Spatial categorization of urban sound environments based on mobile measurement

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Summary
Urban sound environments vary strongly and continuously both in space and time. Moreover, they cannot be described only quantitatively, as their temporal and spectral content has a demonstrated perceptive impact. In this paper, the potential of mobile measurements to categorize spatially urban sound environments is investigated. Analyses are based on a 3 days + 1 night survey where geo-referenced noise measurements were collected over about 20 1h-soundwalks periods, on three different districts. The clustering analysis showed that a limited subset of indicators is sufficient to discriminate sound environments for each district. Interestingly, the same indicators emerge for one district to the other. Finally, the procedure proposed enables the description of the sound environment of each district, which is classified into homogenous sound environment classes, by means of the selected indicators.

PACS no. xx.xx.Nn, xx.xx.Nn

1. Introduction

Noise mapping is acknowledged as a relevant tool to diagnose urban sound environments and to communicate with city dwellers. In order to establish noise maps, the legislation recommends firstly to identify the main noise sources, and then to determine noise emissions and apply sound propagation modelling. Alternative techniques based on geo-referenced mobile measurements have recently gained interest, since they are faster and enable cost reductions compared to the usual methods, while maintaining a good spatial resolution. Moreover, they advantageously take all the urban noise sources into account, while classical modelling tools are confined to the noise sources identified, which are in general road, railway and aircraft traffic, and the main industries. Their disadvantage is however the potential low representativeness of the measurements achieved, which are really short term (sometimes a few samples at each location), and thus limited to the periods of the measurement campaigns.

A procedure has been proposed in [1] for describing the variations of urban sound environments, which consists of mobile measurements, followed by a statistical clustering analysis that selects relevant noise indicators and allows a classification of sound environments and the estimation of their spatial distribution. This approach is complementary to other works which aim at highlighting globally classes of sound environments encountered in urban areas [2].

The three indicators that emerged from the clustering, namely the $L_{eq,A}$, the standard deviation $\sigma_{Leq,A}$, and the Sound Gravity Spectrum $SGC_{[50Hz-10kHz]}$, are consistent both with previous studies on sound environment classification and perceptive studies [3][4]. This approach has been completed in [5] to characterize sound emergences, and in [6] to describe sound environments at different spatial scales and characterize the seasonal variations of sound environments.

The objectives of this paper are to apply the abovementioned procedure on three different sites, in order to test its robustness and define its limitations. The same protocol is applied in three French districts in Marseille, Paris and Toulouse, which consists of a 3 days + 1 night measurement periods where geo-referenced noise measurements are collected over about 20 1h-soundwalks periods. The results obtained on the three sites are compared and discussed.

2. Methods

2.1. Data collection

Three mobile measurement campaigns have been conducted, over three different seasons, in Marseille (18-20/06/2013), Paris (07-10/10/2013), and Toulouse (28-30/01/2014). For each campaign, geo-referenced mobile noise measurements were collected over soundwalks, during 19 to 20 1h-periods, covering different periods of both day and night (see Table I).

The 1s-evolution of A-weighted sound pressure levels $L_{eq,A,1s}$, and the 1s-evolution of the 31 1/3rd octave bands $L_{eq,f,1s}$, from f = 20 Hz to f = 20 kHz, were measured with the DUO Smart Noise Monitor from 01dB-Metravib®. The sound level meter was carried in a backpack, so that as its omnidirectionality was ensured (see Figure 1). The sound level meter was calibrated before each soundwalk using a Sound Calibrator Type 4231 from Brüel & Kjær®. Positions were collected simultaneously every 10 s with a GPS Garmin Oregon 450®, synchronized with the sound level meter.

Each soundwalk followed a predefined path, whose details are given in Table 1. The sites have been selected for their high landscape spatial contrasts, containing both individual houses, residential areas with high buildings, and noisy street (see Figure 1).

Figure 1. Experimental set-up. Sites of Marseille (left), Paris (middle), and Toulouse (right)

Table I. Details on the measurement campaigns

	Marseille	Paris	Toulouse
Number of periods	19	20	20
Average duration	58 mn	59 mn	55 mn
Number of points	150	164	128

2.2. Data post-processing and sound indicators

For each of the 128 points and each 1h-period, the 12 following indicators are calculated based on the $L_{Aeq,1s}$ collected values: the A-weighted sound pressure level $L_{eq,A}$, the $L_{max,A}$, the statistical levels $L_{10,A}$, $L_{50,A}$ and $L_{90,A}$, the $L_{min,A}$, the $L_{10,A}$ - $L_{90,A}$, the $L_{max,A}$ - $L_{min,A}$, the standard deviation $\sigma_{Leq,A}$, and the average of the differences between consecutive sound level values $\delta_{Leq,1s,A}$, $\delta_{Leq,3s,A}$ and $\delta_{Leq,5s,A}$, which are calculated as:

$$\delta_{Leq,xs,A} = \text{mean}\left(\left|L_{eq,xs,A}(t) - L_{eq,xs,A}(t-x)\right|\right).$$

The $\delta_{Leq,1s,A}$, the $\delta_{Leq,3s,A}$ and the $\delta_{Leq,5s,A}$ inform about short term (a few seconds) sound fluctuations.

The same 12 indicators are also calculated for each of the 31 1/3rd octave bands f from 20 Hz to 20 kHz, and will referred with a f in subscript in the paper (ex: $L_{10,500Hz}$, $\delta_{Leq,3s,2kHz}$, etc.). In addition, the $L_{eq,f}$ – $L_{eq,A}$, which reflects the contribution of the 1/3rd octave band on overall sound pressure levels, is calculated for each frequency band. Finally, three Spectrum Gravity Centrums, $SGC_{[20Hz-20kHz]}$, $SGC_{[50Hz-20kHz]}$ and $SGC_{[50Hz-10kHz]}$, are calculated as:

$$SGC_{[f_{\min}-f_{\max}]} = \frac{\sum_{f=f\min}^{f\max} f * 10^{L_f/10}}{\sum_{f=f\min}^{f\max} 10^{L_f/10}}$$

The SGC indicators reveal if overall sound pressure levels result more from contributions in high or low frequencies. As a result, the total number of indicators calculated is n_{ind} = 12 + (12+1)*31+3 = 418.

3. Results

3.1. Selection of sound indicators

The acknowledged high correlations between noise indicators encourage the reduction of the number of indicators used to describe sound environments. This reduction is achieved through an agglomerative hierarchical cluster tree that uses the Ward method [7]. The dendrogram that results from the clustering (see [1] for the example in Marseille) underlines that three indicators are sufficient to describe the sound environment; this is confirmed for the sites of Paris and Toulouse. Similar groups of indicators emerge for each site, as depicted in Figure 2. This consistency in both the groups formed and the three selected indicators, namely the $L_{50,A}$, the standard deviation $\sigma_{Leq,A}$, and the Sound Gravity Spectrum $SGC_{[50Hz\text{-}10kHz]}$, which was already observed in the site of Toulouse at three different seasons (see [6]), advocates for the use of these same three indicators to describe urban sound environments.

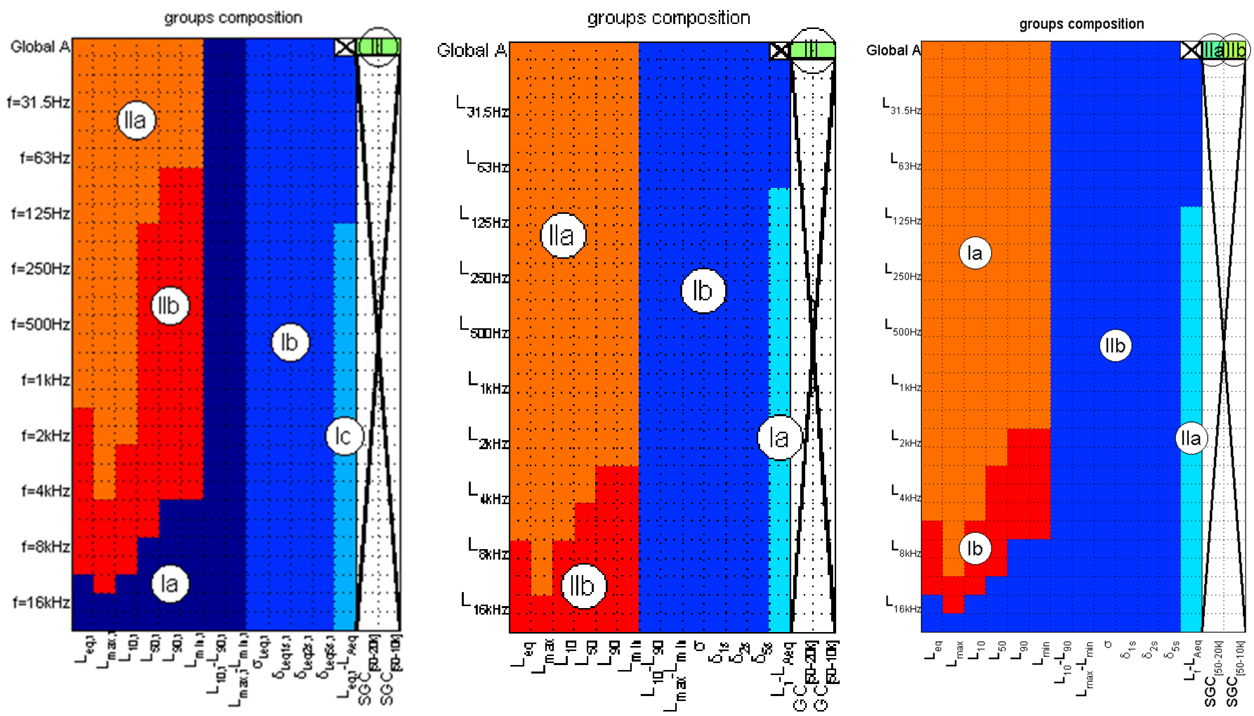
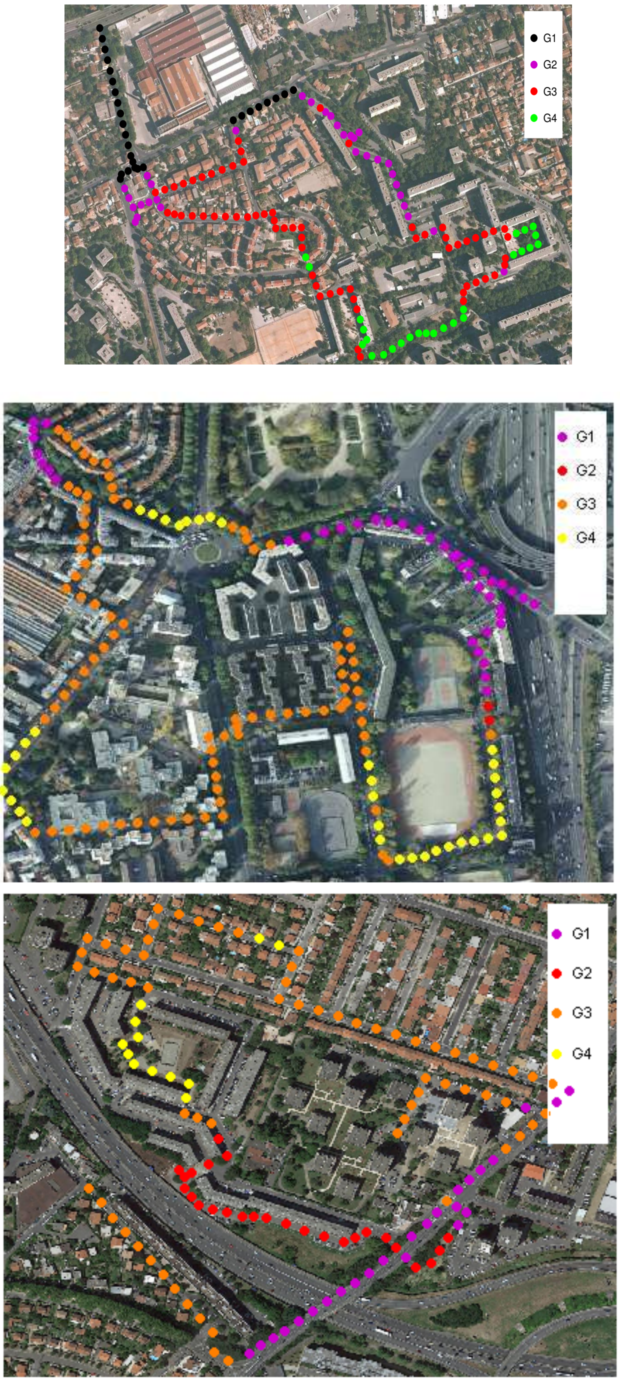


Figure 2. Classification of indicators. Sites of Marseille (left), Paris (middle), and Toulouse (right)

3.2. Description of sound environments

The three selected indicators are calculated at each location and each measurement period. An agglomerative hierarchical clustering is achieved for each of the three sites. The resulting dendrograms prove that this is relevant to divide each study area into 4 groups (see [1] for the example in Marseille). Each group corresponds to a zone homogenous in terms of its sound environment. The spatial categorization is depicted for each zone in Figure3. Interestingly, the categorizations are similar in several points. The method clearly distinguishes, for each site, the noisy zones from the calm ones. Moreover, it points precisely where the modification of the Figure 3. Description of the space distribution of the sound environments, based on $L_{50,A}$, $\sigma_{eq,A}$ and

$SGC_{[50Hz\text{-}10kHz]}$ hierarchical clustering, for the three sites. Up: Marseille; middle: Paris; down: Toulouse.



sound environment takes place. This can be a great help to support perceptive studies, which

Table II. Centroids values of each group for the three sites

highlights transitions between sound environments as crucial places [8]. Moreover, the description based on three indicators suits more closely the physical and perceptive meaning of sound environments. For example, the sites of Marseille and Toulouse clearly distinguish zones where natural sounds predominate; these zones are located in the most natural places of the district, and are characterized by high SGC values ; see Table II.

4. Discussion

Geo-referenced noise measurements open the possibility to describe sound environments through advanced indicators, and characterize their temporal and spatial variations. In this paper, a method for describing these variations is validated over three measurement campaigns. The method is really robust from one urban site to another and from one season to another (three different seasons in this study, and three different seasons on the same site in [6]). Thus it appears as a powerful tool to detailing the description of urban sound environments. However, this extensive measurement campaign highlighted two limitations that are listed here below and will require further investigations.

First, the protocol was defined to adapt to any new site, in order to highlight the specificities of a site and accompany perceptive studies, suggesting that the quality of a sound environment is relative. Thus the sound environment classes depend on the site. For example, the Group G4 from Paris and the group G4 from Marseille describe different sound environments (nearly 5 dB(A) of difference in the $L_{50,A}$ values, different SGC values). This is appropriated to describe locally sound environments both physically and perceptively. Nevertheless, a complementary and generalizable approach would be of interest, based on general sound environment classes, as proposed in [2]. It has however to be answered if general environment classes would be fine enough to differentiate sound environment variations at the neighborhood scale.

	$L_{50,A}$				$\sigma_{Leq,A}$				SCG			
	G1	G2	G3	G4	G1	G2	G3	G4	G1	G2	G3	G4
Marseille	65.3	54.5	49.0	47.6	4.2	3.8	3.3	3.2	373.4	341.0	457.0	731.3
Paris	67.9	57.5	56.9	52.3	3.2	3.2	3.6	1.7	206.6	306.4	736.4	389.1
Toulouse	64.5	61.7	52.9	52.0	3.4	1.5	3.1	3.0	206.6	306.4	261.0	435.1

Second, the risk of inaccuracy associated to the mobile measurements, which stands in the reliability of the GPS values collected, has to be pointed. According to the surrounding (height of buildings, narrowness of streets, etc.), the quality of the signal varies; as a consequence the accuracy of the collected positions is not constant along the measurement path. Some filtering procedures can be proposed to reduce some errors: (i) in [9], weighting the noise values collected with the noise values collected in the vicinity was proposed to artificially increase the duration of the samples, (ii) the GPS values that are too far from the correct GPS track can be filtered out, as done in this study, or brought back to the real track thanks to a specific procedure. However, some mistakes in the positions remain despite these corrections. For example, in this study for the experimental site of Paris, some noise measurements supposed to belong to a noisy place (e.g. the roundabout in the center of the district) seem to be quiet, because the signal was lost and thus the noise values pasted to the wrong location. Proposing a method to point and filter out or correct these positions will be crucial before proposing noise maps based on mobile or participative measurements.

Acknowledgement

This research is part of the project ANR-11-VILD-0006 named Eurequa "Evaluation mUltidisciplinaire et Requalification Environnementale des QUArtiers", financially supported by the French National Research Agency (ANR).

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