A realistic environmental approach for the construction of a perceptual typology of industrial noise sources

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Industrial noise sources are various and may cause annoyance around industrial sites, especially when the installations work 24 hours a day. To better understand the environmental impact of permanent industrial sources, a first step consists in creating a perceptual typology of these sources. This typology will be used in future laboratory studies in order to assess the relative annoyance of industrial noise sources. Based on a bibliographical study, a physical classification of major industrial sources has been drawn up. A recording campaign was set up, aiming at collecting each noise source separately in the proximity of the source in order to avoid unwanted noises. Seventy sources were recorded with a stereophonic system (ORTF technique), mainly on French electricity production sites. Sound stimuli are created by filtering the recordings in order to simulate the sound attenuation between the on-site recording point and another point which would represent a dwelling located further away from the source. The filters are calculated with third octave definition by a sound propagation software, which takes into account the influence of distance, atmosphere and ground effects. For a given test-case, the constructed stimuli are compared with real recordings to confirm the choice of propagation parameters for the calculation of filters. A listening test using these stimuli is set up in laboratory conditions in order to obtain perceptual groups of sources. The audio database of industrial sources, the stimuli generation technique and the listening test protocol are presented.

1 Introduction

To assess the noise impact of industrial sources, some countries (France, Australia) base their legislation standards on the concept of sound emergence. In France [1], this criterion is defined as the difference between the A-weighted equivalent sound pressure level of the ambient noise (source on) and the A-weighted equivalent sound pressure level of the residual background noise (source off). The maximum legal value for the sound emergence varies with the type of installation, the working duration and the considered period (day or night). In France, the strictest limits are 5 dB(A) for the day period and 3 dB(A) for the night period, whereas in Australia, the limit is 5 dB(A) for day and night periods [2]. Like the sound emergence, the British standard [3] is also based on a comparison with the background noise level: the estimated A-weighted equivalent sound pressure level of a specific industrial noise should be 5 dB(A) below background noise.

In some cases, the French legislation standard seems inappropriate: a previous study [4] found that at a given emergence level, annoyance judgments differ according to the kind of source.

If penalties accounting for acoustic features of noise (such as tonal or impulsive character) do exist, laboratory experiments show that they are not adapted to sound stimuli where acoustic features are complex, which is often the case for real industrial noises [5]. For instance, listening tests led by Berry and Porter [6] have shown that an addition of penalties corresponding to specific acoustic features cannot account for annoyance of an industrial noise with multiple acoustic features (in the case of an industrial noise with two-tone complexes or an industrial noise with impulsive and tonal character). It would be thus interesting to develop improved descriptors related to perceptual categories of sources.

In order to define noise annoyance criteria that would be related to categories of permanent industrial sources, a first step consists in creating a perceptual typology of these sources. The typology should classify the sources as they are perceived by people living in the neighbourhood of industrial sites. This paper describes a realistic environmental approach for the creation of sound stimuli which simulate the sound of one industrial source at a given distance of the source. Three major points are detailed:

- the general method,
- the construction of a high-quality representative audio database of separate industrial sources and background noises,
- the design of a filtering method for generating representative environmental sound stimuli near dwellings.

2 General method

Let us consider a point M representing a virtual dwelling located at a given distance (typically several hundred meters) from an industrial site. The industrial site can be represented by a set of various industrial noise sources. It is usually not possible to record directly the contribution of one source *S* at point *M*, because of the contribution of other noise sources to the ambient noise at point *M*. It is then necessary to record the noise of the source *S* at a point *R* located near the source itself, in order to avoid unwanted noises. The recordings are filtered to simulate the propagation effects between *R* and *M*. Figure 1 illustrates the principle.

The choice of the point *R* must respect two antagonistic conditions which can lead to a practical compromise. Firstly, *R* must be located in the far-field of the source, which allows us to consider the industrial source as a point-source. Secondly, the point *R* should be chosen so as to minimize the influence of the environment of the source (buildings reflections, other sources…) on the recording.

In far-field conditions, the sound pressure level $L_p(R)$ in a given frequency band can be written as:

$$L_p(R) = L_w - A(S,R)$$

where L_w is the sound power level of the source S in the frequency band, and $A(S,R)$ corresponds to the attenuation between *S* and *R*, due to propagation phenomena (details are given in section 4.1.).

Writing the sound pressure level at the point M, $L_p(M)$, leads to :

$$L_p(M) = L_p(R) + A(S,R) - A(S,M)$$

Therefore, the chosen approach is to simulate the noise at the point M by applying a frequency filter of gain per band $A(S,R)-A(S,M)$ to the recording at the point *R*.

$A(S,R)$ and $A(S,M)$ are calculated with third octave definition by a sound propagation software.

3 Collecting audio recordings

3.1 Functional typology of industrial noise sources

A bibliographical study was conducted in order to identify industrial noise sources. The reference list of sources was extracted from the Imagine Project [7], and completed using references concerning industrial noise [8, 9, 10, 11].

The resulting typology is given in Table 1. Note that all indoor sources have been gathered in one category "machinery halls", considering the sources enclosure as a whole.

Table 1: Functional typology of industrial noise sources

Categories	Details
combustion devices	furnaces, flares, internal combustion engines
electrical machinery	transformers, alternators, motors, high voltage wires
liquid flow devices	cooling towers, mixing tanks, pumps
gas flow mechanical devices	fans, valves, blowers, gas jets, exhaust stacks, compressors, piping, turbines, wind turbines
machinery halls	indoor sources located in a same enclosure
material extraction / handling	conveyors and other devices

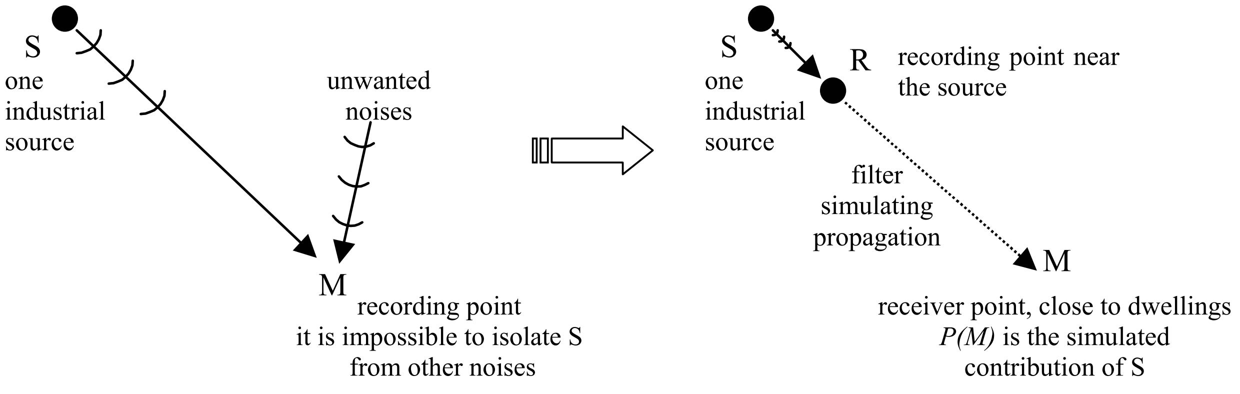

Figure 1: general method for simulating the noise of an industrial source *S* at a point *M*, located several hundred meters away from the source.

3.2 Recording protocol

A stereophonic system (ORTF technique) was used in order to get realistic recordings. Sound level at the recording point was measured in the same time by a sound level meter.

The recording point R was located in the vicinity of the source, considering the following points :

- R is close to the source, so as to avoid noise from other sources,
- R is located in the far-field of the source, i.e. at a distance $d > max\ (3l,\ 3\lambda,\ 3l^2/\lambda)$ if l is the characteristic dimension of the source and λ its emitted acoustic wavelength,
- distances between the microphones and any building are at least 2 m [1],
- the microphones are positioned at 1.2 m above the ground. When possible, the ground is chosen of lesser flow resistivity (for example, grass will be preferred to asphalt).

For noise sources with non uniform directivity pattern, relative position of point R was chosen along the radius corresponding to the maximal measured equivalent sound level.

Dimensions of the source, height of the source, distances between source and point R were measured. The ground was classified into basic flow resistivity categories (grass, gravel, asphalt), the resistivity value was chosen according to material database. A picture of the source was taken on-site.

3.3 The audio database

Seventy industrial noises were recorded, covering all categories listed in Table 1. Far-field conditions were well respected except for cooling towers (because of their dimensions). A database has been set-up, containing the audio recordings and all information relative to the source and the measure itself.

The database also contains a dozen background noises, corresponding to typical locations of an industrial site during the night or the day. Categories are listed in Table 2.

Table 2: categories of background noises

Categories	Details
quiet area in open country	area undisturbed by noise coming from road traffic or from industrial and recreational activities
major road	national roads and highways
water	area near a river, a lake or the sea

4 Simulating outdoor sound propagation

As explained in section 2, sound propagation between points R and M is simulated by filtering the audio signals recorded at point R. Amplitude of the filters depends on the attenuations $A(S,R)$ and $A(S,M)$, which are calculated by a sound propagation software developed by EDF R&D and merely based on ISO 9613-2 [12].

4.1 Phenomena and models

The calculation of $A(S,R)$ and $A(S,M)$ accounts for the following propagation mechanisms:

- geometrical divergence,
- atmospheric attenuation,
- downward refraction conditions,
- ground effect,
- reflections of buildings near the source (for $A(S,R)$ only).

Geometrical divergence corresponds to a sound level decay of 6 dB per doubling of distance from a point source. Atmospheric attenuation is calculated according to ISO 9613-2 [12]. Ground effect is represented by reflection of the acoustic waves on a plane surface with finite impedance, assuming Delany and Bazley complex impedance model [13]. Downward refraction conditions are simulated by adding ground reflections according to ISO 9613-2 method [12]. Reflections on buildings are calculated using an image-source method. Sources are modeled as omnidirectional point sources. Cooling towers were not recorded with far-field conditions (see section 3.3.) and will be modeled as extended sources.

Therefore, the simulated attenuations *A(S,R)* and *A(S,M)* depend of the following parameters:

- geometry of the model {source, ground, *R*, *M*},
- summation of the direct and reflected waves in pressure (interferences) or in energy (no interferences),
- vicinity of buildings (and their façade absorption coefficient),
- ground resistivity,
- position of the added ground reflections for *A(S,M)* (downward refraction conditions).

4.2 Filter design

For every third-octave band from center frequency f_C =16 Hz to 16000 Hz, a gain $G = [A(S,M) - A(S,R)]$ is calculated. A linear phase Finite Impulse Response filter is designed by inverse FFT of a narrow band interpolation of the (f_C ,*G*) values. Audio recording at point *R* is convoluted by this FIR filter to constitute a sound stimulus at point *M*.

4.3 A test-case for optimal choice of calculation parameters

In order to get an optimal choice of the parameters detailed in section 4.1, *filtered* audio recordings at point *R* are compared with *reference noises* (resulting from measurements at point *M*) for a propagation test-case above plane ground, using a reference sound source. Several filters types are designed to study the perceptual influence of the following calculation parameters :

- calculation mode for *A(S,R)*: with or without interferences,
- calculation mode for *A(S,M)*: with or without interferences,
- value of the parameter which determines the position of the added ground reflections (downward refraction conditions) for the calculation of *A(S,M)*,
- ground resistivity value.

For the field measurements, a loudspeaker (B&K 4296) is placed at a height h_S on a flat, grassy terrain. At a distance of *d*=12 m (point *R*) and 100 m (point *M*) of the source, the stereophonic recording system and a sound level meter are positioned at a height of 1.2 m. Audio recordings and third-octave sound levels measurements are performed for two noises (pink noise, transformer noise) and two values of h_S (1.5 m and 3 m). The acoustic power level of the source is also measured with third octave definition by sound intensity technique.

In the idea of testing the filters types for different propagation environments between *S* and *R*, additional recordings are performed: one case with gravel-type ground, and another case with a building located at a distance of 1.5 m behind the source. Configurations are detailed in Table 3.

Table 3: measurement configurations

Name	Source height	Distance Source - microphones	Ground / buildings
(S,R_1)	1.5 m 3 m	12m	grass & no buildings
(S,R_2)	1.5 m 3 m	12 m	gravel & no buildings
(S,R_3)	1.5 m 3 m	12 m	grass & building at 1.5 m behind source S
(S,M)	1.5 m 3 m	100 m	grass & no buildings

For each point *R* (*R1*, *R2* and *R3*), each source height (1.5 and 3 m) and each noise (pink noise, transformer noise), the corresponding filters are calculated and applied to the audio recordings at point *R* to constitute sound stimuli.

In order to choose the optimal filter type, these sound stimuli are compared to the reference noises, using both a physical approach (spectral analysis) and a perceptual approach (listening test).

Results and analysis of the physical and perceptual comparisons will be presented at the conference.

5 Perspectives

The sound stimuli created with optimised filters will be used in future listening tests (categorization tasks) in order to obtain perceptual groups of industrial sources. For each perceptual group, industrial noises will then be mixed with various background noises to assess noise annoyance with the “sound emergence” criterion.

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