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Application of a model for auditory attention to the design of urban soundscapes

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ABSTRACT

Sound forms an integral part of the urban environment, and there is a growing awareness that it should be considered at the same level of importance as visual aesthetics in the urban planning and design process. Although basic principles are shared with the acoustic design of indoor environments, there is a need for soundscaping techniques that are specifically adapted to the outdoor environment, because of the difference in spatial scale as compared to indoor environments, the structure of the ambiance and the nature of sound sources. Models of auditory perception are valuable tools for soundscape design, since they can be used to complement auralization by replacing the listener. This paper presents a simple but computationally efficient model of auditory attention for use in the acoustic design of urban outdoor space. The simulated time-varying sound level at the location of the listener forms the input to the model. Sounds intruding the area under consideration, as well as sounds introduced as part of the design process are considered. The auditory attention model allows assessing the potential of particular sounds for energetic and/or informational masking of the unwanted sound. As an illustration, the model is applied to the design of an urban park, as part of an urban development project.

1. INTRODUCTION

Current urban planning practice is mostly guided by socio-economic and socio-ecologic concerns, visual aesthetics, safety and transport mobility. Although noise limits usually make part of the environmental impact assessment of planning proposals, aspects of noise are often only tackled when all structural/visual planning is finished. Inspired by the work of Schafer [1], there is a growing awareness that sound forms an integral part of the urban environment. Accordingly, sound quality should be considered at the same level of importance as visual aesthetics in urban planning [2–6]. Including aspects of human auditory perception in urban planning, an approach often referred to as *soundscape design*, has great potential [3, 4]. The key idea is to consider sound as a resource, not just as a waste to be managed. Compared to noise control, this represents a holistic approach, aimed at designing entire environments that are pleasing people [7].

When considering the way in which aspects of sound could be handled in the urban planning process, one may roughly distinguish two stages [8]. In the first stage, decisions are made about general building layout. When dwellings are created, important factors to consider are access to quiet areas within short range, or at least the existence of a quiet side at each dwelling [9], in light of providing opportunity for psychological restoration [10]. Often mentioned are the 19th century courtyards, found in some European cities, that offer refuge from the urban rush. In this respect, a good placement of buildings is much more efficient than any remediating measure, such as the installment of noise barriers. In the second stage, the general building layout is considered to be fixed, and areas of opportunity for soundscape design could be identified and worked out in detail. Measures to be taken could be passive (e.g. optimizing roof shape or adding façade covering with climbing plants), or active, by accentuating existing sounds or even generating (or encouraging activities that generate) additional sounds. These sounds do not necessarily need to mask non-fitting sounds energetically; they could just distract attention from non-fitting sound as much as possible (i.e. *informational masking* [11, 12]). An example of this approach is the use of sound from water fountains in the design of urban parks or squares. Measures such as modulating flow strength or altering fountain design may be used to shape the sound spectrum of water features [13], making these ideal instruments for attracting attention and masking traffic noise. Adding greenery in well-arranged spaces may enhance the natural feeling of the environment and alter the sound level distribution, but may also attract songbirds. As a more drastic measure, (camouflaged) loudspeakers or sound art installations (audio islands) could be introduced, playing back fitting sounds, such as singing birds in an urban park [14].

While standard noise mapping software may be suited for determining the most advantageous placement of buildings, there is a clear need for models and techniques for detailed soundscape design. In this paper, we present a computational approach for assessing the potential of particular sounds for energetic and/or informational masking of unwanted sound. Central to this approach is a model that simulates how listeners switch their *(auditory) attention* over time between different sounds. Both unwanted sounds, intruding the area under consideration, and sounds introduced as part of the design process are considered. In Section 2, the model is presented, and in Section 3, its application to the design of an urban park is illustrated.

2. MODELLING AUDITORY ATTENTION

General overview

Recent findings in neurophysiology emphasize the important role of auditory attention in perceiving the complex acoustic environment to which we are exposed [15]. Humans have a great proficiency in *auditory scene analysis*, decomposing the mixture of incoming sounds from different sources into auditory streams [16]. Auditory attention allows us to focus on a particular stream of interest while ignoring others. This stream is then analyzed in working memory, and

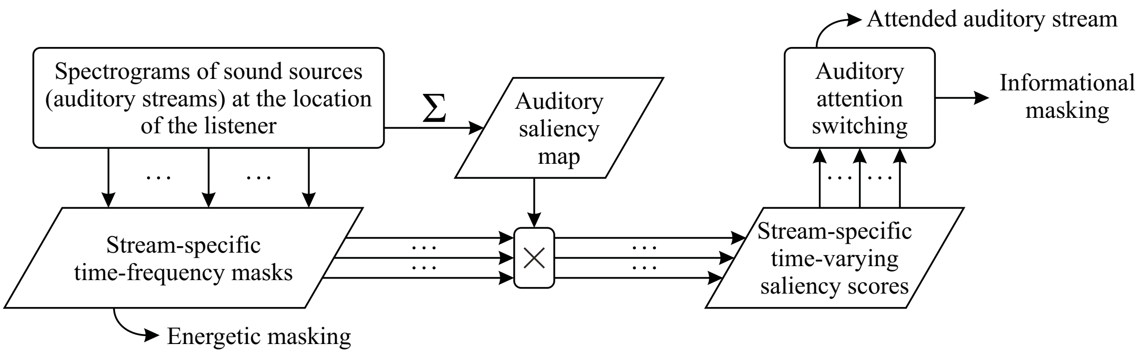

Figure 1. General layout of the computational model for auditory attention.

its information may be used for making decisions and taking actions [17]. On a longer time scale, the sounds to which we pay attention will contribute to the creation of a mental image of our acoustic environment, and ultimately will shape our perception of its quality.
Central in most theories on (auditory) attention is the interplay of *bottom-up* (saliency-based) and *top-down* (voluntary) mechanisms in a *competitive selection process* [17]. The bottom-up mechanism enhances responses to streams that are conspicuous. This is accomplished by a novelty detection system that continuously monitors the acoustic environment for salient events: changes in intensity, frequency, duration, or spatial location of stimuli. The top-down mechanism guides attentional focus to the stream that is most relevant for the current goal of the listener (e.g. listening to a particular voice). A competitive selection process determines, in a winner-takes-all fashion, the stream that is paid attention to, combining the effects of bottom-up saliency and top-down bias, together with information from different senses.

Computational model

The above described mechanisms have been worked out into a computational model, which is described in detail in [18]. Here, we only discuss the general layout. The main conceptual simplifications of the model are that it disregards the influence of spatial cues, and that it does not distinguish between sound sources and auditory streams. The general layout is shown in Figure 1. The model starts from a time-frequency representation (spectrogram) of the sound present at the location of the listener, originating from each sound source (auditory stream) that is considered to be an object of the design process. In this paper we will use a (simulated) 1/3-octave band spectrogram with temporal resolution of 0.1 s [19], but a more detailed time-frequency analysis can be used if (auralized) sound signals are available [18].
In a first stage, for each auditory stream, a *time-frequency mask* is calculated, delimiting those time-frequency units for which the stream dominates the mixture of all other streams. Using the Zwicker model for specific loudness (ISO 532-B), these masks model the phenomenon of *energetic masking* in auditory perception. In parallel, an *auditory saliency map* is calculated for the mixture of all streams. This map emphasizes those time-frequency units that are most likely to be the subject of auditory attention. The various masks are then pointwise multiplied with the saliency map and aggregated over the frequency axis, resulting in a *time-varying saliency score* for each auditory stream. These serve as input for the auditory attention switching submodel, which delimits the time periods during which particular streams are paid attention to, modelling the phenomenon of *informational masking*.
The model makes it possible to conduct “virtual” listening experiments, in which a human listener is replaced by a simulated one. The soundscape designer only has to provide spectrograms of the sounds at the listener’s location, originating from a series of modelled sound sources. Note that no meaning is attached to the sounds: it is left to the designer to decide if particular sounds fit in a given context or not.

3. URBAN PLANNING CASE STUDY

Description of the area

In this section, we will show how the attention model can be applied for designing the soundscape of a real-life urban development project. The area is located in the southeastern part of Antwerp, Belgium; Figure 2(left) shows an aerial photograph. The site mainly consists of an abandoned gasworks plant, a parking lot and a transformer station, and is to be redeveloped into a residential area, with room for an urban park. The acoustic environment at the site is mainly governed by the noise from a freeway and a major road located to the east, and a railway located to the north of the area, carrying goods trains at slow speeds; Figure 2 shows the appropriate noise maps. The authors were involved as acoustic consultants to advice the local authorities in planning decisions, and aspects of acoustic design were considered already in an early stage. Details on the methodology for selecting the building arrangement can be found in [8]. Here, we will consider the soundscape of the urban park for one building arrangement scenario. The urban park is hereby situated in the north of the area, with a series of artificial mounds at the western edge as a noise barrier. As an illustration, the model will be used to assess the potential of sound from a fountain or from birds for energetic/informational masking of the road/railway noise that intrudes the park, and this at a selected listener location.

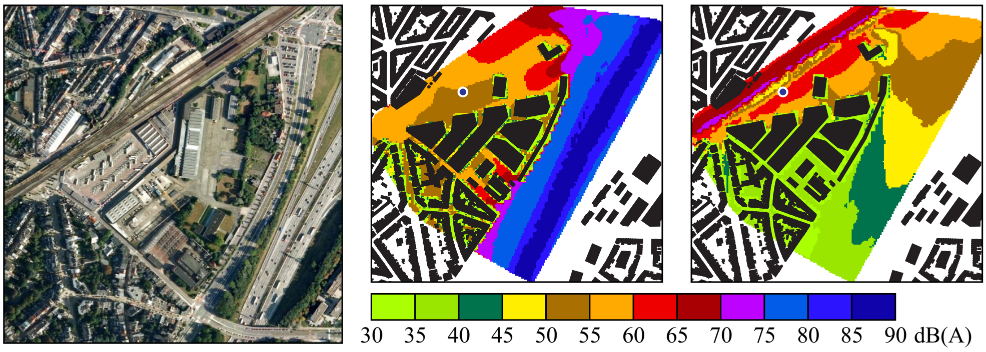

Figure 2. Aerial photograph of the site (left), and $L_{\mathrm{Aeq,day}}$ noise maps for road (middle) and railway traffic (right), for the selected building arrangement. The blue dot shows the listener location.

Construction of spectrograms

Simulating a spectrogram of road/railway noise at a listener location ideally involves simulating the dynamic behavior of vehicles/trains on the roads/tracks surrounding the case study area, coupled with detailed modelling of sound propagation [20]. When more than a single listener location is to be considered, this approach quickly becomes unfeasible because of computational complexity. Instead, a simplified two-stage estimation procedure is followed here, only requiring noise maps of the area, together with some basic properties of the roads/tracks. Firstly, spectrograms are simulated, only considering the freeway, the closest major roads and the railway as sources, and with simplifications for driving pattern (pass-bys according to a Poisson distribution), source strength and sound propagation (free field). We refer to [21] for more details on this procedure. Secondly, the simulated spectrograms are calibrated in such a way that the average spectrum corresponds to that obtained from the noise map (Figure 3a). Noise maps can be calculated with standard software (preferably in 1/3-octave bands). Here, the sound power level of the sources was calibrated based on measurements performed at the site (described in [8]). In essence, the first stage makes sure that the temporal structure is realistic, while the second stage fixes the overall level and spectral structure. Spectrograms of a fountain at short distance, and of birds singing were not simulated but recorded in the field. Figure 3(b–d) shows some excerpts of simulated/recorded spectrograms.

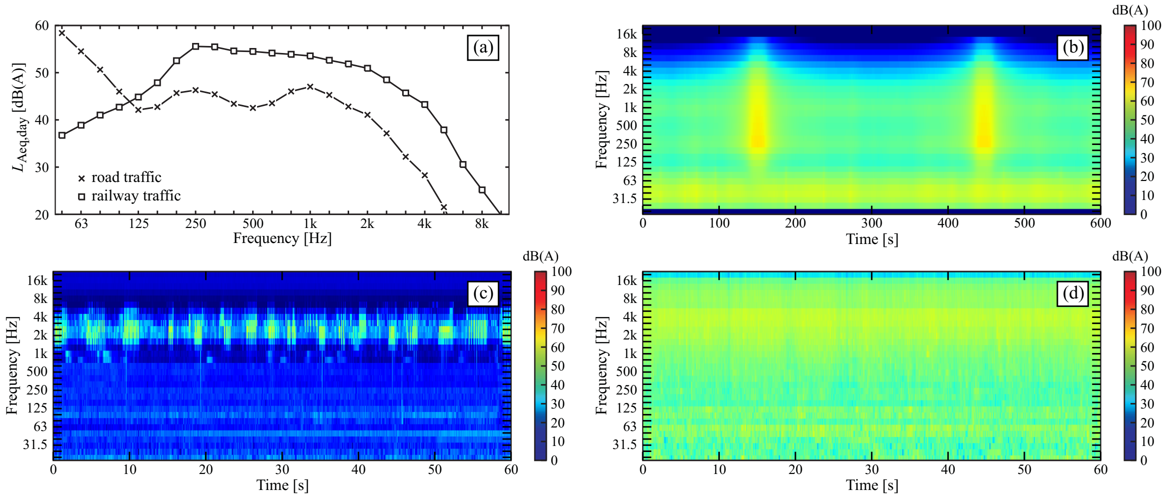

Figure 3. (a) Traffic noise spectrum at the location of the listener; (b) excerpt of a simulated freeway+railway traffic noise spectrogram; (c) birds singing; (d) fountain noise.

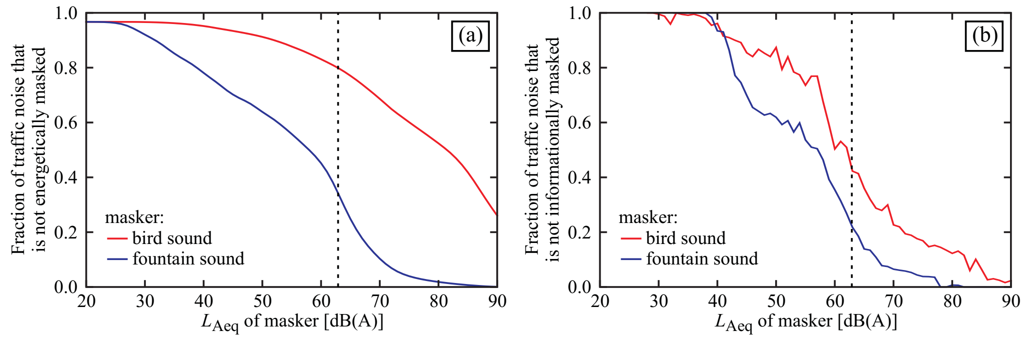

Figure 4. Fraction of traffic noise that is not (a) energetically masked, and (b) informationally masked, as a function of the L_{Aeq} of the masker. The dashed line marks the L_{Aeq} of the traffic sound.

Simulation results

Figure 4(a) shows the fraction of the traffic noise spectrogram that is not energetically masked by the sound from birds or a fountain at the listener location, as calculated from the time-frequency masks. The bird/fountain sound L_{Aeq} was varied, keeping the spectrum unchanged. The energetic masking potential is mainly determined by the spectro-temporal structure of both traffic noise and masking sound. It can be seen that, at equal levels, fountain sound does a better job than bird sound, because of its continuous broadband character. In the masking potential of the fountain, a bend can be seen at around 3 dB(A) below the traffic L_{Aeq}. This indicates an increased energetic masking potential of the fountain sound when its level is not less than 3 dB(A) below the traffic noise, which is in accordance with the results described in [13]. Figure 4(b) shows the time that traffic noise is paid attention to, as a fraction of the total time sound is paid attention to. Clearly, bird sound now does a better job, with an informational masking potential closer to that of the fountain. Because bird sound is much more concentrated in frequency and time, it contains more peaks in its saliency score. Thus, although not very effective for energetic masking traffic noise, the sound of birds still shows potential for informational masking.

4. CONCLUSIONS AND PERSPECTIVES

A model of auditory attention to environmental sound was presented, and its use in soundscape design was illustrated with a case study. The proposed approach makes it possible to assess the potential of design elements such as fountains for energetic/informational masking of road and railway traffic noise. The assessment is based on the spectrograms of the sounds at the location of the listener, originating from a series of modelled sound sources. This paper only considered a recorded spectrogram of the sound of a particular fountain. When the sound power and radiation pattern of design elements is available, it would be possible to draw "masking maps", delimiting the area for which the design element is effective in masking unwanted sound.

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