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Unattended noise measurements: use of new technologies to automatically qualify noise events for greater efficiency, precision and time savings

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ABSTRACT

For more than 40 years, the noise assessment in the environment has consisted of measuring and storing the time history typically every second, then marking the events using post-processing software or automatically or manually by coding. Technological advances now make it possible to enrich the simple measurement of the time history thanks to additional data allowing a better evaluation of the measured phenomena: audio recording and AI analysis of the type of noise, analysis of the predominant direction during a noise event. We propose to present an innovative solution based on a 3D sound intensity probe allowing the determination of the azimuth and the elevation every time a noise event occurs. The results are expressed by frequency bands and A weighted filter. The influence of the type of field (active and reactive intensity) will be developed. Particular attention will be paid to the accuracy and the validity of the measurement as well as the limits of the principle.

1. INTRODUCTION

Determining the direction of noise can be done through various methods, depending on the context and resources available:

- Human Hearing: This is the simplest method. Humans can often detect the direction of a noise by turning their head and listening for where the sound is loudest.
- Visual Cues: Sometimes, you can see the source of the noise. For example, if you see a construction site nearby and hear loud machinery, it's likely coming from that direction
- Sound Intensity: by measuring sound intensity using a 3D probe, you can accurately determine the intensity vector therefore the direction of the energy flow
- Time Delay of Arrival (TDOA) Techniques: By using multiple microphones spaced apart, you can measure the time it takes for sound to reach each microphone. By comparing these time delays, you can estimate the direction of the noise source
- Triangulation: If you have multiple listening points, you can use triangulation to determine the direction of the noise. By comparing the level of the noise at different locations, you can estimate its origin

- Beamforming: This is a signal processing technique that combines the signals from multiple microphones to create a directional pattern. By analyzing the beamformed signal, you can determine the direction of the noise source
- Acoustic Cameras: These are devices equipped with microphone arrays that can visualize sound sources in a particular space, effectively showing the direction from which noise is coming.

2. Goal

The goal is to be able to enrich the sound pressure levels measurements with an additional sensor to determine the sound direction of the predominant noise when an event occurs for unattended measurements in azimuth (0° - 360°) and elevation (-90° - +90°), function of frequency. The required bandwidth is from octave 125 Hz to octave 4 kHz.

3. Challenges

The sensor must be simple and easy to install, low power and the size must be compatible with the constraints of the sites to monitor. It has to be weather proof for unattended long-term measurements outside.

4. Which method has been selected and why?

Due to the physical encumbrance constraint, among the various methods, a 3D intensity probe has been selected as the best compromise in terms of performance and size in a frequency domain compatible with the required bandwidth.
Moreover, using sound intensity techniques, it is possible to quantify the quality of the measurement by checking the dynamic capability of the probe during the measurement.

5. Principle and design

8 microphones are installed at the tops of a cube of 2 cm side:

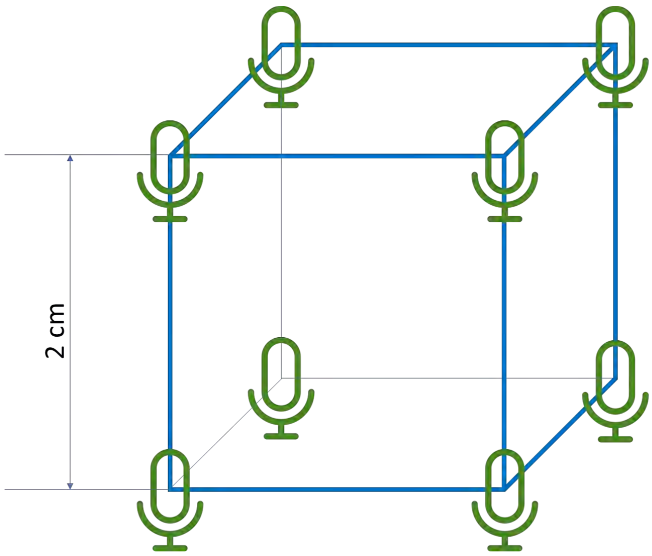

Figure 1: Microphones 3D probe setup.

The intensity vector is measured using 12 single axis intensity probes (2 microphones): the result is obtained by the vector sum of the intensity over the 3 axes:

$$\vec{I} = \overrightarrow{Ix} + \overrightarrow{Iy} + \overrightarrow{Iz}\,, \tag{1}$$

Where the mean intensity vector in each axis x, y and z is calculated:

$$\overrightarrow{Ix} = \frac{1}{4} * \sum \overrightarrow{Ixij}\,, \ldots \tag{2}$$

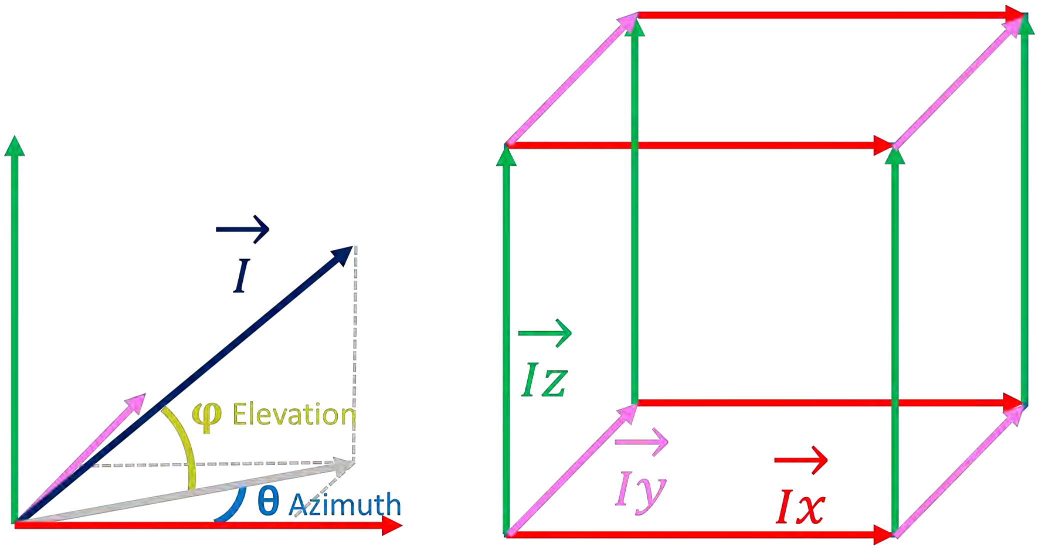

Figure 2: 3D sound intensity probe principle.

Azimuth θ and Elevation φ are deducted using trigonometric formulas.

6. Sound intensity in practice

Reference levels:
Sound pressure ($p_0 = 20\mu Pa$):

$$Lp = 10 * log_{10}(p^2 / {p_0}^2)\,, \tag{3}$$

Sound intensity ($i0 = 1\mathrm{pW/m^2}$):

$$Li = 10 * log_{10}(i / i_0)\,, \tag{4}$$

Under free field conditions:
Acoustical analogy of Ohm's law [1]:

$$u(t) = \frac{p(t)}{\rho * c}\,, \tag{5}$$

Where $\rho * c = 415\ Nsm^{-3}\ @20°C\ and\ 1013\ hPa$:

$$i(t) = p(t) * u(t) = \frac{p(t)^2}{415}, \quad (5)$$

$$i(t) \approx (p(t)/20)^2, \quad (6)$$

$$Li \cong Lp, \quad (7)$$

Under free field conditions, pressure level and intensity level are almost identical.

Under reverberant conditions the sound intensity is zero as the energy flow is coming randomly from all directions. Hence there is no net flow of acoustic energy at any point.

7. Measurements

Various measurements have been performed in an anechoic and a reverberant chamber to qualify the accuracy and determine the limits of the transducer:
A pink noise is used and the results are obtained per octave from 125 Hz to 4 kHz and A weighted. The 3D probe is mounted on a turntable and the angle resolution is 1°.

7.1. Anechoic chamber

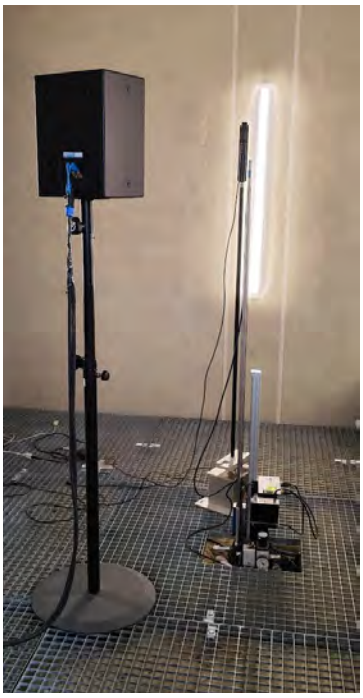

Figure 3: Measurement setup in the anechoic chamber.

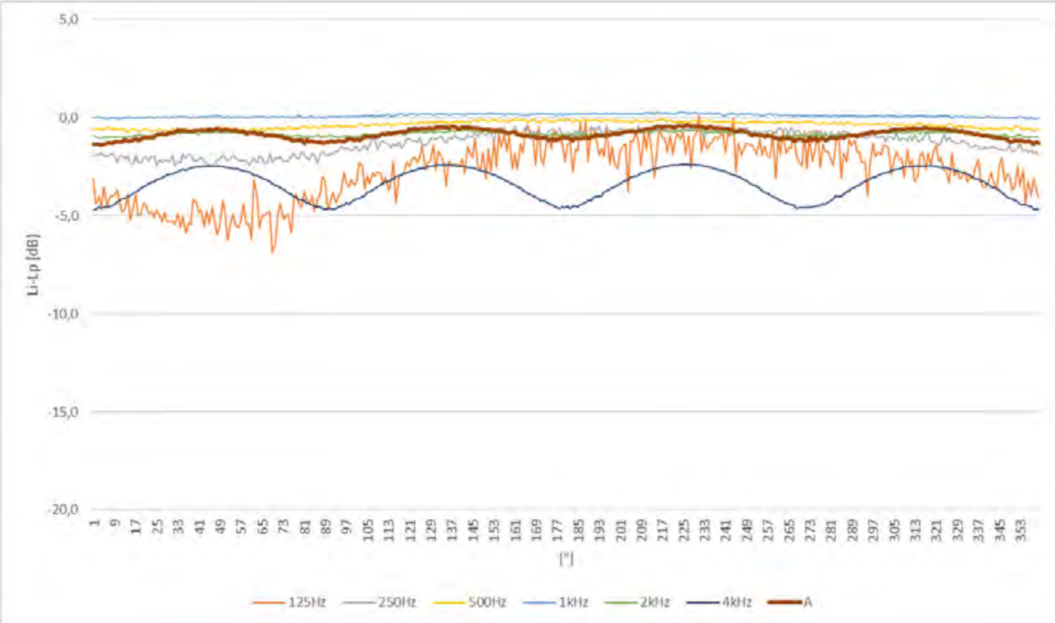

Figure 4: $\Delta p_i: pressure - intensity\ index$.

7.2. Measurement results azimuth

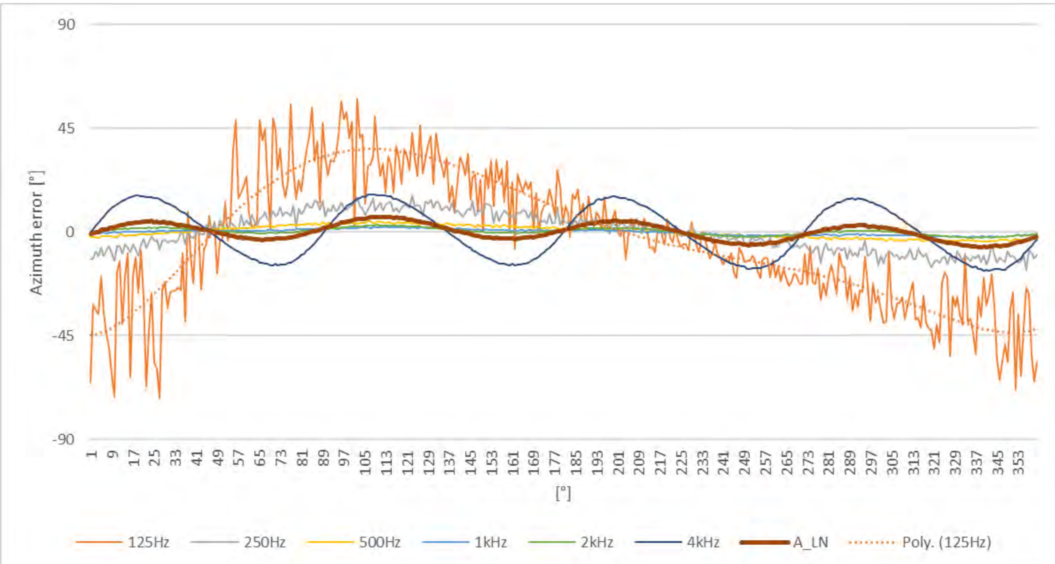

Figure 5: Azimuth error [°]

The azimuth error graph shows:

- For octave 125 Hz a maximal error < 45° on the smoothed curve
- for octaves from 250 z to 2kHz a maximal error < 10°
- for octave 4 kHz a maximal error < 15°. The periodic variation can be explained by the mechanical construction (the tube in the middle of the cube used for the metrological microphone on top has a masking effect)
- for A weighted a maximal error < 5°.

7.3. Measurement results elevation

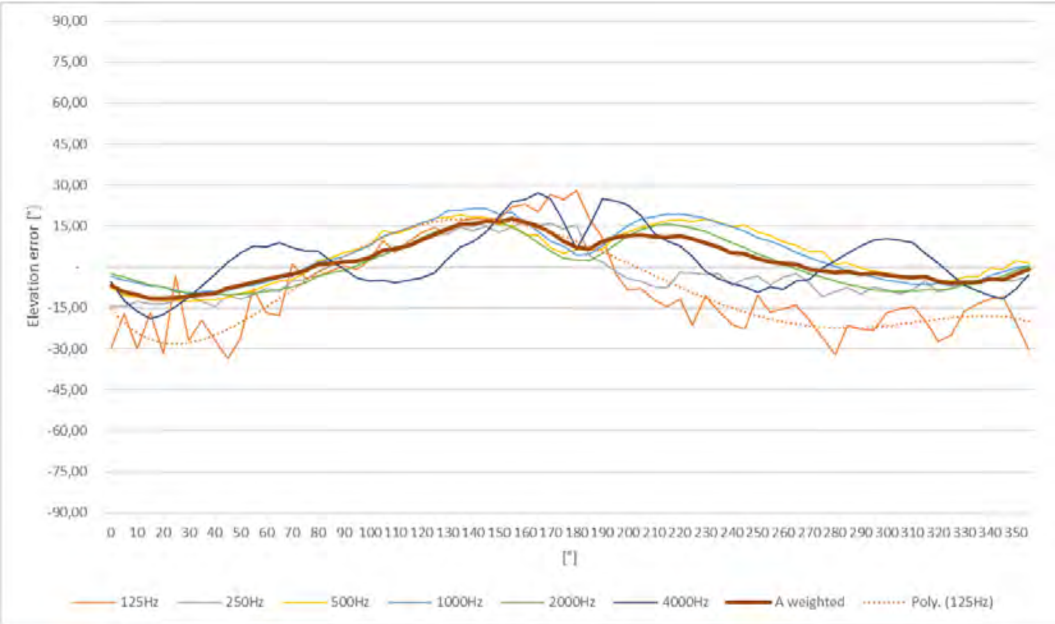

Figure 6: Elevation error [°]

The elevation error graph shows:

- For octave 125 Hz a maximal error < 30° on the smoothed curve
- for octaves from 250 z to 2kHz a maximal error < 20°
- for octave 4 kHz a maximal error < 30°
- for A weighted a maximal error < 15°

When assessing outdoor environmental noise, the field conditions are close to free field if all precautions are taken to avoid reflections.

These results show that under free field conditions the 3D sound intensity probe “NL1 - Noise Locator” allow the determination of the azimuth and elevation of a sound source with a sufficient accuracy in most cases.

7.4. reverberant chamber

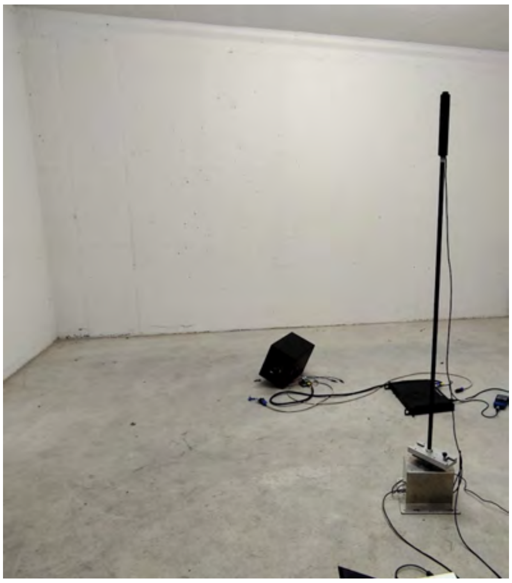

Figure 7: measurement setup in the reverberant chamber

The purpose of the measurement in a reverberant chamber is to determine the residual intensity measured by the 3D probe. The difference between pressure and residual intensity characterizes the dynamic capability of the probe and is called $\Delta p_{i_0}: pressure - residual\ intensity\ index$.

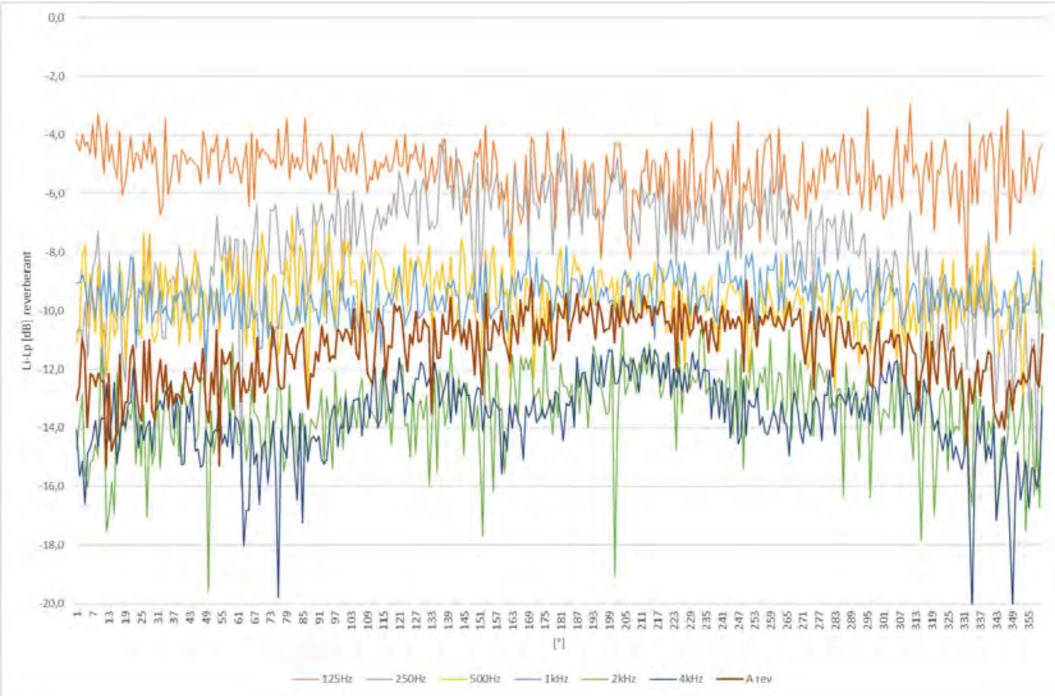

Figure 8: Pressure – residual intensity index

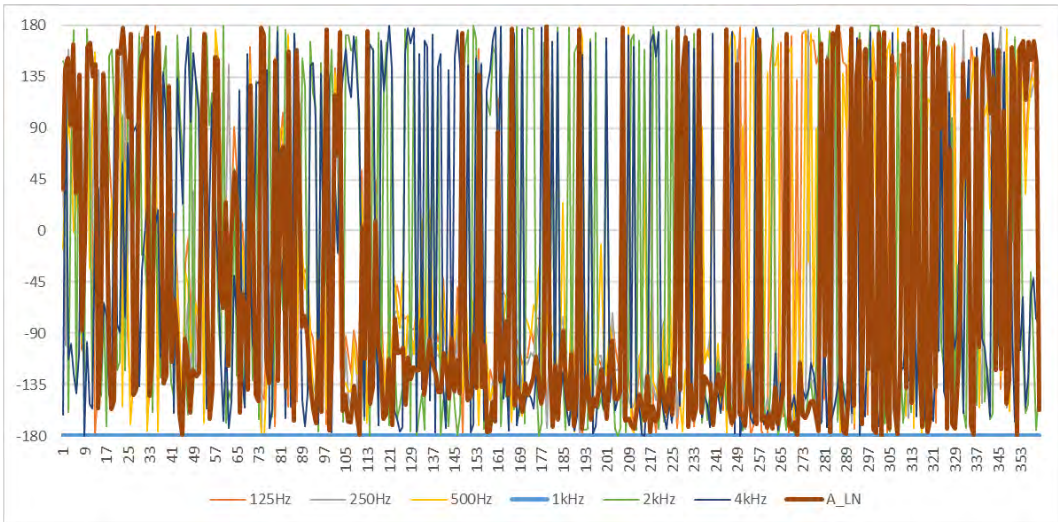

Figure 9: Azimuth error [°]

In a reactive (reverberant) sound field, the difference between pressure and intensity is maximal; the consequence being the measurement of azimuth and elevation are not relevant.

8. Validation of the measurement

The validity of the measurement depends on the type of sound field and the complexity and amount of noise sources. When assessing noise in the environment, the sensor is placed outside usually in a free field (avoiding reflections nearby).

When a single noise event occurs, it is a predominant noise source emerging from the background noise. In this case the measurement in an anechoic chamber is reproduced (Δp_i close to zero) and the measurement is valid.

If several noise sources without predominance appear at the same time the pressure will be higher than the intensity. In this case (Δp_i not close to zero) and the measurement is not valid.

Δp_i: $pressure - intensity\ index$ gives a perfect indication of the reactivity of the sound field. When it is close to zero, it means that free field conditions are fulfilled and the measurement is valid. On the opposite, if Δp_i: $pressure - intensity\ index$ is close to Δp_{i_0}: $pressure - residual\ intensity\ index$, the measurement is not valid.

9. CONCLUSIONS

A 3D sound intensity probe for assessing noise in the environment is a useful tool to determine the direction of a predominant noise source. Despite its small size (cube of 2 cm size), the resolution in frequency starts at 125 Hz with a sufficient accuracy.

When the sound field is complex and the sound sources multiple, the measurement will not give relevant results. Which is predictable as there is no specific direction result to expect!

However, under outdoor free field conditions, if a predominant noise source emerge from the background noise the 3D intensity probe “NL1 – Noise Locator” will measure correctly its azimuth and elevation.

The validity of the measurement is verified by comparing pressure and intensity levels; therefore, the implementation of a specific condition on Δp_i: $pressure - intensity\ index$ for each octave band calculated during the noise events will validate or invalidate the direction determined by the sensor.

ACKNOWLEDGEMENTS

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