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DOA Estimation of Near-Field Coherent Wideband Distributed Microphone Array Signals

Current Progress and Outlook

Present By: Cui Ao

Content

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1. A Summary of Vocation Study

1. Summary of vocation study

Assuming our signal sources are the noises from turbo fan engines installed on commercial jet plane. As left figure shows, this is the sound pressure level(SPL) vs frequency characteristics of a turbo fan engine.[1]
Apparently, this signal is a wideband signal, and the major frequency parts of this signal can be higher than 8000Hz. Respect to the standard sound speed, the wave length of this signal can be shorter that 0.0425m.

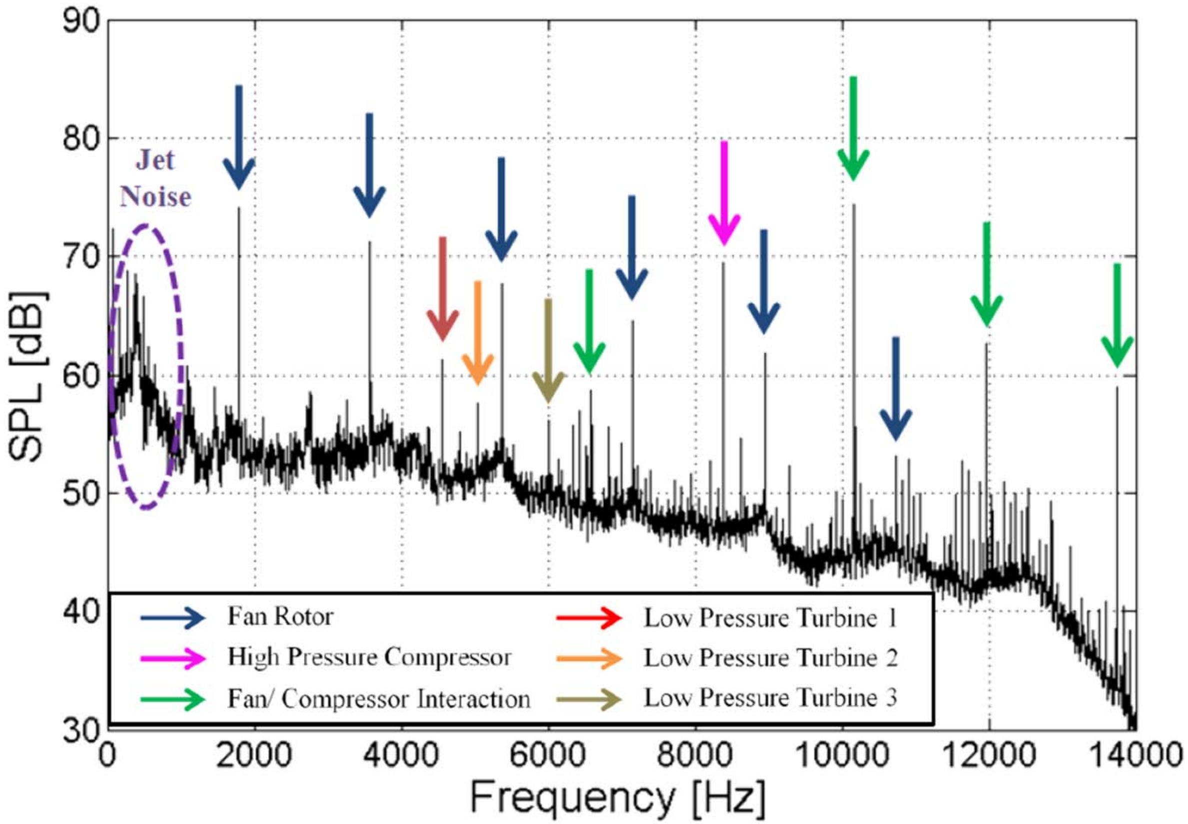

Figure 1-1 Recorded EVNERT Spectrum (48% power setting, 75° emission angle)

1. Summary of vocation study

By considering the application scenarios, the array elements should tied with the light system of airport. Based on the Aerodrome Technical Standard published by CAAC[2], the minimum array aperture D_{min} should be:

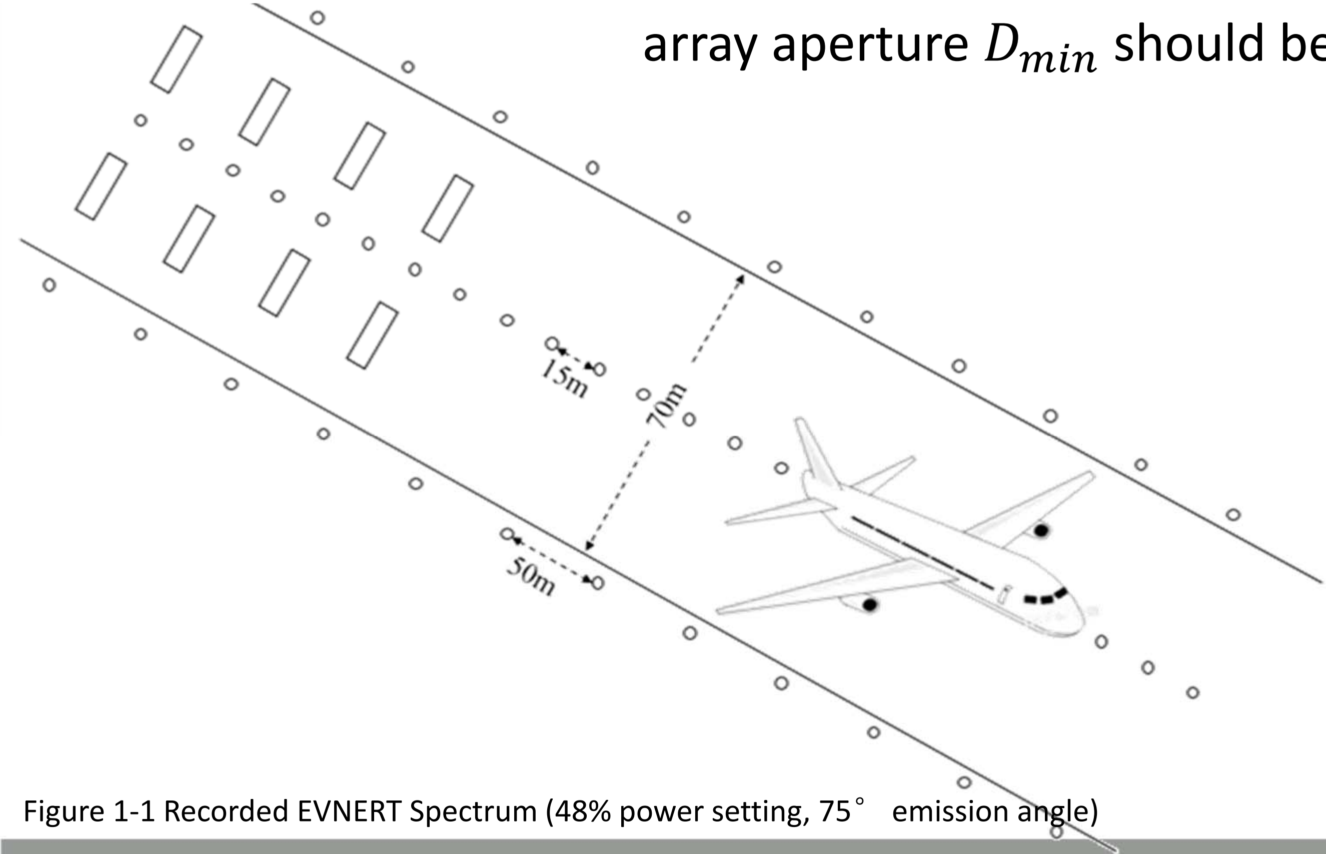

Figure 1-1 Recorded EVNERT Spectrum (48% power setting, 75° emission angle)

$$D_{\min} = 15m$$

Based on the conclusion from [3], we have the Near/Far-Field criterion:

$$r_{normal} = 35 \ll \frac{2D_{\min}^2}{\lambda_{\min}}$$

Thus made this signal source a near-field model.

1. Summary of vocation study

After framing the received signal, assuming the reference element locate at the origin, the position vector of signal source S and the n_{th} element should be:

$$S = r_0 \begin{bmatrix} \sin\theta\cos\varphi \\ \sin\theta\sin\varphi \\ \cos\theta \end{bmatrix} \qquad n_{th} = [x_n \quad y_n \quad 0]$$

Apply the near-field sound signal model based on sphere-sound source, we can derive the steering vector:

$$\begin{cases} r_n = \sqrt{(x_n - r_0\sin\theta\cos\varphi)^2 + (y_n - r_0\sin\theta\sin\varphi)^2 + (r_0\cos\theta)^2} \\ \tau_n = (r_n - r_0)/v \\ v = \lambda_k f_k \end{cases}$$

$$a(f_k) = [\frac{r_0}{r_1}e^{-j2\pi f_k \tau_1}, \ldots .\frac{r_0}{r_n}e^{-j2\pi f_k \tau_n}, \ldots .\frac{r_0}{r_N}e^{-j2\pi f_k \tau_N}]^T$$

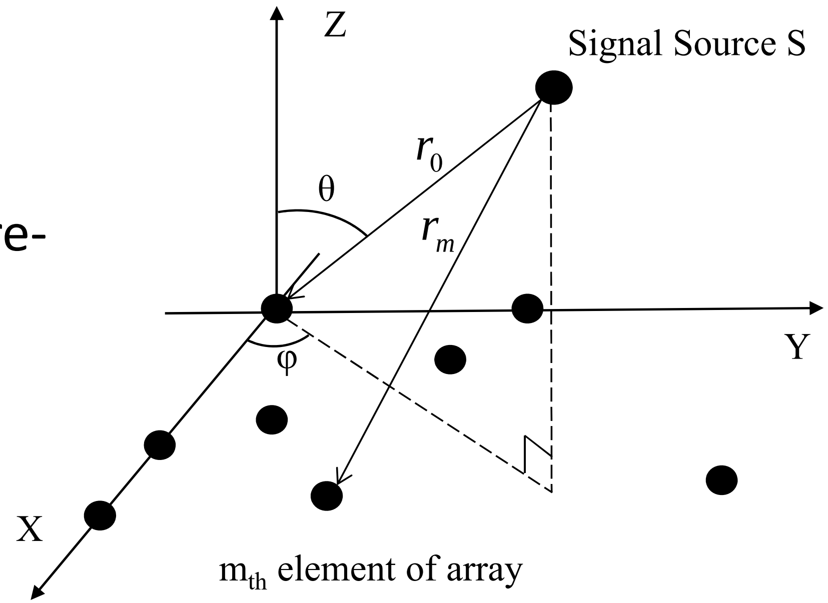

Figure 1-1 Recorded EVNERT Spectrum (48% power setting, 75° emission angle)

1. Summary of vocation study

Extended to M incident signals, based on the priori knowledge of array structure, we can have a steering matrix consist of M steering vectors at f_k:

$$\mathbf{A}(f_k) = [a_1(f_k), a_2(f_k), \cdots, a_M(f_k)]$$

And the received signal at f_k can be expressed as:

$$\begin{bmatrix} x_1(f_k) \\ x_2(f_k) \\ x_3(f_k) \\ \vdots \\ x_N(f_k) \end{bmatrix} = [a_1(f_k), a_2(f_k), a_3(f_k), \ldots, a_M(f_k)] \cdot \begin{bmatrix} s_1(f_k) \\ s_2(f_k) \\ s_3(f_k) \\ \vdots \\ s_M(f_k) \end{bmatrix} + N(f_k)$$

$$\mathbf{X}(f_k)_{N\times 1} = \mathbf{A}(f_k)_{N\times M}\mathbf{S}(f_k)_{M\times 1} + \mathbf{N}(f_k)_{N\times 1}$$

1. Summary of vocation study

In general, commercial plane usually have more than one engine installed. And the sound signals from those engines belong to one plane or sub-band signal from one wideband signal are very familiar or coherent because of the symmetrical thrust applied on them. Therefore traditional ISM DOA method (like MUSIC algorithm) will not meet the need directly. However, current CSM DOA need to built a focus matrix based on the PSD estimation. Then focus on the sub-bands which carry the major power to perform sub-band ISM DOA. The process of this method can be briefly illustrated as:

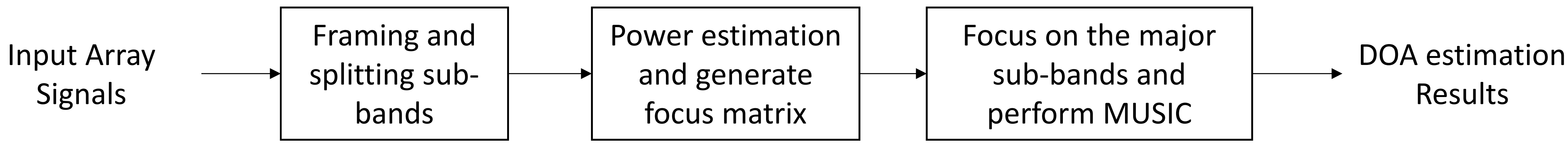

Figure 1-1 Recorded EVNERT Spectrum (48% power setting, 75° emission angle)

1. Summary of vocation study

MUSIC Algorithm:

Correlation matrix of received Signal at f_k:

$$\mathbf{R}(f_k) = E\left[\mathbf{X}(f_k)\mathbf{X}^H(f_k)\right]$$
$$= \mathbf{A}(f_k, r, \theta, \varphi) R_s(f_k) \mathbf{A}^H(f_k, r, \theta, \varphi) + \sigma_k^2 \mathbf{I}$$

Singularity Value Decomposition:

$$\sigma_k^2 \rightarrow \mathbf{U}_{N\times(N-M)}$$

MUSIC DOA Spectrum:

$$P_{MUSIC}(r, \theta, \varphi) = \frac{1}{D}\sum_{i=1}^{D} P_{MUSIC}(f_k, r, \theta, \varphi)$$
$$= \frac{1}{D}\sum_{i=1}^{D} \frac{1}{\mathbf{a}^H(f_k, r, \theta, \varphi)\mathbf{U}\mathbf{U}^H\mathbf{a}(f_k, r, \theta, \varphi)}$$

1. Summary of vocation study

Based on Zhou He’s conclusions, which also related to the array aperture, L-shaped array achieves better performance on CRLB and RMSE by comparing with Y-shaped and V-shaped array structures.

In general, a better performance on space resolution usually related to a larger array aperture. However, limited element number in such a large array may lead to a large element interval. When the element interval larger than a half of the minimum wavelength, ghost peak (or ambiguity) occurs. Zhou He proposed to use two different arrays to apply joint DOA estimation in order to resolve the ambiguity. And the simulation shows that this method works. However, his work mainly based on the experimental observation and didn’t point out what relationship those two array should be satisfied to resolve the estimation ambiguity. We will talk about this question in detail later.

2. Investigation

2. Investigation: Studies on this field

1. Method of Solving Ambiguity for Space Array via Power Estimation(2012)

The method consist of two steps. The first step is to obtain all the DOAs, including true and spurious DOAs, by traditional MUSIC. The second step is to estimate the power values of the all DOAs by substituting the all DOAs to a cost function. And the Newton-like or the particle swarm optimization (PSO) method is used to estimate the power values. The power values of spurious DOAs are very small or tend to zero compared with the values of the true DOAs. The true DOAs are then differentiated easily from the spurious DOAs with the power values.

2. Investigation: Studies on this field

2. Resolving Manifold Ambiguities for Sparse Array Using Planar Substrates(2012)

The ambiguity caused by the fact that the steering vector of spurious DOA of non-trivial ambiguities is a linear combination of the steering vectors of true DOAs. When some substrates, whose parameters are different from each other, are added at some front-ends of the elements of an array, the equivalent positions of the elements change for different DOAs after adding the substrates on the array, and the spurious peaks will disappear or not overlap on the old peaks.

2. Investigation: Studies on this field

3. Method of Resolving Ambiguity for Sparse Array via Modified Sparse Even Array based on MUSIC Algorithm(2009)

Firstly, uses the data from original array to do DOA; Then, modified the array slightly. Finally, uses the two received data to do DOA in the same reference frame, which can separate the ambiguity angle from the two spectrum functions to get the real DOA. At the same time, the least adjust value of resolving ambiguity is given. In additional, both the measure function of resolving ambiguity and the relationship between resolving ambiguity ability and glip space are given.

3. Current Progress and Problems

3. Current Progress and Encountered Problems

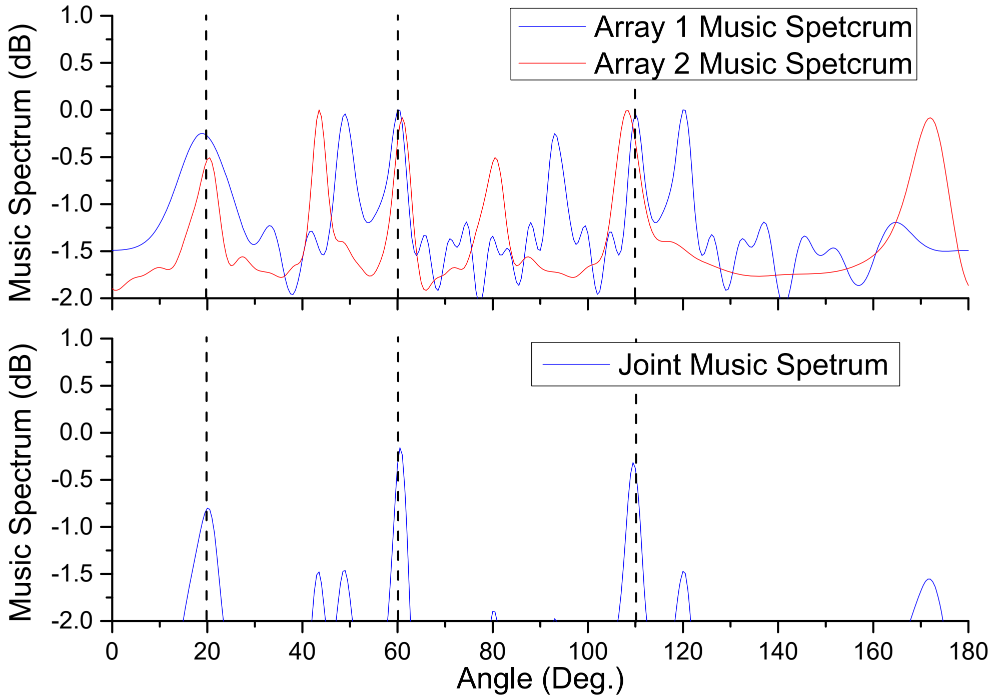

Figure 3-1
MUSIC Spectrums, 3 incident signal at 1000Hz, 15 elements, element interval = wavelength, Array Included Angle=35Deg.

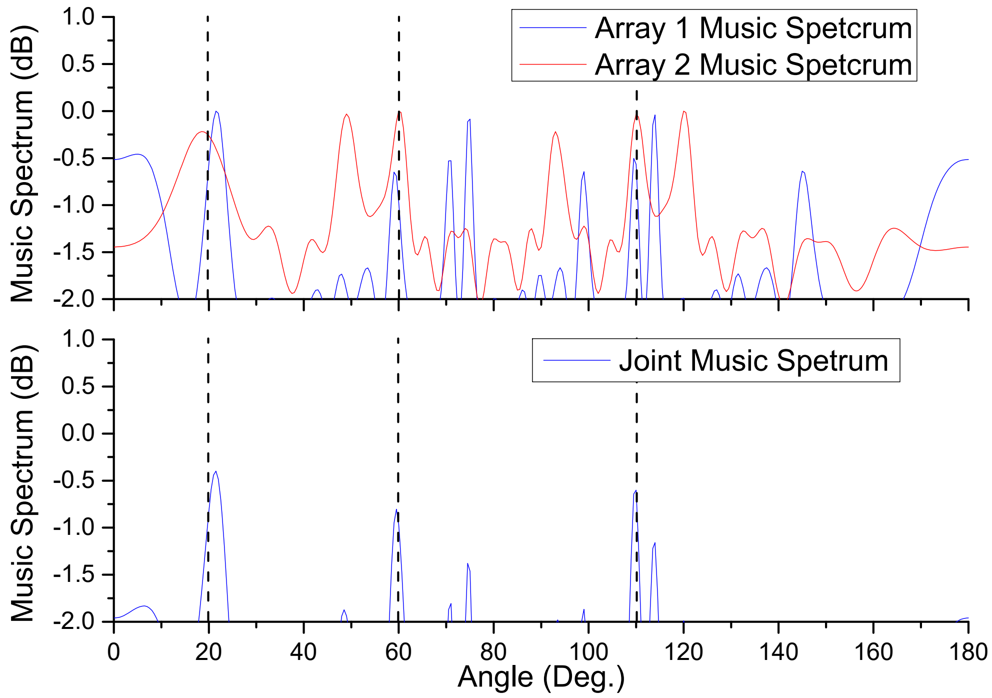

Figure 3-2
MUSIC Spectrums, 3 incident signal at 1000Hz, 15 elements, element interval = 1 and 1.5 wavelength, Array Included Angle=0Deg.

4. Discussion and Outlook

Reference

[1] ALLEN M P. Analysis and Synthesis of Aircraft Engine Fan Noise for Use in Psychoacoustic Studies [D]. Blacksburg, Virginia; Virginia Polytechnic Institute and State University, 2012.

[2] 中国民用航空局. 民用机场飞行区技术标准 [M]. 2013.

[3] JIAN M, KOT A C, ER M H. DOA estimation of speech source with microphone arrays [J]. ISCAS '98 Proceedings of the 1998 IEEE International Symposium on Circuits and Systems (Cat No98CH36187), 1998, 293-6 vol.5.

Thank You!

Present By: Cui Ao