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EXTENDING THE USABILITY OF NEAR-FIELD ACOUSTIC HOLOGRAPHY AND BEAMFORMING BY USING FOCALIZATION

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Abstract

In view of source localization techniques, two methods, Near-Field Acoustic Holography (NAH) and Beamforming, are widely used and well-known techniques. Both techniques have their advantages and disadvantages. Near-field Acoustic holography, the oldest commercially available method, has as major advantage its spatial resolution being equal to the microphone spacing and independent of frequency. This makes it a very powerful technique for low frequency problems. However when trying to analyse higher frequencies, the method becomes very tedious from a measurement standpoint. Beamforming, a far-field technique, has as major advantage that with a limited amount of measurement channels a relative large frequency range can be analysed, making the measurement sequence very simple. On the other hand, Beamforming has as disadvantage that its spatial resolution is proportional to the wavelength making the method not really useful for frequencies under 2000 Hz. In this paper, a technique called focalisation is discussed which can ameliorate the shortcomings from NAH and Beamforming. Focalisation is a near-field beamforming technique that can be used on data taken for NAH to extend the frequency range and double the usable frequency range for the same microphone spacing. In case of beamforming the same array can be used to take data in the near-field. When using focalisation in this near-field data, the spatial resolution is improved by a factor of 2. In addition, the focalisation allows calculating the sound power which is not possible with beamforming.

1. INTRODUCTION

In the last decennia, sound/noise levels have become more and more important. From on site, governmental regulations are imposed to contain noise pollution while on the other hand customers don't accept any longer a noisy product. On top of all this, the competitive pressure to bring products faster to market, has made that sound engineers are desperate looking for tools giving them an insight on where the noise is coming from. In the mid nineties, Near-field Acoustic Holography (NAH) was introduced, while some 10 years later commercial beamforming applications became available. Both techniques have their advantages and disadvantages that will be explained later on in the paper. It will also be explained how focalisation ameliorates some of the disadvantages for both techniques. The paper first starts with a brief summary of the theory behind the different techniques, followed by an overview of the advantages and disadvantages of NAH and beamforming and how focalisation fits into these two techniques.

2. REVIEW OF THE DIFFERENT SOURCE LOCALIZATION METHODS

2.1 Near-field Acoustic Holography

The formulation for acoustic holography is now well known [1]. Its principles are described briefly. The process to propagate a measured pressure field in a plane to another plane can be divided in 3 steps for each temporal frequency ω :

⇒ Transformation of acoustical pressure field on the array from the spatial domain to the wave number domain by means of a Spatial Fourier Transform:

$$S_a(k_x, k_y, \omega) = \iint P_{array}(x, y, \omega).e^{-j.(k_x x + k_y y)}.dx.dy \tag{1}$$

The spatial spectrum will be noted *S*.

⇒ Back-propagation of the different waves to the new defined plane, using Dirachlet Green function:

$$S_d(k_x, k_y, \omega) = S_a(k_x, k_y, \omega) \cdot e^{j \cdot k_z \cdot d} \tag{2}$$

with *d* the distance between the array and the new plane. In order to optimise the spatial resolution evanescent waves have to be included. If too few are included, the spatial resolution is not optimal. Including too many evanescent waves, blurring of the hologram can occur. A special **Wiener Filter** has been implemented in the standard algorithm to define the optimal number of evanescent waves. [2].

⇒ the last step is transforming back the acoustics signal from the wave number domain to the spatial domain by means of an inverse Spatial Fourier Transform:

$$P_d(x, y, \omega) = \iint S_d(k_x, k_y, \omega).e^{j.(k_x x + k_y y)}.\frac{dk_x}{2\pi}.\frac{dk_y}{2\pi} \tag{3}$$

2.2 Beamforming

A second technique for source localization is beamforming. This technique has been first developed for submarines and environmental applications. When the array is placed in the far-field, the sound waves hitting the array are planar waves, Figure 1.

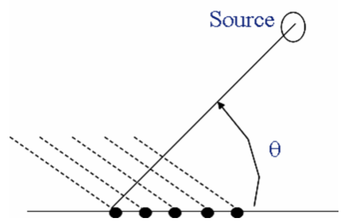

Figure 1: Planar waves hitting the far-field array

Under these conditions, the propagation of the measured sound field to any location in front can be obtained by adding the measured signals of the microphones in the beamforming array, with a delay corresponding to the propagation distance, Equation (4). This formula can be used to calculate the pressure at any point in front of the array, allowing propagation to any kind of surface.

$$s(t) \approx \frac{1}{N}\sum_{j=1}^{N} p_j(t-\tau_j) \text{ with } \tau_j = d\cos\Theta / c \tag{4}$$

2.3 Focalisation

Focalisation is basically a beamforming technique but for an array measured in the near-field. The fact that the array is placed in the near-field, makes that the waves hitting the array are no longer planar but spherical, Figure 2.

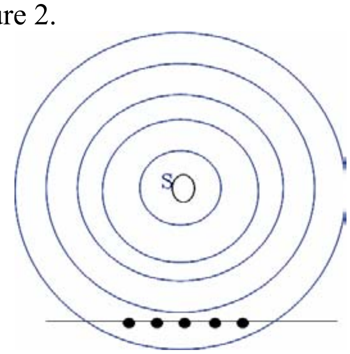

Figure 2: Spherical waves hitting the near-field array

This implies that Equation (4), which is derived for planar waves, is no longer applicable. A phase correction has to be applied which is function of the radius of the wave, Equation (5), rather than the propagation distance. Since focalisation is basically a beamforming technique, focalisation can propagate to any kind of surface and can handle any kind of array layout.

$$S(f) \approx \sum_{j=1}^{N} P_j(f) e^{ikR_j} \text{ with } kRj = 2\Pi f \tau_j \tag{5}$$

3. ADVANTAGES/DISADVANTAGES OF THE DIFFERENT SOURCE LOCALIZATION METHODS

3.1 Near-Field Holography

NAH has following major advantages.

- The spatial resolution is equal to the microphone spacing in the hologram and is independent of the frequency.
- Secondly, there is a Dirachlet Green function which allows propagating the measured pressure field to a velocity field. This implies that with this method intensity can be calculated and therefore also the sound power of different zones/components.

This makes of NAH method the true engineering source localization tool. However this comes with a price.

- NAH can only propagate to a surface parallel to the measured surface and the size of the propagated plane is identical to the measured plane. So if one wants to do source localization on a complete vehicle, the measured plane has to span the complete vehicle. However, for stationary application and repeatable transient applications such as slow engine run-up and e.g. door slams, the data can be acquired in batches. This makes that one can perform NAH measurements with a 20 to 30 channel system.
- The spacing between the microphones is defined by either the desired spatial resolution or the wavelength at the highest frequency one wants to analyse. So an increasing maximum frequency implies closer spaced microphones. So from a practical standpoint, NAH is limited to analyse higher frequencies because of the large amount of data that needs to be acquired.

3.2 Beamforming

Beamforming requires that all data is measured simultaneously and is typically done with a measurement system of 40 channels or more. The beamforming technique has following advantages.

- The propagation to a surface is not limited to the size of the measurement array, but can be quiet larger than the array. So with an array with diameter 0.5m, one can propagate the pressure onto e.g. an entire car. Since all data is measured simultaneously, results can be viewed minutes after the acquisition of the data
- Because of the relative small acquisition time and analysis time, Beamforming allows to evaluate several configuration in a limited amount of time

However this flexibility has some negative aspects too.

- The spatial resolution is proportional to the wavelength:

$$spatial\ resolution = \frac{d}{D} \quad \lambda \tag{6}$$

where d= distance between the array and the source, D the diameter of the array and λ the wavelength. So in the 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 to see e.g. the complete vehicle the resolution becomes even worse. This

makes that beamforming in general is only usable at frequencies above 2000 Hz.
- Beamforming has no capabilities to calculate the power. So no proper source ranking can be done with this technique.

3.3 Focalisation

Focalisation is a near-field beamforming technique. So focalisation has all the same advantages as beamforming but not the disadvantages.
- The spatial resolution is still linked to the wavelength but since the data is taken in the near-field, the obtained spatial resolution is 0.44 λ.
- Secondly, the method can also be adapted such that the sound power can be calculated. So with this method, source ranking can be done as with NAH.

4. REDUCING THE DRAWBACK FOR NAH AND BEAMFORMING BY USING FOCALIZATION.

Figure 3 shows the resolution of NAH and beamforming as a function of frequency. NAH has a constant resolution but is limited in frequency range. Beamforming is not limited in frequency, but in lower frequencies the resolution becomes so poor that the method has no engineering added value. By using focalisation, the usability of the two methods can be largely extended.

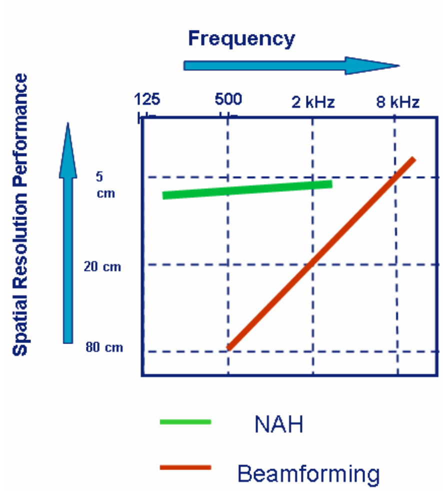

Figure 3: Resolution for NAH and Beamforming as a function of frequency

In case of NAH, the method is limited in upper frequency due to practical acquisition reasons. Focalisation can take data from any surface and any layout as input data. So the NAH data, which is equidistance measured, can be processed by focalisation. Secondly, at the maximum frequency for NAH the spatial resolution is equal to the microphone spacing which is normally ½ λ. At this frequency, the spatial resolution of focalisation is equal to 0.44 λ. So the data that has been acquired for NAH can be processed by focalisation at the higher frequencies with a spatial resolution smaller than the microphone spacing. Therefore by using focalisation on the same data, the frequency range one can analyse has been doubled. This is shown in Figure 4 and Figure 5. Figure 5, has two sources spaced at 20 cm from each other. Below 2000 Hz, NAH is used to analyse the data, while above 2000 Hz, focalisation is used.

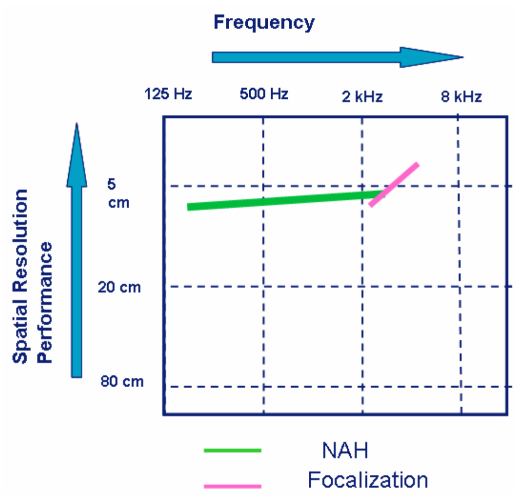

Figure 4: Frequency range and resolution combining NAH and focalisation

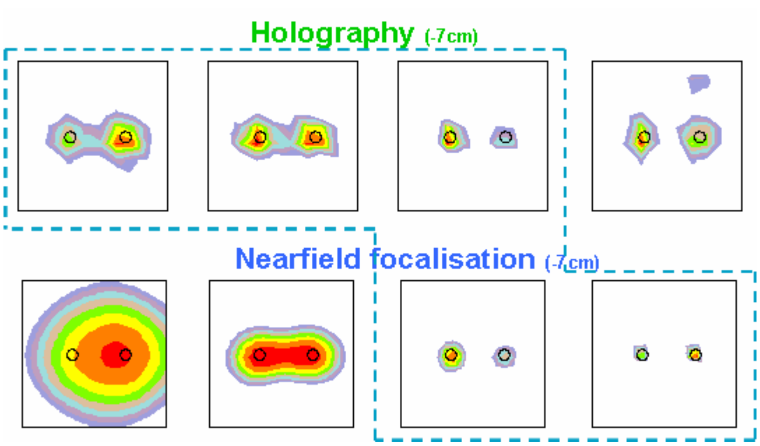

Figure 5: Frequency range extension of NAH by using focalisation

Beamforming on the other hand has as advantage that the measurements and analysis is fast but that the spatial resolution is poor, especially at lower frequencies and when the distance between source and array is larger than the array size. Focalisation can be used on data taken with the same array as beamforming but measured in the near-field. The focalisation has as advantage that the spatial resolution becomes 0.44 λ. So from a practical point of view, a sound engineer can work as follow. First a measurement is taken in the far-field to have an overview of where the sources are coming. In case source are found at lower frequencies and the spatial resolution is insufficient. A second measurement can be taken in the near-field, which takes at the most view minutes, in creasing the spatial resolution to 0.44 λ. This spatial resolution improvement is shown in Figure 6 and Figure 7.

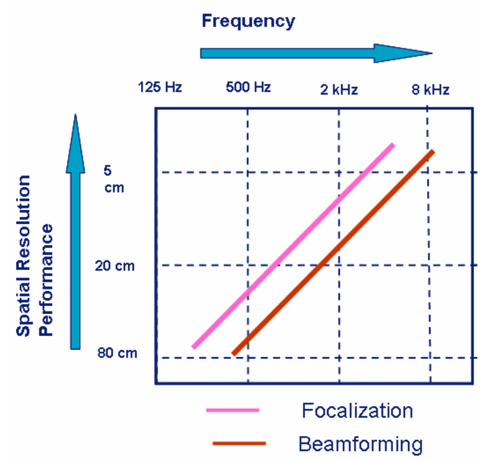

Figure 6: Spatial resolution improvement using Focalisation with Beamforming

Figure 7 shows a measurement on an engine. The top two figures are a propagation using beamforming. The lower pictures are pressure propagations using focalisation. When looking at the left side, we have an analysis frequency of 752 Hz. The beamforming propagation is a big red spot over the whole engine, which has little or no engineering meaning. When analysing the same frequency, but on data taken in the near-field and with focalisation, lower left picture, a source is found with a lot higher accuracy. At a higher frequency 3230 Hz, right side, the difference between beamforming and focalisation is not as drastically but one can still see that the focalisation, lower right picture, is still superior to the beamforming result.

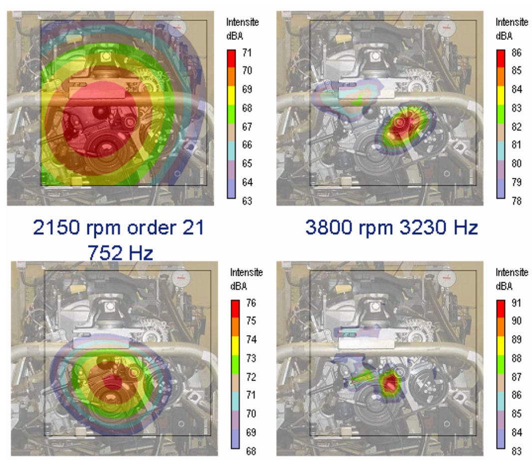

Figure 7: Spatial resolution improvement using Focalisation with Beamforming

5. CONCLUSIONS

Beamforming and NAH are both two good source localization techniques with their merits but also short-comings. It has been shown in this paper, that by marrying these two techniques with focalisation some of these short-comings have been lifted, making both techniques a more complete engineering tool. In case of NAH, focalisation extends the analysis frequency range without any measurement penalty. In case of beamforming, with one additional measurement, which requires very little acquisition time, focalisation improves the resolution to 0.44 λ.

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