Acoustic Beamforming: A Modern Sound Source Localization

Finding out the exact source of a sound is a tough challenge for any acoustics engineer. Since the early 90’s, a number of methods, based on microphone arrays, have matured and are used throughout numerous industries. In general, the methods fall into three categories: near-field acoustic holography, acoustic beamforming, and inverse methods. Depending on the test object, the nature of the sound and the actual environment, engineers will have to select one method or the other. What that means for the Beamforming technique used as an acoustic camera is described in more detail below.

Which criteria are most important for accurate sound source localization?

These are two important criteria to assess the validity of sound source localization methods:

- **Spatial resolution** is the ability to separate 2 sound sources. This is usually expressed in centimeters. It represents the closest distance between two sources, where they still appear to separately and do not merge into a single source. The lower the spatial resolution, the better the source localization.

- **Dynamic range** expresses sound level differences in dB between real sound sources and their surrounding mathematical artifacts inherent to the sound source localization techniques. The higher the dynamic range, the better the source localization.
What is acoustic beamforming?

Acoustic beamforming is a technique where the microphone array is placed in the far field. As a rule of thumb, the far field is defined as being further away from the source than the array dimensions or diameter. The area between near field and far field remains a grey zone. In the near field, sound waves behave like circular or spherical waves whereas, in the far field, they become planar waves.

Numerous microphone configurations are possible in acoustic beamforming arrays. In general, the configuration is usually a trade-off between dynamic range and source localization accuracy. To get the best of both worlds, it is preferred to select a circular array with a pseudo-random microphone distribution.

The ring array in middle of figure 2 provides good results when the exact distance to the source is not known, but dynamic range is low. Also, spiral-shaped arrays on the right result in lower dynamic range, compared to arrays that have more microphones distributed over the entire area of the array. More important, arrays without uniform microphone distribution will not have enough dynamic range when used in the near field. Employing acoustic beamforming arrays in the near field is a major research topic today, also for LMS, as it substantially improves the classical acoustic beamforming technique.

The acoustic beamforming technique was first developed for submarines and environmental applications. In the far field, sound waves hitting the array are planar waves. Under these conditions, it is possible to propagate the measured sound field directly to the test object. All microphone signals measured by the acoustic beamforming array are added together, taking into account the delay corresponding to the propagation distance. The pressure can be calculated at any point in front of the array, allowing propagation to any kind of surface. Acoustic beamforming is sometimes called “sum and delay” since it considers the relative delay of sound waves reaching different microphone positions. Acoustic beamforming requires that all data is measured simultaneously. It is typically done with a measurement system of 40 channels or more.

What are the advantages and disadvantages of acoustic beamforming?

Acoustic beamforming has the following advantages:

- Propagation does not relate to the size of the measurement array. The test object can be larger than the array. With an array with a 0.5m diameter, it is possible to propagate pressure to an entire car. Since all data is measured simultaneously, results can be viewed almost instantly after data acquisition.
- Because of the relatively fast acquisition and analysis speed, acoustic beamforming lets engineers evaluate several configurations in a limited amount of time.

This flexibility has some negative aspects:

- The spatial resolution is proportional to the wavelength:

\[
\text{spatial resolution} = \frac{d}{D} \lambda
\]

Where d is the distance between the source and array, D the array diameter, and \( \lambda \) the wavelength. In an ideal situation, when the antenna is at a distance D to the source, the resolution is equal to the wavelength. If the array is placed farther from the structure, the resolution becomes worse. Acoustic beamforming, in general, is only usable at frequencies above 1000Hz.
- Acoustic beamforming can not be used to calculate sound power. Proper source ranking cannot be done with this technique.
How can the disadvantages be overcome?

The main disadvantage is that acoustic beamforming does not perform well in the low frequency range. This can be improved by using a dedicated acoustic beamforming technique called near-field focalization.

To overcome this, the problem is rewritten as an inverse method. The transfer function in this formulation includes both propagative and so-called evanescent wave functions, and needs an optimal and stable principle component analysis-based regularization which includes evanescent wave filtering. The method is called irregular near-field acoustic holography or irregular-NAH.

Figure 5 shows example results for both near-field focalization and irregular-NAH techniques using the same circular 36-microphone array measured at the same distance of 20cm. This provides a very low frequency analysis band of 60-70Hz.

Figure 5: source localization 60-70Hz: focalization (left) and irregular-NAH (right)

Summary

As a general rule, near-field techniques should be preferred for sound source localization. They provide the best results in terms of dynamic range and spatial resolution. There are situations where a near-field technique is not applicable: (1) it is not possible to measure in the near field, (2) the array size becomes too big, or (3) it is not possible to measure in patches due to rapidly changing operational conditions. In these cases, an acoustic beamforming solution will be chosen.

Acoustic beamforming with near-field focalization is a good alternative, providing results with good spatial resolution and dynamic range, depending on the frequency range. It uses an array with pseudo-random distributed microphones. Acoustic beamforming obtains analysis results in a single shot wide-angle measurement, making it an ideal tool for troubleshooting, as it offers a quick preview with improved spatial resolution using near field focalization, but also for in-depth root cause analysis, when using the irregular-NAH technique.

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