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WIDE BAND ACOUSTIC IMAGING OF MOVING SOURCES USING SYNTHETIC APERTURE SONAR; APPLICATION TO TRANSPORTATION NOISE

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ABSTRACT
A new method to locate and identify moving sound sources is presented: the Synthetic Aperture. Using a short array associated to an appropriate signal processing the vehicle movement is explicitly integrated in the array beamforming in order to improve the resolution. After compensating the Doppler effect, the spatial sampling of the sensor (or source) trajectory is used to define a set of virtual fixed sensors that will form the synthetic aperture. The problem can then be solved by using conventional beamforming. The array length can be comparable in length with the trajectory. This leads to an improved resolution that is independent of the frequency. The performance of the proposed method is evaluated with numerical simulations.

1 - INTRODUCTION
Noise reduction of road vehicle is of major importance for environmental concerns. This reduction can be achieved by the designers as far as they can identify the predominant radiating sources. Noise identification is usually achieved by conventional beamforming (CBF) which well-known results are limited by the array size especially for low frequencies. Various "high-resolution" methods have been investigated to improve the angular resolution of conventional processing [1]. However it is necessary to have a more accurate model of the acoustic field to obtain an asymptotic resolution performance, i.e. an adequate signal to noise ratio and a good knowledge of the ambient noise spatial coherence. Furthermore, both the conventional beamforming and the high-resolution methods are not designed for moving sources because of the non-stationarity of the received signals. The motion indeed introduces a time compression and expansion of the received acoustic signal due to the Doppler effect. Hence a new approach primarily used in radar and underwater acoustics [2] was implemented that integrates the source movement in order to enhance the performance of the CBF. The basic idea consists in using the source-sensor relative movement to create a set of virtual fixed sensors, which forms a virtual array comparable in size to the source trajectory called synthetic aperture.

2 - SIGNAL MODEL AND DEDOPPLERISING PROCESS
Figure 1 shows the general geometric configuration for the source and the sensor. A moving source follows a rectilinear trajectory at constant speed v. The range and azimuth of the source at time t are given by $R(t)$ and $\theta(t)$ respectively. The source emits continuously an acoustic signal $x(t) = A\cos(2\pi f_0 t)$.
Due to the propagation delay, the signal emitted at time t_E is received by sensor at time

$$t = t_E + \frac{R(t_E)}{c} \tag{1}$$

where c is the celerity of sound in air and

$$R(t_E) = \sqrt{d^2 + (L - vt_E)^2} \tag{2}$$

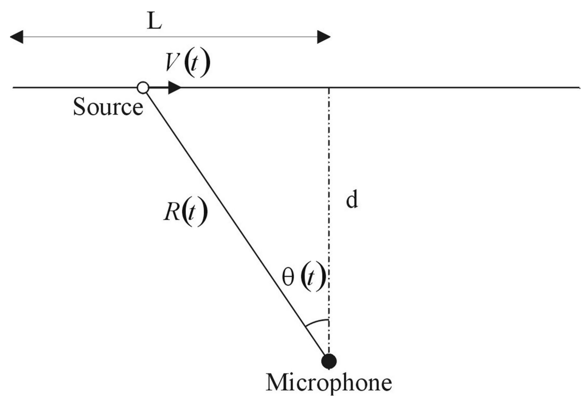

Figure 1: Geometrical configuration of source and sensor.

At the sensor, the received signal $x_R(t)$ is then [3, 4]:

$$x_R(t) = \frac{A}{R(t_E)(1 - M\sin\theta(t_E))^2} \cos\left(2\pi f_0 \left(t - \frac{R(t_E)}{c}\right)\right) \tag{3}$$

where $M{=}v/c$ is the relative velocity. Equations (1) and (2) allow to determine t_E as a function of t:

$$t_E = t - \frac{v(L - vt) + \sqrt{(c^2 - v^2)\, d^2 + c^2 (L - vt)^2}}{c^2 - v^2} \tag{4}$$

The received signal is sampled at regular time intervals Δt. Dedopplerising the received signal consists in resampling it at varying time interval Δt_E compensating the time expansion and dilatation due to the varying propagation time. Knowing the exact position of the source at $t = 0$, this can be done easily with equation (4), under the assumption that parameters v, L, and d are well known. Since the received signal is digitised at regular intervals, it is necessary to interpolate between individual sample.

3 - ARRAY SYNTHESIS AND BEAMFORMING

There is an equivalence when considering a moving sensor in front of a fixed source or a moving source in front of a fixed sensor. In the coordinates of the source referential the sensor follows a linear trajectory at constant speed v, at a distance d from the source. After dedopplerising the received signal, a spatial sampling of the sensor trajectory is achieved which consists in dividing the output signal into N sub-signals of equal length. Each of them represents the output of a virtual independent sensor for consecutive time intervals and spatial locations as shown in figure 2. The length of the N sub-signals, T_N, must be chosen, for a given frequency, so that the intersensor separation does not exceed half a wavelength.

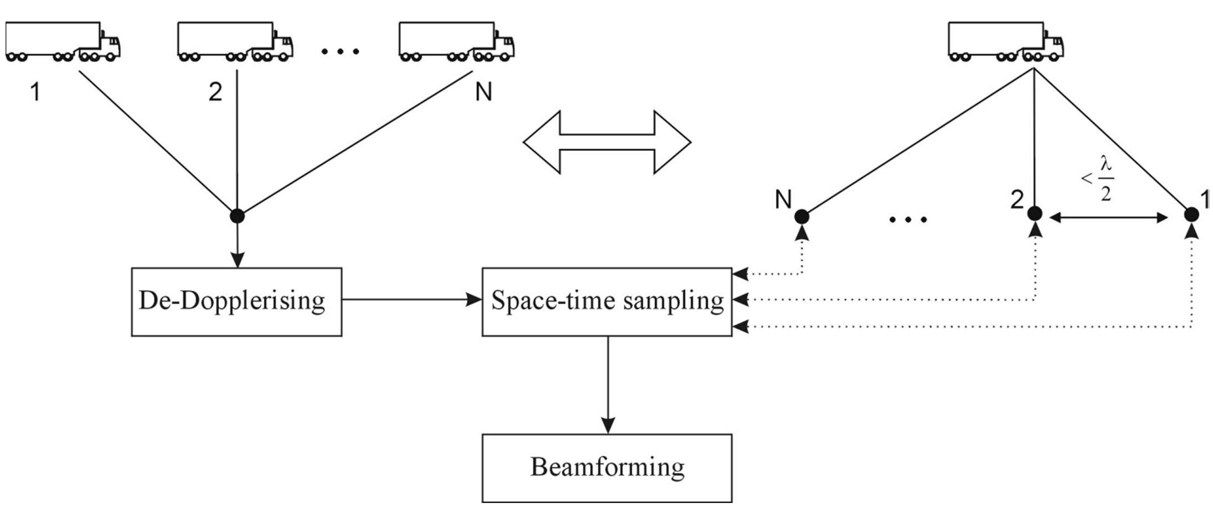

Figure 2: Schematic of the virtual array synthesis associated with a beamformer.

That means that the length of the sub-signals T_N is less than $\frac{c}{2f_0v}$. It is important to note that the signals issued from the virtual sensors are not quite identical to those obtained with a physical array. The dedopplerising process compensates the propagation time delay for a supposed position of the source, the focusing point. The only time shift between all the sensors is due to the sensor path from a spatial position to the next. The beamforming consists then in summing coherently the N sub-signals and the synthetic array output is:

$$\mathrm{A}\left(x,f\right)=\sum_{n=1}^{N}X_{n,x}\left(f\right)\exp\left(-2j\pi f\frac{\delta}{v}\right) \tag{5}$$

where δ is the intersensor separation, v the lorry speed, x is the source location in the lorry referential and $X_{n,x}(f)$ is the Fourier transform at frequency f of the signal issued from the n^{th} virtual sensor while the dedopplerising process is used for a focalisation point locating in x.

4 - RESULTS

4.1 - Single source

A moving source at speed v = 13,8 m.s^{-1} following a rectilinear 60 m trajectory at 7,5 m from the sensor was simulated. The synthetic array response was computed using equation (5). The result is shown in figure 3 together with conventional near-field array response for an identically still source and with a 60 m long physical array (same length as the trajectory). The figure shows that thanks to the movement of the source, a single microphone allows to synthesise an aperture equivalent to a physical aperture comparable in size to the source trajectory.

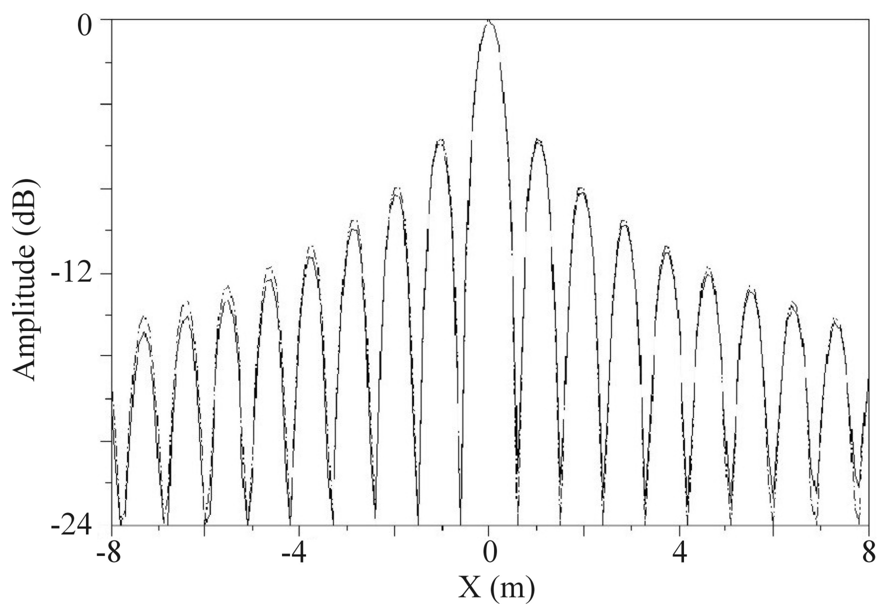

Figure 3: Simulated beams for a source frequency at 200 Hz located at x = 0 m; dashed line: a 70 sensors physical array, L = 60 m, v = 0 m.s^{-1}, d = 7,5 m; solid line: a 70 sensors synthetic array, L = 60 m, v = 13,8 m.s^{-1}, d = 7,5 m.

4.2 - Multiple sources

The aim of the processing is to obtain an acoustic image of the field radiated by several moving sources. The synthetic aperture response is then computed for each frequency in a given bandwidth. The same processing can also be applied to a small horizontal array [5] in order to reduce the final array sidelobes. Figure 4 shows the response of a 70-microphones synthetic array achieved from a 12-microphones linear array for three simulated sources, which frequency and location are respectively 200 Hz/8 m, 200 Hz/9 m and 210 Hz/0 m.

5 - CONCLUSION

A method for locating and characterising moving acoustic sources has been described. Thanks to the movement of the source, a long virtual array is synthetised with a single microphone or a short array. It

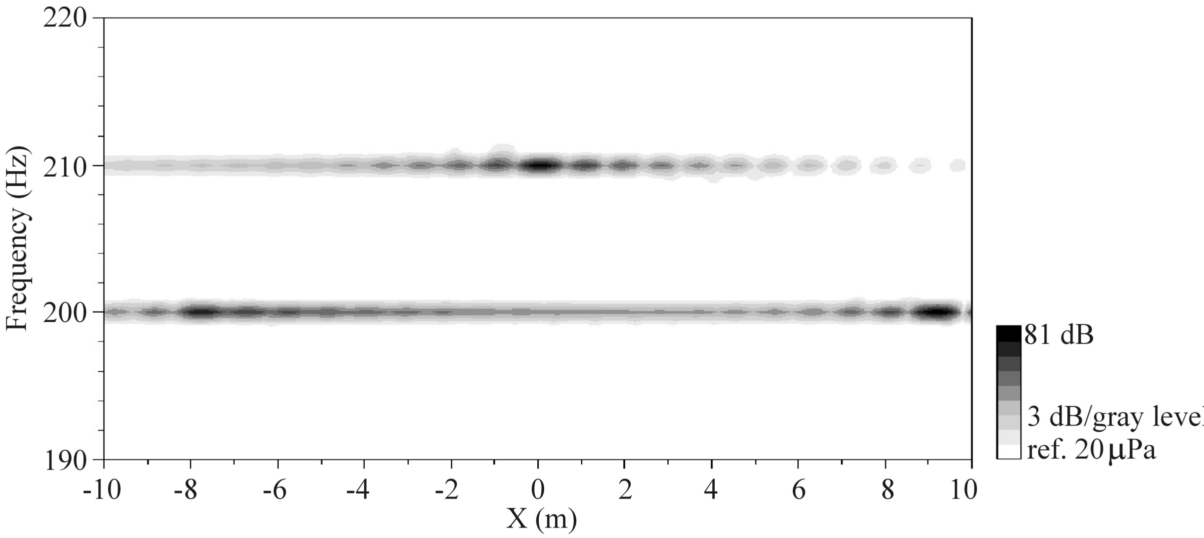

Figure 4: Synthetic array response for three simulated sources; v = 13,8 m.s^{-1}, d = 7,5 m and L = 60 m.

allows to obtain the same performance as the Conventional Beamforming or the Barsikow's method [5] with a reduced instrumentation, assuming that the trajectory of the vehicle is well-known.

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