is correctly estimation not 3 desired signals but 2 desired signals. Existing method decreased resolution than proposed method.

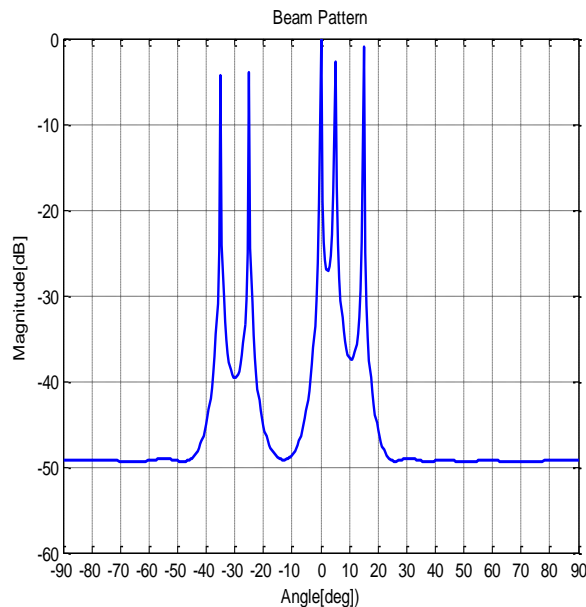


Figure 2. DOA of proposed Method

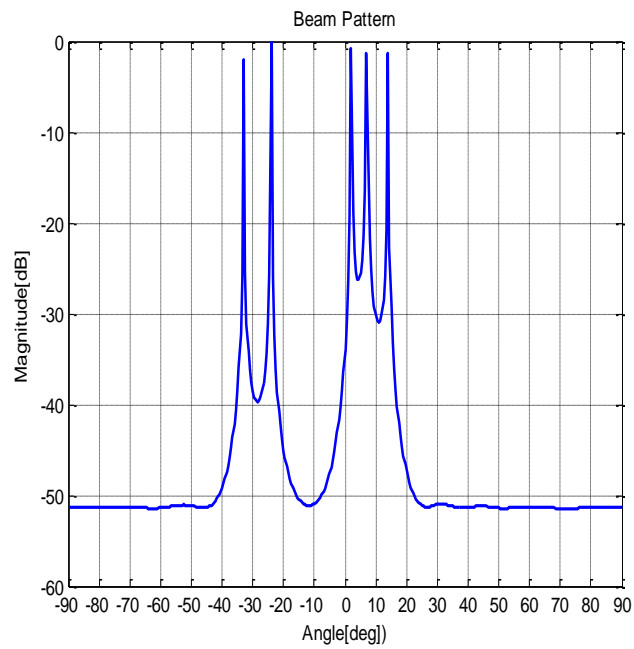


Figure 3. DOA of MUSIC Method

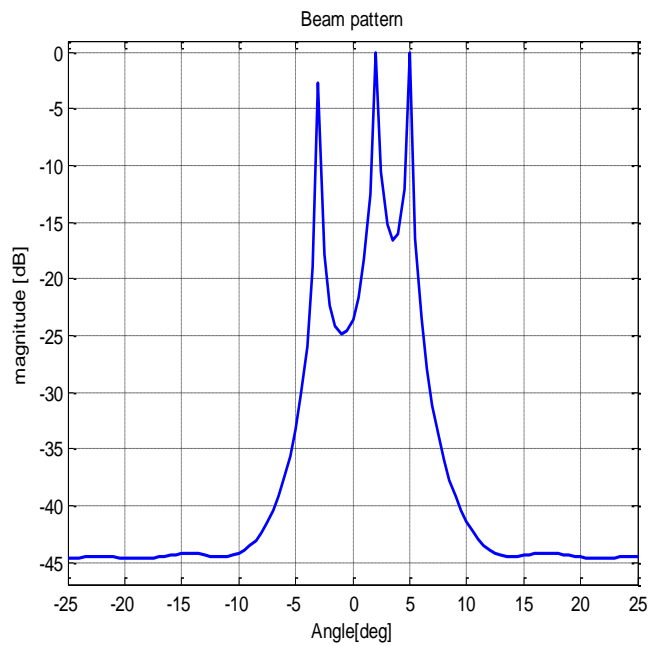


Figure 4. DOA of proposed Method

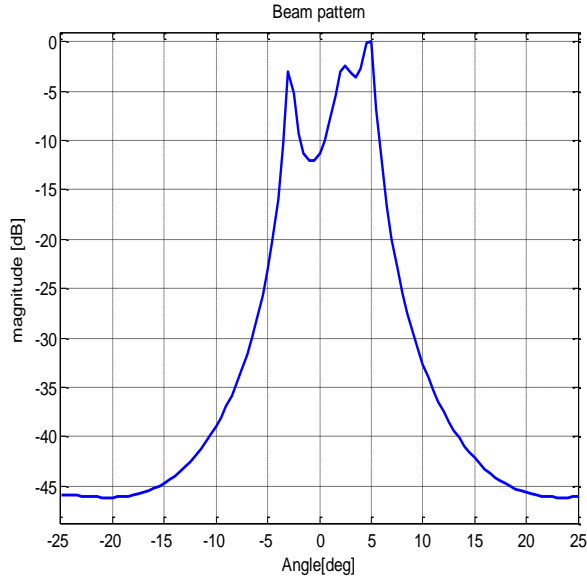


Figure 5. DOA of proposed Method

Table 1. DOA Estimation in Simulation

Method	Estimation angle	
	[-35° 25° 0° 5° 15°]	[-3° 2° 5°]
MUSIC	[-33° 23.5° 0.5° 3° 13.6°]	[-3° x° 5°]
Proposed	[-35° 25° 0° 5° 15°]	[-3° 2° 5°]

5. Conclusion

In this paper, we develop a enhance estimator for DOA, and extend it to a new approach called new DOA method for Bayesian and beamforming. We are proposed that is an adaptive beamforming with a Bayesian method. The proposed beamformer balances the use of observations and a priori knowledge about the source DOA. It is not necessary to detect the number of sources before estimation of DOA. A number of numerical examples clearly demonstrate that the adaptive beamforming algorithm with a Bayesian method described here yields considerably superior performance as compared with the other adaptive beamforming method. The results of computer simulation show that proposal method is good performance better than MUSIC method in DOA.

Acknowledgements

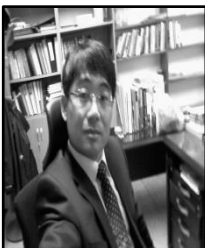
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