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.

\[ A = \{ a(\theta_i): \theta_i \in \Theta \} \] (1)

The region of \( \Theta \) is extracted from the region of \( \Theta \). \( a(\theta) \) 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 \( \{n(t)n^H(t)\} = \sigma_n^2 I \). The eigen value

\[ \lambda_n = \lambda_1 > \lambda_2 > \ldots > \lambda_k > \lambda_{k+1} = \sigma^2_n \]

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

$$E = [E_s, E_n]$$

$$= E_s \Lambda_r E_r^H + \sigma_n^2 E_n E_n^H = E_s \Lambda_r E_r^H + \sigma_n^2 I \quad (2)$$

Where $E = [e_1, e_2, \ldots , e_N],

E_s = [e_1, e_2, \ldots , e_K],

E_n = [e_{K+1}, e_{K+2}, \ldots , e_N],

\Lambda = \text{diag} \{ \lambda_1, \lambda_2, \ldots , \lambda_N \},

\Lambda_s = \text{diag} \{ \lambda_1, \lambda_2, \ldots , \lambda_K \},

\Lambda_n = \text{diag} \{ \lambda_{K+1}, \lambda_{K+2}, \ldots , \lambda_N \},

\text{and}

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

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

**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

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

$$= A_1\Theta s(t) + n_1(t) \quad (5)$$

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

$$= A_2\Theta s(t) + n_2(t) \quad (6)$$

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

Let $J_1$ and $J_2$ represent the $M \times m$ selection matrix.

$$J_1 = 0_M \times (m-M) : I_m \quad (7)$$

$$J_2 = 0_M \times (m-M) : I_m \quad (8)$$
I_m is the M x M identity matrix and 0_{M x (m-M)} is the M x (m-M) matrix of zeros. The two identical sub arrays satisfies

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

(9)

Where \( \Phi \) is the diagonal matrix and

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

(10)

\( \beta_i \) = 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

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

(11)

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

Solving the equation (11) we can get

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

(12)

Where \( \Psi = T^{-1} \Phi T \) or \( \Phi = T \Psi T^{-1} \). So eigen values of \( \Psi \) must be equal to diagonal elements of \( \Phi \).

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 \( \Psi \), \( E_1 \) and \( E_2 \), DOA can be determined.

$$\theta_k = \sin^{-1}\left\{\frac{\text{arg} \{\Psi_i\}}{2\pi \frac{D}{\lambda}}\right\}, i=0,1...K$$

(13)

\( \Psi_i \) is the each eigen value of \( \Psi \) 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, [I] if \( p \) users transmit signals from different locations, and each user's signal arrives at the array through multiple paths.

Let \( L M_i \) denote the number of multipath components of \( i^{th} \) user. We have \( \sum_{i=1}^{p} L M_i = p \). 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-

$$x(t) = \sum_{i=1}^{p} \sum_{k=1}^{L M_i} a_i(\theta_i, k) s_i(t) + n(t)$$

(14)

or we can write

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

(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

$$G_i = \sum_{\theta} a(\theta) a^*(\theta)$$  \hspace{1cm} (16)

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

$$X_n = A \exp(j2\pi nd\sin \theta \cos \phi / \lambda)$$  \hspace{1cm} (17)

$$Y_n = A \exp(j2\pi nd\sin \theta \sin \phi / \lambda)$$  \hspace{1cm} (18)

Where $A$= complex amplitude of the signal, $\varphi$ = Direction of Arrival (DOA) of the signal (Azimuth Angle) (unknown), $\theta$ = Direction of Arrival (DOA) of the signal (Elevation Angle) (unknown), $d$= spacing between antenna elements and $\lambda$ = wavelength.

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

$$X_n = A \exp[j2\pi f (\sin \theta \cos \phi / c)]$$  \hspace{1cm} (19)

$$Y_n = A \exp[j2\pi f (\sin \theta \sin \phi / c)]$$  \hspace{1cm} (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 –

$$X_n^1 = A \exp[j2\pi f (\sin \theta \cos (\phi + \delta \phi) / c)]$$  \hspace{1cm} (21)

$$X_n^2 = A \exp[j2\pi f (\sin \theta \sin (\phi + \delta \phi) / c)]$$  \hspace{1cm} (22)

$$X_n^1 = A \exp[j2\pi f (\sin (\theta + \delta \theta) \cos \phi / c)]$$  \hspace{1cm} (23)

$$Y_n^2 = A \exp[j2\pi f (\sin (\theta + \delta \theta) \sin \phi / c)]$$  \hspace{1cm} (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-

$$\frac{\text{frequency} \rightarrow X_n}{\text{frequency} \rightarrow X_n^1} = \frac{\cos \phi}{\cos(\phi + \delta \phi)} = \frac{1}{k} \quad (k \text{ is known})$$

Hence

$$\phi = \tan^{-1}\left[\frac{\cos \delta \phi - k}{\sin \delta \phi}\right]$$  \hspace{1cm} (25)

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

$$\frac{\text{frequency} \rightarrow Y_n}{\text{frequency} \rightarrow Y_n^1} = \frac{\sin \theta}{\sin(\theta + \delta \theta)} = \frac{1}{k} \quad \theta = \cot^{-1}\left[\frac{k - \sin \theta}{\cos \delta \theta}\right]$$  \hspace{1cm} (26)

Now using the simple relation given in (25) & (26) one can determine the unknown DOA ($\theta$ & $\varphi$)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
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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

Fig 5. Rectangular pattern due to Novel Algorithm

Fig 6. Polar pattern due to Novel Algorithm

Fig 7. Actual freq. Vs Actual DOA

Fig 8. 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< 90°.

<table>
<thead>
<tr>
<th>ANGLE in DEGREE</th>
<th>DOA BASED ON MUSIC</th>
<th>DOA BASED ON NOVEL ALGORITHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELIVATION AZIMUH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 45</td>
<td>19.9983</td>
<td>20.1067</td>
</tr>
<tr>
<td>30 55</td>
<td>29.9967</td>
<td>29.9850</td>
</tr>
<tr>
<td>40 48</td>
<td>39.1880</td>
<td>40.0276</td>
</tr>
<tr>
<td>50 37</td>
<td>53.5397</td>
<td>49.9955</td>
</tr>
<tr>
<td>60 25</td>
<td>60.0032</td>
<td>60.0051</td>
</tr>
<tr>
<td>70 15</td>
<td>70.0125</td>
<td>70.0009</td>
</tr>
</tbody>
</table>

At x₁, x₂, x₃, x₄, x₅, x₆, 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.

REFERENCES

[5] Mainak Mukhopadhyay, Ajay Chakrabarty “ low side lobe adaptive array processing with multipath constraint for anti-jam gps receiver” ursi.org/proceedings/procGA05
AUTHORS’ BIOGRAPHY

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