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Soundscape categorization on the basis of objective acoustical parameters

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ABSTRACT

A soundscape assessment method that is suitable for the automatic categorization of binaurally recorded sound in urban public places is presented. Soundscape categories are established as a result of an automatic clustering algorithm based on multi-parameter analysis by 13 acoustical parameters used as similarity measures, on a large set of sound recordings. One of the main advantages of the followed approach allows to take into account an optimized set of parameters that are judged relevant and necessary for an appropriate description of the sampled acoustical scenarios. The Euclidian distance based clustering of the 370 recordings of typical situations based on these parameters, allows to categorize each binaurally recorded sound sample into one of 20 proposed clusters (soundscape categories). The common features among members within each cluster allow to identify "how the acoustical scenario of the members sounds like". The hybrid use of an optimized set of standard acoustical quantities, such as sound pressure level, together with well known psychoacoustical parameters that directly relate to human perception of sound, makes the propose method very robust.

1. Introduction

Creators of municipal laws prefer to regulate sound in quantitative terms which are easy to measure or estimate. Assessments that can by expressed by a single value are usually desired when defining standards. For regulations concerning the building interior, the target, i.e. to achieve a sufficiently silent situation, (or other well defined situation) is clear, and it can be achieved by proper building design as a combination of sound insulation and absorption of interior surfaces. The development of guidelines for urban public places (UPPs) is a process with higher complexity. Defining universally desired properties of an ideal soundscape of an UPP is not possible. The goal of urban planners can definitely not be simplified to creating as much as possible silence. Ideally, for establishing a method and developing tools for the assessment of urban soundscapes the requirements for the acoustical situation in an UPP should be clearly described and supported by advanced sociological research reflecting the expectations of the main users of the UPP.

Urban soundscapes consist of a mixture of many different sounds with various duration, spectrum and intensity envelope, which together reveal the context. Holistic approaches for mapping soundscapes attract more and more attention. Also a large variety of non-standardized evaluation methods have been used for the description of soundscapes [1–6].

Standardized assessment methods of urban sound are typically focusing on objective noise quantification defined through equivalent sound level parameters such as ($L_{A,eq}$), L_{day}, $L_{evening}$, L_{night}, and L_{den} according to EU directive on environmental noise [7], or through parameters such as the traffic noise index [8] and estimates for the level of noise pollution [9]. One widely used regulation related to noise has been produced by the World Health Organization (WHO) [10]. It contains guidelines for community noise and describe the effects of noise on health, such as noise-induced hearing impairments, sleep disturbance effects, cardiovascular and psycho-physiological effects to effects on performance, speech intelligibility and social behavior. The WHO document also defines specific environments where noise is an important issue and gives guideline values for community noise related to the earlier mentioned critical health effects, by using two values $L_{A,eq}$ and $L_{A,max,fast}$. Other policy related documents are OECD 2008 [11] as well as many documents published on the national level of different countries. However, none of these documents focuses on a more detailed classification or typology of urban soundscapes. The particular attention to noise levels is a result of their obvious impact on human health [12–14], in the context of growing amounts of traffic, causing quasi permanent and continuous low frequency background noise levels in the urban environment [15–17].

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Most researchers agree that measurements of $L_{A,eq}$ are not sufficient for the description of an overall soundscape. An overview about the urban evaluation approaches can be found in the work of [18–22].

The work of Adams et al. [23] gives an overview of the information about sustainable soundscapes. It also shows how policy makers treat sound (as noise) and how individuals treat sound (with more aesthetic nuances). The authors also put forward the question how positive sounds in an urban area can be mapped and included in the evaluation of an urban soundscape [20]. A significant amount of work that relies on human-centerd categorization, such as exploring the essential features of a soundscape and the establishment of semantic criteria, were introduced by Schafer [24]. However, the main question remains open how to deal with the problem of soundscape identification, and which guidelines to propose to urban planners, in order to achieve a desirable soundscape.

Some research has been done on objective sound event recognition [25], and soundscape identification [26] but only a few authors deal with objective classification and categorization of soundscapes in urban public places. In most of the cases only features related to spatial factors were addressed or acoustical properties of building facades were investigated [27]. Polack et al. [28] focused on the soundscape in streets, analysing factors like road width, surrounding buildings pavement and road material, speed of the cars, and their influence on noise exposure and proposed a morpho-typological approach, dividing urban sound into four-classes based on the number of lanes in the street, and based on the question whether it concerns a one-way street or not. Their approach uses noise measurements and multi-parameter analysis, extended by cluster analysis in order to obtain the classification.

A clustering algorithm for classification of outdoor soundscapes using a "fuzzy ant" approach was proposed by Botteldoren et al. [29]. A-weighted sound pressure level histogram, the 1/3 octave band frequency spectrum and the spectrum of temporal fluctuations were chosen as similarity measures.

The evaluation of the acoustic comfort and subjective sound level with the final goal to produce soundscape quality maps has been explored by [30] by means of an artificial neural network approach.

In this paper, we propose a classification method that is based on classifying binaural recordings made in UPPs into categories defined by a set of acoustical parameters related to the sound intensity (defined through sound pressure level), the temporal changes of the sound, evaluated through roughness and fluctuation strength, the frequency spectrum (via the sharpness parameter), and the spaciousness via the so-called urban interaural level difference [31].

The main objective of this study is to show to what extent these parameters can serve for the identification of a soundscape. Our ambition is to demonstrate to what level of detail it is possible to automatically categorize binaural sound recordings in terms of soundscape identification. In other words, we verify if and how, based on objectively measured parameters, we are able to decide how does a place sounds like.

The incentive behind this categorization approach is the hypothesis that the subjective perception of a soundscape in a given location is based on a process of comparison between the heard acoustic features, and the expected features that one is subconsciously associating with, and thus expecting for that category of location. If a "park" sounds like a "park" most people will be satisfied with the soundscape, but if a park would sound like a street with heavy traffic, people might be irritated. The negative impact of the mismatch between different components of the living environment on one hand, and the perceived soundscape quality on the other hand, have been investigated by several authors. See overview in [5,1].

2. Method

2.1. Schematic overview

The proposed classification algorithm focuses on a categorization of sound samples that have been binaurally recorded in urban public places, i.e. streets, squares and parks, during so-called "soundwalks (SW)" that last for 15–20 min. The recordings were stored to an M-Audio® solid state recorder in wave format. The calibrated binaural recordings were performed by means of in-ear microphones so as to gather the sound in the ear of a city user. The sound samples were later on analyzed in the acoustical laboratory, where thirteen acoustical parameters were calculated. In a next step, the acoustical parameters were normalized and used as similarity measures in a clustering analysis that sorted locations with similar values into 20 different clusters. Finally, the clustering-based categorization was verified by identifying systematic analogies between acoustical as well as non-acoustical properties of different elements within the clusters, and by identifying systematic differences between different clusters.

2.2. Choice of the urban public places

The acoustical categories contain together 370 recordings in different UPPs in Leuven, Brussels, Namur and Bratislava, where no or few complaints of people were noted, so that these soundscapes could be considered as "normal" or "typical" for given cityscapes. One could wonder if it was not possible to combine the automatic clustering algorithm with subjective listening tests in the laboratory. Though strictly speaking this would be possible, it is not straightforward, due to the long duration (15–20 min) of the samples. Shortening the sound samples to "typical" fragments would be possible only for a few cases that have a stationary soundscape.

2.3. Acoustical descriptors as similarity measures

The acoustical parameters that were used as similarity measures for clustering, relate to (1) the sound intensity defined through the sound pressure level A-weighted ($L_{p,A}$), (2) temporal changes of the sound evaluated through Roughness R and Fluctuation strength F, (3) some information about the frequency spectrum given through the center of gravity of the frequency spectrum defined as Sharpness S and (4) the spatial sound impression described through the so-called urban Interaural level difference $uILD_2$ [31].

The statistics of the evolution of each parameter over a sound sample (L_x, R_x, S_x and F_x) is expressed by the values of the parameter that has been exceeded during a fraction of x% of the recording time, with the fraction typically taking the values 5% (exceptional events), 50% (probable situation) and 95% (quasi continuous situation).

The calculation of the values of four acoustical parameters ($L_{p,A}$, R, F and S) in time domain was performed in the 01 dB Sonic® software and the determination of their statistical values as well as the calculation of $uILD_2$ was performed by a home-made Matlab® routine.

2.3.1. Sound pressure level L (dB)

The sound pressure level L has been chosen as one of the similarity measures due to its simplicity and general use in acoustics. "A-weighted" spectra of recorded sound fragments for the calculation of the instantaneous sound level were chosen, and a "fast" time constant of 125 ms was selected for sound level. Statistical noise levels were calculated in the standard way, described in the previous paragraph.

2.3.2. Roughness R (cAsper) and fluctuation strength F (cVacil)

Temporal variations of sound result in two kinds of impressions: the fluctuation strength, which expresses slow variations of the loudness (<20 Hz), and the roughness. The sensation of fluctuations reaches a maximum level of perception at 4 Hz and then decreases towards higher and lower frequencies. Above 10 Hz, a new sensation appears. The loudness is perceived to be constant and an increasing feeling of roughness appears, reaching a maximum around 70 Hz. The unit of fluctuation strength can be understood as follows: a 1 kHz signal of average level L_p = 60 dB that is amplitude modulated by a sinusoidal modulation function of frequency *f* modulated = 4 Hz with a modulation depth of 100% yields a fluctuation strength of F = 1 Vacil [32].

To calculate roughness, more methods are known. In our research the method developed by Zwiker and Aurés, is used which calculates a specific roughness by critical band and the global roughness being the sum of all specific roughnesses. The calculation of roughness is based on the determination of the relative fluctuations of the envelope of excitation levels of 24 critical bands. A 1 kHz signal of average level L_p = 60 dB that is modulated by a sinusoidal modulation function of frequency *f*modulated = 70 Hz with a modulation depth of 100% yields a roughness of R = 1 Asper [32].

The calculation of all psychoacoustic parameters was based on a time series of Loudness values, which were determined from the sound recordings in time intervals of 2 ms. Roughness values were calculated over intervals of 500 ms from the Loudness time series. For the fluctuation strength the sequence length was 1000 ms.

2.3.3. Sharpness

The sharpness S (acum) of a sound sample is related to the center of gravity of the envelope of its amplitude spectrum. Neither the detailed spectral structure, nor the overall level, have significant influence on calculated sharpness values; sharpness increases only with a factor of two for a level increment from L_p = 30 dB to L_p = 90 dB. When few one of more tones fall within one octave band, they cannot be distinguished by the sharpness parameter. The unit of sharpness, 1 acum, is achieved for narrow-band noise of one critical octave bandwidth at a center frequency of 1 kHz and of a sound pressure level of L_p = 60 dB [32].

2.3.4. Binaural parameter

The importance of the binaural aspects of hearing on the perception of acoustical comfort in the urban environment has been mentioned only in few studies and a related quantifier has been rarely used for describing urban soundscape. For our research, the parameter called "urban interaural level difference" ($uILD_2$) was developed [31]. $uILD_2$ reflects the level difference between the left and right and is defined as:

$$uILD_2 = \sum_{i=1}^{n} \sqrt{\frac{(L_{Li} - L_{Ri})^2}{n}} \tag{1}$$

where L_{Li} and L_{Ri} are respectively the value of sound pressure level in the left and right ear channel at time i, and n is the number of values. $uILD_2$ expresses the directivity of the received sound, and thus reflects to what extent sound sources sound localized. $uILD_2$ increases as the direct to reverberant sound level difference increases.

2.4. Clustering method

The categorization of UPPs by multi-parameter analysis was done by hierarchical agglomerative clustering, a method that is available, e.g. in SPSS® software. Hierarchical clustering analysis is based on the calculation of Euclidian distances between the samples, which is then followed by an agglomerative or divisive method to categorize them. In the agglomerative method used here, first each object is treated as a separate cluster. Then, grouping is done into bigger and bigger clusters [33].

Previous research [31] has demonstrated the use of statistical values based on *L, N, R, S, F* for categorizing a set of 90 soundwalks. Clustering by using only L_{95}, N_5, F_5, R_5, and S_{50} was not very successful. Later on [34] an extended set of 27 parameters, also based on binaural parameters, was used with satisfactory results.

However, strong correlations were found between some parameters (such as between R_{95} and R_{90}, and between S_5 and S_{10}) and therefore here a reduced and optimized set of the 13 following parameters is used: L_5, L_{50}, L_{95}, F_{10}, F_{50}, F_{95}, R_{10}, R_{50}, R_{95}, S_5, S_{50}, S_{95} and $uILD_2$.

3. Results and analysis

The 13 parameters defined above were calculated for 370 "soundwalks" (Figs. 1–3).

Fig. 1(left) shows that the spread of the data used for the analysis ranges between the most silent samples, with L_{95} less than 35 dB and L_5 = 45 dB, up to noisy samples that have L_{95} higher than 75 dB, and L_5 almost 90 dB. The curves have also different slopes. This expresses differences in the temporal structure, and thus also differences in the peak to basic sound level contrast quantity L_5–L_{95}.

The spread of Sharpness values (Fig. 1-right) follows an almost normal distribution, except for a few samples with S_{50} varying between 1 and 2 acum.

Fig. 2 shows that the roughness and fluctuation strength have a relatively broad spread in overall values, in slopes, and mainly in peak values. The statistical distribution of $uILD_2$ over the whole set of soundwalks is depicted in Fig. 3. Most of the values range between 2 dB and 3 dB.

Since each of the similarity measures is defined in different units and with a typically different range of values, normalization of the data is necessary. Two ways of normalization were tried. A linear normalization (rescaling of the data in a given interval [min, max] to the standard interval [0, 100]) of the values was tested [34] but several inconveniences were observed, e.g. just a few extreme sound situations with very extreme value of, e.g. R_{10} caused a loss of differentiation between samples on basis of the R_{10} and a less adequate classification. Normalization on the basis of the mean <M> and the standard deviation σ_M of the population (370 cases) of every similarity measure M, i.e. rescaling every value M to $(M - \langle M \rangle)/\sigma_M$, led to much better results and was used in this paper.

3.1. Analysis of the found clusters

The main objective of the following analysis is to find out whether the recorded UPPs were clustered in a logical way, i.e. consistent with the overall "spatial features" (such as architectural characteristics in the urban place) of the members of the cluster, and with their "temporal features" (such as auditory event structure).

The automatic clustering algorithm has produced clusters with different number of elements in each of the cluster. Seven out of twenty identified clusters contain more than 10 elements and one of the clusters is significantly larger in comparison with the rest, containing more than 100 elements. This result is a logical consequence of the dominance of recordings of main streets in cities in the examined set of UPPs, and the presence of a number of acoustical recordings that were taken in a particular acoustical scenario (such as during a football match or a cycling competition in a city). Those circumstances were recorded less often and so the clusters containing these recordings are relatively smaller.

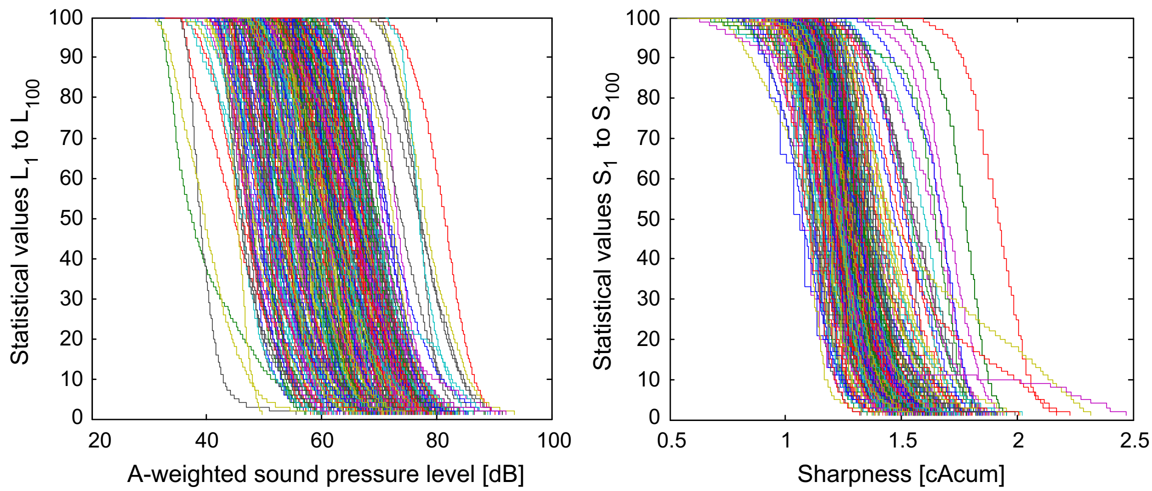

Fig. 1. Distribution of the statistical values of sound pressure level (left) and sharpness (right) calculated from 370 soundwalks.

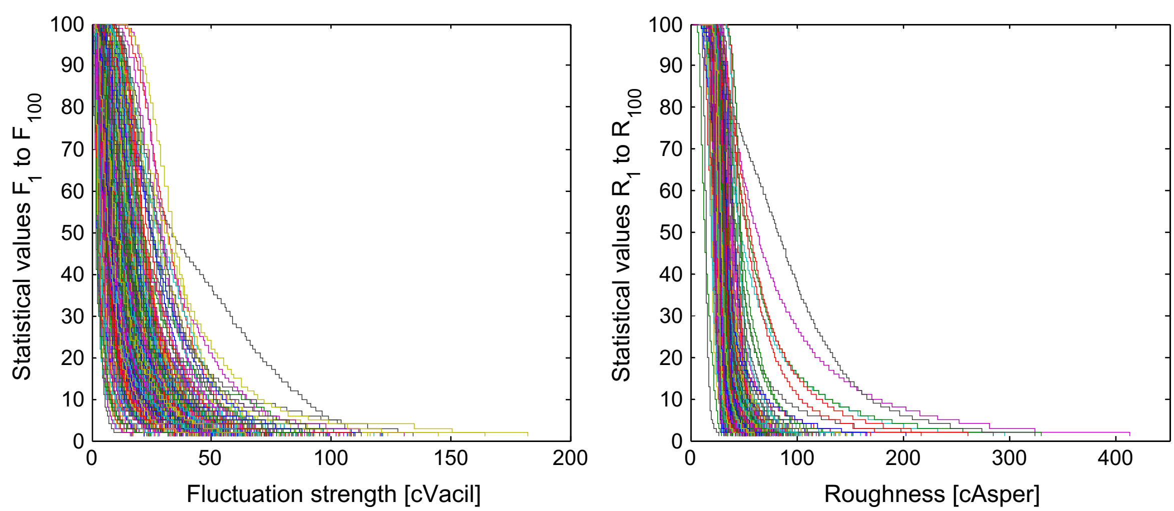

Fig. 2. Distribution of the statistical values of roughness (left) data fluctuation strength (right) calculated from 370 soundwalks.

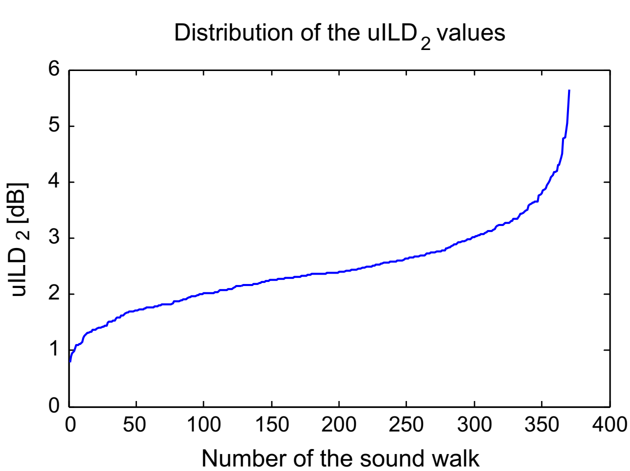

Fig. 3. Distribution of $uILD_2$ values.

In the following, we address the important question whether the separation between all clusters and the similarity between the properties of different members within each cluster is consistent with global expectations by humans. If yes, the proposed method effectively can be used to categorize urban soundscapes, and the categories can be used for descriptive or normative purposes.

Cluster 1 contains 61 sound samples from which 17 are side streets in residential areas in urban zone recorded during the evening, 18 are side streets in the city center with a combined function, i.e. they connect dwelling houses and shops, recorded during the periods when shops are closed (evenings and Sundays), both without or with little traffic, with a speed limit of 30 km/h. Eight sound samples had been recorded on squares in the city center accessible by cars, typically at the end of a dead end street or with very limited traffic. Some of the squares are used as parking places. The remaining eighteen sound samples in cluster 1 were recorded during day time in parks along not too busy bicycle pads.

Cluster 1 can be in general understood as a category for urban soundscape where different urban sounds are balanced, without a typical sound being dominant. In these places cars are passing by from time to time at low speed. People were walking through the area rather rarely and sometimes a few natural sounds like birds were also present. The mean L_5 in this cluster was measured 60 dB, L_{50} = 50 dB, and L_{95} = 45 dB. Radar plots of the clusters are shown in Fig. 4. To illustrate the shapes of the clusters better, the data plotted in all radar plots have been linearly rescaled to the range 0–100. The dotted lines in the radar plots indicate the minimal and maximal values of each parameter in the cluster.

At first sight, Cluster 2 looks similar to cluster 1, but if we have a look at the data in more detail, the difference is clear. In cluster 2, higher values of sound levels and roughness can be observed, due to increased traffic. Most of the samples clustered here were obtained for the same streets in residential areas as in the cluster 1, but now during the day time, rather than in the evening (respective recordings in cluster 1). Cluster 2 has 23 elements from which 11 are the streets mentioned, five samples are from parks in the city center situated next to a traffic sign indicating a 30 km/h speed limit and recorded during day time. Six squares of a smaller size with some public functionality (such as a pub or shop present) and a speed limit also 30 km/h where categorized in this cluster too. One sample in this cluster was recorded on a main road. This can be explained by the fact that the recording was done during a 15 min period during which the intensity of the traffic situation was coincidentally exceptionally low.

The sound intensity parameters in this cluster were L_5 = 66 dB, L_{50} = 56 dB and L_{95} = 50 dB. On average, these values are about 5 dB higher than in cluster 1.

Cluster 3 contains the largest amount of elements (1 1 0). It is worth to mention that most of the recordings in this study were performed in main streets of four cities. Sixty-nine of those, recorded in evening time in the city center, with speed of the cars between 30–50 km/h, appeared in cluster 3. Fourteen side streets with speed limit 50 km/h, recorded during the day, were clustered here as well. Other cases categorized in cluster 3 are five parks situated close to the main road in the city center, separated from the roads only by trees (thus no wall or buildings), and 22 squares in urban zone, where traffic is passing through the square. On average L_5 = 72 dB in this cluster, L_{50} = 62 dB and L_{95} = 53 dB.

Cluster 4 contains 53 main streets in the city center and urban zone during peak hours at day time, with a dominant sound of vehicles moving at a speed of 50 km/h. On average L_5 = 78 dB, L_{50} = 69 dB and L_{95} = 60 dB in this cluster.

Clusters 1–4 have typically low values of fluctuation strength, typical for soundscape a without dominant sound of human voices. On average, the sharpness values in these clusters are low, due to more neutral spectrum of sound or more low frequency components in the sound in these clusters. The radar plots of these 4 clusters have a similar shape, increasing from 1–4 mainly in two directions, e.g. vs higher sound pressure levels and vs a higher roughness of sound.

Cluster 5 and 6 were found to be very quite and silent clusters. Cluster 5 contains recordings performed in an urban residential area during night hours, between 1–3 a.m. with the average L_5 = 50 dB, L_{50} = 38 dB and L_{95} = 34 dB. It can be seen that all parameters have very low values (Fig. 4).

Cluster 6 contains measurements in a quiet place in the middle of the large park during the day without wind. L_5 = 49 dB, L_{50} = 45 dB and L_{95} = 43 dB.

The sharpness measures S_5 and S_{50} during the night in residential areas are slightly higher in comparison with the measurement done in a silent park place during the day. The sound levels L_5 were the same in both situations, though L_{50} and L_{95} were higher in the park. This is logical since the basic background noise level in cities is higher during the day than during the night hours.

Cluster 7 contains seven recordings from parks close to main roads in an urban zone where the speed of cars almost never drops under 50 km/h. These parks were open, with large grass surfaces or a big lake, and not protected from traffic noise (not even by trees). Measurements were done during day time and on average L_5 = 76 dB, L_{50} = 63 dB and L_{95} = 57 dB. These values are very similar to the ones in cluster 4. The difference between clusters 4 and 7 lies mainly in the fluctuation strength and in a very stable $uILD_2$ value in cluster 7. High and stable values of $uILD_2$ indicate an acoustic scenario where a good identification of dominating sound sources is possible, in this case the noise of cars on the nearby main road on one side of the park. Due to the open character of the situation in the absence of surrounding buildings, reflections of sound waves are absent, so that the noise of the cars is clearly coming from one direction. The $uILD_2$ value along a main road surrounded by buildings is obviously lower, since the reflections of buildings result in spreading of sound to all directions.

Cluster 10 can be described as collection of streets and bicycle pads in the campus, with few students passing by walking or cycling, and of residential areas with family houses and large gardens in front of the house during the time when people leave their homes to go to work and or return home from work. In this cluster L_5 = 68 dB, L_{50} = 56 dB and L_{95} = 50 dB on average.

The sound pressure level values are similar to cluster 2, however, a higher fluctuation strength was found in cluster 10, due to the presence of more bicycles and talking people passing by.

Cluster 13 contains four sound samples recorded in a park during maintenance activities, such as the cutting of trees. This cluster is thus related more to a particular sound event, rather than to a location as such. Obviously, due to the rough, low frequency noise of the cutting machines, very high values of roughness and fluctuation strength F_{50} and F_{10} and very low values of sharpness were observed. $uILD_2$ and sound level values are also not very high, since the maintenance was recorded from a distance of few 20–30 m. On average L_5 = 62 dB, L_{50} = 52 dB and L_{95} = 47 dB.

All recordings in Cluster 14 were taken in relatively quiet places where one of the dominant sounds were footsteps of people passing by. Recordings originate from quite parks or residential areas with family houses and the average L_5 is 58 dB, L_{50} = 46 dB and L_{95} = 38 dB.

If the clustering algorithm was based only on statistical noise levels, the recordings from the cluster 15 and 16 would be probably clustered together in the cluster 2. However, their qualitative properties are rather different and this is a nice example of how the proposed method can handle these qualitative differences.

Cluster 15 can be defined as category of residential areas in relatively quiet streets with lots of trees or parks during windy summer days. Sharpness and roughness values reach from moderate to high values, whereas the fluctuation strength is minimal. Average values were L_5 = 64 dB, L_{50} = 56 dB and L_{95} = 51 dB. This cluster illustrates the influence of the weather and season on the recordings and on the soundscape categorization.

Cluster 16 contains four recordings performed by a person walking through narrow streets (6–10 m width) not accessible for cars, with lots of restaurant terraces during warm summer evening nights. Human voices form the dominant sound, which is confirmed by high fluctuation strength values. $uILD_2$ is rather low, due to the terraces being on both sides of the street so that the "soundwalking" person was continuously surrounded by sitting and talking people. Average L_5 = 66 dB, L_{50} = 57 dB and L_{95} = 52 dB.

Cluster 9 contains 49 samples recorded in UPPs with many people present: 27 traffic free shopping streets during opening hours of shops with talking people passing by, and 22 squares during warm summer evenings and nights with people sitting in outdoor restaurants or crossing the square. Mean values of L_5 = 69 dB, L_{50} = 62 dB and L_{95} = 57 dB.

In cluster 19 two streets and two squares were found that are characterized by people passing by at shorter distance from the "soundwalking" person. In this cluster L_5 = 69 dB, L_{50} = 63 dB and L_{95} = 58 dB. This cluster differs from cluster 9 mainly concerning the value of $uILD_2$ and the fluctuation strength, which are much higher in cluster 19 due to the wider character of the site, which helps to make differences in sound intensity between the left

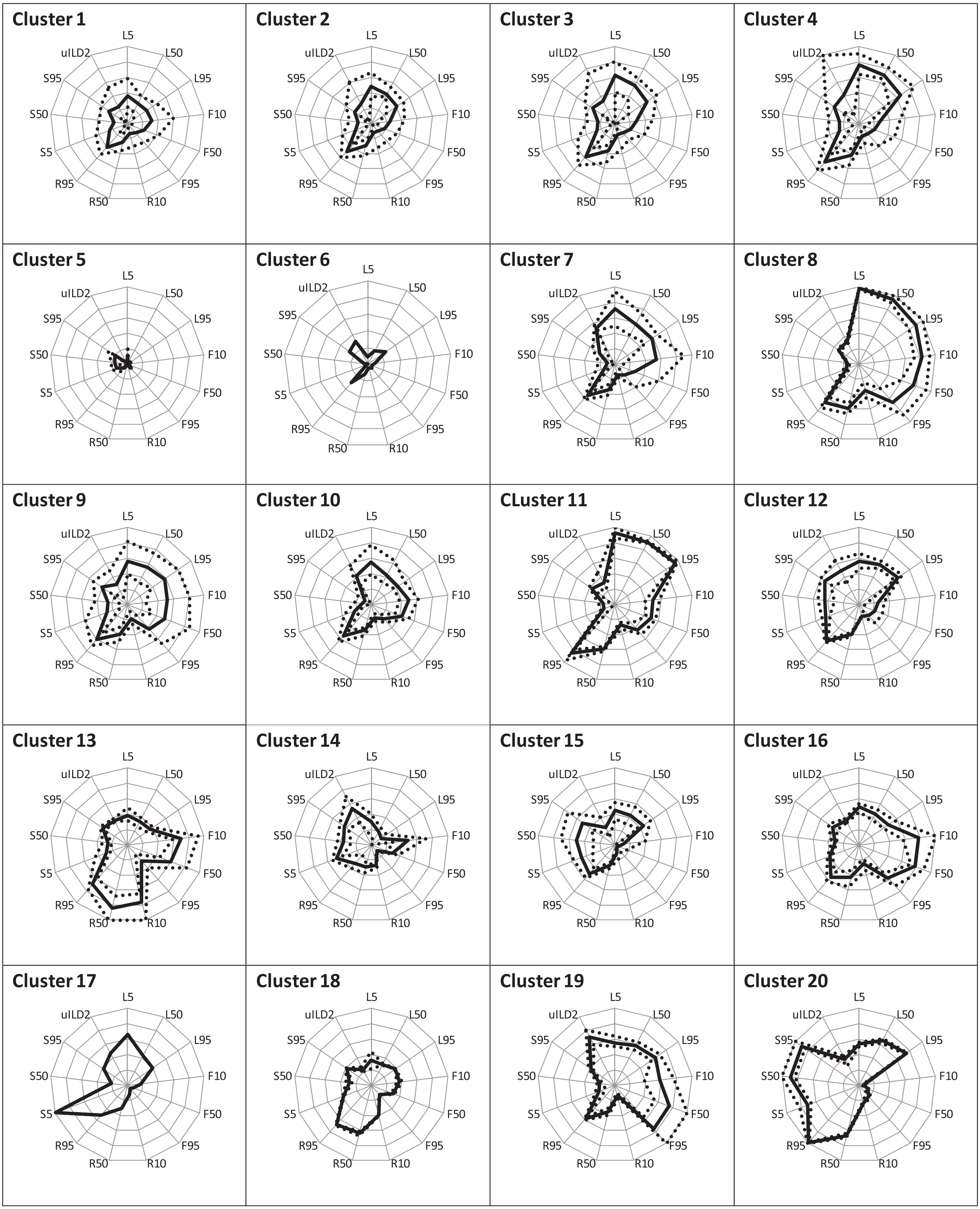

Fig. 4. Overview of the clusters categorizing the soundscape in urban public places.

and right ear larger than in situations where the reflections from the surrounding building are more significant. It is also possible that the reflections from the buildings can help in smoothing the fluctuation strength when comparing cluster 9 to cluster 19.

Samples clustered in cluster 12 strongly relate to sound events in the squares and streets, particularly to cleaning of the UPP by a dedicated vehicle. The mean values of L_5 = 69 dB, L_{50} = 63 dB and L_{95} = 58 dB.

Cluster 18 collects sound samples recorded while walking in the park that is moderately quite, with hearable footsteps of the "soundwalking" person. Without the footstep sound, these soundwalks would probably be associated with cluster 2. Cluster 18 differs from cluster 14 (where the footsteps were a dominant sound) not only in the sound level but also in $uILD_2$ value, since the sound of the footsteps from the "soundwalking" person itself is equal in both ears (cluster 18), whereas sound of the footsteps of people passing by creates larger differences in sound intensity in the left and right ear (cluster 14). Average L_5 = 66 dB, L_{50} = 57 dB and L_{95} = 52 dB.

Cluster 17: One recording in our research was done at a restaurant terrace which is situated in the square very close to a railway road. The sound of a train passing by changes the local soundscape so much that this sample appeared in a separate cluster (cluster 17), with L_5 = 73 dB, L_{50} = 57 dB and L_{95} = 49 dB.

Cluster 20: Some acousticians often recommend designing a fountain in the park or a square, where the noise of the cars can be a disturbing issue. Three parks with a fountain have been recorded in our study and all of them have been grouped correctly together in cluster 20, which is characterized by very high values of sharpness and roughness R_{95}. The average sound level in these situations reached values L_5 = 68 dB, L_{50} = 67 dB and L_{95} = 63 dB.

Cluster 8 and cluster 11 express sport events. Recordings performed during the cycling competition were associated with the cluster 8 which soundscape can be described as people speaking, shouting and applauding, mixed with car and helicopter sound. The mean values are L_5 = 87 dB, L_{50} = 79 dB and L_{95} = 70 dB.

Cluster 11 contains 4 recordings during soccer games with similar mean values of sound pressure level (L_5 = 85 dB, L_{50} = 77 dB and L_{95} = 72 dB), as in Cluster 8 related to cycling competition, but different fluctuation strength and roughness values. $uILD_2$ in both cases is very small due to relatively large envelopment by sound of talking shouting people when sitting/standing in the crowd.

4. Conclusions

A novel approach to acoustical categorization of urban public places, based on objective analysis of binaural sound recordings *in situ* has been outlined. The objective clustering is found to be consistent with subjective expectations on the basis of the typology of the recording locations and activities.

The definition of clusters by multi-parameter analysis performed on *in situ* recordings is thus useful for categorization of the recording in terms of expressing "how an acoustic scenario sounds like".

The 20 clusters identified in this study reflect typical acoustical situations in particular UPPs as well as special sound events. New clusters will be added in future, as new records will be added to the database.

Most of the 370 sound samples were clustered according to selection rules that can be useful and detailed enough for urban public place evaluation from the acoustical point of view.

It has been demonstrated to what detail the differentiation between particular UPP or sound events can be successfully performed by using only objective acoustical parameters. Extension of the current approach to a hybrid clustering method that is based on the current acoustic measures, enriched by a semantic description, in terms of, e.g. Soundmark, Sound signals and Keynote Sound in the UPP, can be expected to give a full and comprehensive impression of the evaluated soundscapes.

A strong advantage of the proposed method is the use of the well known and generally used objective acoustical parameters for physical quantification of noise, i.e. sound pressure level, together with known psychoacoustical quantities that directly relate to human perception of sound and that have been thoroughly tested in acoustical laboratories.

In this way, locations measured by our approach can be still evaluated by data from classical approaches that deal with statistical noise levels only if necessary (since Lp is one of our similarity measures). In this case, further discrimination on the basis of clusters can be used for more detailed specification of the soundscape in a given place.

Given this objective classification of soundscapes into clusters or categories, the next research step will be to seek for correlations between the cluster structure on one hand, and *a priori* subjective categorization by people experiencing the respective urban public places on the other hand. If such a correlation could be established, this would open the way to design or adapt urban public places to match people's expectations solely on the basis of objective numbers and without the need of consulting.

While preparing a method for assessment of the urban soundscape, experts from other field (such as mobility, density, wind comfort, biodiversity and universal design) should be involved as well, and a guideline for urban public place must be understood as a compromise between different scientific fields.

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