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Optimization of the acoustic measurement duration in urban environment through Kohonen self-organizing map

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Abstract

In order to minimize the duration of acoustic measurements and to characterize homogeneous areas in a temporal point of view, a series of measurements were carried out continuously at crossroads during 3 months in Paris. 27 000 samples of 5-min, 10-min, 15-min, 20-min, 1-h and 2-h were extracted.
Each sample is characterized by 11 energy indicators and 10 event descriptors. Through a neural network (Kohonen map), it is shown that 5 homogeneous periods can be detected: two during the night, two during the day and one transition corresponding either to the awakening or to the moment when the city falls asleep. 15 min-measurements are necessary to discriminate these time periods.

Keywords: Sound environment, acoustic measurements, neural networks.

1 Introduction

This paper focuses on urban sound environment and tries to determine the appropriate length of time needed to measure acoustic parameters which are used to discriminate urban situations. A lot of studies which try to characterize the sound environment quality are associated to acoustic measurements whose duration varies from some few seconds [1] [2] to about 15 minutes [3] [4] (even 80 minutes [5]). This length of time is generally justified by the experimental constraints (duration of tests if sound environments are recorded and used as stimuli, battery performance of the recording system, etc.). The research presented in this paper is part of a general program whose aim is to determine the appropriate duration of measurements, long enough to discriminate different situations (different locations and different periods), but short enough to gain time during measurement campaigns. Therefore, a measurement campaign in Paris was carried out in six different locations, but this paper presents the results of only one location. 21 acoustic variables were extracted from about 3-

month recordings. The data are analyzed through Kohonen maps [6] which make it possible to determine homogeneous sound environments. As the analysis presented here is focused on only one location, the homogeneous environments correspond to typical periods of the day at this particular point.

2 Methodology

2.1 Measurement campaign

Six locations were selected to be continuously measured for a long time period (about 3 months). This paper focuses on the analysis of one of them. It is located in the 12th district of Paris at the intersection of the thorough fare of "J. Kessel" (2x2 lanes with two lanes dedicated to the buses) and the street of "Pommard" (2x1 lanes).(Figure 1)
The microphone was located between 2.5 and 3 meters above ground level on a lamppost. (Figure 2)

In order to collect data from very similar days, the days of the weekends (Saturdays and Sundays) and days that are school free (Wednesday in France) are excluded from the analysis. In total, about 43 days (Mondays, Tuesdays, Thursdays and Fridays) have been observed.

Figure 1 – View of the location.

Figure 2 – Picture of the crossroads where the microphone was set up.

2.2 Indicators

Two kinds of indicators were calculated, on one hand the energy indicators such as the sound equivalent level L_{Aeq} or percentile levels, and on the other hand the event indicators related to the number of events or their duration. All the indicators were calculated for 6 data sets of samples during the three months of recordings: each 5 minutes (12313 samples), each 10 minutes (6157 samples), each 15 minutes (4105 samples), each 20 minutes (3079 samples), each 1 hour (1027 samples), and each 2 hours (514 samples). In total, about 27 000 samples were characterized with 21 acoustic indicators each.

2.2.1 Energy indicators

In addition to the sound equivalent level L_{Aeq} (1) calculated for a period T = $t_2 - t_1$, the percentile levels from the time evolution of the instantaneous levels (in this research, the acquisition period Δt is set up to 1s) were also calculated. These levels L_{AN} represent the sound level exceeded N percent of the time T. The most common percentile levels used are: L_{A5}, L_{A10}, L_{A50}, L_{A90} and L_{A95}.

$$L_{Aeq,T} = 10 \log\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{P_A^2(t)}{P_0^2}\,dt\right]. \quad (1)$$

Among these statistic indicators, the difference L_{A10} - L_{A90} and the standard deviation σ characterize the variability of the levels. The Traffic Noise Index TNI was developed in the UK and is used for road traffic noise [7].

All the energetic indicators are presented in the Table 1.

Table 1 – Definition of the energetic indicators calculated for each sample.

Indicator	Definition
$L_{Aeq,T}$	"A" weighted equivalent sound level, calculated from 1s measurements $L_{Aeq,1s}$ over a period T. $L_{Aeq,T} = 10\,log\left(\frac{1}{T}\sum_{t=1}^{T} 10^{\frac{L_{Aeq,1s(t)}}{10}}\right)$
L_{Amax}	Maximum "A" weighted equivalent sound level, extracted from 1s measurements $L_{Aeq,1s}$ over a period T.
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 T
L_{Amin}	Minimum "A" weighted equivalent sound level, extracted from 1s measurements $L_{Aeq,1s}$ over a period T.
σ	Standard deviation of the $L_{Aeq,1s}$ where N is the number of values $\sigma = \sqrt{\frac{1}{N}\sum_1^N\left(L_{Aeq,1s} - \bar{L}_{Aeq,1s}\right)^2}$ with $\bar{L}_{Aeq,1s} = \frac{1}{N}\sum_1^N L_{Aeq,1s}$
L_{A10} - L_{A90}	Difference of percentile levels L_{A10} and L_{A90}
TNI	Traffic Noise Index, TNI = 4 (L_{A10} - L_{A90}) + L_{A90} – 30

2.2.2 Event indicators

In this research, the source recognition on the sound level recordings was not possible due to the huge number of samples. So, the event detection is based only on the evolution of the sound levels.

The number of noise events exceeding a given threshold L_α ($NNE_{L>L\alpha}$) was calculated for different values of L_α [8] [9]. In order to be able to compare this value between samples of different durations, this number has always been related to 5 minutes (mean number of events during 5 minutes). The cumulative time when $L_{Aeq,1s}$ exceeds L_α, named the "Mask Index" ($MI_{L>L\alpha}$), has been also calculated [8] [9]. It is evaluated as the percentage of time when the events are detected. In this study, the threshold L_α can reach different values: 75 dB(A), 80 dB(A), L_{A10}, $L_{Aeq,T}$ + 10 dB(A) and $L_{Aeq,T}$ + 15 dB(A). The event indicators are presented in Table 2.

Table 2 – Definition of the event indicators calculated for each sample.

Indicator	Definition
$NNE_{L>L\alpha}$	Number of noise events exceeding the L_α level, over a period T, related to 5 minutes. L_α : 75 dB(A), 80 dB(A), L_{A10}, $L_{Aeq,T}$ + 10 dB(A) and $L_{Aeq,T}$ + 15 dB(A)
$MI_{L>L\alpha}$	«Mask Index» MI is the time ratio corresponding to the event duration which exceeds L_α over a period T.

2.3 Kohonen map classification

In order to discriminate the different periods of the day, the 6 data sets of samples were analyzed successively and independently through a Kohonen map [6]. The map is organized with a reduced number of neurons [10] compared to the number of objects.

This analysis is a non supervised classification. It aggregates similar situations into a same neuron or into neurons which are near each other. More clearly, we consider n objects (the moments of the day) described by p variables (21 in our case). Each neuron is characterized by a weight vector of p dimensions too. This vector links each neuron with the indicators. For example, the first component of the weight of each neuron corresponds to the sound equivalent level L_{Aeq}. Similarly, the sixth is the percentile level L_{A90}, etc.

The algorithm may be described as follows. Randomly, an object is presented to the network. The neuron whose weights vector is the closest (in Euclidian distance) to the object, which is also a vector in dimension 21, is said to code for this object. The weights of this neuron are modified so that the distance between them and the presented object is reduced. The weights of the nearby neurons are also modified, the nearer the neuron, the higher the modification. Then a second object is presented, and the same computation is performed until the weights do not significantly change any more. In this study, 20 iterations have been necessary to satisfy this condition.

As opposed to k-mean clustering for instance, neighbour neurons code for close objects in variable space (thus the name "map"). As the number of objects can be very large (12313 objects for the set of 5-minute samples) each neuron can code for a lot of objects. In order to regroup the neurons into clusters we use a hierarchical Ward classification. The advantage of carrying the classification on the neurons instead of the initial objects (here the moments of the measurements) is that (1) the number of neurons in each cluster is limited and (2) we understand with the neuron weights which variables are responsible for gathering data into one cluster [11].

3 Results

3.1 Set of samples

As indicated above, 6 sets of samples are analyzed through Kohonen map, and clustered with Ward classification. For the two sets of 2-hour samples and 1-hour samples, 3 clusters are needed to discriminate the homogeneous periods of a day. For these two analyses, the set of 514 2-hour samples (respectively 1027 1-hour samples) x 21 (indicators) data has been analyzed through a Kohonen map designed with about 160 neurons. For each recording time, we compute the number of neurons belonging to each cluster. Each cluster has a different colour (Figures 3 and 4): red for cluster 1 (or day), green for cluster 2 (or transition) and purple for cluster 3 (or night). Hence, the radial axis in Figure 3 corresponds to the number of neurons in each cluster (labelled with the appropriate colour).

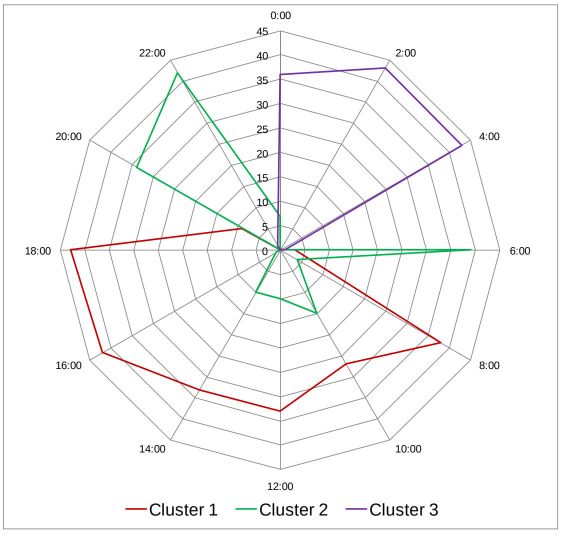

Figure 3 – 2-hour samples.

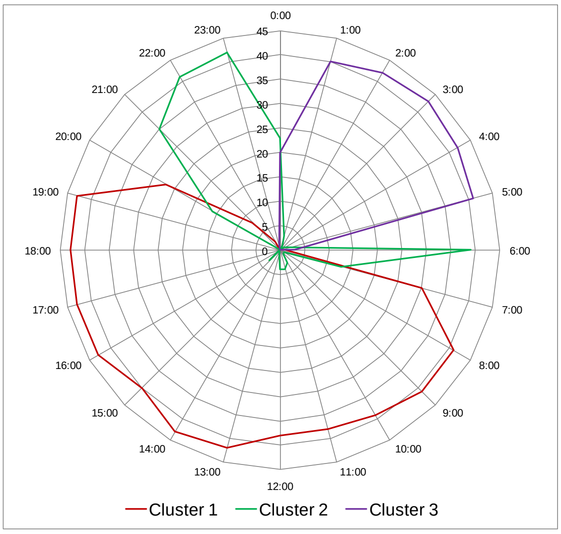

Figure 4 – 1-hour samples

On the Figure 3, it can be observed that one cluster corresponds to the night period (beginning at midnight and ending at 6AM), one to the day period (from 8 AM to 8 PM) and the last period is a transition one spread over the morning (6AM to 8 AM) and the late evening (8 PM to midnight). On the Figure 4, when samples are shorter, the time limits of the three periods are more precise, showing that the beginning of the day period is 7AM (instead of 8AM). It is interesting to notice that, sometimes, some samples corresponding to day hours coded neurons from the transition cluster. This Kohonen classification, based on the 21 indicators, does not completely succeed to discriminate correctly all different time periods, especially around noon for 2-hour samples.
For the sets of 20-minute, 15-minute, 10-minute and 5-minute samples, 5 clusters are needed to discriminate the homogeneous periods of a day. For these three analyses, the set of 3079 20-minute samples (4105 15-minute samples, 6157 10-minute samples, 12313 5-minute samples) x 21 (indicators) data was analyzed through a Kohonen map containing about 450 neurons.

The analyses of 20-minute and15-minute samples seem to be very similar (Figures 5 and 6). There is a period which characterizes the deep night (between 2AM and 5AM, cluster 5 "purple") and another one for the beginning and the end of the night (1AM-2AM and 5AM-6AM, cluster 4 "blue"). There are two clusters (cluster 1 "red" and cluster 2 "yellow") for the day period beginning at 7AM and finishing at 8PM. One of these two clusters (cluster 1) is more representative of the morning (between 8AM and 9AM) but is anyway spread out over the day. The last cluster (cluster 3 "green") corresponds to all the other samples and characterizes the period of transition between day and night. It is noticeable that a lot of samples measured between 10AM and 4PM are connected to the transition cluster with the 20-minute samples (Figure 5) but the Kohonen classification seems to be clearer with the 15-minute samples (Figure 6).

The interpretations of the 10-minute and the 5-minute analyses are more complex. It seems that there are more confusions between transition samples and the day samples for 10-minute recordings. For 5-minute samples, the period of the morning seems to disappear, and confusion between clusters still exists.

Therefore, based on all these results, we consider that 15-minute measurements are long enough to characterize five homogeneous periods over a 24-hour period of a crossroads in Paris. Shorter measurements are not long enough to clearly discriminate these periods. Longer measurements cannot explain subtle differences during the day or the night. Thus, in the following, we will only keep the data obtained with the 15-minute measurements.

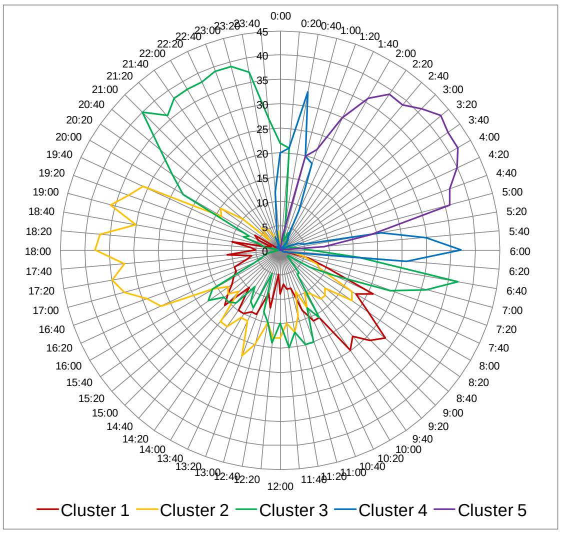

Figure 5 – 20-minute samples

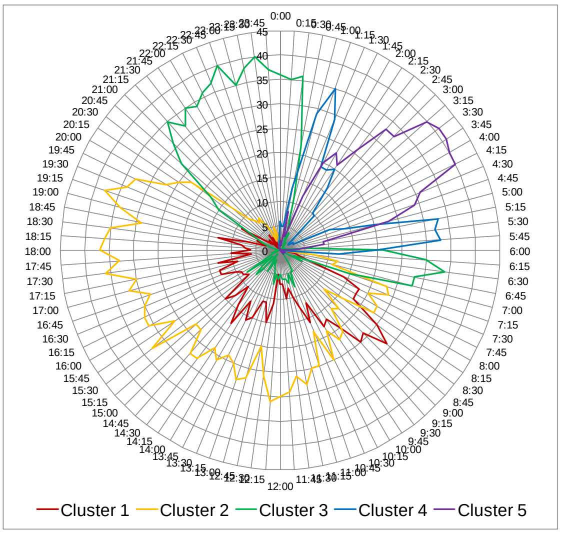

Figure 6 – 15-minute samples

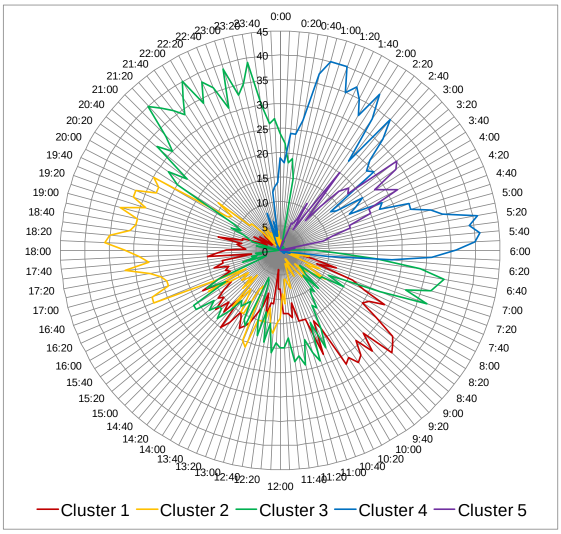

Figure 7 – 10-minute samples

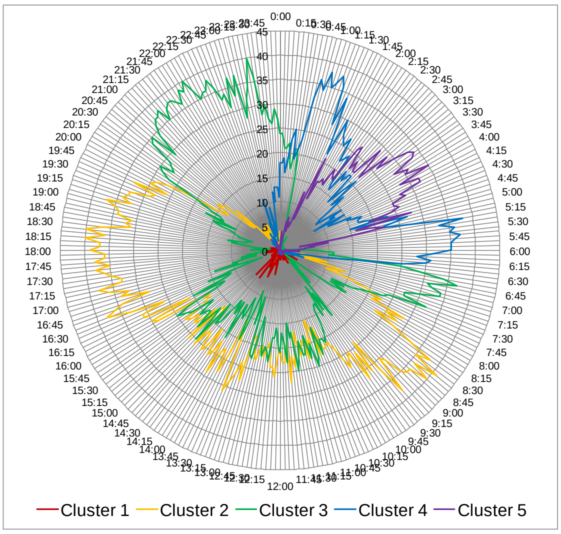

Figure 8 – 5-minute samples

3.2 Weights of neurons for 15-minute samples

The final weights of the neurons, extracted from the 15-minute sample analysis, can explain why a particular neuron responds to one moment of the day or another. On the panels of Figure 9, each square is a neuron set at its x-y location. The colour of the neuron (or square) is one of the components of the weight vector arriving on that neuron. For instance Figure 9a indicates the value of the L_{Aeq}, and Figure 9b the value of L_{A90}. Since there are 21 indicators, there are 21 such diagrams. The yellow colour characterizes high values of the indicators whereas dark colour characterizes low ones. We also draw on each diagram the boundary between clusters as we know for each neuron to which cluster it belongs to (see previous section).

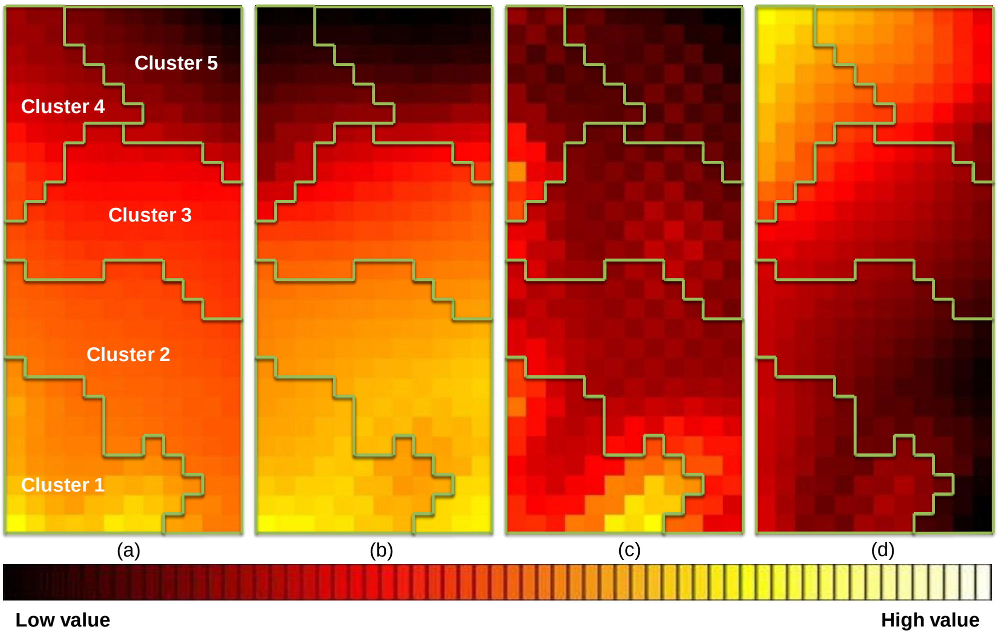

Figure 9 – Weights of the neurons for different variables, with the colour scale.
(a) L_{Aeq}, (b) L_{A90}, (c) L_{Amax}, (d) Standard deviation σ.

From these diagrams, it can be seen that the first and the second clusters (corresponding to the day measurements) are characterized with higher values of L_{A90} (Figure 9b) whereas clusters 4 and 5 (corresponding to the night measurements) are characterized with low values of L_{A90}.

The cluster 1 is characterized by very loud events which increase the L_{Aeq} and increase also the variability of the time evolution (high values of standard deviation). It corresponds mostly to some morning measurements. The cluster 2 is characterized by lower values of L_{Aeq} and smaller standard deviation which means that the time evolution of the sound level is quite constant for these measurements. The flow of vehicles seems to be more regular than for the cluster 1.

The clusters 4 and 5 are characterized by very low levels of background (low values of L_{A90}). The cluster 4 which corresponds to the beginning and the end of the night is characterized by the presence of some loud events (Figure 9c) which maximizes the standard deviation (Figure 9d). The cluster 5 corresponds to the middle of the night. It is characterized by low L_{Aeq}, with no sound event (low L_{Amax}).

The cluster 3 is characterized by medium values of each indicator. Actually, this cluster gathers all the sound sequences which are not typical. They correspond to periods which are in between day and night. This transition period is quite short in the morning when the town is awaking, and quite long in the end of the evening when the town is slowly getting asleep (see § 3.1).

4 Conclusions

The purpose of this study was to determine the optimal length of time for measuring acoustic parameters which characterize the urban sound situations. To do this, sequences of different durations (2-hour, 1-hour, 20-minute, 15-minute, 10-minute, 5-minute sequences) were analyzed through Kohonen maps. Long duration measurements (2 hours and 1 hour) make it possible to determinate 3 classes (the day, the night and the "in between" period), but cannot reveal differences during day and night periods. Shorter measurements are able to discriminate 5 periods: 2 during the day (one in the morning and one during the end of the afternoon), 2 for the night and 1 "in between" period which can be named the transition period. However, analysis of small durations less than 10 minutes is complex. There is much confusion between classes, especially between the day and the transition periods. 15-minute measurements seem to be the most appropriate in this particular case of crossroads to discriminate the different periods of the 24 hours of the day. Now it will be interesting to study other locations, with other typical sound environments, to see if the optimized duration of the measurements remains the same.

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