# SOURCE LOCALIZATION WITH ACOUSTIC VECTOR SENSORS

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**Abstract**: In this paper a localization method is analyzed, which uses Acoustic Vector Sensors (AVS). An AVS measures the directed velocity and the pressure in an area approaching a single point. In order to localize sound sources, the Multiple Signal Classification (MUSIC) was applied, which determines the signal and the noise components. MUSIC only uses the noise components (Noise Subspace) to estimate the direction of arrival. To estimate the quality of this method, the accuracy and the resolution of the localization were compared with an established pressure-based method. The accuracy and resolution of the AVS-based method are higher. MUSIC was more robust against calibration errors of phase and frequency. Our measurements showed that the combination of AVS, and MUSIC provides an efficient localization system.

## 1 Introduction

Common localization methods use the phase difference of pressure between spatially distributed points on an array to localize the sound sources. To estimate the phase difference, the measured oscillation has to be in the same period at the points of the array. This spatial sampling causes aliasing. To reduce this effect the distance between the points should be minimized. This, however, leads to a lower resolution, since the distance between the points is proportional to the resolution of the localization. In this paper an alternative localization method is analyzed, which uses Acoustic Vector Sensors (AVS).

## 2 Arrays of acoustic vector sensors

AVS measure directed velocity and pressure in an area approaching a single point [2]. AVS are a combination of three orthogonal velocity sensors and an omnidirectional pressure sensor. In consequence, we do not need a spatial distribution of the AVS in order to measure phase differences.

To get a better understanding of the AVS we executed several simulations. For example we analyzed the relation of two AVS rotating around each other. During all simulations the effect to the source localization was in the point of focus.

## 3 Calibration of the AVS

Since the AVS measure the incident angles of sound a small error in the orientation of the sensor elements can cause a significant error in the measured direction of arrival. For this reason a calibration of direction was implemented, which consists of the translation, the rotation and the shearing of the sensor elements. These three possible movements are the integral part of a calibration matrix $M$:

$$\vec{u}_c = M \cdot \vec{u}_m \,, \tag{1}$$

with $\vec{u}_m$ as the measured direction of arrival and $\vec{u}_c$ as the calibrated direction of arrival. To determine the calibration matrix $M$ a sound source is measured at different, exactly defined positions. With these measurements we can build a system of linear equations. The best approximation to the solution of the system of equations is the generalized inverse.

## 4 Multiple Signal Classification (MUSIC)

As a localization algorithm, Multiple Signal Classification (MUSIC) [5] was applied, which allows to include directed velocity into computation [3]. MUSIC performs a principal components analysis in order to determine source and noise components. These principal components can be assigned to all theoretical possible directions of arrival. The possible directions of arrival are determined by using a physical model of the AVS array.

A three-dimensional array should have a specific response according to the direction of arrival of a plane wave. This particular response can be characterized by specific amplitude and phase differences between the sensors. The plane model determines the differences of amplitude and phase for all possible directions of arrival.

Beside the plane wave model the directivity of the sensors have influence on the amplitude and phase differences. In figure 1 the directivity of an acoustic vector sensor is schematically shown.

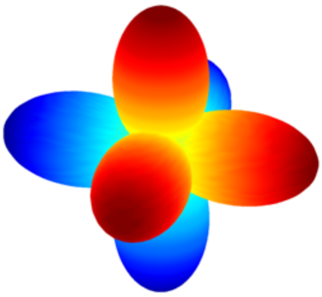

**Figure 1.** Spherical directivity of the three sensors of an AVS (stretched)

Combined with the plane wave model we get the weights of the sensor elements:

$$w_{x,y,z} = \frac{s_{x,y,z}}{\rho} \exp\left( j2\pi s_x kx + j2\pi s_y ky + j2\pi s_z kz \right) \tag{2}$$

with $s_{x,y,z}$ as the directivity of the three sensor elements of the AVS. The Noise Subspace is multiplied with these weights of all possible directions of arrival.

MUSIC uses only the noise components ('Noise Subspace') to estimate the direction of arrival. The noise components are masked by the source signal in the direction of the source and therefore equal zero. As a consequence, the reciprocal value of the noise components creates sharp peaks in the directions of the sources [4].

## 5 Results

In order to evaluate the quality of the array of AVS, we compared it in measurements with an array of microphones. We were able do the measurements in the anechoic room of the Delft University of Technology. We used a spherical array of 50 points and two sound sources.

Since the AVS include an omnidirectional pressure sensor, we could ensure exact the same array positions for pressure and AVS array.

## 5.1 Array

As a result of the simulations described in paragraph 2 we used a spherical array for the measurements. A spherical array has a specific response according to the direction of arrival of a plane wave. The sensitivity of a spherical array is the same for every direction [6].

## 5.2 Calibration

The calibration, described in paragraph 3, reduces the error of direction from *5°-20°* to *0.5°-4°*. The improvement of accuracy is shown in figure 2 and figure 3.The most accurate results could be reached in a frequency range from *0.7 kHz* to *1.3 kHz* . Since reflections cause disturbance, the measurement were executed in an anechoic room.

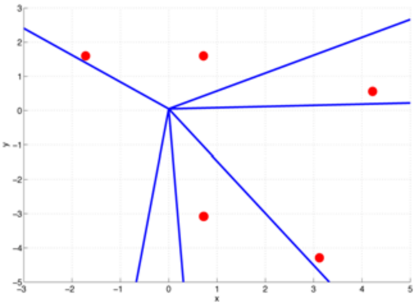

**Figure 2.** Calibrated directions of arrival; red: real sources / blue: measured directions; error: 5° - 20°

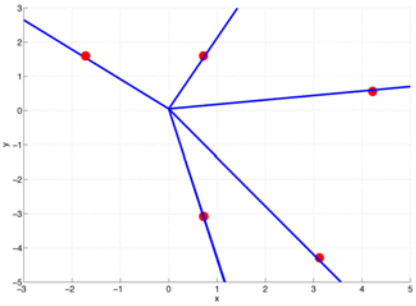

**Figure 3.** Calibrated directions of arrival (top) red: real sources / blue: calibrated directions; error: 0.5° - 4°

## 5.3 Localization

In figure 4 and 5 the results of the localization with the pressure array and with the AVS array are shown at a frequency of *570 Hz* (*560 Hz* is the limit frequency of the spatial sampling). The possible directions of arrival are projected on a sphere. The probability of the existence of a source is indicated by the color: blue indicates a low and red a high probability.

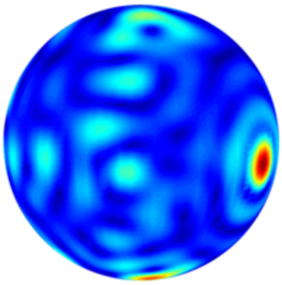

**Figure 4.** Pressure array: result of the localization at 570 Hz (directions of arrival projected on a sphere); blue: low probability / red: high probability

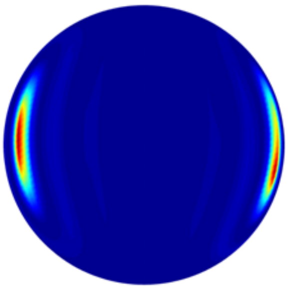

**Figure 5.** AVS array: result of the localization at 570 Hz (directions of arrival projected on a sphere); blue: low probability / red: high probability

At a frequency of 570 Hz the localization with the pressure array causes aliasing (figure 4). However the AVS array provides at 570 Hz a sharp peak in direction of the two sources (figure 5).

At a frequency of 2.9 kHz the localization with AVS array also causes aliasing (figure 7). At this frequency the pressure array does not result in a source localization (figure 6).

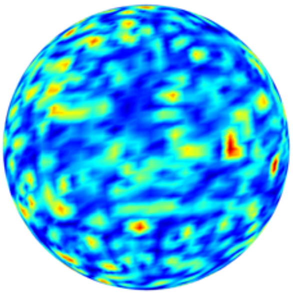

**Figure 6.** Pressure array: result of the localization at 2.9 kHz (directions of arrival projected on a sphere); blue: low probability / red: high probability

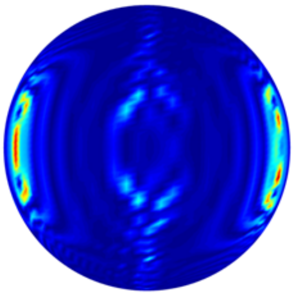

**Figure 7.** AVS array: result of the localization at 2.9 Hz (directions of arrival projected on a sphere); blue: low probability / red: high probability

We computed the accuracy and the resolution of the results of the localization. This computation showed a higher stability of the localization with the AVS array at all frequencies.

## 6 Conclusions

We can conclude that the number of necessary measuring points can be reduced with an AVS array. Of course, one could also increase the limit frequency.

The influence of aliasing on the AVS array is much less strong. For the same reason, pressure arrays are much more sensitive against errors in phase or position. For the correct estimation of direction of arrival the calibration is essential. On one hand, using MUSIC with correlated sources produces a disappointing result. On the other hand, with a moderate SNR, MUSIC provides an estimation which other beamformers would only achieve under optimal conditions. The combination of AVS array and MUSIC offers an appropriate localization method for uncorrelated sources in a broad frequency band.

## References

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