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IMPROVING THE LOCALIZATION OF NOISE SOURCES INSIDE A VEHICLE

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Abstract: *Sound source localisation (SSL), such as NAH and beam-forming, have been around for the last decennia. SSL techniques have been mainly used for free field conditions and only the last couple of years these techniques have found their way into interior acoustic applications where non-free-field conditions are met.*
Since the measurement happens in a cavity where reflections are present and sources all over the volume, the classical 2D free field antennas will not work and a 3D solid spherical antenna is required to perform a SSL on the complete interior compartment. The uniqueness of this solution lays in the fact that the SSL propagation is not only based upon a beam-forming solution, but takes also into account the acoustic diffractions that happen around the solid sphere. The result of this measurement campaign gives an overview of all sources present in the interior enclosure. A key factor in having accurate results however is the availability of having an accurate geometry to which one propagates the pressure to.

Keywords: sound source localization, beam-forming, near-field acoustic holography

1. INTRODUCTION

Engineers have been developing SSL techniques for the last ten years and industrial techniques now exit to measure in free field for example on engine testing bench and perform a SSL. Because of the free field conditions, these systems normally use a planar 2D antenna. The data processing can combine acoustic holography for accurate low frequency analysis and near field focusing for high frequency localization with a few number of microphones [1-2].

Measurements inside cabin involve additional challenges. Inside a cabin, the sources can be in front or behind the antenna. Secondly inside a cabin, there are reflective waves that can be identified as additional ghost sources. Inside cabins, the objective of a SSL system is to minimize the influence of the reflective waves and have a proper localization of the sources that are in front or behind the antenna. These two points avoid the use of a planar array which cannot separate properly sources in front and behind of the antenna.

The quality and accurateness of the results very much depend on the correct geometry to which the pressures are propagated. So in order to perform a proper interior SSL one needs a proper 3D sphere, a correct geometry and the correct algorithms that can optimize the results.

This paper will elaborate on two of these required parts:

- Solid versus open sphere: as mentioned above, for cavity measurements a 3D sphere is required as measurement array. In this section the advantages of a solid sphere versus an open sphere are explained.
- Geometry influence. In this section, the importance of the propagation geometry is ilustrated.

2. SOLID VERSUS OPEN SPHERE

When working on interior acoustics in a cabin, it is not always obvious where the noise is coming from. In order to be able to quantify a 3D sound field, a solid spherical antenna has been positioned in one of the front seats as can be seen in Figure 1.

Figure 1: Spherical solid antenna

The data processing for the solid sphere is modified to take account of diffraction. That is done with a decomposition on the spherical harmonics which can also be called spherical beam forming (or SRTF), equations 1 and 2. For the transparent /open sphere, the treatment remains the traditional beam-forming.

Beam forming :

$$S(f) = \sum_{j}^{N} P_j(f) e^{ikR_j} \quad \text{with} \quad kR_j = 2\pi f \tau_j \tag{1}$$

Sphere related Transfer function (SRTF) :

$$p_s(r,a,\omega,\theta,t) = \frac{i\rho_0 c S_\omega}{4\pi a^2} \Psi e^{i\omega t} \tag{2}$$

Figure 2 presents the resolution for a 23 cm diameter sphere located at 50 centimeters from the sources. The red curve corresponds to the resolution of a transparent sphere and the green curve for a solid sphere. The spatial resolution improvement in low frequency is about 40%. The acoustic holograms of a source located on the upper face of a virtual cube surrounding the sphere are presented for different frequency on the Figure 3, Figure 4 and Figure 5. The sphere diameter is noted a, and the cube volume is equal to $(10a)^3$.

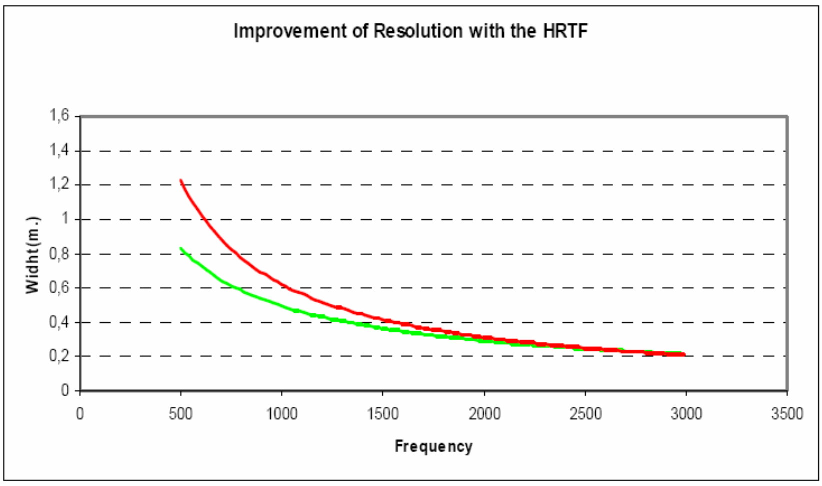
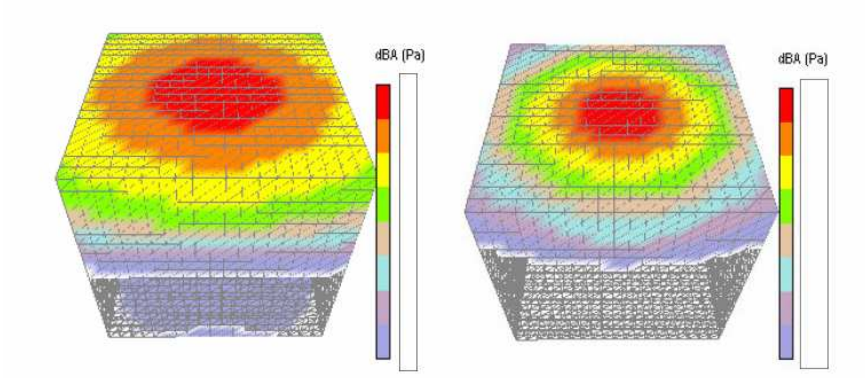


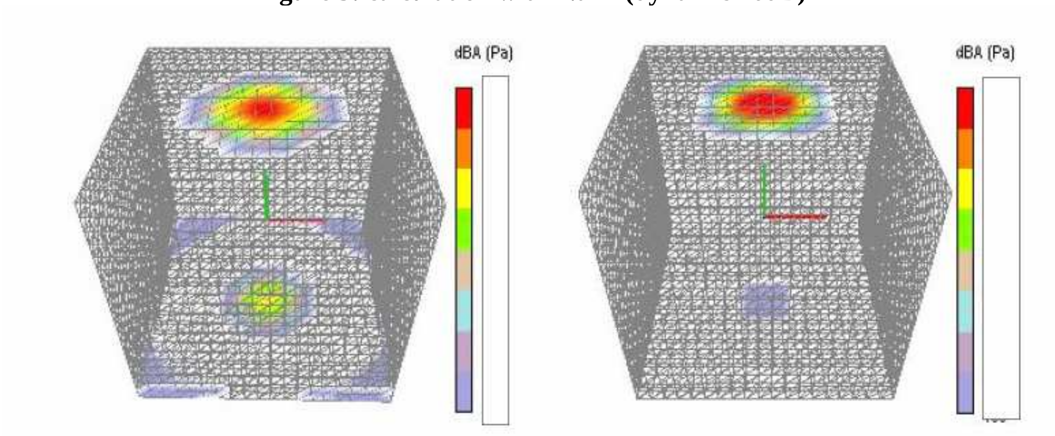
Figure 2: Resolution of the solid sphere ___ and the open sphere___

Figure 3 presents the results obtained for the open sphere and the solid sphere for a frequency k.a=2 with k the wave number. The green ring is 3 dB lower that the main source. One can easily observe the solid sphere provides a finer source localization than the open sphere.



Open sphere   Solid sphere

Figure 3: calculation with k.a=2 (dynamic 16dB)

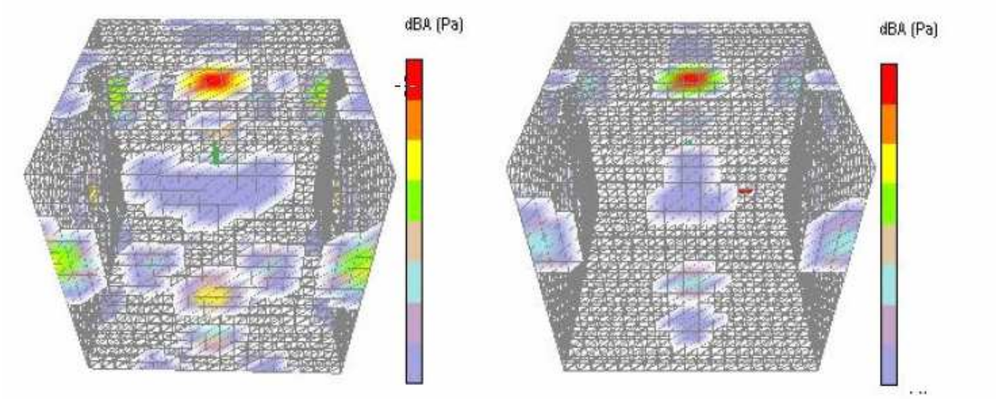


Open sphere   Solid sphere

Figure 4: calculation with k.a=5 (dynamic 10 dB)

Figure 4 presents the results for a frequency k.a=5. We can note that ghost images are mainly located on the face opposed to the source. Ghost images are displayed source that are art effects of the used array and that can be confused with real sources. For the open sphere, the level of this ghost images is only 3 dB lower than the main source. For the solid sphere, the level of the ghost images is 8 dB below the main source giving the solid sphere a dynamic range of 8 dB.

Figure 5 presents the results for a frequency of k.a=10. In this case we can observe spatial under sampling of the acoustic wave.

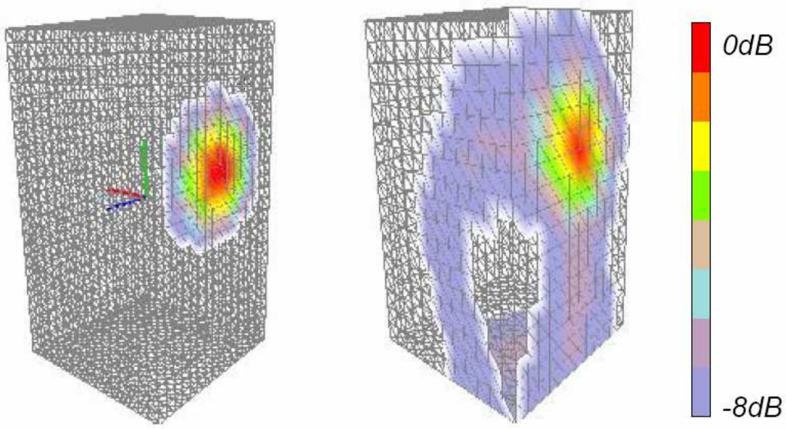


Open sphere   Solid sphere

Figure 5: calculation with k.a=10 (dynamic 10 dB)

For the open sphere, we observe ghost images at -3dB on the face opposed to the source and at -4dB on the side faces. With the solid sphere, all these ghost images are at least to -6 dB below the main source. Having a dynamic range of 6 dB or more is very important in performing a proper SSL.

The previous provided results were for free field conditions. To find out the influence of immersing the sphere in a diffuse field versus a free field, the solid sphere was once place in a cube of roughly 15m by 1m by 1m that was acoustically treated providing a free-field condition. For the second measurement the acoustic material was remove from the cube giving a diffuse field.



Space with absorption Reflective space

Figure 6: measure with k.a=4 (dynamic 8 dB)

Figure 6 shows the results obtained for a frequency of k.a=4. For the free-field conditions, the dynamics range of the solid sphere is higher than 8 dB, whereas it is less than 6 dB in a diffuse field. In the examples described in Figure 3, Figure 4 and Figure 5 were executed in free field conditions. For these applications the open sphere had an inferior dynamic range than the solid sphere and was around 3 dB. Bringing the open sphere in an enclosure will only worsen this dynamic range.

3. GEOMETRY INFLUENCE

When doing source localization inside a cavity, a surface has to be provided to the analysis to which the pressures have to be propagated. Getting a geometry is not always easy for a test person, so the question can be raised if one could propagate to virtual geometry that has no relation with the actual geometry of the vehicle versus the actual geometry of the cavity, Figure 7. Propagating to an arbitrary surface is from a users standpoint as from an software integration standpoint very tempting but will this approach have a cost in accuracy?

In Figure 7 are 3 source located on the surface of the car geometry. When propagating to a virtual sphere, dotted line in Figure 7, the top source falls in front of the sphere, while the bottom source is falling behind the sphere. Question becomes now if there will be a difference in localization results between a sound source localization using the virtual sphere as geometry, where the source don't line up with the used propagation geometry versus a propagation using the proper geometry.

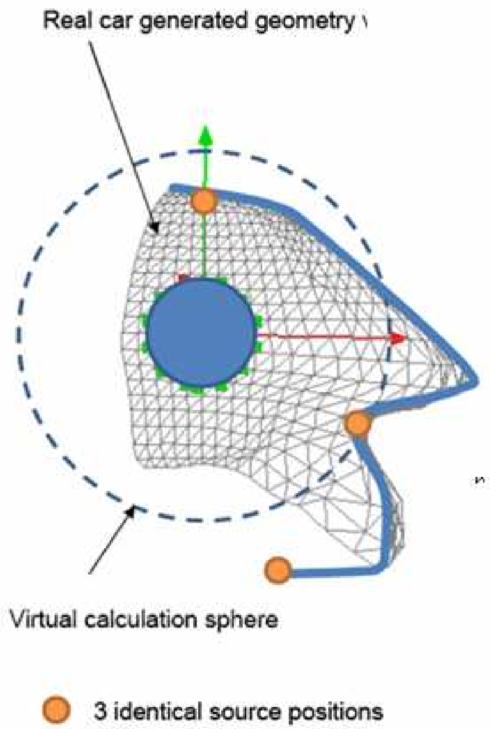


Figure 7: Propagation geometries

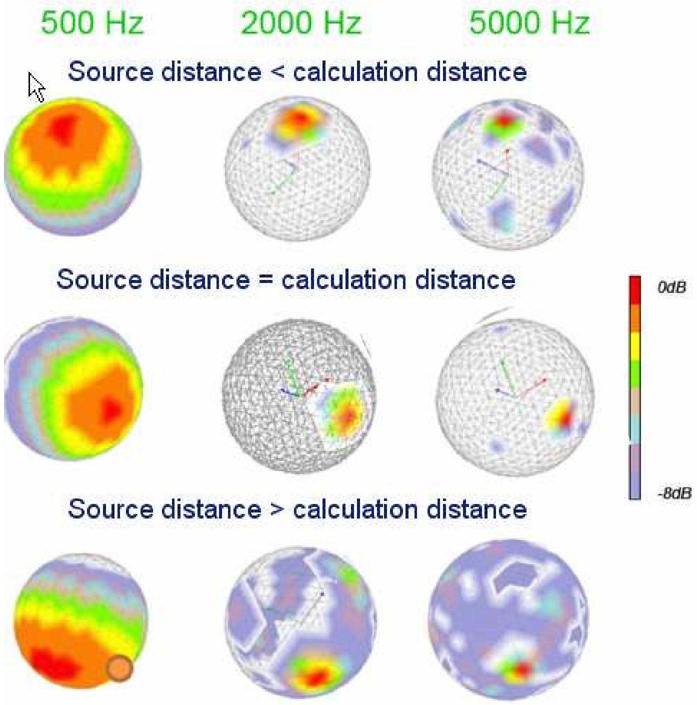


Figure 8: Propagation results for different geometry locations

Figure 8 shows a simulation of what the results are if the results are propagated to the virtual sphere surface. The first row of Figure 8 shows the source localization results for a source in front of the surface, the middle row shows the results for a source on the surface and the last row shows the results for a source behind the propagated surface. Each column in Figure 8 shows the propagation for a different frequency. For the lower frequency 500 Hz, we see that when the source is well localized for the case when the source is in front of the surface or on the surface. When the source is behind the surface, last row, the localization of the source at 500 Hz is not only less accurate, larger red spot, but also wrong. The small circle indicates the proper source location. When comparing the other frequencies, 2000 Hz and 5000 Hz, we can basically conclude that in all three cases the source is well localized and that the fact of the source being on the propagated geometry or not doesn't influence the localization. However when looking at the dynamic range, we do see a significant difference. Each of these propagations is simulated when only one source is present. This is done to make the results easier to read and interpret for the non-experienced user. Since each simulation is done with one source, each propagation should have only one red spot, where the actual source is located, and for the rest the pressure on the propagated sphere should be zero. However, a sphere has certain directivity, implying that in the propagation some sources show up that are physically not there. This is linked to what people refer to as the side-lobes of the sphere. From a practical point of view, this means that below this pressure level where the ghost images start showing up, one can no longer distinguish real source from ghost images.

So when looking at the blue spots on the different propagations, we can see that for the middle row only some small blue spots show up at higher frequencies. All results in Figure 8 are shown with a dynamic range of 8 dB. So when the source is located on the propagated geometry we see that for the higher frequency the dynamic range drops to 8 dB. This is normal. The dynamic range decreases with increasing frequency. When we look at the propagations where the actual source is laying in front of the sphere, we see for the 2000 Hz propagation one small blue spot while for the 5000 Hz we have a significant number of large blue spots. When the source is behind the propagated surface we basically have a blue sphere for the 2000 Hz and 5000 Hz frequency band. So for both cases where the source is not laying on the propagated surface we notice that the dynamic range drops versus when the source is located on the propagated surface. This drop in dynamic range is worse when the source is behind the propagated surface. Similar conclusions were found by Olaf Jaekel [4].

The results in Figure 8 are based upon simulations. In order to validate these results/conclusions actual measurements were taken. A speaker was placed on the dashboard of a car and placed at different distances from the center of the sphere: 55 cm, 65 cm and 73 cm. For each of these cases, the pressure was propagated to a sphere surface with a radius of 65 cm, Figure 9.

Figure 9: Validation Measurement set-up

The results of this analysis are shown in Figure 10 through Figure 12. The distance underneath the results indicates the distance between the speaker and the sphere. All the results are propagated to a sphere with radius of 65 cm. So only the middle propagations are propagations where the source is actually laying on top of the propagated geometry. From Figure 10 we see that for the high frequencies the source are well localized but that the dynamic range drops when the source is not aligned with the propagated geometry. The drop in dynamic range is very bad when the source is in front of the geometry. For the middle frequency range, Figure 11, the spatial resolution is worse when the source is not on the propagated geometry. When going lower in frequency, Figure 12, we notice a wrong localization when the source is in front of the propagated geometry. When the source is behind the geometry, the localized source is slightly out of the center.

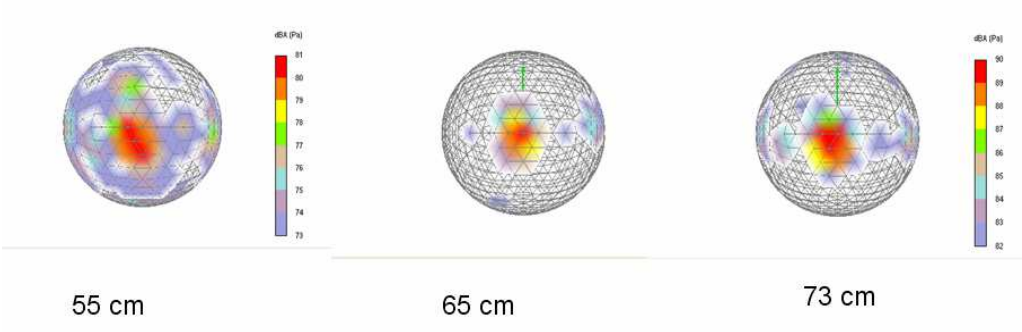


Figure 10: Propagation Results for frequency band from 2630 Hz to 3420 Hz.

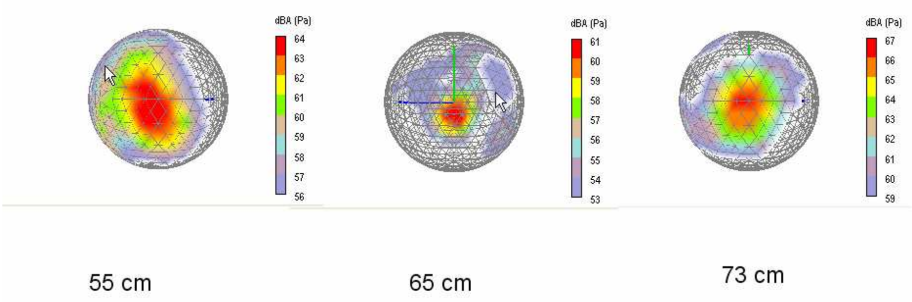


Figure11: Propagation Results for frequency band from 1000 Hz to 1500 Hz

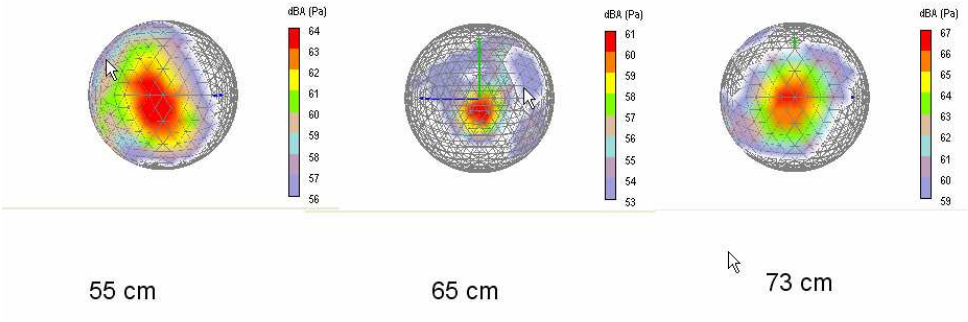


Figure 12: Propagation Results for frequency band from 500 Hz to 1000 Hz

4. CONCLUSIONS

This paper elaborated on two main topics. In the first topic the advantages of a solid sphere where discussed for the localization of sources in a cavity. A solid sphere gives better spatial resolution in the low frequencies and has a better dynamic range for the higher frequencies.

In the second part a deeper investigation was done on the influence of the propagated geometry versus the accuracy of the results. The conclusions from the simulation results as well as from the actual measurements are that when the source is not located on the propagated surface a loss in accuracy and dynamic range is noticed.

5. REFERENCES

[1] Bernard BEGUET, Maxime ROBIN: “*Combining acoustical imaging and identification techniques to localize and identify sound sources* “, Automobile comfort conference SIA Le Mans, nov. 2006.

[2] Filip Deblauwe, Karl Janssens, Bernard Beguet, *“A focalization technique to extend the usability of Near-Field Acoustic Holography and Beam-forming”*, Inter-noise 2007, Istanbul, Turkey.

[3] Lucille LAMOTTE, Quentin LECLERE: *“Improving the localization of sources based on shaped arrays with a reduced number of microphones* “, Acoustic’08 Paris, July 2008.

[4] Olaf Jaeckel, Ralf Schröder and Dirk Döbler, *“ Comparison of various Array Geometries with Respect to their Depth of Field for Acoustic Mappings”*, NAG/DAGA 2009, Rotterdam, 23-26 March 2009.