EFFECT OF THE ERROR ON THE SOUND SPEED AND MICROPHONE POSITION 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 [1].

[1]École de technologie supérieure, Montréal, Québec, Canada.

[2]Institut de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal, Québec, Canada.

[3]Université de Sherbrooke, Sherbrooke, Québec, Canada.

1 Introduction

To reduce the noise level in a workplace, the main sources have to be localized. This task can be done with a spherical microphone array (SMA). When the microphones are flush mounted to a rigid sphere surface, the SMA is referred to as rigid. In this case, the Spherical Harmonic Beamforming (SHB) algorithm is preferred since it allows to account for the scattering effect of the acoustic waves on the rigid sphere [1,2]. When the microphones are fixed on an open wire frame, i.e., transparent with respect to the acoustic waves, the SMA is referred to as open and the Generalized Cross-Correlation (GCC) algorithm in the time domain can be used [2]. Both algorithms require the knowledge of the sound speed and the microphones position. In this study, the effect on the acoustic image of an error committed on these parameters is investigated numerically. The error is introduced by using a reference value for both parameters which is different from the one used to generate the microphones signals. More specifically, the microphones signals captured by a rigid or an open SMA placed in a room are obtained numerically using a sampled range of sound speed values and degrees of precision of microphone position. Then these signals are used as input to the SHB and GCC algorithms to calculate the acoustic image but with the reference value for the sound speed and the microphone position instead of those used to generate the input signals. The main lobe area is the criterion used to evaluate the parameters influence on the acoustic image.

2 Algorithms

2.1 Spherical Harmonic Beamforming

The SHB algorithm principle is the decomposition of the acoustic wave field measured on the surface of a sphere into spherical harmonics. Modal matrix of weights is given by

$$\boldsymbol{w}_{nm}^{*}(kr_a, \theta_l, \varphi_l) = \boldsymbol{Y}_n^m(\theta_l, \varphi_l)\,\frac{d_n}{\boldsymbol{b}_n(kr_a)} \quad (1)$$

with k the wavenumber, r_a the SMA radius and (θ_l, φ_l) respectively the elevation and azimuthal coordinates of the scan grid points. In Eq. (1), $\boldsymbol{Y}_n^m$ is the spherical harmonic matrix, $\boldsymbol{b}_n$ is the contribution of plane waves amplitude on the sphere and d_n is a weight parameter used to optimize the directivity. The modal pressure is given by

$$\boldsymbol{p}_{nm}(kr_a, \theta_q, \varphi_q) = \alpha_q \boldsymbol{Y}_n^{m^*}(\theta_q, \varphi_q)\boldsymbol{p}(kr_a, \theta_q, \varphi_q) \quad (2)$$

with α_q a weight parameter and $\boldsymbol{p}$ the acoustic pressure measured at the microphone located at (θ_q, φ_q). The spherical harmonic function is then given by

$$Y_n^m(\theta, \varphi) = \sqrt{\frac{2n+1}{4\pi}\frac{(n-m)!}{(n+m)!}}P_n^m(cos\theta)e^{im\varphi} \quad (3)$$

2.2 Generalized Cross-Correlation

The GCC algorithm employs the inverse Fast Fourier Transform of the cross spectrum C_{uv} to estimate the cross-correlation $R_{uv}(\tau)$ between two microphones signals (u, v)

$$R_{uv}(\tau) = \sum_{j=0}^{N_f-1} C_{uv}(\omega_j)e^{i\omega_j\tau/N_f}, \quad (4)$$

with the time lag τ, discrete frequency j and number of elements of the frequency vector N_f [2]. The acoustic image $\boldsymbol{A}(\theta_l, \varphi_l)$ is then obtained with the arithmetic mean of the projected cross-correlations

$$\boldsymbol{A}(\theta_l, \varphi_l) = \frac{1}{Q_p}\sum_{p=1}^{Q_p} R_{uv}(\tau_{uvl}) \quad (5)$$

where Q_p is the number of microphone pairs included in an array composed of Q microphones and τ_{uvl} is the time difference of the time delays of two microphones (u, v).

3 Methodology

3.1 Simulation parameters

The simulated environment is a room of 18 m in length, 12 m in width and 5 m in height. The room reflection coefficient β is 1%. The SMA is in the center of the room. The source is a monopole located at 4 m, φ = 0° and θ = 90°, relative to the SMA. The source signal is a sine wave with frequencies ranging from 250 to 2000 Hz. The microphones signals are provided by the convolution of a source signal with the room impulse response. One rigid and one open SMA are considered. Both SMA have a radius of 20 cm and include 48 microphones following a t-design geometry.

3.2 Sound speed parameter

Speed of sound at atmospheric pressure depends on the temperature and humidity. The range used for the sound speed is based on the value of the sound speed between -40°C to 50°C. Different sound speed values are considered for the calcul-

* julien.st-jacques.1@ens.etsmtl.ca

ation of the microphone's signals (as described in sec. 3.1) ranging from 306 to 360 m/s. To simulate the error on the sound speed, the reference value of 343 m/s (20 °C) is used to obtain the acoustic image using the SHB and GCC algorithms for each set of microphones signals instead of the actual sound speed used to generate the microphones signals.

3.3 Microphone position parameter

This study considers multiple degrees of precision of microphone position on the SMA. First, the microphones signals are computed by each SMA with microphones coordinates rounded to 0.001°, 0.01°, 0.1°, 1°, 2°, the nearest factor of 5° and finally the nearest factor of 10°. To simulate the error on the microphones position, the computation of the acoustic image using the SHB and GCC is done using the coordinates rounded to 0.001° for each set of microphones signals instead of the actual positions used to generate the micro-phones signals.

3.4 Ellipse area at -3 dB

The quality of an acoustic image can be defined by the width of its main lobe. On a 2D map, an ellipse can be drawn at -3 dB from the maximum of the main lobe. The area of this ellipse is then used as a criterion for the acoustic image. A smaller ellipse area translates to a more precise acoustic image. The ellipse area for the sound speed assessment is normalized by the value measured at 343 m/s. For the microphone position, the ellipse area is normalized by the value measured with positions rounded to 0.001°. The normalized ellipse area is denoted NEA in the following.

4 Results

4.1 Sound speed

Figure 1 compares the NEA for both the SHB algorithm with a rigid SMA and the GCC with an open SMA for frequencies ranging from 200 to 2000 Hz and sound speed values ranging from 306 to 360 m/s. The sound speed has a low impact on the NEA for both the SHB and the GCC. The NEA is either increased or decreased by less than 15% which is not visible on the acoustic image. For the SHB, the NEA increases as the sound speed value grows for the frequencies lower than 1000 Hz and close to 2000 Hz. For the GCC, the NEA increases as the sound speed value grows for the full frequency range.

4.2 Microphone position

Figure 2 compares the NEA for both SMA's. The frequencies range from 200 to 2000 Hz and the precision of the microphone positions range from 0.001° to 10°. For the GCC, the microphone position has close to no impact on the NEA for the full frequency range. When the microphone position is rounded to 1° and higher, the SHB is not able to localize the acoustic source at the lower frequencies. In this case, the NEA values are meaningless.

5 Conclusion

This paper investigated separately the effect of an error on the sound speed and microphones position on the acoustic image obtained using the SHB algorithm (rigid SMA) and the GCC algorithm (open SMA). The microphones signals captured by a rigid and an open SMA were numerically generated beforehand using a sampled range of sound speed values and degrees of precision of microphones position. Then, the computation of the acoustic image was done using the reference values (343 m/s, 0.001°) instead of the actual value for each set of microphones signals. The ellipse area at -3 dB is the criterion used to evaluate the influence of both parameters. Results have shown that an error on the sound speed has a low impact on the SHB and GCC. It has been observed that the SHB is sensitive to an error committed on the microphones position, while the GCC is more robust. This can be explained by the dependency of the SHB on the orthogonality property which depends on the microphone position on the spherical array.

a)

b)

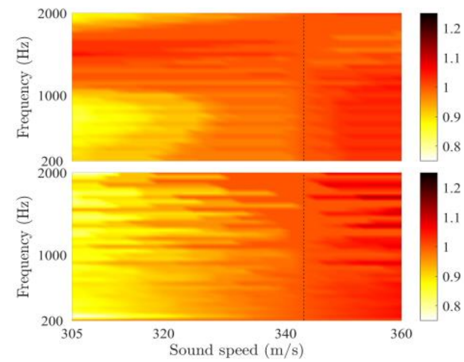

Figure 1: Normalized ellipse area per value of sound speed, a) rigid SMA, SHB, b) open SMA, GCC. Dashed line at sound speed reference value (343 m/s).

a)

b)

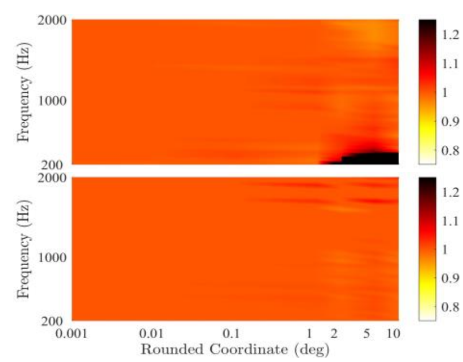

Figure 2: Normalized ellipse area per rounded coordinates of microphone position, a) rigid SMA, SHB, b) open SMA, GCC.

References

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