The Temporal Structure of the Urban Soundscape

D. Botteldooren, B. De Coensel, T. De Muer

Acoustics Group, Department of Information Technology, Ghent University, B-9000 Gent, Belgium,
Email: dick.botteldooren@ugent.be, bert.decoensel@ugent.be, tom.demuer@ugent.be

Introduction

Studies of the effect of environmental noise on man have classically focused on negative aspects such as annoyance, sleep disturbance, physical and mental health. The relaxing or exciting effect of a soundscape that is perfectly matched to its context, are recently introduced in environmental noise research. The concept stems from music-inspired interpretation of urban sound [1]. Soundscape research typically follows a more holistic approach. The urban acoustic environment is regarded as an aggregate of many sounds that is interwoven with the urban structure and looses part of its character when separated from visual environment (landscape), feeling of safety, perceived air quality, etc.

Urban soundscapes emerge naturally due to the typical activities that take place in the public area. Over time, urban soundscapes have evolved. Today, road traffic noise often dominates the acoustic environment. This can result both in a more stressing or a rather dull soundscape. In any case part of the richness of the urban living environment gets lost. Therefore, soundscape design should be included in future urban planning. This requires the selection and use of a number of quality indicators for the acoustic field.

An overview of recent developments in the area of urban soundscape research and the quest for relevant indicators for the acoustic field can be found in [2]. Some of this work, mainly based on semantic differential description of the sound environment by laypersons, shows that loudness related measures explain a large part of the subjective categorization. Additional factors include spectral characteristics, temporal structure, and spatial character.

This contribution focuses on finding a good indicator for describing the temporal structure of a soundscape and identifying desirable features.

Self-organized criticality, 1/f-noise, and the urban soundscape

Long-term fluctuation of characteristics such as loudness, pitch, and sharpness of a sound (music, speech, natural sound, noise) are characterized by the dynamic and the temporal structure. Statistical levels are typically used to quantify the dynamic range of the varying signal. However, they do not present the whole picture. For example, it is perfectly possible that a periodic sequence of short acoustic events produces the same statistics as a slow varying level, while these two sounds are perceived as distinctly different.

When looking for an additional indicator for the temporal structure of a sound, there are several reasons to consider the linearity of the spectrum of amplitude (and pitch) fluctuations on a log-log scale:

- Many natural (complex) systems exhibit a 1/f characteristic on a log-log scale and this characteristic has been positively linked to self-organized criticality (SOC) in the system [3].
- The 1/f characteristic has been found in different types of music [4] suggesting that man tries to imitate natural time patterns in music.
- A correlation has been suggested between the presence of noise having a 1/f characteristic and brain activity [5], indicating that the characteristic could be relevant for perception and mental health.
- The possible presence of self-organized criticality in the mechanisms underlying the emergence of the urban, rural, and natural soundscape has been discussed [6], illustrating why it is not unlikely to find this desirable characteristic in these soundscapes.

To illustrate what is meant by the spectrum of loudness and pitch fluctuation and how the 1/f behavior presents itself, a few examples are given in Figure 1. In these figures the logarithm of the spectral power of the A-weighted instantaneous sound pressure level (alternatively we used $L_{Aeq,1sec}$ and instantaneous loudness) is plotted against the logarithm of frequency. Note that a frequency of 1 Hz corresponds to a periodicity of once-per-second, thus giving the amount of acoustic energy in once-per-second events.

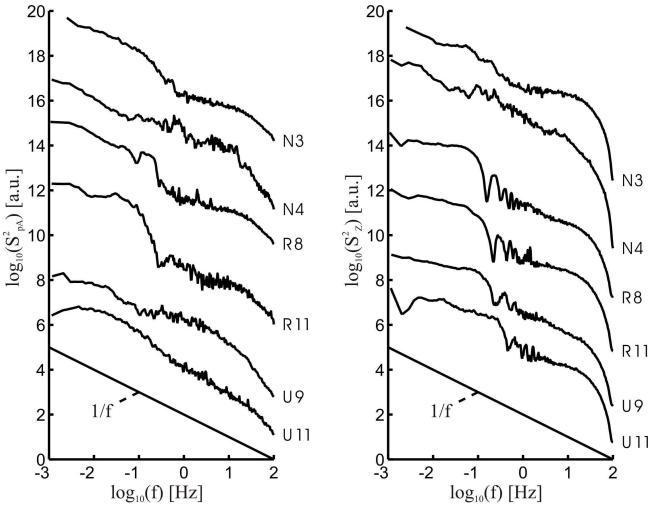

Figure 1: Amplitude fluctuation spectrum (left) and pitch fluctuation spectrum (right) for natural (N3 and N4), rural (R8 and R11), and urban (U9 and U11) soundscapes.

Towards single value indicators

In an effort to characterize the temporal structure of a soundscape by noting the presence of the 1/f type characteristic that is so common in music, two points must be considered:

- In most of the recordings of urban, rural and natural soundscapes that were made, the spectrum (Figure 1) shows a discontinuity in its slope between 0.1 Hz and 1 Hz, the cause of which is related to the difference between intra-event and inter-event temporal structure.
- The linearity of the spectrum on a log-log scale and its 1/f-slope in complex systems governed by SOC and in music must be interpreted in a soft, human-like way. A perfectly straight line or an exact slope is not expected

The proposed single value indicator is therefore based on the intervals I_1=[0.002Hz, 0.2Hz] and I_2=[0.2Hz, 5Hz] in case of 15 minute recordings are analyzed. For each interval the best-fitted straight line is constructed and its slope, *s*, and the deviation of the observations from a straight line, *d*, are recorded. To conclude whether a combination of *s* and *d* are "good enough" for the temporal structure of the sound fragment under consideration to be called music-like, a large number of music fragments was analyzed. This resulted in fuzzy sets *S* and *D*, where membership to these fuzzy sets indicates the degree of music-likeness of the temporal structure. The indicator *ML* is the product of the membership degrees of *s* and *d* to the sets *S* and *D* respectively.

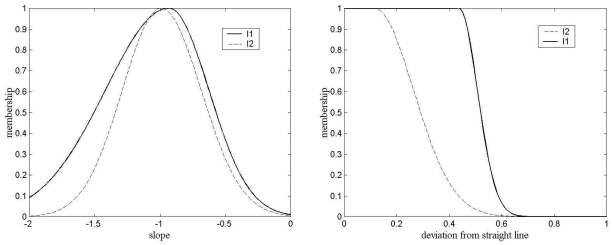

Figure 2: Fuzzy sets *S* and *D* of slope and deviation from straight line spectrum that can be called music-like.

Subjective evaluation of the soundscape

Several methodologies can be used to analyze whether the proposed indicators bare any resemblance to subjective evaluation of the soundscape. Two approaches were used so far. The first one consists in finding typical soundscapes and analyzing them as good examples. Choosing the typical soundscapes is the privilege of the environmental noise expert and is basically guided by common sense. In this way, high music-likeness was found in a few rural soundscapes where there was almost no local traffic, in typical natural soundscapes, but also in a city park, a natural reserve close to a town and even in a pedestrian shopping area (in spring). Very low degrees of music-likeness were found in several urban and rural soundscapes dominated by traffic noise (busy road, railway, military aircraft).

The second approach involves interviewing several passers-by. It has the advantage that subjective preference of a larger group is included. However, it is difficult for a layperson to grasp subtle differences between soundscapes. In particular, it is difficult to ask them about temporal structure or resemblance to music. Inspired by the work of Voss and Clarke [4] - a flatter spectrum sounds too chaotic to be recognized as music while a steeper spectrum sounds boring and dull - music-like was contrasted to boring/dull and to chaotic in a triangular scale. This clarifies the context. The scale is quite uncommon and the question difficult, but randomly selected passers-by were able to use it. For each questionnaire the distance to the three points was measured to represent the dissimilarity. Figure 3 shows the proposed indicator as a function of the subjective distance to *not like music*. Although the spread in the subjective data is large, these results are hopeful, especially when one takes into account that music is more than the temporal structure alone.

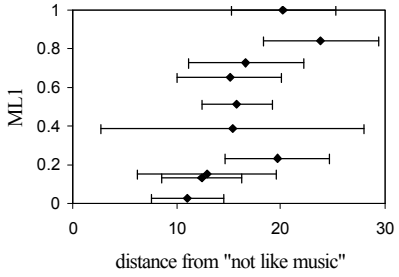

Figure 3: Resemblance to music *ML* of the temporal structure based on interval I_1 as a function of subjective distance to "not like music" character of the soundscape.

Conclusion

It was observed that objective indicators for the temporal structure of the soundscape are rare. A set of indicators based on the spectrum of sound level or loudness fluctuation was proposed. Its validity is mainly found in earlier work on music, the importance of self-organized criticality in nature, and relation to brain activity. It was however also demonstrated that a basic subjective categorization of soundscapes shows acceptable trends: natural and undisturbed rural soundscapes score high. And it was shown that there is at least some correlation to perception by the average layperson. Further research is needed to correlate this additional indicator to effects of noise on man in the broadest sense of the word.

References

[1] R.M. Schafer, *The New Soundscape*, Toronto 1969

[2] P. Lercher and B. Schulte-Fortkamp, The relevance of soundscape research to the assessment of noise annoyance at the community level, Proceedings of the 8th international Congres on Noise as a Public Health Problem, Rotterdam, 2003, pp. 225-231.

[3] J. Davidsen and H. Schuster, 1/f noise from self-organised critical models with uniform driving, Phys. Rev. E, **62**(5) (2000) 6111-6115.

[4] R.F. Voss and J. Clarke, 1/f noise in music: music from 1/f noise, J. Acoust. Soc. Am. **63** (1) (1978) 258-263.

[5] Jaeseung Jeong, Moo Kwang Joung, Soo Yong Kim, Quantification of emotion by nonlinear analysis of the chaotic dynamics of electroencephalograms during perception of 1/f music, Biol. Cybern. **78** (1998) 217-225

[6] B. De Coensel, D. Botteldooren, and T. De Muer, 1/f noise in rural and urban soundscapes, Acta Acustica united with Acustica, **89** (2) (2003) 287-295