A single broad banded 3D beamforming sound probe

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Introduction

Traditional beamforming arrays have acoustic limitations regarding low frequency sensitivity, dynamic range and mirror sources. The high number of data channels is often a practical and/or financial problem. In this paper the possibilities of a new sound probe are investigated as an alternative for such an array. The probe uses the acoustic particle velocity in two directions and the sound pressure in one single point. It will be demonstrated that with such a single probe the aforementioned limitations can possibly be overcome. With relatively straightforward signal processing techniques, the acoustic data can be transformed in such a way that the probe behaves like a beamforming system. Such a compact system is broadbanded, has a high dynamic range and is not affected by mirror sources. The theory will be explained and some results will be presented.

The Microflown

The Microflown is an acoustic sensor measuring the acoustic particle velocity instead of the acoustic pressure which is measured by conventional microphones [1]. It measures the velocity of air particles across two tiny resistive strips of platinum that are heated to about 200° C, see Figure 1.

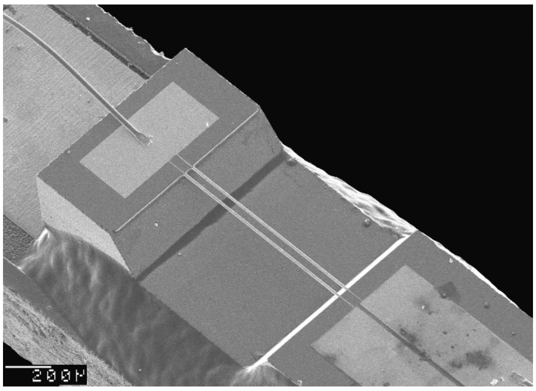

Figure 1: A microscope picture of a standard Microflown sensor.

Directivity

A sound pressure microphone has no directionality; the sensitivity is similar in all directions. In Fig. 2 (left) the graphical representation of the directionality of a pressure microphone is shown in a polar plot; it shows the relative sensitivity as function of the direction.

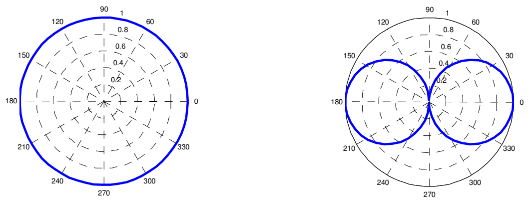

Figure 2: The directivity patterns of a microphone (left) and a Microflown (right).

A single Microflown measures the acoustic particle velocity in one direction; the directional sensitivity equals a so-called figure of eight. The polar representation is shown in Fig. 2 (right). In the positive direction (0°) the Microflown has maximum sensitivity, in 90° and 270° the sensitivity is zero and in 180° the sensitivity is similar as in the 0° direction but with negative phase.

Combining pressure and particle velocity sensors

By combining pressure and particle velocity sensors, various sensitivity patterns can be obtained. A cardioid type of directivity will appear if the signal of a particle velocity sensor is summed with the signal if a sound pressure microphone, see Fig. 3 (left). The cardioid has maximum sensitivity in the 0° direction and no sensitivity in the 180° direction.

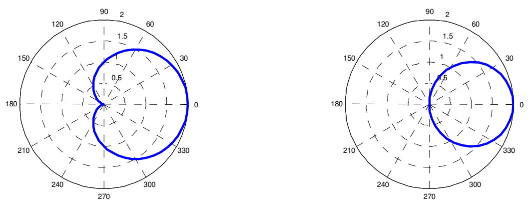

Figure 3: The directivity patterns of a cardioid microphone (left) and an unidirectional microphone (right).

The polar pattern of an ideal unidirectional microphone is given in Figure 3 (right). Such an unidirectional sensor is sensitive in only one direction and can for instance be used to create a beamforming system as will be demonstrated further. The response is similar to a particle velocity sensor, but with only one (positive) sensitivity lobe. Such a pattern can be created by summing the particle velocity with the absolute value of the particle velocity:

$$u_{unipolar} = ue^{i\varphi_{pu}} + |u| \tag{1}$$

So for the half plane where particle velocity is positive (i.e. in phase with the pressure), the unidirectional sensor is sensitive. In the half plane where the particle velocity is negative (i.e. out of phase with pressure) the sensor gives no signal.

Mathematical rotation of probes

If signals are obtained from two orthogonally oriented particle velocity sensors, it is possible to mathematically rearrange the vector orientation. For Microflown signals this is e.g. proven in [2]. It is therefore possible to mathematically 'rotate' the probe in any orientation. The mathematical rotation is demonstrated for two orthogonal particle velocity sensors. It is possible to create a particle velocity sensor that has a sensitivity in any direction that is desired. Assume two sensors that are oriented in the x- and y-axis, see Fig. 4 (left). A rotated figure of eight directionality is obtained if the signals of the two probes are processed in the following way:

$$u(\theta) = u_x \cos(\theta) + u_y \sin(\theta) \tag{2}$$

The response for a rotation of θ=45^o is shown in Fig. 4 (right).

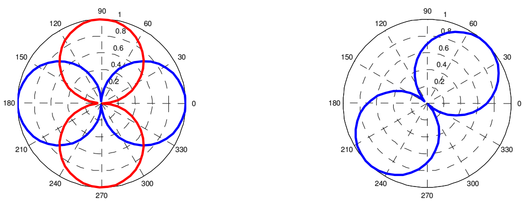

Figure 4: The particle velocity response in any direction can be obtained by combining two perpendicular particle velocity sensors.

With this technique the probe orientation can be rotated in any desirable direction. This mathematical rotation can also be applied in three dimensions. It is then also possible to create two unipolar sensors (these two are mathematically derived from the signals of two particle velocity sensors at 90^o and a microphone, see Fig. 5 (left). The directionality is increased if the signals of those unidirectional probes are multiplied, see Fig. 5 (right).

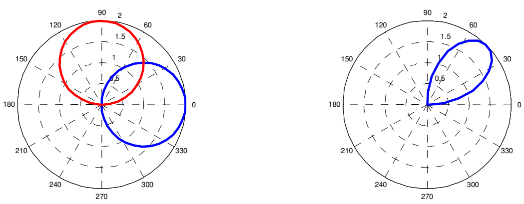

Figure 5: Multiplication of two rotated unidirectional probes.

So the product of a set of two unidirectional probes will increase the directivity. As can be seen in Fig. 5 right: the directivity is high and the side lobes are low. This means that with just a few sensors good beamforming properties are reached.

Simulation with single and multiple sources

When such a probe is used in a sound field where only a single source is present and the directivity is rotated over 360 degrees, the response is given in Figure 6 (left). From this figure it is clear that the source is located at 120^o. When a second source at 0^o is present, the response is given in Figure 6 (right). The two sources can now hardly be separated, showing the limitations of the current way of signal processing.

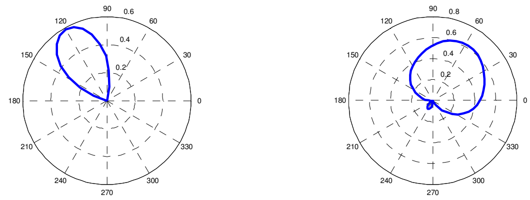

Figure 6: Response of a probe with rotated directivity over 360^o with a single source at 120^o (left) and two sources at 0^o and 120^o (right).

Discussion

With the presented signal processing technique, it is simple to find the direction of a single source. Multiple sources are still difficult because phase information is discarded. Alternative strategies are subject of research. It is clearly shown that mathematical rotation of the probe direction is feasible. This property can also be used in a procedure for realigning misaligned velocity probes [3], [4].

Conclusion

In this paper it is shown that directional acoustic sensors can be created by combining pressure and particle velocity sensors. The sensitive direction can be rotated over 360^o by simple signal processing. In this way source locations can be found. The presented results are subject of ongoing research. The goal is to find an alternative for beamforming arrays based on processing of a data obtain by three perpendicular particle velocity sensors and a single pressure microphone.

Literature

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