Acoustic Goniometry Antennas and Algorithms

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0. Introduction

Our laboratory is involved in several research and development projects that require the use of acoustic goniometry. For example, we have demonstrated that it is possible to carry out avalanche activity surveillance within the infrasonic frequency range: using goniometry to detect the azimuth and avalanche location. Other applications, in particular in the field of active outdoor noise control, require that the direction of propagation of the noise wave be detected, right up to several kHz.

The principles of acoustic goniometry will be presented, followed by the design and optimization criterion of the antenna, composed of a certain number of microphones set up in an ad hoc configuration according to the application. The various algorithms will then be described. First of all that of the goniometry itself (searching of cross-correlation peaks in conjunction with energy criteria). Then the selection algorithm for the different types of waves (for example the separation of the direct sound wavefrom the reflection on the ground. Finally, the experimental results of the goniometry based on the principles and algorithms described will be presented. The first validations were carried out in an anechoic chamber, followed by outdoor experimentation in real-life conditions.

1. Principe

The acoustic goniometer presents itself in the form of an antenna with several microphones distributed in space (Figure 1). The signals are amplified, digitized, stored and then processed by DSPs in order to deliver goniometer results in real time.

The development and implementation were carried out on a PC with Matlab, but not in real time.

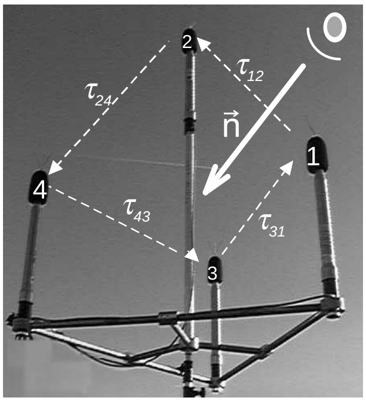

Figure 1 : tetrahedral antenna, wave vector, delay vectors

The design and placing of the antenna are optimized according to the nature and wave paths of the sources to be localized. The antenna is made up of at least 4 microphones (goniometer without ambiguity). The wave vector of the source is calculated from the propagation delays between the antenna microphones. These delays are obtained by locating the peaks of the cross-correlation functions of the recorded sections taken 2 at a time (Figure 2). By following a sound source, the need to distinguish between the incident and reflected direct sound wave was demonstrated. A simultaneous goniometer algorithm of several sources is planned.

Figure 3 represents the goniometer principle for two microphones. The following quantities are represented: $\vec{n}$ the wave vector, $\vec{\tau}$ the delay vector, c the speed of sound, D the microphone position matrix, C_{12} the cross-correlation of the signals 1 and 2 and τ_{12} the delay between microphones 1 and 2.

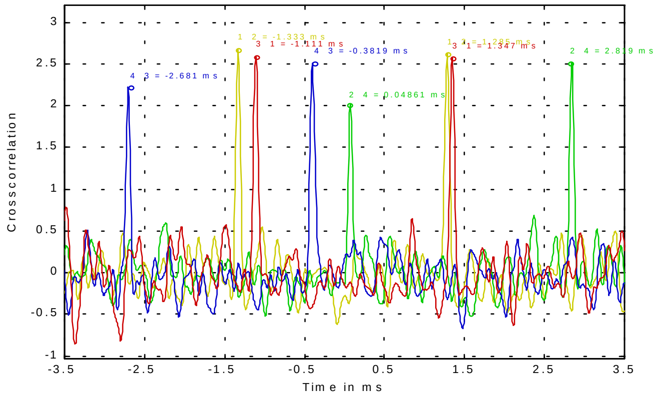

Figure 2 : cross-correlation of two white noises (anechoic chamber)

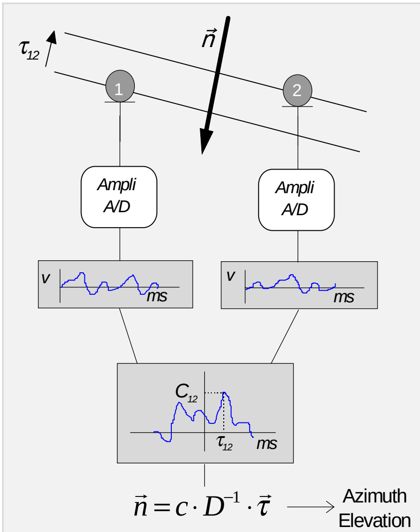

Figure 3 : principle

2. Selection criterion

Once the cross-correlation peaks have been stored, they each have to be attributed to the different sound waves picked up. The main difficulty lies in establishing a combination criterion as selective as possible. The latter is defined by a weighted function of three sub-criteria based respectively on the wave vector norm, the sum of the delays and the energy of the cross-correlation peaks. The combinations selected minimize the overall criteria, that is to say:

1. The difference of the wave vector norm compared to 1.
2. The sum of the delays following a closed path (optimal = 0).
3. The difference between the selected combination peaks and the sum of the four greatest peaks.

$$\Gamma = \alpha \cdot \left| \sqrt{\sum_{i=1}^{3} n_i^2} - 1 \right| + \beta \cdot \left| \tau_{12} + \tau_{24} + \tau_{43} + \tau_{31} \right| + \gamma \cdot \left| \sum_{n=1}^{4} C_n^{\max} - \sum_{n=1}^{4} C_n^{MAX} \right|$$

Γ overall selection criterion,
α, β, γ: weightings,
n_i wave vector components,
τ_{12} propagation time between microphones 1 and 2 corresponding to the cross-correlation peak considered,
C_n^{max} peak considered of the n^{th} cross-correlation,
C_n^{MAX} greatest peaks of the n^{th} cross-correlation.

3. Algorithm

The goniometer algorithm was implemented using Matlab. The following commands had to be implemented:

- data acquisition,
- computation of the four cross-correlation functions (by FFT),
- interpolation of the cross-correlation functions (SINC),
- for each cross-correlation, storage of the 3 energy peaks, therefore 12 overall,
- computation of the delays corresponding to these peaks,
- determination of the 2 best delay combinations as regards an overall selection criterion,
- computation of the azimuths and elevations of the selected combinations.

4. Validation in an anechoic chamber

Goniometry of a vented box loudspeaker is capable of separating the cone from the vent, even when they are located at virtually the same angle. The test sound used was a large band 20 - 2000 Hz white noise. Figure 4 represents the azimuths of the cone (dense plot) and vent (lighter plot).

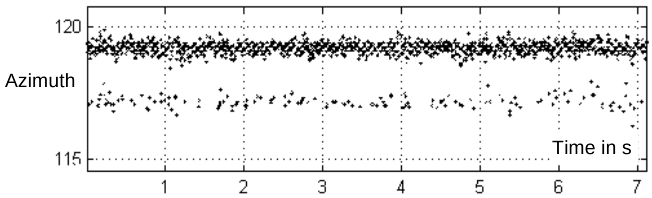

Figure 4 : cone and vent azimuths

The repeatability of the experiment (a result every 5 ms) enables the quality of the measurement to be assessed. The standard deviation of the azimuth and elevation values around the mean value is less than 1/2 a degree. It cannot be better in view of the size of the cone and vent (cone and vent diameters of respectively 20 cm and 8 cm, computed angular distance of 2 degrees in the horizontal plane).

5. Validation outdoors

An outdoors trial was carried out in the Sionne valley in Central Valais (14.11.97). A helicopter was traced with a degree of uncertainty regarding azimuth and elevation of, on average, less than a degree, compared to the position of the helicopter calculated using differential GPS. The helicopter-antenna distance varied between 500 m and 3 km.

Figure 5 gives the azimuth and elevation values of the helicopter during its last two flight paths. The comparison of the results obtained by GPS (light curve) and those obtained by the goniometer is very satisfactory. A ground reflection can be seen on the elevation graphic (cement slab).

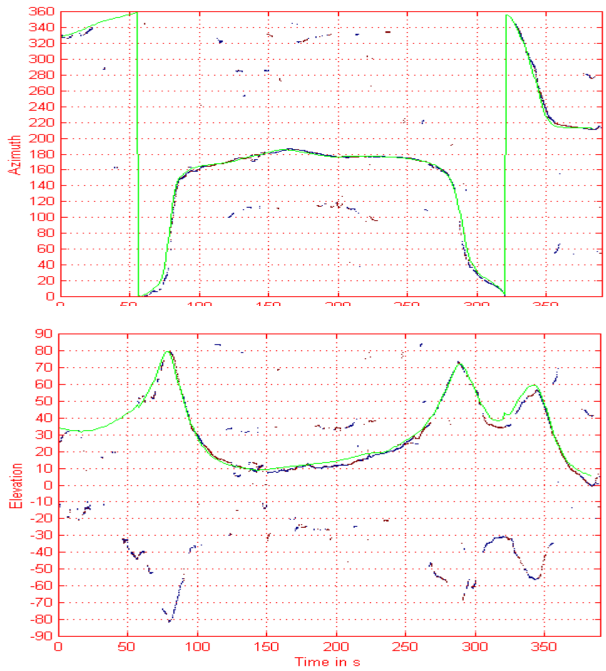

Figure 5 : helicopter trace; azimuth and elevation computed by the goniometer and GPS values.

In the infrasonic frequency range, goniometry of natural phenomena such as avalanches, is carried out with large-sized antenna (ARFANG Project). Four infrasonic ECHO microphones are set up in a star shape (20 m points) guarantee localizazation precision up to 1 degree, within a radius of several kilometres.

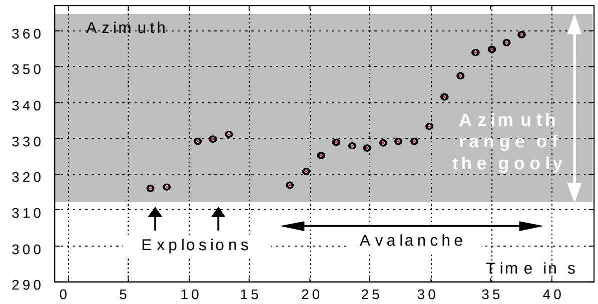

Figure 6 : results from an infrasound goniometer of two explosions and 1 avalanche (Anzère-Valais-13.12.97)

Although it would be out of the scope of this paper to discuss in detail the elements that disturb goniometry, they have been studied. For example, wind blinds the goniometer and bends the sound waves. As regards the infrasound goniometer, the layer of snow that covers the microphones introduces additional delays.

6. Conclusion

Concerning the wide-band signal goniometer processed by the tetrahedral antenna, experiments have shown that, by working with cross-correlation windows of 10 ms and a sampling frequency of 48 kHz, goniometry, implemented as described earlier, enables 2 wave vectors to be simultaneously localized with an uncertainty of less than a degree as long as their levels differ by less than 9 dB. The performances of goniometry in an anechoic chamber in the absence of sources of disturbance, is of the order of a tenth of a degree with a discrimination angle of less than 1/2 a degree. In parallel, infrasound goniometry (ECHO star) yields optimal results for sections corresponding to 2.5 s.

7. Future work

Further work involves optimizing the selection criteria of the algorithms for each application as well as integrating the goniometers (real-time operation). Moreover, an antenna made up of directional microphones is currently being studied.