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A Novel 2Directional Blind Direction of Arrival Estimation Algorithm for Smart Antenna

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ABSTRACT

It is shown Smart antenna is one of the dynamic research areas in wireless communication systems. The demand for smart antenna increases drastically when dealing with multiuser communication system, which needs to be adaptive, especially in time varying scenarios. Direction of Arrival (DOA) estimation is considered as an important task in smart antennas. It is an important signal parameter which can be used for source localization or source tracking by determining the desired signal location.

Also, it plays a key role in enhancing the performance of adaptive antenna arrays for wireless communication system and other numerous applications in the field of radar and sonar. Therefore, research has been accomplished about DOA estimation during last recent decades. Various DOA estimation methods have been proposed. These methods differ in technique, speed, computational complexity, accuracy and their dependency on the array structure. Different methods have been suggested to enhance the performance of available algorithms including the increase in the accuracy and resolution of DOA estimation algorithms.

Keywords: DOA, MUSIC, ESPRIT.

INTRODUCTION

The accurate and fast DOA estimation of transmitted signals can be done by adaptive array antennas. By suppressing the interfering signals the performance of system can be enhanced [1].Many researcher put effort to develop many algorithm to enhance and estimate the performance of adaptive array antenna system. The DOA estimation algorithms sub-categories to conventional algorithms and subspace algorithms. The MUSIC (Multiple Signal Classification) and ESPRIT (Estimation of Signal Parameters via Rotational Invariant Techniques) are belongs to subspace algorithms. These two algorithms are widely accepted as defacto algorithms for estimation of DOA. We introduce a new algorithm which is as faster as MUSIC.

DOA ALGORITHMS

Music

MUSIC is the most general algorithm to estimate multiple source parameters like azimuth, elevation, range, polarization etc. MUSIC require a priori knowledge of spatial background noise and interferences. It says The desired signal array response is orthogonal to noise subspace [2] . The signal and noise subspace are indentified by using eigen decomposition of the received signal covariance matrix. MUSIC spatial spectrum is calculated. From this DOA is estimated.

In general an array is set in the region of interest in the DOA space.

$$A= \{ a(\theta_i): \theta_i \in \Theta \} \quad (1)$$

The region of θ is extracted from the region of Θ. $a(\theta)$ is the array response vector. The subspace estimation is achieved by eigen decomposition of the auto-covariance matrix of the received data R_{xx}.

It is assumed that the spatial whiteness $\varepsilon\{n(t)n^H(t)\}=\sigma_n^2 I$.The eigen value

$$\lambda_n = \lambda_1 > \lambda_2 > \ldots > \lambda_k > \lambda_{k+1} = \sigma_n^2$$

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The eigenvectors $e_n \in C^N$,n=1,2, . . . N, for R_{xx}

$$E = [E_s, E_n] \tag{2}$$

$$= E_s \Lambda_s E_s^H + \sigma_n^2 E_n E_n^H = E_s \bar{\Lambda}_s E_s^H + \sigma_n^2 I \tag{3}$$

Where E = [e_1, e_2, . . . e_N],

E_s = [e_1, e_2, . . . e_k],

E_n = [e_{k+1}, e_{k+2}, . . .e_N],

Λ = diag { λ_1, λ_2, . . . λ_N},

Λ_s= diag { λ_1, λ_2, . . . λ_K},

Λ_n= diag { λ_{k+1}, λ_{k+2}, . . . λ_N}, and

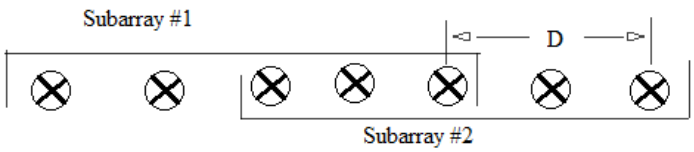
$\bar{\Lambda}_s = \Lambda_s - \sigma_n^2 I$. The eigen vector $E = [E_s, E_n]$ can be assumed to form an orthogonal basis. The span of K vector E_s defines the signal subspace and E_n defines the noise subspace. After determining the subspaces the DOA of the desired signal can be calculated through MUSIC algorithms [3]

$$P_{MUSIC}(\theta) = \frac{a^H(\theta)a(\theta)}{a^H(\theta)E_n E_n^H a(\theta)} \tag{4}$$

ESPRIT

Estimation of Signal Parameters via Rotational Invariance Techniques

An antenna comprise of two identical sub arrays. Some antenna array elements may be member of both sub arrays[4]. Let an array contains M elements and m elements are member of both sub array(so that M < 2m). The individual elements of sub array can have arbitrary polarization, directional gain, phase response.



Let "d" signals impinging onto the array. Let **x**1(*t*) and **x**2(*t*) are signal received by the two sub arrays and let the received signals are corrupted by additive noise **n**1(*t*) and **n**2(*t*). Each of the sub-arrays has *m* elements. The elements are separated by a fixed displacement vector D. The received signals be expressed as

$$x_1(t) = [a(\mu_1), \ldots a(\mu_d)]s(t)] + n_1(t)$$

$$= A_1 \Theta s(t) + n_1(t) \tag{5}$$

$$x_2(t) = [a(\mu_1)e^{j\mu 1}, \ldots a(\mu_d)e^{j\mu d}]s(t)] + n_2(t)$$

$$= A_2 \Theta s(t) + n_2(t) \tag{6}$$

$x_1(t)$ and $x_2(t)$ are the m x 1 vectors represents received data of ist and 2nd sub array. $n_1(t)$ and $n_2(t)$ are m x 1 noise vectors. $A_1\Theta$ and $A_2\Theta$ belongs to $C^{m \times k.}$ This indicates the manifold of each sub array is unitary diagonal matrix

Let J1 and J2 represent the M x m selection matrix .

$$J_1 = 0_M \times (m - M) \vdots I_m \tag{7}$$

$$J_2 = 0_M \times (m - M) \vdots I_m \tag{8}$$

I_m is the M x M identity matrix and $0_{M \times (m-M)}$ is the M x (m-M) matrix of zeros. The two identical sub arrays satisfies

$$\theta_K = \sin^{-1}\{\frac{\arg\{\}}{\frac{2\pi}{\lambda}D}\}, i=0,1...K \quad JA(\Theta)=\begin{bmatrix} J_1 \\ J_2 \end{bmatrix} A(\Theta)=\begin{bmatrix} A_1(\Theta) \\ A_1(\Theta)\Phi \end{bmatrix} \tag{9}$$

Where Φ is the diagonal matrix and

$$\Phi_i = \exp\{-j\beta_i^T.D\}, i=1,2..K \tag{10}$$

β_i = vector wave number of incident plane from i^{th} narrow band source

D= vector displacement between two sub array.

E_s = eigenvector corresponding to K largest eigenvalues of received signal

$$E_s \triangleq \begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \begin{bmatrix} A_1(\Theta) \\ A_1(\Theta)\Phi \end{bmatrix} T \tag{11}$$

T is full rank matrix and $T \in C^{K \times K}$.

Solving the equation (11) we can get

$$E_2 = E_1 T^{-1} \Phi T = E_1 \Psi \tag{12}$$

Where $\Psi = T^{-1}\Phi T$ or $\Phi = T\Psi T^{-1}$. So eigen values of Ψ must be equal to diagonal elements of Φ. This is the fundamental relation in the properties of ESPRIT. If M > K and D= $|D| < \frac{\lambda}{2}$. From the eigen values of operator Ψ, E_1 and E_2, DOA can be determined .

$$\theta_K = \sin^{-1}\{\frac{\arg\{\Psi_i\}}{\frac{2\pi}{\lambda}D}\}, i=0,1...K \tag{13}$$

Ψ_i is the each eigen value of Ψ matrix.

DIRECTION OF ARRIVAL ESTIMATION BY ADAPTIVE ARRAY ANTENNA PLANE

A new technique for 2 D DOA estimation of signals impinging on the array, [5] using mechanical rotation of the array plane by small angle (Azimuth & Elevation) has been proposed for further analysis and discussion. For an adaptive antenna system, [if p users transmit signals from different locations, and each user's signal arrives at the array through multiple paths.

Let LMi denote the number of multipath components of ith user. We have $\sum_{i=1}^{p} LM_i = p$. Let's further assume that all of the multi path components for a particular user arrive within a time window which is much less than the channel symbol period for that user, then the input data vector could be expressed as-

$$x(t) = \sum_{i=1}^{p}\sum_{k=1}^{LMi} \alpha_{i,k} a(\theta_{i,k}) s_i(t) + n(t) \tag{14}$$

or we can write

$$x(t) = \sum_{i=1}^{p} G_i s_i(t) + n(t) \tag{15}$$

where $\theta_{i;k}$ is the DOA of the k-th multi path component for the i-th user, $a(\theta_{i;k})$ is the steering vector corresponding to $\theta_{i;k}$, $\alpha_{i;k}$ is the complex amplitude of the k-th multipath component for the i-th user, and G_i is the spatial signature for the i-th user and is given by

$$G_i = \sum_{k=1}^{L_{Mi}} \alpha_{i,k} a(\theta_{i,k}) \tag{16}$$

The signal component arriving on *n*th antenna element at a particular instance of time is given by [6]

$$X_n = A\exp(j2\pi\, ndsin\theta\cos\phi/\lambda) \tag{17}$$

$$Y_n = A\exp(j2\pi\, ndsin\theta\sin\phi/\lambda) \tag{18}$$

Where A= complex amplitude of the signal, φ = Direction of Arrival (DOA) of the signal (Azimuth Angle) (unknown), θ = Direction of Arrival (DOA) of the signal (Elevation Angle) (unknown), d= spacing between antenna elements and λ = wavelength.

Now one can view (4) & (5) as-

$$X_n = A\exp[j2\pi f(dsin\theta\cos\phi/c)] \tag{19}$$

$$Y_n = A\exp[j2\pi f(dsin\theta\sin\phi/c)] \tag{20}$$

Where f= frequency of the signal and c= velocity of wave.

Now if we mechanically steer the antenna plane by $\delta\varphi$ & $\delta\theta$, then (19) & (20) becomes –

$$X^1{}_n = A\exp[j2\pi f(dsin\theta\cos(\phi+\delta\phi)/c)] \tag{21}$$

$$Y^1{}_n = A\exp[j2\pi f(dsin\theta\sin(\phi+\delta\phi)/c)] \tag{22}$$

$$X^2{}_n = A\exp[j2\pi f(dsin(\theta+\delta\theta)\cos\phi/c)] \tag{23}$$

$$Y^2{}_n = A\exp[j2\pi f(dsin(\theta+\delta\theta)\sin\phi/c)] \tag{24}$$

Now taking the frequencies (which can be known by seeing the spectra of the signal) of the signal from (19) and (21), and taking their ratio one could get-

$$\frac{frequency \to X_n}{frequency \to X^1{}_n} = \frac{\cos\phi}{\cos(\phi+\delta\varphi)} = \frac{1}{k} \text{ (k is known)}$$

Hence $$\phi = \tan^{-1}[\frac{\cos\delta\phi - k}{\sin\delta\phi}] \tag{25}$$

And from (20) & (24), we could get

$$\frac{frequency \to Y_n}{frequency \to Y^1{}_n} = \frac{\sin\theta}{\sin(\theta+\delta\theta)} = \frac{1}{k} \quad \theta = \cot^{-1}[\frac{k-\sin\theta}{\cos\delta\theta}] \tag{26}$$

Now using the simple relation given in (25) & (26) one can determine the unknown DOA (θ &φ)of all incoming signal impinging on the array with suitable algorithm based on (19), (20), (21),(22),(23),(24),(25) and (26).

Simulation

The simulation for DOA based on MUSIC, ESPRIT and our novel algorithms for 2 D are simulated through MATLAB 13.

Patterns due to MUSIC

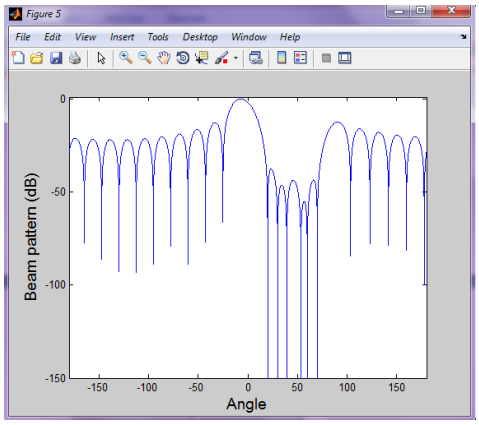


Fig1. *Rectangular pattern due to MUSIC*

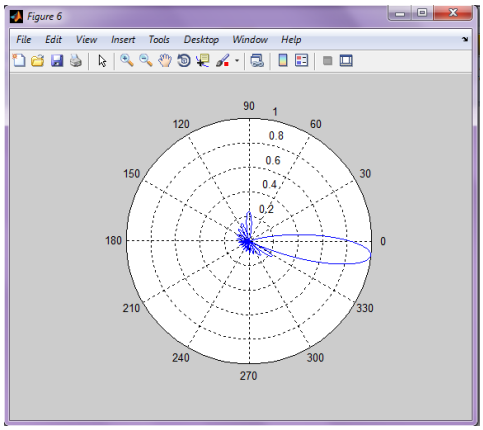


Fig2. *Polar pattern due to MUSIC*

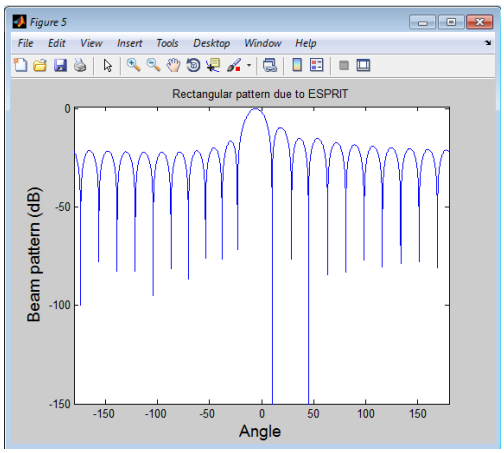


Fig3. *Radiation pattern based on ESPRIT algorithm*

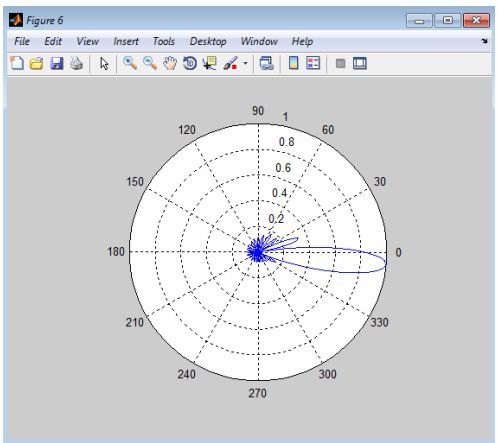


Fig4. *Polar pattern due to ESPRIT*

Pattern Due to Our Novel Algorithm

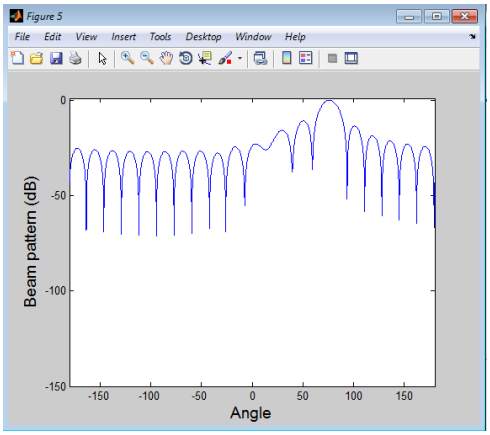


Fig5. *Rectangular pattern due to Novel Algorithm*

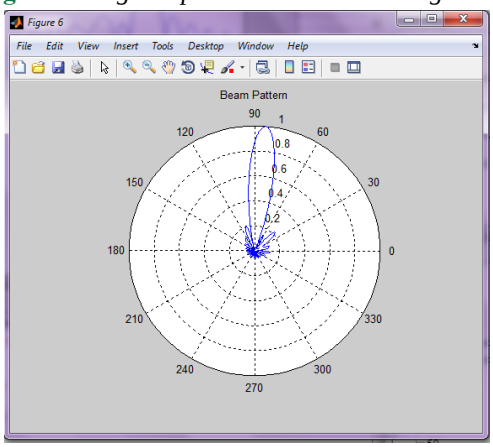


Fig6. *Polar pattern due to Novel Algorithm*

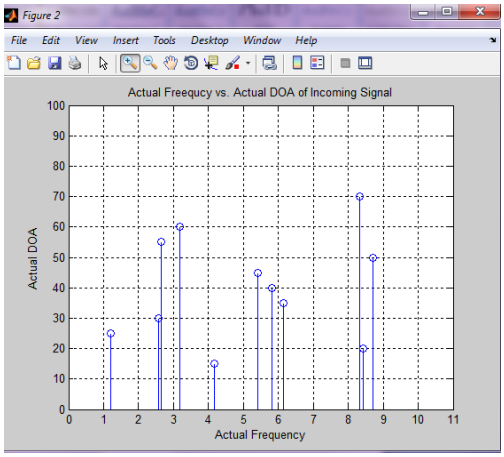


Fig7. *Actual freq. Vs Actual DOA*

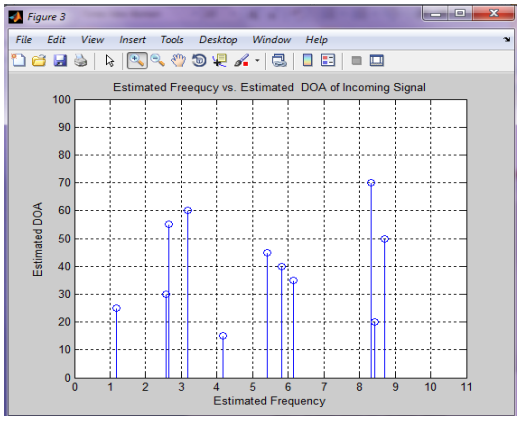


Fig8. *Estimated Freq. Vs Estimated DOA*

OBSERVATION

We did a compared our algorithm with MUSIC and ESPRIT. We simulate all three algorithms. From the Polar plot patterns it is observed that the minor lobe is substantially cancelled and the major lobe is more directional towards the desired angle.

The DOA estimation is presented in tabular form. There are 6 pair of angles are considered between 0 $<x_i<90^0$.

Table1.

ANGLE in DEGREE		DOA BASED ON MUSIC	DOA BASED ON NOVEL ALGORITHM
ELIVATION	AZIMUH		
20	45	19.9983	20.1067
30	55	29.9967	29.9850
40	48	39.1880	40.0276
50	37	53.5397	49.9955
60	25	60.0032	60.0051
70	15	70.0125	70.0009

At x_1, x_2, x_3, x_4, x_5, x_6, are 20 45;30 55;40 48;50 37;60 25;70 15.

The comparative DOA based on MUSIC and our proposed algorithms are presented in the above table.

CONCLUSIONS

For DOA estimation through MUSIC, it requires a priori knowledge of spatial background noise and interferences. In the case of ESPRIT is required minimum 2 sub arrays and very complex computation.

The proposed algorithm is very simple & it neither required a priori knowledge of background noise nor it needs complex calculations. It consumes minimum time for calculation the DOA. A adequate hardware can be designed for use.

The main lobe is more directional and side lobes are cancelled and more reduced w.r.t that of MUSIC and ESPRIT.

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