Mobility and life quality relationships – Measurement and perception of noise in urban context

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ABSTRACT

Noise in urban context is one of the main concern in terms of societal impact. In fact, sound environment is adressing issues at various levels: transmission of information, social relations, perception of comfort, and in the worst cases, health effects on city-dwellers. The paper will present the first steps of an academic research concerning measurement and perception of noise in urban context – otherwise integrated into the broader framework of a Chair of Research dealing with relationships between mobility and quality of life in urban environments, in terms of air/sound pollution and healthcare. The following content will be developed : i/ elements of a state-of-the-art in the joined fields of measurement/simulation and perceptual evaluation of urban soundscapes; ii/ first planned axes of research focusing on interactions between elementary sources mainly coming from urban mobility – assuming that transportation is one of the main source of noise in the city – with their context either in physical and perceptual points of view; iii/ according to the work progress, first results concerning preliminary experiments conducted on dedicated urban environments.

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1. INTRODUCTION

It is generally admitted that arising and consideration of relationships between sound and environment mostly started in the XIXth century, after the Industrial Revolution. From that period of important mutations, the main societal change – at least in the occidental part of the world – was a gradual but significant human exodus clearing out the rural zones and growing the urban areas where small villages tended to be deserted and little towns progressively became large cities with increasing economic and social activities. As Robert Murray Schafer wrote, this revolution was accompanied by the development of a lot of new sounds – often unknown by people – and was followed by another one, the "Electric Revolution", that brought other kinds of sounds, still mostly unheard, but more artificial, able to quickly travel in time and space – then extending at infinitum – and finally contributing to the main characteristic of most of the current modern sound environments, or soundscapes: the "*lo-fi*", resulting in ever more dense, complex and permanent noises in the background and the foreground [1].

This being, it is also admitted that there are fundamentally two ways for considering noise in public spaces, especially in urban context [2] – and that can be seen, at best, as complementary:

- the *normative* way, dealing with the problem by means of objective measurement protocols and normative approaches that mainly aim at identifying the main sources responsible for noise (factories, transportation artefacts, etc.) and specific areas in terms of noise exposure, defining sound level thresholds for emission, quantifying – or predicting – noise annoyance or health impact and then proposing operational solutions (noise barriers, soundproofing, etc.) to fight against this form of pollution;

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- the *sensitive* way, investigating sound perception mechanisms and sound meanings, based on the fact that each auditory events, either it is natural or artificial, are representative of local specifities and then considering sounds and noises in a double typological approach:
    - the study of their nature and cause, grounded on Acoustic Ecology foundations and especially the *World SoundScape Project* initiated by Schafer [1,3];
    - the study of their production and reception modes, especially grounded on Pierre Schaeffer's theoretical work [4].

  Besides, this latter approach has been recently implemented and developed in the prevailing "Soundscape of European Cities and Landscapes" COST Action[3] which mainly promotes a multidisciplinary approach on this particular topic, especially arguing that "reducing sound level does not necessarily lead to improved quality of life in urban/rural areas", and pleading to consider environmental sounds "as a 'resource' rather than a 'waste'" [5].

More precisely, in this overall framework, we make the assumption that, in the commonly established *lo-fi* soundscape of modern cities, transportation modes are one of the main causes of noise emission. In fact, a significant number of studies about urban soundscapes cited this class of sources as predominant. Among them, Raimbault et al. clearly distinguished road traffic (car, truck) and other transportation (railway, aircraft) as part of a soundscape sources classification [6]; whereas Guastavino, in a study on people's representation of an ideal urban soundscape, found out, among more than 250 descriptions of 77 persons, that cars and traffic were uppermost cited as negative elements, representing respectively 9% and 7% of the total answers [7]. In complement, Gold stated that "sounds of transportation are an integrated part of the modern urban environment", in a 2010 conference on the promotion of soundscapes of high acoustic quality in urban planning and design [8]. Moreover, with the advent of mechanization that especially occurred in the transportation domain, the link between people and their acoustic environment becomes significantly more active and contribute to deeply integrate this kind of acoustic source in citizen's everyday life.

Taking advantage of a transdisciplinary scientific framework of a 5-year research program (Chair) dealing with relationships between mobility and quality of life in urban environments, in terms of air/sound pollution and healthcare[4], this paper will, first, present some elements of state-of-the-art in the joint domain of soundscape physical measurement and perceptual characterization then, main research axes that will be conducted inside this program, in the acoustics, psychoacoustics and auditory perception fields. Finally, a third part will present and discuss the preliminary results yet obtained in the current workflow.

2. STATE OF THE ART

This section gathers some elements of the state-of-the-art concerning auditory scene objective measurement and simulation together with soundscapes subjective characterization and perception. However, it doesn't claim to be exhaustive as it only presently tends to draw the frame of interactions between both disciplines involved in this part of the project: acoustics, hard metrology, computer modeling and psychoacoustics, soft metrology, perception. Naturally, the bibliographic study will be largely completed in the first part of the research program.

2.1 Soundscape Measurement and Simulation

In order to elaborate noise maps of urban agglomerations, which is aimed at by some European noise programs, sound pressure level measurements are evaluated by two complementary means: physical measurements and numerical simulations.

2.1.1 Acoustic Measurement

The physical measurement of relevant acoustical parameters is a first step in evaluating the environment. Methods of measurement and analysis range from the simple measurement of overall A-weighted level samples, to time histories, statistical and spectral analyses.

For the purpose of objective noise assessment of an area, statistical measurements are carried out at given points, using generally a sound level meter. The measured parameters are various (L_{Aeq}, L_n, L_{Zeq}, etc.) and evaluated in terms of level over octave or one-third octave bands (see section 2.2.1). The amount and location of measurement points are determined so as to reveal the general behavior of the area, at significant times. The measurement protocols generally follow national standards.

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[3] http://soundscape-cost.org

[4] http://www.upmc.fr/fr/recherche/pole_4/chaire_mobiltie_quatlite_de_vie_urbaine_intro2/interdisciplinarite.html

To our knowledge the remote sensing of relevant acoustical parameters using arrays of microphones has not yet been attempted. This challenge is one of the objectives of our project and some preliminary experiments tend to show that it may be possible (see section 4). The idea is to evaluate physical attributes of the sound field combining signals recorded by microphone arrays arbitrarily distributed inside and around the area of interest: streets, parks, etc. The signal processing technique to be used at first is the standard beamforming whose implementation is straightforward and which is able to monitor soundfields in real time. The main challenge will be to achieve in the end absolute evaluations of the remote sound pressure levels and provide high resolution maps of the soundscape taking into account diffraction/diffusion phenomena. Therefore more sophisticated techniques are also to be investigated ranging from standard high resolution technics to sparsity promoting or hybrid techniques.

2.1.2 Simulation

Numerical simulations are widely used in urban acoustics to predict sound level. Nevertheless, these two words covered a large variety of methods and technics going from operational– efficient but limited – to very sophisticated, allowing to take into account complex phenomenon but with a significant computational time – which is prohibitive in an operational context. Extensive surveys can be found in classical textbooks by Salomons [9], Attenborough [10] or Kang [11].

Basically two families of methods can be distinguished: those based on the wave approach taking into account many phenomena and those based on geometrical acoustics or energetic approaches which are well suited to describe high frequencies waves.

From a modeling point of view, the first family (wave approach) relies on fewer assumptions and is valid for most cases. Nevertheless from a numerical point of view, it takes a lot of time for computation because it implies large meshes. On the other hand, the second family, based on more assumptions, is efficient from a numerical point of view but can suffer from physical limitations especially to describe low frequencies propagation or phenomena that need to take into account complex wave interactions, such as resonances or multiple reflexions.

In the framework of this project, it has been decided to use an hybrid approach by building a new tool combining different solvers developed at UPMC such as a parallel discontinuous Galerkin method for the low frequencies and an Eulerian ray tracing technique to deal with higher frequencies. The current challenge will be to couple these codes and produce sound maps able to be linked with perceptual indicators developed in a parallel stream of the project.

2.2 Soundscape Characterization

Soundscape, and especially urban soundscape, is a complex auditory stimuli that mixes a lot of different nature of sounds. From a raw physical description (audio signal captured by acoustic measurement, type/morphology of its components, etc.), it then can be interpreted in terms of objective – quantitative – features (e.g., integration of the sound pressure level physically measured) or in terms of subjective – qualitative – attributes (for instance, the judgement of ‘quietness’ or ‘pleasantness’). Soundscape characterization will then consist in finding out the most suited objective/subjective relationships in order to be able to specify perceptual evaluation of urban noise.

2.2.1 Objective metrics

A large set of acoustic/psychoacoustic features for describing sounds, and more specifically environment auditory scenes, can be found in standards and literature. Here is a list of the most cited ones in many sources and mainly compiled from three of them: Kang’s 2007 publication on urban sound evaluation [11], Payne et al.’s 2009 official report on policy applications of soundscape concepts and techniques in urban areas [12] and Torija’s 2013 JASA paper [13]. Formulas and further details can be found in these three references. Note moreover that, because most of these features are computed from raw data of sound pressure level (SPL) in dB, they can also be expressed in dB(A), taking into account the standard A-weighting function; for that, the correspondant features are labelled either with or without the ‘A’ mention.

- L_{eq} (L_{Aeq}): equivalent continuous sound pressure level. It is the standartized integration of sound pressure level over the measurement period (ANSI 1994); it provides a single-figure level of soundscape. But, even if it has been widely used to provide a basic description of sonic environment – especially in noise maps required by policy directives – or environmental quality and annoyance, it is largely considered to be not sufficient for soundscape assessment.
- L_n (L_{An}): statistical sound level. It is the level of noise exceeded for n percent of the measurement period. The forms currently used for this feature are:

. L_{95} or L_{90} which is considered to provide a good estimation of background sound level;
. L_{50} which gives the median level and which is found out by several studies to be the best soundscape acoustic indicators either for urban or quiet areas;
. L_{10} which represents the value of intrusive level;
. L_1 which gives the value of the maximul level.

• L_{den} (L_{Aden}): day-night-evening level. It is a corrected sound pressure level for 24 hours incorporating three time frames (day: 7h-19h, evening: 19h-23h, night: 23h-7h) penalising the evening and night periods by a respective addition of 5 and 10 dB (dB(A)). This standard measure is used in the European Directive (2002/49/EC) for indicating impact on humans of the sonic environment, but as L_{eq}, it has been found by some studies to be not adequately sufficient to predict people's reaction against noise exposure. In some cases, derived versions could be considered: L_{day}, $L_{evening}$, L_{night} or L_{dn}, also called day-night equivalent level (DNL).

• L_{SE} (L_{AE}): sound exposure level (SEL). It is the sound level that, if maintained constant for 1 second, contains the same acoustic energy as a varying noise level. It is mainly used to quantify short duration noise events (aircraft flyover, impact noise, vehicle pass-by, etc.).

• L_{10}-L_{90} (L_{A10}-L_{A90}): transient/noise events level. It measures soundscape temporality, i.e. the way soundscape level evolves along time. This feature can be associated to the Traffic Noise Index (TNI) also depending on fluctuations in noise level over time and on background noise level.

• Slope: sounscape specific feature. It allows the measure of number of sound events (peaks) that occur in the soundscape and how long are these events (peaks width) in relation to the background sound level. It has been found to be able to detect greater soundscape variations than traditional psychoacoustic indices (loudness, sharpness or fluctuation strength.

• N: Loudness (according to Zwicker's model). It renders the sound pressure level that accounts for the human ability to mask certain frequencies when listening to acoustic stimuli; it is related to what is commonly called the 'perceived sound level'.

2.2.2 Subjective Description

On a perceptual point of view, soundscape can be considered as a long-term auditory stimuli formed with a background – mostly amorphous noise texture [14] – and a foreground – salient sound events [15] –, the balance between these two elements being modulated with regards to structural (urban configurations), temporal (day periods), geographical (urban/rural natures) or even cultural (city/country types) factors. Then, to a certain extent – and in a macro-scale of time and amplitude – soundscape could be defined with the formula used by Nelken and Cheveigné in their recent study on sound texture perception: "a skeleton of events on a bed of texture" [16].

But, basically the perceptual approach of soundscape was taken by Schafer and colleagues in the *World Soundscape Project*, following Truax's definition: "an environment of sound (sonic environment) with emphasis on the way it is perceived and understood by the individual, or by a society" [17]. Schafer, in his seminal work [1], defined the following basic components of a soundscape:

- *keynotes*, related to fundamental tonality – by analogy with music –, unconscioulsy perceived but permanently present in the scene; by analogy with visual perception, it could also be considered as the *ground* (by opposition to the *figure*)
- *sound signals* (or foreground sounds), related to emerging sounds that are heard knowingly, attracting attention and often transmitting or carrying informations; by analogy with visual perception, it could also be considered as the *figure* (by opposition to the *ground*).
- *soundmarks*, related to specific sounds, attached to a person or group of persons for whom these artefacts are taken into consideration and get meaning; similar to *landmark*, again by analogy with visual perception.

From this typology, Schafer defined also two important notions characterizing soundscapes:

• "*hi-fi*", where the global – and perceptual – signal-to-noise ratio is "adequate", i.e. relatively high, allowing a clear discrimination of the *figure* thanks to the low level of the *ground*, and a distant listening thanks to a good perspective of the scene;

• "*lo-fi*", where, on the contrary, this same signal-to-noise ratio is quite low, mixing *ground* and *figure* together, then preventing from getting the perspective and listening to details in the scene and sometimes leading to an over-amplification of the sound signals in order to be heard.

After this theoretical – and experimental – important approach of soundscapes realised in the 70's, a large number of studies have been conducted since the 90's with the objective of identifying, categorizing, and assessing soundscapes with perceptually relevant attributes. These studies were –

and are still – mainly achieved by means of listening experiments, either in situ or in laboratory, and by using methodologies taken from psychoacoustics, psycholinguistic or cognitive psychology scientific fields.

Among them, Niessen et al. achieved a linguistic study on the basis of a large collection of papers (166) published within the soundscape research community with the aim of proposing a systematic classification of soundscapes. They globally found different level of categorization and, at each of these levels, types of categories; for instance, as most general and conceptual, bakground / event, or at a lower level, natural / human / mechanical sounds, and in each of these classes, transportation, construction, voices, etc. [18]

Kang et al. defined key factors characterizing urban soundscape perception. With a complex 3-stage experimental procedure based on in-situ listening, interviews and semantic differential analysis, and involving different level of expertise (designers/architects vs. general public), they found that even if soundscape evaluation is rather difficult, several major factors can despite be identified, among wich : i/ relaxation, involving notions of comfort, quietness, pleasantness or naturalness ; ii/ communication, involving notions of meaning, calm and roughness together with a social aspect ; iii/ spatiality, involving notions of distance, reverberation and complexity; iv/ dynamics, mainly involving the notion of temporal evolution [19].

With a psycholinguistic approach, Guastavino investigated the question of soundscape quality and especially the concept of "ideality". She built an open questionnaire containing general questions about the ideal urban soundscape and more specific ones about transportation noise ("In urban areas, are you sensitive to transportation noise ? How would you describe it ?"). The first general result is that the ideality for soundscapes can be specified in terms of variety (non-uniform sound scene, but structured environment), tranquility (quiet and relaxing environments, but in no case, reduced to silence), animation (lively places with significant human activities) and non-agressiveness. A second result, concerning transportation, revealed the perceptual reality of different classes related to sound sources (bus, motorcycles, subway, cars, train/tramway and trucks) and that this structure was clearly split in two when considering the hedonic judgement of ideality: only public transportation – specifically bus and train/tram – were assessed to contribute positively to the ideal soundscape. Furthermore, Guastavino proposed a cognitive interpretation of this result that could be explicited as follows: even if the physics of a bus is globally worse that the ones of a car (louder sound instensity and lower frequency range), a bus is better accepted – or judged as less annoying – because it "means" something in people's mind, more positive for the environment than a personal car [7].

2.2.3 Perception of Annoyance

Then, according to previous partial conclusions in the two previous sub-sections, annoyance appears to be a multi-dimensional percept related not only to physical parameters but also to a serie of other factors of different natures. In his seminal book, Kang has mainly identified four additional categories: psychological/social situation, demographic configuration, noise familiarity and cultural differences (for further details and bibliographic references, see [11]).

First, annoyance can be directly linked with physical factors. This question – especially focused on L_{eq} type of features – has been intensively studied and is at the the root of several standards and regulations, like the European Directive (2002/49/EC). For instance, L_{Aday} values could reveal 3 distinct zones: before 55 dB(A) no annoyance, between 55 and 60 dB(A) potential annoyance, and after 60 dB(A) definite annoyance. In the same way, it has been found that, specifically for urban road traffic noise, a DNL > 60/62 dB(A) will increase the feeling of annoyance. This being, it should also be noticed that relationships between L_{eq} and annoyance depends on the type of noise: for a same L_{eq}, aircraft noises will be judged more annoying than road traffic which will be judged, in its turn, more annoying than railway noise. This latter findings advocate for considering other kind of parameters responsible for annoyance perception.

In fact, other physical parameters than energetic considerations are also partially responsible for annoyance. For instance, tonal or low-frequency components significantly increase this percept, together with temporal structure of the auditory scene: large amplitude fluctuation or dense emergence of punctual events.

But, annoyance is also influenced by other factors than physical. In fact, among other results, for Berglund et al., just 30 per cent of annoyance can be explained by L_{Aeq} [20] or, for Morel et al., energy-based indices can explain only one third of the total reponses on annoyance [21]. The remaining part of the variance in annoyance assessment is definetely due to other aspects, mainly including:

- psychological/social/economic factors: fear (noise linked to danger), causality (economic dependency/independency about source of noise), individual sensitivity (on specific sources), type of activity (like oral communication or intellectual tasks), neighbourhood perception and global perception of the environment (interaction with other modalities and physical components like dust, smell, light, temperature, vibration or landscape – for instance, exhaust fumes increase annoyance whereas trees tend to decrease it);
- demographic factors: even if influence of these kind of factors seems to be light, and more often controversial (especially concerning age, gender, marital status or education level), the type of occupancy (owner or tenant) – what Faburel et al. called "local fondness" [22] – appears to be the most influential factors of this kind;
- familiarity factor: also called noise experience, i.e. the level of knowledge of sound, or source, acquired by the invidual over time; in a shorter temporal term, this is also what De Coensel et al. called "mental habituation", considered as playing a role in attention focusing and finally integrated in their notice-events based environmental sound perception model [23];
- cultural factors: regional customs, lifestyle and even weather tendencies could significantly affect the evaluation of annoyance. A semantic based cross-cultural study in Japan, Germany, United States and China on sound quality of environmental noises showed significant different results and especially in the connotative meanings of the term ‘annoyance’ [24].

3. FIRST AXES OF RESEARCH

As mentionned above, the present initiating work falls within a broader transdisciplinary research program materialized by an academic Chair leaded by Fondation UPMC and supported by two french automotive manufacturers (PSA Peugeot-Citroen and Renault). Considering that the relationships between quality of life and urban environment are rather complex, the aim of this program is to explore and quantify the impact of two major sources of pollution on quality and health – and their potential mutual interactions: air pollution (gaz and particles) emitted by local sources and noise exposure in all its aspects (temporal, spectral and perceptual). Moreover, within this framework, the program will study more specifically the role of transportation in these differents impacts and interactions.

Thus, one of the two main components of this program deals with acoustics or, more precisely, with the effect of transportation on noise measurement and perception in urban contexts. Basically, this contribution aims at, first, improving the understanding of interactions between sound environment and the individuals (either in a psychoacoutic and healthcare point of view), and second, to propose new tools for representation and prediction of urban soundscapes. These tools will be mainly based on a strong coupling between specifically developped simulation software and innovative models for perceptual evaluation of urban sounds quality.

More in details, this approach proposes two singularities. Firstly, as the whole program, it is a multi-scale study, meaning that the issue regarding impact of noise exposure will be adressed at different source levels: first, focused on sources, then considering a urban elementary entity (street), and finally at the macro-scale of a district. Secondly, the prediction tool, aiming at building a cartography of perceived annoyance in urban areas, will integrate psychoacoutic and cognitive features in order to cover, as much as possible, the factors explaining this percept (see section 2.2.3 above). For that, and in a first step, the definition of loudness will be considered and extended to face at the complexity of transportation noise in urban context.

The next two sections are derived from the approved research program proposal and outline the first parts of the workflow as initially imagined by the contributing teams – so, subject to be adjusted and slightly modulated in the course of the project.

3.1 Measurement and perception of acoustic sources emitted by a vehicle

The goal of this phase is to identify and perceptually classify the many acoustic sources produced by a vehicle, whatever its type. For that, a psychoacoustic study coupled with an advanced multi-channel microphone measurement protocol will be conducted. The measurement will be performed by means of a Megamicros antenna [25] which will allow identification and localisation of sound sources in different vehicles (public / fret transport, passenger cars, 2/4-wheel; ICE, HEV or EV modes of propulsion). Categorization and/or dissimilarity paradigms will be used to realize the subjective characterisation of these same sources.

The physical measurement of the different sources will be held by a high-order microphonic antenna (Megamicros – more than 1000 channels), a currently unique device, developped at Institut Jean-le-Rond-d'Alembert (IJLRA), which allows a flexible 3-D measurement – for instance in a test room –, with a very high resolution. In fact, the microphones are based on MEMS technology and get a weak bulk. It is then possible either to perform an acoustic image of the source by using standard beamforming or hyper-resolution methods, or to perform a fine source localization or identification.

On the perceptual point of view, the goal is to investigate the differents acoustic sources attached to transportation and able to be present in the urban environment. For that, standard experimental paradigms related to recognition, discrimination and categorization of sound will be conducted (free/forced categorization, dissimilarity testing), and possibly supplemented by preference judgements [26,27]. In this approach, the definition of the vehicles will try to be as representative as possible of a urban use. For that, different types of vehicles / brands and driving conditions (idle, acceleration/deceleration, constant passing-by, etc.) will ideally be investigated; moreover, different vehicle functioning modes (gearbox state, air-conditionning sytem enabled, etc.) will also be taken into account, as each of them is able to produce a specific sound signature.

The findings of this first phase might be a perceptually relevant structure (categories or continuous dimensions) of transportation sound sources coupled with a physical description by means of acoustic or structural features.

3.2 Simulation and perception of a vehicle, in basic urban context

The goal of this phase is to develop annoyance indicators and implement them in a simulation software environment. It will be articulated according to the following pattern: i/ development of perceptual descriptors expliciting noise annoyance in urban context; ii/ numerical simulations of urban acoustic fields and coupling with the pre-defined indicators; iii/ in-situ validation by means of listening tests and high-order multi channel measurement.

The development of perceptual indicators might be done at two different levels:

- firstly, at first order, by associating the percept of annoyance with the perceived sound level factor and then by developping a model of loudness for urban sounds. In fact, the current loudness models – based on energy integration into critical bands [28] – can reliably predict simple and constant sounds. But, we assume that urban sounds generally get more complex properties (binaurality, non stationarity, saliency, multi-source aspects, etc.) which largely contribute to the feeling of annoyance but are not yet integrated into current models. For instance, it has been demonstrated that, for time-varying sounds, the global perception of loudness depends either on maximum sound level [29], position in time [30] or sequence duration [31]. This issue will be adressed in parallel with the LoudNat[5] ANR project.
- secondly, at higher orders of annoyance, by taking into account other dimensions that contribute to this percept (psychological, social, cultural, etc – see section 2.2.3 above). From this point of view, two directions might be taken: i/ a semantic characterization of urban soundscape categories, in parallel with some developments of the HOULE[6] ANR project; ii/ a psycholinguistic and sociological approach aiming at investigating the pain of citizens significantly exposed to urban noises, by means of a specific methodology (stories collection) and a semiotic analysis of related speech.

Numerical simulations will be realised thanks to existing codes and computing infrastructures at IJLRA (CPU clusters and GPU computers). According to what will be required for computing the perceptual indicators (temporal precision, frequency resolution, etc.), several acoustic propagation models might be operated – from geometrical acoustics techniques to linearized Euler equations resolution. Moreover, these models could be coupled to other ones dedicated to micro-meteorolgy, in order to get more accurate results, in terms of urban soundscape simulation.

4. PRELIMINARY RESULTS

The aim of this work is to realize urban noise mapping using a home made multi-channel system of acquisition called Megamicros. The possibility to use this system for urban acoustics has been evaluated by imaging the main campus of the University Pierre and Marie Curie (UPMC).

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[5] http://www.agence-nationale-recherche.fr/en/anr-funded-project/?tx_lwmsuivibilan_pi2%5BCODE%5D=ANR-11-BS09-0016

[6] http://houle.ircam.fr/wordpress/

4.1 General Framework

Acoustic imaging can be used in many applications such as seabed imaging or characterisation of acoustic sources for the transport industry. The classical imaging technics are limited in resolution and in range. Indeed, the number of microphones and the dimension of the microphone array will impose the precision of the measure.

The Megamicros system, developed at Institut Jean le Rond d'Alembert (UPMC), is an all new acquisition system that can deal with up to 128 microphones for now but the final version will be made of 1024 microphones. This project was feasible thanks to a new technology: the MEMS microphones (stands for *Micro Electric and Mechanical Systems*). The great advantage of these microphones is that the whole acquisition chain is contained in it: signal conditioning, analog-to-digital converter and anti-aliasing filters. Moreover, MEMS microphones used (ADMP441 of Analog Device) have a very low current consumption of 1.4 mA. Based on these advantages, the Megamicros system is an interface between the microphones and a computer. It aims at concentrating the signals provided by the microphones, serializing them and transferring the serialized signal to a computer by a USB 2.0 port. The functional scheme of the Megamicros system is presented in figure 1. Although these microphones aren't expensive they have good acoustics characteristics such as the fact that they are omnidirectional and have a flat frequency response from 60 Hz to 15 kHz.

Another force of the Megamicros system is the modularity of the microphone antenna. The antenna is made of 16 sets of 8 microphones. Each set of microphones is embedded on a cable and can be folded or arranged with a high versatility. In this first study, microphones have been installed on steel bars and linearly spaced by 17cm. Combining the bars as wanted, different kind of antenna can be created: linear, planar or 3D.

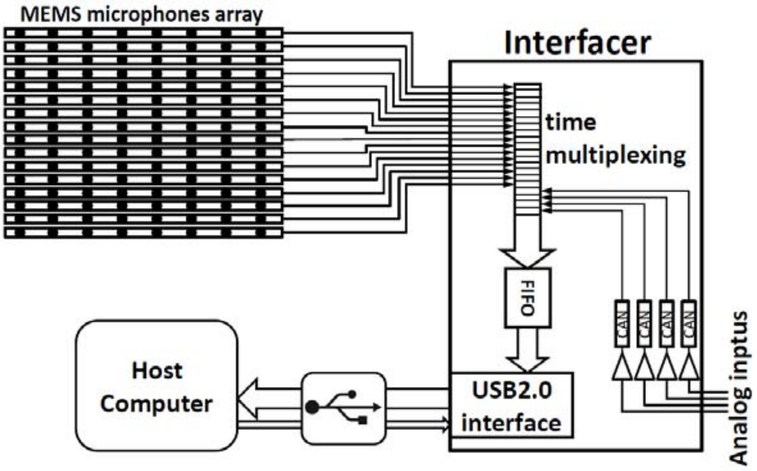

Figure 1 - Functional Scheme of the acquisition system

4.2 Measurement Protocol

As discussed before, a first approach to describe the annoyance due to urban noise can be done by measuring the equivalent acoustic level (L_{eq}). This indicator is measured by using a microphone antenna. The idea is to record the noise coming from a urban scene – as large as possible when considering an antenna – and get back to the noise map in the scene.

The first works have been done measuring the noise level on the working site of Jussieu campus in Paris using the height of the central Zamansky tower (height : 90 m) to 'listen' to the noise. The classical beamforming technique is used to build images, we suppose that the location of the antenna on top of the tower allows the free field conditions. Beamforming assumes that it is possible to estimate the pressure $b_p(\omega)$ at the pixel p of an image at the pulsation ω by writing:

$$b_p(\omega) = \frac{1}{N_m} \sum_m r_{mp} \cdot e^{jkr_{mp}} \cdot p_m(\omega) \qquad (1)$$

where $k = w/c_0$ is the wavenumber, N_m the number of microphones of the array, $p_m(\omega)$ the pressure at the m^{th} microphone and r_{mp} the Euclidean distance between the location of pixel p and the microphone *m*. This last term balances the spherical decrease of the waves. Equation (1) can be written in matrix form, underlying the ω dependency:

$$\boldsymbol{b} = \boldsymbol{A}^{\boldsymbol{H}} \boldsymbol{p},$$

where the elements of $\boldsymbol{A}$ are written $A_{mp} = r_{mp} e^{-jkr_{mp}} \big/ N_m$ and ^{H} denotes the hermitian transpose of matrix $\boldsymbol{A}$. Thanks to this formulation we can write the estimated energy for a given pulsation as:

$$\boldsymbol{b}^2 = \boldsymbol{A}^{\boldsymbol{H}} \boldsymbol{R}\ \boldsymbol{A},$$

with $\boldsymbol{R} = \boldsymbol{p}\ \boldsymbol{p}^{\boldsymbol{H}}$ the covariance matrix of the microphones. This formulation is the one used because it allows to reduce noise artifacts by averaging the covariance matrix along time.

The results presented in the following have been obtained using a linear antenna with 128 microphones installed on top of the 24th (and last) level of the Zamansky tower, on the eastern side, as shown in figure 2.

Figure 2 - Photographs of the linear antenna used for our study

4.3 First results

Results presented below have been computed on the 1 kHz octave band over an image plan that is just above the rooftops of the campus buildings (23 m).

It is important to notice that the visualization of the results is quite particular. Indeed, if we were displaying the real map – when applying the equation (1) – we would get an increase of the global noise when pixel is getting far from the antenna (due to the r_{mp} term) and won't be able to detect sources position. For this reason, we calculated two maps, both with and without the r_{mp} term in equation (1). Then, we used the second one to display the results (as in figure 3-left) and picked out some true values from the other map for some specific pixels. We display the results over 20 dB of dynamic (red is max, green is middle (-10 dB) and dark is min. (-20 dB) level value).

Results presented on figure 3-left have been recorded on June (13th) 2014, while renovation works where in progress. They show that global noise on the campus is very important, the average equivalent acoustic level over a minute of acquisition being 78.5 dB. Moreover, we can see two sources side by side, with a high acoustic level.

Figure 3-right shows L_{eq} over two seconds (almost instantaneous level) during the emergence of a specific noise: a drill. As mentionned, the level of the source is measured at 93.5 dB. It is interesting to observe that, on figure 3-left, we had a quite low L_{eq} at this location, coherent with the fact that during the minute of acquisition the drill appeared only two times during one or two second – so L_{eq} indicator didn't really notice that event. Let's recall that calculating the level over the 1 kHz octave band means that we summed the energy from 707 Hz to 1414 Hz. This detail is important because from 1 kHz and upper, our system and the beamforming technique will compute grating lobes. Indeed when space between two adjacent microphones is bigger than half of the wavelength, a spatial aliasing effect appears and 'true' sources are replicated elsewhere in the image. Then, the source

detected at 89.6 dB is clearly an artefact due to a grating lobe, level difference between the principal lobe (the drill) and this one being due to the sum over the frequency. In fact, over the frequency range, the position of grating lobe changes and sum averages these artefacts.

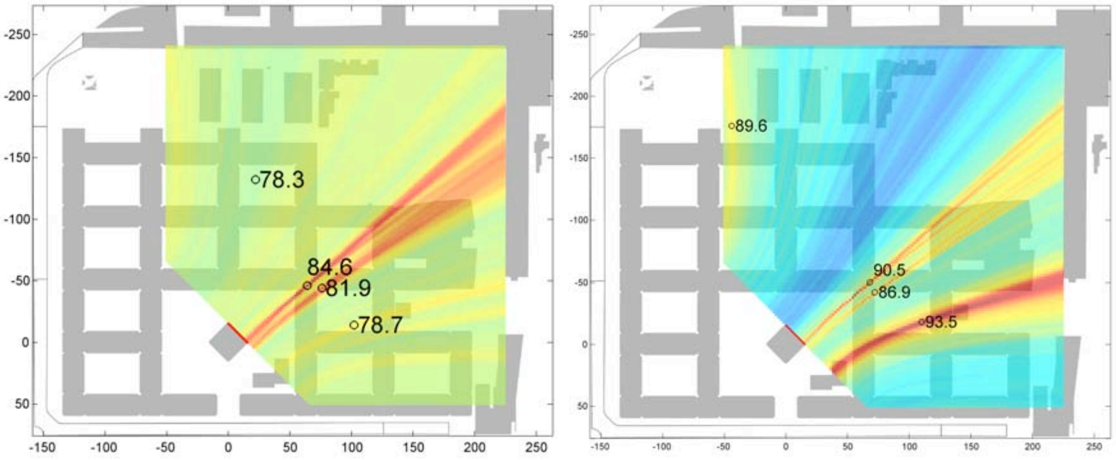

Figure 3: Equivalent level L_{eq} during one minute (left) and two seconds with specific sound emergence (right), over the Jussieu campus using a linear antenna (dynamic range: 20 dB from the maximum level

5. CONCLUSIONS

Within an interdisciplinary research framework dealing with mobility and quality of life in urban context, and on the basis of a selective state-of-the-art focused on acoustic measurement, simulation and perceptual characterization of sound environments, the paper has presented and developed initial guidelines of research around the following topics: influence of transportation modes in the current state of urban soundscape and assessment of soundscape quality – especially, noise annoyance – by definition of relationships between physical data (measured or simulated) and perceptual factors potentially responsible for annoyance (loudness, at a first level).

The paper has also given an overview of experimental protocol and preliminary results of a first study focused on outdoor measurement by means of an operational and scalable muti-channel microphone array (Megamicros); a first step in demonstrating the potential and efficiency of this device for urban acoustics developments has been shown.

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