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OPTIMUM ARRAY MICROPHONE CONFIGURATION

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ABSTRACT
Computer simulations regarding various array microphone configurations (spiral, grid, circle, X), searching a better one than those commonly used, in resolving/quantifying noise from by-passing trains, shows that the spiral array, microphones irregularly distributed, performs better than the (commonly used) X-array. With diameter D=4.0 m, microphone spacing d=0.4 m, and distance r_0=7.5 m from the source plane, the spiral yields a useful frequency range from 200 Hz up to at least 3.4 kHz.

1 - INTRODUCTION

With a high performing microphone array it is possible to resolve and quantify different noise sources (wheels, rail, aerodynamic) from by-passing trains, and e.g. determine which is the most important one in a certain frequency range. So far, most reported results are from line- and X-arrays [1-3]. Naturally, a 1D line array can "see" along a line only. The 2D X-array can scan over a surface, but leaves a "print" of its own shape in the picture displaying source strengths and positions. The aim here is to find a better array/microphone configuration than those commonly used, to better resolve/quantify noise from by-passing trains.

2 - THEORY

A noise source $s_i(t)$ passes a microphone array (Fig. 1) causing N pressure signals $p_j\left(t + r_{ij}\left(t\right)/c\right)$, where $r_{ij}(t)$ is the distance between source s_i and receiver p_j at time t, and c is the sound speed, so

$$s_i\left(t\right) \approx \frac{\sum_{j=1}^{N} p_j\left(t + r_{ij}\left(t\right)/c\right)}{\sum_{j=1}^{N} r_{ij}^{-1}\left(t\right)} \tag{1}$$

represents the source strength as picked up by the array [3]. A rectangular amplitude weighting window is assumed. Note that (1) does not suffer from the Doppler effect. By accounting for the propagation durations from source to the individual receivers, $r_{ij}(t)/c$, it is possible to steer the array and focus on the moving source $s_i(t)$ as it passes by. Contributions from other sources, out of focus, cancel each other out through destructive interference (1). However, due to the finite number of microphones, those sources "leak" into the array, reducing the S/N-ratio and the resolution. First, the finite microphone distance d allows waves to enter the array through side and grating lobes (secondary maxima), worsening the S/N-ration; by choosing $d < \lambda$ (λ is the sound wavelength) grating lobes are eliminated, as long as the beam is steered with a restricted viewing angle. Assuming that sources at great viewing angles may be neglected, d may be chosen greater than λ. Second, the finite array size (diameter) D limits the resolution, particularly at low frequencies, since the beam width is proportional to λ/D. What is more, beam width increases with viewing angle, so that the shapes and strengths of objects away from the origin are distorted; a point source at a great viewing angle apparently "shines" brighter than one near the origin. With a fixed microphone number, the only way to increase the resolution is to increase

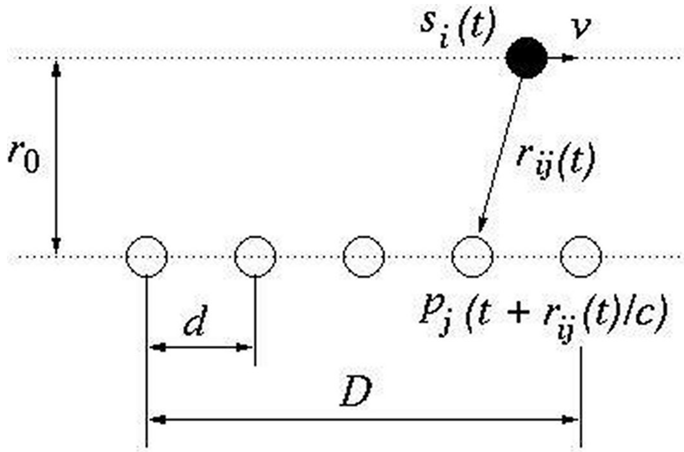

Figure 1: Noise source passing an array with N microphones.

the microphone spacings d, at the same time worsening the S/N-ratio, however. So, optimum array performance is a compromise between S/N-ratio and resolution.

3 - NUMERICAL SIMULATIONS

Random, uncorrelated points sources, distributed over a surface roughly equal to that of two wheels spaced 2.5 m apart (a wheelset) and over the rail surface underneath, passes the array with velocity v=50 m/s. The simulations regard four different microphone configurations (Fig. 2): spiral, with microphones irregularly spaced; grid, with microphones regularly spaced; circle; and X. The arrays all have diameters D=4.0 m and 90 microphones. Typical microphone spacings are d=0.4 m for the spiral and grid arrays, and d=0.1 m for the circle and the X arrays. Processing (localisation, quantification, spectrum calculation) occurs for microphone pressure signals caused by the wheelset as it travels a length of 2 m, straight ahead of the array.

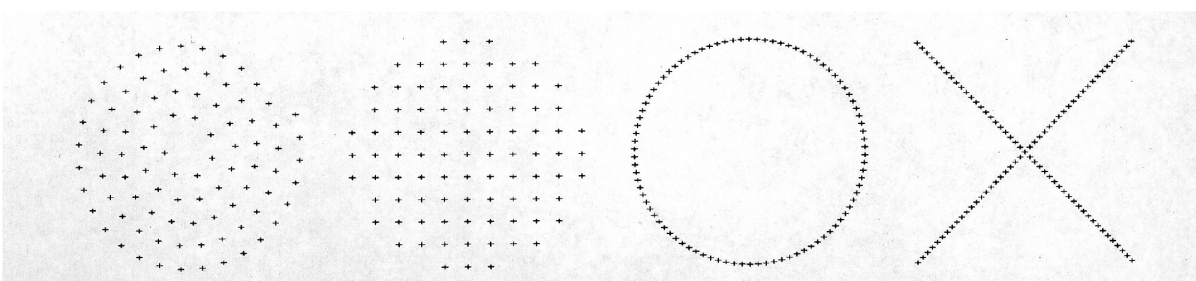

Figure 2: Microphone configurations: spiral, grid, circle, X.

Source distributions (Figs. 3 and 4) are displayed for total sound pressure levels (1^{st} row), frequency band 200-600 Hz (2^{nd} row), 1.0-1.4 kHz (3^{rd} row), 1.8-2.2 kHz (4^{th} row), 3.0-3.4 kHz (5^{th} row), and 3.8-4.2 kHz (6^{th} row), with 10 dB-levels from black to white. Fig. 3 shows results for all four arrays at a measurement distance of r_0=5 m from the source plane, columnwise from left to right: spiral, grid, circle, and X. The first four columns of Fig. 4 shows results with the spiral array, D=4.0 m and d=0.4 m, at four different distances, columnwise from left to right: r_0=2.5 m, r_0=5.0 m, r_0=7.5 m, and r_0=10.0 m. The last column shows results with a smaller spiral array, D=2.0 m and d=0.2 m, at r_0=5.0 m distance.

4 - DISCUSSION

4.1 - Microphone configurations

Apparently (Fig. 3), the spiral array, with microphones irregularly distributed, yields the best results regarding (a compromise between) resolution and S/N-ratio, while the (commonly used) X-array, with an "X-print" in the source images, yields the worst results. The circle array suffers from interference patterns in the mid-frequency range The grid array, with microphones regularly distributed, yields practically the

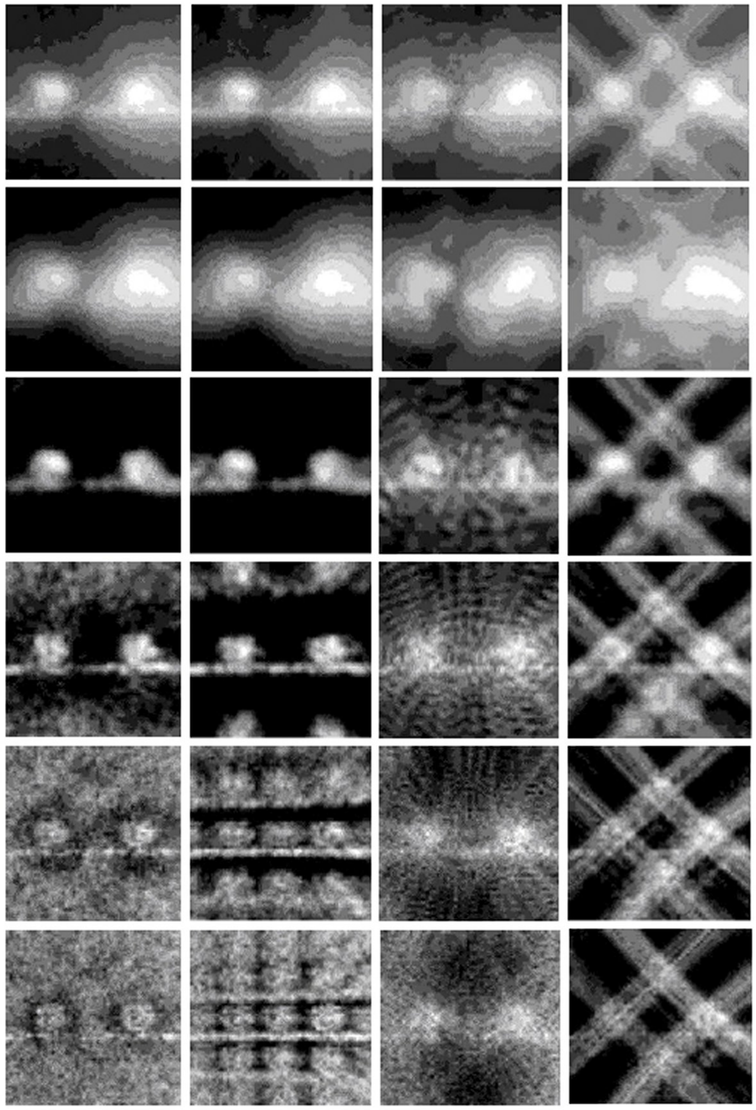

Figure 3: Source distributions for different array configurations: 1^{st} col. spiral; 2^{nd} col. grid; 3^{rd} col. circle; 4^{th} col. X; frequency bands: 1^{st} row, total levels; 2^{nd} row 200-600 Hz; 3^{rd} row 1.0-1.4 kHz; 4 th row 1.8-2.2 Hz; 5^{th} row 3.0-3.4 kHz; 6^{th} row 3.8-4.2 kHz.

same results as the spiral array up to mid frequencies, but produces a disturbing interference pattern higher up. The irregular microphone distribution of the spiral array effectively shatters this pattern, though leaving S/N-ratio worsening specks some distance away from the sources.

4.2 - Focal plane distance vs. Array size and microphone spacings

By adjusting the measurement distance r_0, it is possible to tune the array to the frequency range of interest (Fig. 4). A short distance yields a useful range at lower frequencies, while a long distance shifts the useful range towards higher frequencies. The spiral array with diameter D=4.0 m, microphone spacing d=0.4 m, and distance r_0=7.5 m from the source plane, yields a range from 200 Hz up to at least 3.4 kHz. When moving the array away from the source plane, to r_0=10.0 m, the range also includes frequencies up to 4.2 kHz, but at the same time loses the ability to resolve sources at the lowest frequencies. A spiral with D=2.0 m and d=0.2 m at r_0=5.0 m yields about the same resolution and S/N-ratio as the one with D=4.0 m and d=0.4 m at r_0=10.0 m.

5 - CONCLUSION

A spiral array, microphones irregularly distributed, performs better than the (commonly used) X-array. With diameter D=4.0 m, microphone spacing d=0.4 m, and distance r_0=7.5 m from the source plane, the spiral yields a useful frequency range from 200 Hz up to at least 3.4 kHz.

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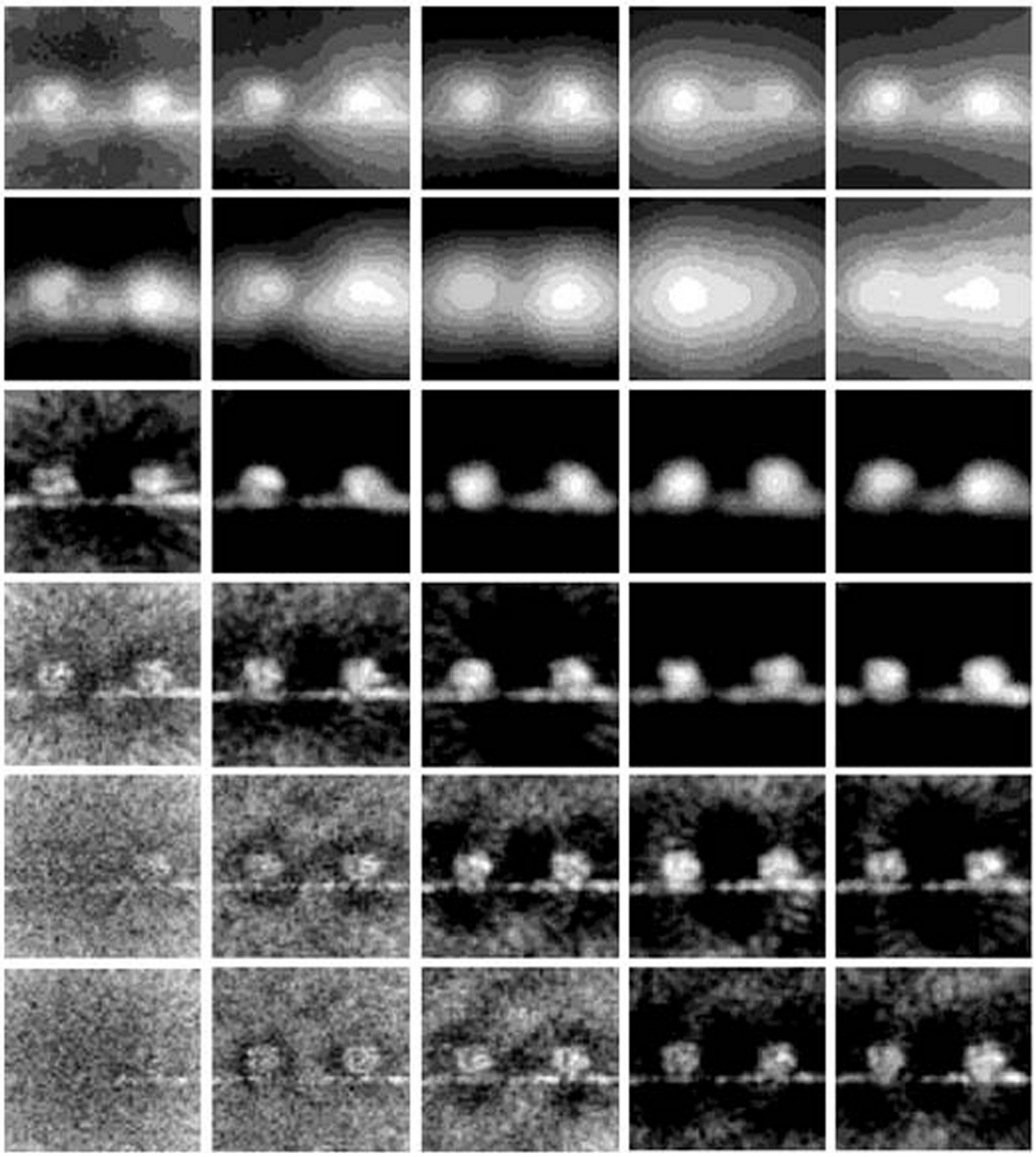

Figure 4: Source distributions for spiral array (D=4.0 m, d=0.4 m, unless otherwise stated) at different measurement distances, r_0: 1st col. r_0=2.5 m; 2nd col. r_0=5.0 m; 3 rd col. r_0=7.5 m; 4th col. r_0=10.0 m; 5th col. D=2.0 m, d=0.2 m, r_0=5.0 m; frequency bands: 1 st row, total levels; 2nd row 200-600 Hz; 3rd row 1.0-1.4 kHz; 4th row 1.8-2.2 Hz; 5th row 3.0-3.4 kHz; 6th row 3.8-4.2 kHz.