

Dynamics in the Soundscape

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Abstract—Time patterns in the fluctuations of sound level or frequency play an important role in the perception of sound. For urban sound environments in particular, this temporal structure can be rather complex, due to the presence of many screening and reflecting surfaces and many different sound sources. From the point of view of research on outdoor sound environments – shortly called environmental soundscapes – the background level as well as the level and time structure of noise peaks are important. The main goal of this research is to introduce the temporal aspect into the study and design of soundscapes. The emphasis is put on the most important source of noise in urban and rural environment: road traffic. A dynamic traffic noise model is developed, based on microscopic traffic simulation. A novel indicator is introduced, based on the spectrum of fluctuations in sound level or frequency, and its link with complex systems is explained.

Keywords—Soundscape, Temporal Structure, Complex System, 1/f.

I. INTRODUCTION

One of the main challenges for sustainable development of our society, is to guarantee mobility, while minimizing its negative impact on man and environment. Disturbance by noise is an important factor, particularly but not only in urban environment. The assessment of the impact of mobility on the urban sound climate and the quality of life is mostly based on the calculation of noise maps, using a set of standard calculation schemes for the evaluation of the contribution of different sources. To describe the outdoor acoustic field, some indicators have become very commonly used. The A-weighted averaged sound level L_{Aeq} (and derived measures) has traditionally been used as a primary indicator because it is easy to measure and to calculate and it correlates reasonably well with perceived loudness and specific annoyance.

However, the typical frequency-time structure of urban or rural sounds is seldom taken into account. There is a consensus that road traffic noise causes annoyance, but some recent studies have shown that the time pattern of noise of vehicles passing by may explain anomalies, such as unexplained peaks of annoyance in quieter places (references can be found in [1]). Moreover, almost exclusively only the negative aspects of the sound climate are nowadays taken into account (annoyance, stress, heart diseases...).

Soundscape research takes a more holistic approach. The acoustic environment is regarded as an aggregate of many sounds that can evoke specific emotions. The soundscape is seen as an integral part of the living environment. This way, the soundscape is not studied in isolation, but is interwoven within the whole context of visual environment (landscape), feeling of safety, perceived air quality, etc. Mismatch between different components of the living environment, including soundscape, may be at least partly responsible for a negative evaluation of its quality.

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The introduction of the temporal aspect into the study of soundscapes is faced with two challenges. Current noise prediction models, based on static emissions for different environmental sound sources, can not estimate the temporal structure easily. For this, a time-dependent noise prediction model had to be designed. This model will be discussed in Section II. Moreover, it is not clear which indicators to use to describe the time variations, and what their relation is to human perception. Various indicators associated with fluctuating noise that have peviously been proposed, will be discussed in Section III, and a novel indicator, based on the spectral density of fluctuations, will be introduced. Finally, a case study will be presented in Section IV.

II. TIME-DEPENDENT NOISE PREDICTION

Predicting the dynamics of urban noise requires using a model for road traffic – the most important driving force – that can account for traffic flow dynamics. A traffic simulation model based on cellular automata, shortly called a *micromodel*, was used for this purpose: Paramics [2]. In such a computer model, each individual vehicle is modelled as an object with its own properties and behaviour. This way the impact of traffic management measures, such as the use of traffic light timing, can be evaluated.

By developing a noise emission extension to this micromodel, it became possible to simulate the time-varying noise emission caused by transportation. This micromodel add-on calculates the noise emissions of all vehicles at each timestep. Several noise sources at different heights are associated with each vehicle. Tyre/road and propulsion noise contributions are separately modelled. The noise emission depends on the vehicle type, its speed and acceleration, but also on characteristics of the road it is travelling on, such as the surface type, temperature and age.

To know the sound level at the observer and to be able to make maps of noise levels, possibly varying in time, one has to know the path the sound follows from its source. For this, a state of the art noise propagation model, in development at our research group, was used. The paths are generated using a beamtrace method, which is a sort of ray-tracing technique, also used in computer graphics modelling. The simulation environment consists of a terrain model with superimposed blocks which represent the buildings. The model is able to take into account multiple reflections and diffractions in the horizontal plane. A single path from each source to each receiver over the buildings is also generated.

This dynamic noise prediction model (which we call *MicroBASS*) makes it possible to draw maps of various dynamic descriptors of a simulated traffic situation. Such maps describe the dynamic state of the sound environment of the urban area under consideration.

III. SUITABLE INDICATORS

There is not yet a universally accepted theory about the perception of soundscapes. In this research a two-fold approach is handled: the soundscape is split up into an always existing background noise and sound events. These two components contribute to the overall perception of the soundscape, but are perceived differently. The background noise indicates the basic quality of the soundscape, because it is heard during the “quiet periods” between sound events, which can break the silence.

The background sound is usually perceived as *holistic*, that is, without making a distinction between its components. The information content (for humans) of the components of the background noise is low enough not to be perceived consciously, because they do not attract attention. In spite of this, the background noise can have a significant influence on the overall well-being when one is in such an environment, or can create a feeling of anxiety or aggression. The perception of sound events is largely based on the recognition of the sound. This may explain why different types of sources with the same sound level can give rise to different annoyance ratings.

Various indicators exist to describe the quality of a soundscape. The sound events can be described by their maximum sound pressure level ($L_{1\text{sec,max}}$) or their overall sound energy (SEL). A more recent measure is N_{emerg} , which counts the number of noticeable events. The background noise is mostly described by statistical levels such as L_{50} or L_{95} (the level which is exceeded 50% or 95% of the time).

All the indices mentioned above have in common that they do not consider the time pattern of the exposure. A few long noise events separated by long periods of relative silence may result in the same statistical levels as a large number of short events separated by short periods of silence. In particular for the evaluation of soundscape quality, it can be important to distinguish between the above-illustrated situations by using a suitable indicator. It is proposed to use the slope of the spectrum of level fluctuations over a sufficiently long time period (15 minutes) as an indicator. In this spectrum, periodic events will show up as peaks. However, this spectrum has much more interesting characteristics. If the events contributing to the soundscape result from a complex system, then the spectrum will be linear on a log-log scale. Self-organization of the underlying system will lead to a $1/f$ behaviour. Steeper slopes tend to indicate high predictability; less steep slopes are an indication of a chaotic process.

It was observed that $1/f$ spectral characteristics are quite common in rural, natural, and urban soundscapes with a mixture of activities [3]. By drawing the link to music, where this temporal structure was observed earlier [4], it is suggested that perception of soundscape dynamics and the spectrum of sound level fluctuation are related and that the slope of the spectrum on a log-log scale may be a suitable additional soundscape descriptor [5] that summarizes the dynamics of the sound field.

IV. CASE STUDY

A first validation of the model presented was made on a part of Gentbrugge, a suburban area near Ghent, Belgium. A micromodel of the area was coded in Paramics; the network con-

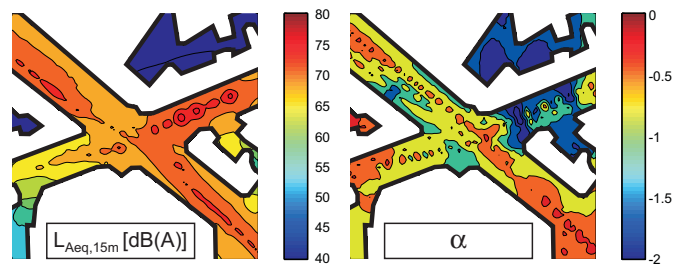


Fig. 1. Noise maps at a signalized junction.

sisted roughly of about 450 roads and 180 junctions. Traffic demand data, needed to simulate the traffic realistically, was extracted from various sources, such as traffic counts gathered by the Flemish Community and the City of Ghent, and timetables of busses, trams and trolleys provided by the Flemish public transport company De Lijn.

Noise levels generated by our dynamic traffic noise prediction model were compared with noise measurements made in situ, and in general a good agreement was found. As an example of a map showing the dynamics of the acoustic field, a signalized junction in the area was chosen for a closer look. Figure 1 shows the resulting maps for the average noise level L_{Aeq} and the slope of the spectrum of fluctuations in the time-varying sound level. One can see that the average sound level on the minor road in the northeast is about the same as on the major road, from the northwest to the southeast. However, the slope α of the spectrum of fluctuations is much steeper (< -1) than on the major road (> -1), which indicates a more predictable flow of traffic on the minor road.

Other validations of this model were done for networks of the alpine area of the Brenner pas in Austria and Italy, and the quiet area Dender-Mark in Flanders, Belgium.

V. CONCLUSIONS

A dynamic traffic noise prediction model was introduced, which makes it possible to visualize the dynamics of the part of the soundscape which is caused by transportation noise. Several acoustic measures for the classification of soundscapes were discussed, and a novel indicator based on the spectrum of the fluctuations in the noise level was introduced, which makes it possible to evaluate the patterns in time variations in the soundscape.

REFERENCES

- [1] B. De Coensel, T. De Muer, I. Yperman, and D. Botteldooren, “The influence of traffic flow dynamics on urban soundscapes,” *Applied Acoustics*, vol. 66, no. 2, pp. 175–194, Feb. 2005.
- [2] “<http://www.paramics-online.com/>,” Paramics is being developed by Quadstone Ltd.
- [3] B. De Coensel, D. Botteldooren, and T. De Muer, “ $1/f$ noise in rural and urban soundscapes,” *Acta Acustica united with Acustica*, vol. 89, no. 2, pp. 287–295, 2003.
- [4] R. F. Voss and J. Clarke, “‘ $1/f$ noise’ in music: Music from $1/f$ noise,” *J. Acoust. Soc. Am.*, vol. 63, no. 1, pp. 258–263, Jan. 1978.
- [5] B. De Coensel, D. Botteldooren, and T. De Muer, “Classification of soundscapes based on their dynamics,” in *Proceedings of the 8th International Congress on Noise as a Public Health Problem (ICBEN)*, Rotterdam, The Netherlands, 2003.