INFLUENCE OF THE SCATTERING EFFECT ON ACOUSTIC IMAGE OBTAINED WITH A SPHERICAL MICROPHONE ARRAY

Julien St-Jacques [*1], Kevin Rouard [1], Franck Sgard [2], Hugues Nélisse [2], Alain Berry [3], Nicolas Quaegebeur [3], François Grondin [3], Loic Boileau [3], Olivier Doutres [1] and Thomas Padois [†2].
[1]École de technologie supérieure (ÉTS), Montréal, Québec, Canada.
[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), Montréal, Québec, Canada.
[3]Université de Sherbrooke (UdeS), Sherbrooke, Québec, Canada.

1 Introduction

In Quebec, occupational deafness was the most identified work-related disease representing 89% of the cases from 2015 to 2016 [1]. The most efficient solution is to reduce the noise emitted by the source. To do so, each source must be characterized by their spatial location and contribution. In a workplace, a Spherical Microphone Array (SMA) can be used. When the microphones are held on a wireframe structure or on thin rods, the SMA is considered acoustically transparent and is referred to as open. For open SMAs, the Conventional Beamforming in the Frequency domain (CBF) can be used and does not account for the scattering effect. When the microphones are flush mounted to a rigid sphere, the SMA is referred to as rigid. Rigid SMAs may cause the scattering of the sound field around the sphere. Consequently, frequency dependent errors in the time delays measured by the microphone pairs in the shadowed zone are expected [2]. The aim of this study is to assess the influence of the scattering effect on acoustic images obtained with a rigid SMA using the CBF. First, the microphone signals are obtained numerically and then the acoustic images are generated using the CBF algorithm for the case of a rigid and a transparent SMA. Then, the influence of the scattering effect is assessed using two image quality criteria. Section 2 presents the formulation of the CBF. Section 3 details the SMA design, the simulation parameters, and the image quality criteria. Section 4 presents the numerical results.

2 Convetional Beamforming

In the frequency domain, the acoustic image $\boldsymbol{A}(\omega)$ is provided by

$$\boldsymbol{A}(\omega) = \boldsymbol{W}^*(\omega)\boldsymbol{C}(\omega)\boldsymbol{W}(\omega), \tag{1}$$

where $\boldsymbol{W}(\omega)$ is the steering matrix, $\boldsymbol{C}(\omega)$ is the cross-spectral matrix and $(\cdot)^*$ denotes the complex conjugate transpose operator [3]. Using an SMA of Q microphones and a scan grid of L points, the dimensions of $\boldsymbol{W}(\omega)$ and $\boldsymbol{C}(\omega)$ are $[Q \times L]$ and $[Q \times Q]$ respectively. For the CBF, the steering matrix is obtained

using the free-field Green's function with

$$\boldsymbol{W}(\omega) = \frac{1}{Q}\frac{\boldsymbol{g}(\omega)}{\boldsymbol{g}^*(\omega)\boldsymbol{g}(\omega)}, \tag{2}$$

where one element of the Green's free-field matrix $\boldsymbol{g}(\omega)$ is given by

$$g_{ql} = \frac{1}{4\pi r_{ql}} e^{\frac{i\omega r_{ql}}{c_0}}. \tag{3}$$

In equation (3), c_0 is the sound speed, i is the complex imaginary number and r_{ql} is the distance between the q^{th} microphone and the l^{th} grid point. The cross-spectral matrix is obtained with

$$\boldsymbol{C}(\omega) = \boldsymbol{p}(\omega)\boldsymbol{p}^*(\omega) \tag{4}$$

where $\boldsymbol{p}(\omega)$ is the microphone signal vector of dimension $[Q \times 1]$.

3 Methodology

3.1 Array Design

To assess the influence of the scattering effect, two types of SMA are considered. A rigid array (Figure 1-a) is compared to a theoretical perfectly transparent array (Figure 1-b) referred as the empty SMA. The chosen microphone geometry is based on a commercial SMA commonly used in the literature [4]. The SMA radius is 9.75 cm and has 36 microphones.

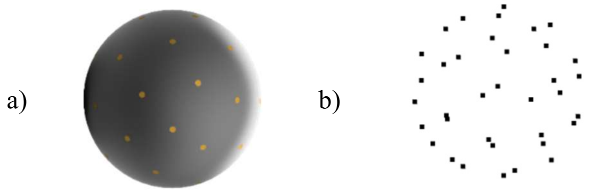

Figure 1: a) Rigid array b) Empty array, 36 microphones geometry, 9.75 cm radius.

3.2 Simulation Parameters

The microphone signals are obtained using a Finite Element Analysis (FEA) model to simulate a point source located at 1 m in front of the SMA. The model is a spherical domain of 1 m in diameter with a perfectly matched layer of 0.1 m to mimic an open infinite domain and avoid reflections. The simulation was done for frequencies ranging from 50 to 4000 Hz.

3.3 Image Quality Criteria

To assess the influence of the scattering effect on the acoustic image, two criteria are used, *i.e.,* the Ellipse Area Ratio

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[*] julien.st-jacques.1@ens.etsmtl.ca
[†] thomas.padois@etsmtl.ca

(EAR) and the Mainlobe-to-Sidelobe Ratio (MSR). The EAR is the mainlobe area at -3 dB from the maximum value normalized by the total image area expressed in (%). The mainlobe area is surrounded by an ellipse using the covariance method [5]. A small EAR is preferred to allow for a better localization. The MSR is the level difference between the mainlobe and the highest sidelobe. Since sidelobes are spurious sources, an ideal MSR should be high.

4 Numerical Results

4.1 Ellipse Area Ratio

The EAR results for the rigid and the empty arrays using the CBF algorithm, and the 36-microphones geometry are presented in Figure 2-a. When the EAR criterion is greater than 30%, the image is considered of poor quality, as the mainlobe is too wide (red dashed line). If two sources are to be localized, a mainlobe greater than 30% for both sources would represent more than half of the image, making the localization difficult. The EAR assessed with the rigid array and the CBF is smaller than the ones obtained with the empty SMA for the full frequency range. With the rigid SMA, the source is first considered localized at 670 Hz, while the same result is observed with the empty SMA at 800 Hz. This result could be explained by the time delay between two microphones since the EAR is dependent of the frequency and the SMA radius. Using the CBF, a larger SMA radius will result a smaller mainlobe width for a given frequency. For the empty SMA, the acoustic wave travels through the sphere, therefore the largest distance is the SMA diameter. On the other hand, for the rigid SMA, the acoustic wave is diffracted and travels along the surface of the sphere thus the largest distance is half the perimeter [6].

4.2 Mainlobe-to-Sidelobe Ratio

Figure 2-b presents the MSR measured with the rigid and empty SMA using the CBF for the 36-microphones geometry. The red dashed line represents a -6 dB threshold where the sidelobes are considered too high to properly localize the source. The grey zone delimits the frequency range where no sidelobe are measurable for the rigid SMA since the mainlobe is very large. The MSR assessed with the rigid SMA is higher when compared to the empty SMA for the full frequency range with a maximum difference of 4.75 dB at 2800 Hz. At 3550 Hz, the MSR measured with the rigid SMA reaches a maximum of -6.15 dB, which is barely inside the permitted zone by the threshold. Therefore, the empty SMA provides a better MSR since there is no scattering effect.

5 Conclusion

The aim of this study was to assess the influence of the scattering effect on the acoustic images obtained with a SMA using the CBF. A rigid and an empty SMA with a radius of 9.75 cm and a 36-microphones geometry were considered. The microphone signals were obtained numerically with an FEA model for the case of a single point source in front of the SMA. The acoustic images were generated using the CBF algorithm, which does not account for the scattering of the acoustic waves, for both SMAs. The EAR and the MSR criteria were used to assess the influence of the scattering effect on the image. Results show that the uncorrected scattering effect will provide a smaller mainlobe width. This effect could be related to the time delay between microphone pairs. Also, the scattering effect increases the sidelobes levels, especially in the higher frequencies. The results of this study are valid for the case of a single point source located in front of the SMA. For the case of multiple point sources, different MSR values are expected.

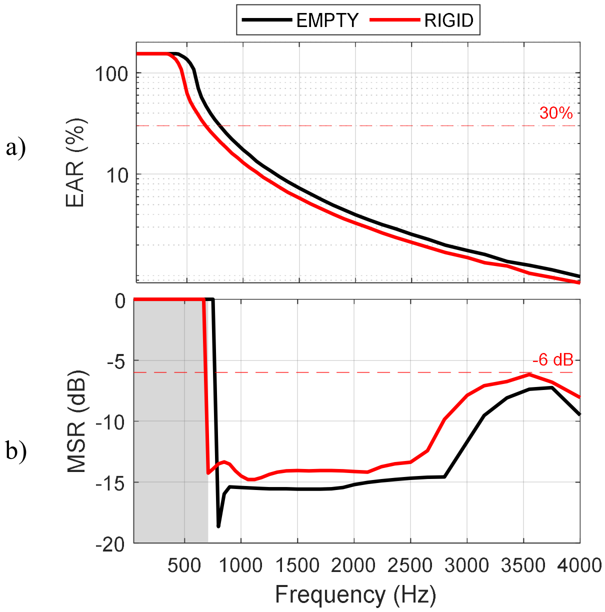

Figure 2: Acoustic images obtained with the CBF algorithm for the rigid and empty SMA of 9.75 cm radius for a point source located at 1 m a) Ellipse Area Ratio b) Mainlobe-to-Sidelobe Ratio. The grey zone delimits the frequency range for which no sidelobe can be measured for the rigid SMA since the mainlobe is too large.

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