Global and local sound quality indicators for urban context based on perceptive and acoustic variables

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Summary
The aim of this project is to propose urban sound quality indicators based on acoustic and perceptive data. A mobile application has been then developed. After calibration of the mobile microphone, the application proposes to collect, in addition to the noise levels, perceptive data in about 30 places of Paris. More than 3000 measurements have been performed by 60 participants. Each measurement corresponds to a 10-minute recording of sound pressure level (stored each second). Energy indicators such as L_{Aeq}, L_{A10}, L_{A50} or L_{A90} and event indicators such as the number of noise events exceeding a certain threshold Lα ($NNE_{L\geq L\alpha}$) are extracted from these acoustic measurements. Following the recordings, participants have to answer a short questionnaire: the first questions are related to the sound environment characterization with semantic scales (pleasantness, liveliness, overall loudness and envelopment feeling), the next questions concern the perceived loudness of some special sources such as cars, motorbikes, trucks etc. and the last questions regard the presence time ratio of other sources (traffic, voices, steps, birds, etc.). One global and different local sound quality indicators are proposed, based on multiple linear regression models built on perceptive variables. The overall loudness has the most important impact on sound quality for all models but the presence of some sources influence also this quality on a negative (traffic) or positive (steps, voices or birds) way. Each influent perceptive variable is correlated to the acoustic parameters. The global loudness is best correlated to L_{A50}. Oddly a small difference between L_{A10} and L_{A90} seems to characterize the human presence. Generally no global acoustic indicator is able to characterize noise sources which are nevertheless influent for sound quality. Spectral information has to be tested.

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1. Introduction

The study presented in this paper is part of a French project (Cart_ASUR) which aims at developing new indicators of urban sound quality. In order to collect perceptive and acoustic data, a mobile application has been specifically developed by the BrusSense Team of the Vrije Universiteit Brussel. The Cart_ASUR application is based on the NoiseTube one which makes it possible to record noise levels after relevant calibration of the mobile phone's microphone [1].

2. Mobile application

This new application proposes to collect, in addition to noise levels, perceptive data in specific places (parks, squares, thoroughfares, streets, schools, markets, pedestrian streets, etc.). 60 mobiles have been distributed to 60 persons living or working in the 13th or 14th districts of Paris for conducting the measurements and the evaluations. Each person has to assess 51 objectives in summer ie. about 15 locations in these two districts, each at four or five homogeneous periods (day, evening, night, week ends) and the same 51 objectives in winter. Consequently, there are 102 objectives in total. Each measurement corresponds to a 10-minute recording of sound pressure levels (stored each second).

Table I. Perceptive variables of the mobile questionnaire.

Dependent variable	Sound pleasantness	
	Global variables	**Source variables**
Independent variables		Time ratio of traffic
		Perceived loudness of light vehicles
		Perceived loudness of two wheel vehicles
		Perceived loudness of heavy vehicles
	Visual pleasantness	Perceived loudness of sky trains
	Global loudness	Perceived loudness of horns
	Liveliness	Perceived loudness of urban activities
	No envelopment	Time ratio of voices
	Familiarity	Time ratio of footsteps
		Time ratio of birds
		Time ratio of water sound
		Time ratio of wind sound

Table II. Acoustic indicators calculated for each measurement.

Indicator	**Definition**
$L_{Aeq,10\ min}$	"A" weighted equivalent sound level, calculated from 1s measurements $L_{Aeq,1s}$ over 10 minutes.
$L_{Amax,\ 1s}$, $L_{Amin,\ 1s}$	Maximum and minimum "A" weighted equivalent sound level, extracted from 1s measurements $L_{Aeq,1s}$
L_{A5}, L_{A10}, L_{A50}, L_{A90}, L_{A95}	"A" weighted sound level exceeded respectively 5%, 10%, 50%, 90% and 95% of the time
σ	Standard deviation of the $L_{Aeq,1s}$
L_{A10} - L_{A90}	Difference of percentile levels L_{A10} and L_{A90}
TNI	Trafic Noise Index, TNI = 4 (L_{A10}-LA_{90}) + L_{A90} - 30
Harmonica Index [2]	HI = 0,2*(L_{A95}-30)+0,25*(L_{Aeq}-L_{A95})
$NNE_{L>L\alpha}$	Number of noise events exceeding the Lα level. Lα : 70 dB(A), 75 dB(A), 80 dB(A), L_{A10}, L_{Aeq} + 10 dB(A) and L_{Aeq} + 15 dB(A)
$MI_{L>L\alpha}$	Duration of noise events exceeding the Lα level.
$\partial L_{10,\ 1s}$	Suddenness, 10% percentile value of ∂L_{Aeq} with $\partial L_{Aeq} = \lvert L_{Aeq}(k) - L_{Aeq}(k-1) \rvert$

Following this recording, participants have to answer a short questionnaire. The questions have been designed to cover three categories of perceptive variables. The first questions are related to the characterisation of the overall feelings on semantic scales. In addition to these questions about the sound environment, a question is dedicated to the visual pleasantness (Table I). The second type of variables is connected to perceived loudness and concerns only sources whose sounds emerge from the background noise such as mopeds, trucks, buses or horns, whereas the third type of variables is connected to the time ratio of presence and concern sources whose sounds disappear in the background. For the variables which emerge from the background noise and thus can be evaluated as "events", perceived loudness assessment is rated on an intensity scale (weak/loud). The presence of non-event sources (voices, steps, birds, water and wind) is assessed on a time ratio scale (rarely/continually). Some sound sources can be heard as events or as background. For example, cars can be considered as events during the night, when only few are passing, but can be considered as background when there is heavy traffic. As such, this particular source appears in the two categories. Participants are also asked to take as many photographs of the locations as they want in order to study the influence of the visual context on the soundscape.

In this study, 1934 measurements have been conducted between September 2013 and February 2014, and 1484 measurements have been conducted between March 2014 and September 2014. In each location, and at each period, between 20 and 30 participants evaluated the sound environment. So it is possible to calculate the mean or the median values of each variable and each acoustic measurement for each location.

3. Acoustic measurements

3.1. Calibration of mobiles

The mobile phone "HTC one X" is chosen to conduct this project because the microphone range is between 50 and 90 dB(A). As no spectral indicator is calculated, the calibration is only carried out on the global dB(A). The *in situ* measurements delivered by calibrated mobile phones are compared with the measurements made with standard LadyBird® stations installed for 6 months on street lamps at 4 meters in two different locations. For the first location which is a boulevard, the time evolutions are very similar (Figure 1.) because the sound environment is dominated by the traffic noise. For the second one which is a square (Figure 2.), the difference is more important because the soundscape is dominated by voices. Then, the position of the mobile microphone is closer from sources than the LadyBird® station.

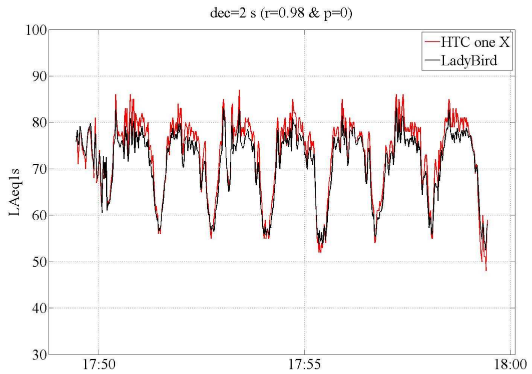

Figure 1. Comparison between one mobile measurement (red curve) and standard measurement (black curve) along the boulevard.

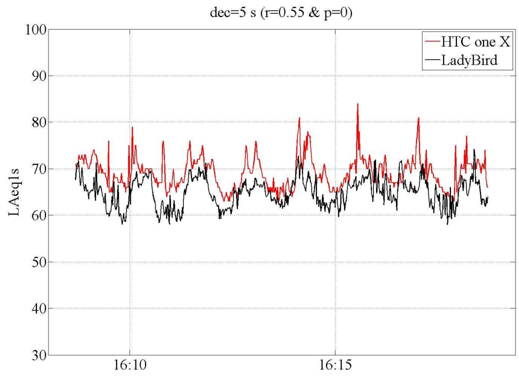

Figure 2. Comparison between mobile measurement (red curve) and standard measurement (black curve) along the square.

3.2. Indicators

The duration of the sound level recording is limited to 10 minutes. This duration is long enough to characterize the acoustic environment of an urban situation [3]. Two kinds of indicators are calculated (Table II.): on one hand energy indicators, such as the sound equivalent level L_{Aeq} or percentile levels, and on the other hand indicators related to the events (number, duration and suddenness).

The correlations between the indicators extracted from the mobile and the standard measurements are calculated. They are significant ($p<0.05$) for both locations for σ, L_{A10}–L_{A90}, L_{A50}, L_{A90}, L_{A95}, L_{min}, TNI and $NNE_{L>70dB(A)}$. The L_{Aeq} and L_{Amax} indicators as well as the $MI_{L>70dB(A)}$ extracted from the mobile measurements are significantly correlated to the standard measurements only for the Boulevard Raspail station.

Table III. Mean differences between indicators extracted from mobile and station measurements.

Indicators	Mean Δ (Mobile-Station)	
	Boulevard	Square
L_{Aeq}	1,7 dB(A)	4,2 dB(A)
L_{50}	1,1 dB(A)	3,1 dB(A)
L_{90}	0,7 dB(A)	2,3 dB(A)
L_{10}-L_{90}	0,9 dB(A)	1,5 dB(A)
σ	0,5 dB(A)	0,8 dB(A)
$NNE_{L>70\ dB(A)}$	9,3	30,5

Generally, measurements from mobiles are higher than the standard measurements. It can be explained by a shorter distance to the sound sources with mobiles, especially for human sources in the square. It is worth noticing that the number of events is over estimated with the mobiles especially in the square, due to the noise level of this location. Indeed, the mean equivalent sound level of this square measured with mobiles is 68.4 dB(A) which is just under the 70 dB(A) threshold, whereas the mean equivalent sound level measured with the station is 65.3 dB(A).

4. Global model for sound quality indicator

A predictive model is calculated on all the individual evaluations through various steps. The first step consists in verifying the independence between each variable with the correlation coefficients. When variables are found correlated, only one is chosen and kept for the predictive models. The significance of the correlations is always very high ($p<0.001$) because of the number of data, even for a poor correlation. It has been decided to consider that two variables are correlated when the correlation coefficient is greater than 0.5. Variables that do not vary are also removed from the analysis.

The second step consists in choosing the best model from linear regressions calculated with Statgraphic® software. The best model has the highest value of adjusted R^2. When the best model is found, the correlation coefficient between the model prediction and the evaluated perceived sound quality is calculated.

4.1. Perceptive model

The Table IV presents in the left column the variables that are considered as independent. The visual pleasantness is the best correlated variable with the sound pleasantness ($r = 0.63$), so, in the P3 model, its β coefficient is the greater. Previous studies have already highlighted the relation between audition and

Table IV. Pearson correlation coefficients between independent variables. Variables with r > 0.5 are considered.

Pearson correlation coefficients "r" over 0.5	
Visual pleasantness	-
Global loudness	-
Time ratio of voices	Liveliness (0,65) Time ratio of footsteps (0,57)
No envelopment	-
Time ratio of traffic	Loudness of 2W (0,57) Loudness of LV (0,68) Loudness of HV (0,54)
Loudness of sky trains	-
Loudness of horns	-
Loudness of urban activities	-
Time ratio of birds	-
Time ratio of water	-
Time ratio of wind	-

Table V. Global predictive models for sound pleasantness with different set of variables: P1 corresponds to the linear relation between sounds pleasantness and global loudness. P2 corresponds to the best model without visual pleasantness. P3 corresponds to the best model with visual pleasantness.

P1	Sound pleasantness = 9,07 - 0,44 * Global loudness (R²aj=0,19 & r = 0,44)
P2	Sound pleasantness = 8,11 - 0,38 * Global loudness - 0,14 * Time ratio of traffic + 0,20 * Time ratio of voices + 0,15 * Time ratio of birds (R²aj=0,34 & r = 0,58)
P3	Sound pleasantness = 4,48 - 0,27 * Global loudness + 0,12 * Time ratio of voices + 0,52 * Visual pleasantness - 0,12 * Time ratio of traffic (R²aj=0,52 & r = 0,72)

vision. But the importance of the visual setting is more an artefact in this study where the preferred sound environments (parks) are always the green ones. Moreover, this variable is impossible to predict from the sounds signature. The P2 model has been then calculated without this variable. It is possible to evaluate the gain of fit thanks to the additional variables, compared to global loudness only (P1 model). It shows that the identification of sound sources is important for the sound pleasantness in an urban context.

4.2. Acoustic model

It is interesting to correlate each perceptive variable with all acoustic indicators, for individual data (3418) or for median values of objectives (102). Focusing on the P2 model, the correlations with the four variables are presented in Table VII.

Table VII. Correlations between perceptive variables and acoustic indicators.

Perceptive variable	Acoustic indicators (individual)	Acoustic indicators (median)
Global loudness	L_{Aeq} (0,49) L_{10} (0,49) L_{50} (0,58) L_{90} (0,52) $MI_{L>70}$ (0,54)	L_{Aeq} (0,76) L_{10} (0,72) L_{50} (0,82) L_{90} (0,71) $NNE_{L>70}$ (0,75) $MI_{L>70}$ (0,77)
Time ratio of traffic	L_{50} (0,43) $MI_{L>70}$ (0,42)	L_{Aeq} (0,63) L_{50} (0,62) $MI_{L>70}$ (0,66)
Time ratio of voices	-	σ (-0,61) L_{A10}–L_{A90} (-0,61)
Time ratio of birds	-	L_5 (-0,55) L_{10} (-0,53)

The indicator which is best correlated with global loudness is the L_{50}. Unfortunately, almost all these acoustic measurements are correlated together, except with dynamic indicators (σ, L_{A10}–L_{A90}). The best acoustic model can be written as follow:

Sound pleasantness = 16,92 - 0,15 * L_{50} - 0,06 * L_{A10}–L_{A90} (R^2aj=0,21 & r = 0,45) (1)

It's worth noticing that the L_{A10}–L_{A90} variable characterizes the presence of voices. Nevertheless the acoustic model brings less information about sound quality compared to the perceptive one.

5. Local models

With all the perceptive data, it should be interesting to cluster the different urban sound environments, in order to adapt the perceptive models to each class. Clustering is performed on the Kohonen's Self-Organizing Maps (SOM), followed by a Ward classification [4].

5.1. Clustering

In this study, all the 3418 perceptive data correspond to the input of the clustering. The analysis leads to 6 clusters which can be described as follow:
- Class 1 is composed mainly of measurements performed in streets, boulevards or crossroads during day. These locations are rather loud with a lot of traffic.
- Class 2 is composed mainly of measurements performed in streets whatever the period, and in boulevards or crossroads during evening and night.
- Class 3 is composed of various locations: small streets, crossroads in evening, schools during class, etc. All variables are medium in this group, showing that all kind of sources are present.
- Class 4 is composed mainly of measurements performed in market streets, restaurants and pubs streets. Footsteps and voices are present in these places. This class can be divided into two subclasses: 4A where traffic noise is also noticed and 4B where no traffic is heard.
- Class 5 is composed only of measurements performed in parks. These places are very pleasant with noise of birds and water.
- Class 6 is composed of various places: parks, markets, streets, mixed areas, etc. These locations are characterized by the silence with an absence of animation. It leads to an "unfamiliar" feeling.

5.2. Perceptive models

The Table VIII. presents the different perceptive models for the different clusters. The correlations are not so good compared to the global model, because the data within a same class are more homogeneous. But it is interesting to note that, compared to the global model, for some clusters, the loudness of sources becomes significant in the models (Class 2, Class 4A and Class 5). That is to say that, for the same type of sound environments when the range of the sound levels is limited

Table VIII. Best local predictive models for sound pleasantness without visual pleasantness and without familiarity.

Class 1	Sound pleasantness = 6,58 - 0,42 * Global loudness + 0,29 * Liveliness - 0,19 * Time ratio of traffic + 0,09 * No envelopment + 0,08 * Time ratio of footsteps (R^2aj=0,24 & r=0,50)
Class 2	Sound pleasantness = 7,16 - 0,41 * Global loudness + 0,15 * Liveliness - 0,07 * Loudness of horns + 0,06 * No envelopment (R^2aj=0,16 & r=0,40)
Class 3	Sound pleasantness = 9,01 - 0,56 * Global loudness + 0,15 * Time ratio of voices (R^2aj=0,30 & r=0,55)
Class 4A	Sound pleasantness = 7,93 - 0,31 * Global loudness + 0,18 * Time ratio of voices - 0,11 * Loudness of heavy vehicles (R^2aj=0,11 & r=0,33)
Class 4B	Sound pleasantness = 7,16 - 0,31 * Global loudness + 0,26 * Time ratio of voices (R^2aj=0,10 & r=0,33)
Class 5	Sound pleasantness = 8,74 - 0,32 * Global loudness - 0,24 * Loudness of light vehicles + 0,16 * Time ratio of voices + 0,12 * Time ratio of birds (R^2aj=0,20 & r=0,45)
Class 6	Sound pleasantness = 8,09 - 0,26 * Global loudness (R^2aj=0,05 & r=0,22)

within a same class, the loudness of the events has an impact on the sound quality.

5.3. Acoustic models

The same methodology applied for global model has been used to the clusters in order to propose specific acoustic models. The result is quite disappointing because only one variable (L_{50}) leads to the best model for half of the clusters, with a maximum R^2aj. equal to 0.14 and r equal to 0.37 for Class 3. For Class 2 and 4A, the L_{Amax} is still significant in the regression. For Class 5, the additional significant variable is the NNE $_{L>LA10}$. It is in line with the perceptive models for clusters which are sensitive to the events. These values extracted from the mobile measurements are not always correlated to the standard measurements.

6. Discussion and conclusion

A large number of perceptive and acoustic data collected with mobile phones have been correlated together in order to propose predictive models for sound pleasantness. (1) The calibration made it possible to collect relevant indicators. (2) The global loudness is best correlated with L_{50}. (3) Perceptive global and local models showed that the global loudness is not the only variable which has an impact on sound pleasantness. This pleasantness depends also on the time of presence of sources for the global model and on the loudness of sources for local models. It depends also on liveliness and envelopment for boulevards and streets. (4) Acoustic models build on global acoustic indicators are not as rich as the perceptive models. This is due to the fact that some perceptive variables are not correlated with classical acoustic indicators. The list of acoustic indicators is then too short. Spectral information has to be collect in order to characterize specific sound sources. One difficulty could appear in the relevance of such characteristics measured with mobile phones.

Acknowledgement

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