INTER-NOISE 2007

28-31 AUGUST 2007
ISTANBUL, TURKEY

Models for soundscape perception and their use in planning

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ABSTRACT

In this paper, our ongoing research towards a unified model for the perception of the sonic environment is discussed in the context of planning. In contrast to most research, which relates soundscape descriptors to perception in a fashion strongly related to epidemiologic research, a bottom-up approach is followed. The individual sensory, cognitive and emotional mechanisms that play a role in soundscape perception are discerned, and a first step is taken into making the knowledge available in literature explicit, by building a human mimicking software model. In particular, such a model is able to reproduce and explain, in a qualitative way, trends as observed in epidemiological research on soundscapes.

For urban soundscape planning, the proposed model can complement or substitute auralisation. A mixture of existing and planned sounds is fed to the model. Taking into account the variability in personal characteristics of a synthetic population of visitors, noticing of natural, human, and mechanical sounds is evaluated. Taking into account the meaning of these various types of sounds within the given context (e.g. a city park), the sonic environment is evaluated. This evaluation conceptually involves cognitive processes that depend on personal and cultural background of each visitor.

1 INTRODUCTION

Since modern times, noise effect research has focused strongly on negative effects of mainly the mechanical and electronic sounds that have invaded our society since the 1930’s. The workplace and homes of the population are of main concern in this research because of the substantial amount of time people spend there. Soundscape research takes a more positive approach. The sonic environment is studied in a particular physical and social context taking into account its typical use. The description and evaluation of the sonic environment approaches the level of detail that music or landscape researchers have reached – or have been trying to reach – for many years. Appraisal by individual users of the soundscape is a key factor. It depends on personal factors in many different ways. An overview of recent advances in the field can be found in [1].

In soundscape research, remarkably little use has been made of simulation. Simulation involves incorporating all available knowledge on perception, appreciation, evaluation, etc. in a human-like computer model. By running this model, insight can be gained in the complex mechanisms involved. These models often exhibit emergence: new overall behavior that was not explicitly modeled is observed. Constructing the model on itself is a fruitful process since it forces the scientist to make available knowledge explicit.

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In previous work [2][3], we constructed a human-like model for noise annoyance emerging during daily activities and used it to explain at least part of the difference in annoyance caused by road traffic noise and railway traffic. In this paper, we adapt this model (Section 2) for studying a particular class of soundscapes: the urban park and natural soundscape. The main adaptation needed for this purpose was to include natural sounds (possibly including human vocalizations) in the sonic environment mix. Additionally the meaning of sounds needs to be modeled more carefully. The theoretical model proposed for the latter purpose is not fully implemented and will only be described theoretically (Section 2).

The proposed simulation technique will be used to demonstrate how such models could be used in urban planning (Section 3). The reader should nevertheless realize that this is the beginning, by far not the end of this endeavor.

2 A MODEL FOR SOUNDSCAPE PERCEPTION

2.1 Modeling synthetic populations

Many authors have pointed out the importance of personal factors, including personality treats, in the assessment of soundscape quality and its degree of fit to both the environmental context and the purpose [1][4][5][6]. It is therefore quite evident that a model with the ambition of imitating a human observer has to include such personal factors. This automatically implies that useful results will only be obtained by simulating a population rather than an individual. In this paper we will refer to the computer model that mimics the human response to the auditory stimuli as the *modeled individual* (MI). The simulated group of MIs with slightly different personal factors applied to each of them will be referred to as the *synthetic population* (SP). The SP is analyzed with essentially the same methods as the real population. This implies that there is as much information to be found in the spread produced by the simulation as in its mean.

2.2 Noticing components of the sonic environment

The first and currently most advanced part of the model analyses the sonic environment and identifies its components. A key idea here is that the modeled individual should notice the sound before it can affect the MI’s appreciation of the soundscape. It could be argued that the non-noticed background sound level could affect mood, stress, and certainly health. For the application envisaged in this paper these effects are assumed to be of minor importance and are therefore ignored.

The notice-event model [2] considers the difference in level between any particular sound and the background to be a key feature. Once this difference exceeds a threshold, noticing occurs. Attention and alertness of the MI for environmental sounds largely determine noticing. This is accounted for by making the threshold depend on these factors. Attention and alertness in turn depend on the instantaneous intentions of the MI and thus on its activity. Activity also influences the noise produced by the MI itself while exercising its activity.

Note that the notice-event model does not include source recognition. Time sequences of sound level from cars and truck, trains, planes, birds, etc. are either simulated based on the presence of sources in the environment or measured. The difference between noticing and identifying is thereby ignored or in other words, it is assumed that a non-identifiable sound is not noticed.

For the simulation to work, several feed forward and feedback paths with a variety of time constants had to be included. They can be identified with human processes like gating, attention focusing, adaptation, habituation … described in psychoacoustics and psychology literature (e.g. [7][8]).

When moving from studying mere noise annoyance to urban soundscape design, perception of the sonic environment needs to be studied with more care. One of the sub systems of the notice-event model that needs more detailed consideration is the attention focusing subsystem (Figure 1). The soundscape typically is a multi noise source environment and thus attention can drift between sources: a train passage, the continuous hum of a distant highway, a song bird, a rustle in the bush … The proposed model instantaneously increases attention for one of these sources when a notice event occurs but attention slowly starts to drift away afterwards. This model is a simplification of the attention sub-model used in auditory stream segregation models such as the one presented in [9]. Inspired by the limit on attentional load [10] both the sudden increase and the drift are made dependent on the overall (sum) of attention levels and thus noticing of different sounds influences each other. Moreover, the model assumes that the overall attention for environmental sounds that basically depends on the instantaneous activity and intention of the MI may increase due to noticing environmental sounds. This process involves an integration (averaging) over time. Finally, the model assumes that the degree to which attention is volatile depends on the MI through what we called attention "elasticity".

A model for human perception (and appreciation) of the sonic environment can never be complete. This implies that the model has to account for imprecision and uncertainty. Three types of imprecision are treated separately:

- Person specific characteristics can not crisply be identified based on demographic data. Based on population wide probability density distributions, these characteristics are sampled for each MI in the SP.
- Instantaneous (1 second) values of some important parameters can fluctuate due to influences outside the model. This fluctuation is reconstructed based on probability density distribution and power spectrum of the fluctuation.
- There is inherent vagueness in some of the psychological and psychophysical constructs involved. Fuzzy sets are well suited to handle this vagueness. Due to CPU-time limitations these methods were thus far not deployed in the model.

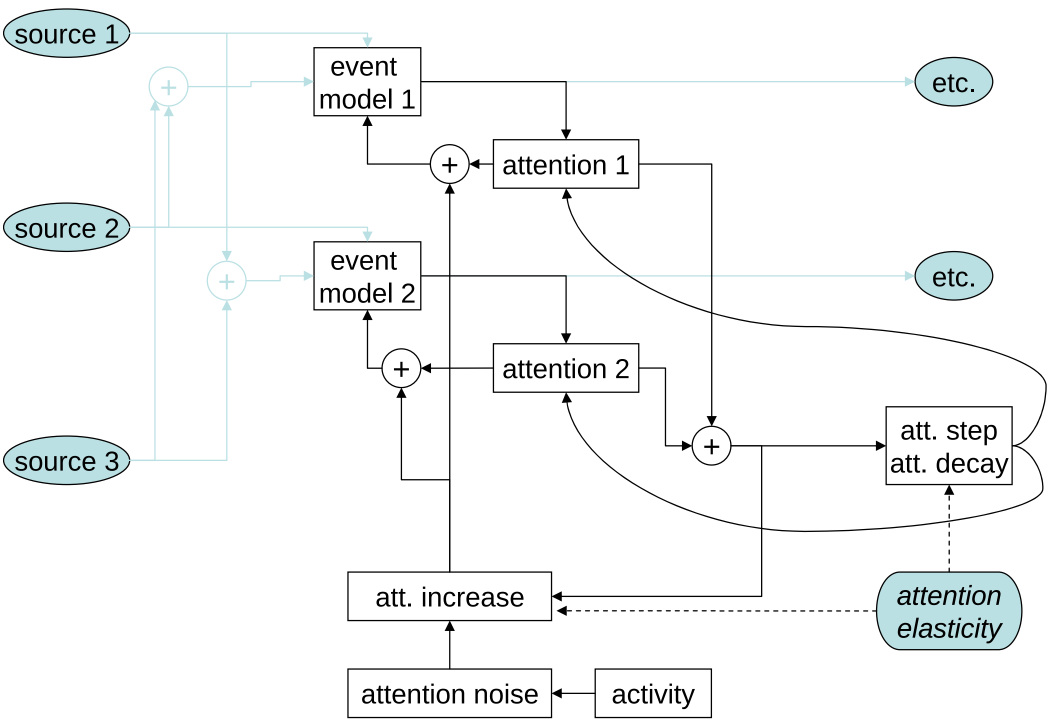

Figure 1: Detailed view on the attention sub-model of the notice event model.

2.3 Cognitive and emotional evaluation

Noticed sound events trigger cognitive and emotional evaluation. This evaluation is a multi-level process including several layers of abstraction (Figure 2). Intentions and context create a reference model (expectation) that is used to contrast the models triggered by the sensory observation against [11]. The result of this comparison evokes particular (aesthetic) emotions. Both the associations and more abstract models triggered by the notice-events and the reference model are very personal. Strong statistical variance between MI's can be expected. The impact of culture at this stage is nevertheless obvious. Indeed, it could be expected that associations are fine-tuned over time both through personal experience and reports of experience by peers. The latter can be thought of as part of culture.

Modeling soundscape evaluation – as opposed to pure perception – may be based on explicitly formulating knowledge about the culture and the personal factors it is based on. This is nevertheless a very difficult task. Including a learning phase may help. Learning based on past personal experience is extremely hard to simulate due to the very long time frame needed. The initial software implementation of the model therefore is based on learning from written material only.

Focused listening and fixation or denial will eventually feed back into the perception model, most likely in the attention sub-model. This has thus far not been implemented.

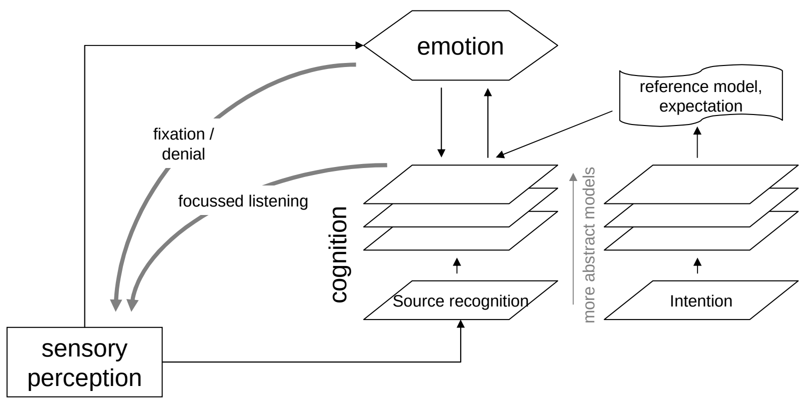

Figure 2: Outline of the perception and evaluation model.

3 NUMERICAL EXPERIMENT ON INTRODUCING NATURAL SOUND

In the numerical experiment the sonic environment includes four components: the sound from a highway at a distance d_{hw}, the sound of a local road at distance d_{rd}, the sound of trains at distance d_{rw}, and natural sound surrounding the listener (Figure 3). Propagation conditions between these sources and the MI consist of a flat terrain free of screening obstacles. More complicated propagation environments could be added [12] but do not give much more insight in the soundscape perception and slow down simulations considerable. The same could be said about adding additional roads. Also note that the model in its current form does not include binaural effect and thus the exact location of sources is not relevant. The sonic environment is varied by changing the number of vehicles on the roads and railroads, the distances to the different sources, and the level of natural sounds (Table 1). In all this resulted in 10 000 person-environment combinations being simulated.

The results shown in this written paper are preliminary in a sense that the parameters of the model have not been chosen in an optimal way and some interactions are neglected. In Figure 4 the time that road traffic noise is noticed during one hour is shown as a function of the average (L_{Aeq}) level of natural sounds. The presence of natural sound alters noticing road traffic noise (within the range of parameters considered and with current noise emission) only when its average level is above 40 dB(A) but the influence on road traffic noise perception is

Table 1:Range of distances and traffic intensities used in the numerical experiment

indicator	d_{hw}	d_{rd}	d_{rw}	$N_{hw,cars}$	$N_{hw,heavy}$	$N_{rd,cars}$	$N_{rd,heavy}$
average	430	79	293	1998	400	378	52
min	20	1	10	1500	300	50	5
max	2000	499	1499	2500	500	700	100

significant only when levels above 50 to 55 dB(A) are reached. Increased distance to the highway seems to increase the effect, but the trend is less than could be expected. Probably the absence of highway noise reduces adaptation to traffic noise and thus increases noticing traffic on other streets. Quite remarkable is the observation that for low natural noise levels, road traffic noise is noticed most of the time even if the highway is at 2 km and the nearest road is at 500m.

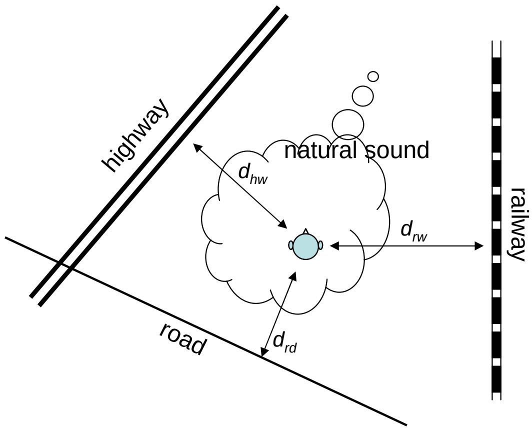

Figure 3:Theoretical layout of the sources surrounding the observer..

Figure 5 shows equivalent results for railway noise. Since the number of trains is much lower (between 1 and 5 trains an hour), the time that railway noise is noticed is generally less. The effect of natural sound level on noticing time is more gradual since it influences mainly the instance when the train is first noticed and the instance when the MI stops noticing it. Again, about 50 dB(A) of natural sound level is needed before the effect becomes significant. It may look quite remarkable at first that even with on average high levels of natural sound, trains are sometimes still noticed at large distances. This observation is explained by probability. Since natural sound levels fluctuate, there may be occasions where the natural noise level is very low exactly at the time a train passes at a distance of over one kilometer which would make it still noticeable.

4 CONCLUSIONS

A theoretical model for perception and evaluation of soundscapes was presented. The perception part of the model is implemented as software that allows studying a synthetic population of modeled individuals. It is illustrated how this type of simulation can help to gain insight into the complex mechanisms that lead to the appreciation of urban and rural soundscapes. In particular we presented in this paper the effect of adding higher levels of natural sound on the perception of road traffic and rail traffic noise.

Further improvements of the model will include the implementation of the cognitive and emotional evaluation part which should allow including the effect of personal preference and culture.

Additional simulations should allow distinguishing between different types of natural sounds. Indeed the simulations reported on in this paper model natural sound as rather monotonous, nearly white noise. This is a reasonable approximation for some types of water sounds and wind noise for certain species of vegetation and meteorological conditions, but it certainly fails to approximate the wide variety of animal vocalizations.

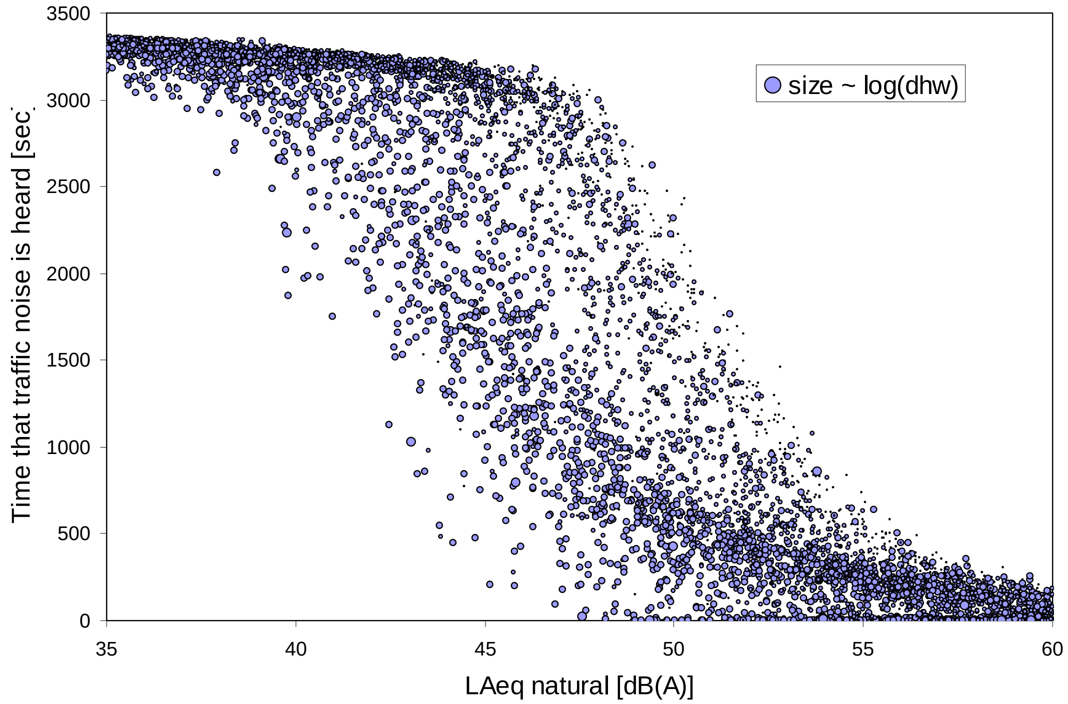

Figure 4:Time that road traffic noise is heard within one hour (size of dots indicates distance to highway)

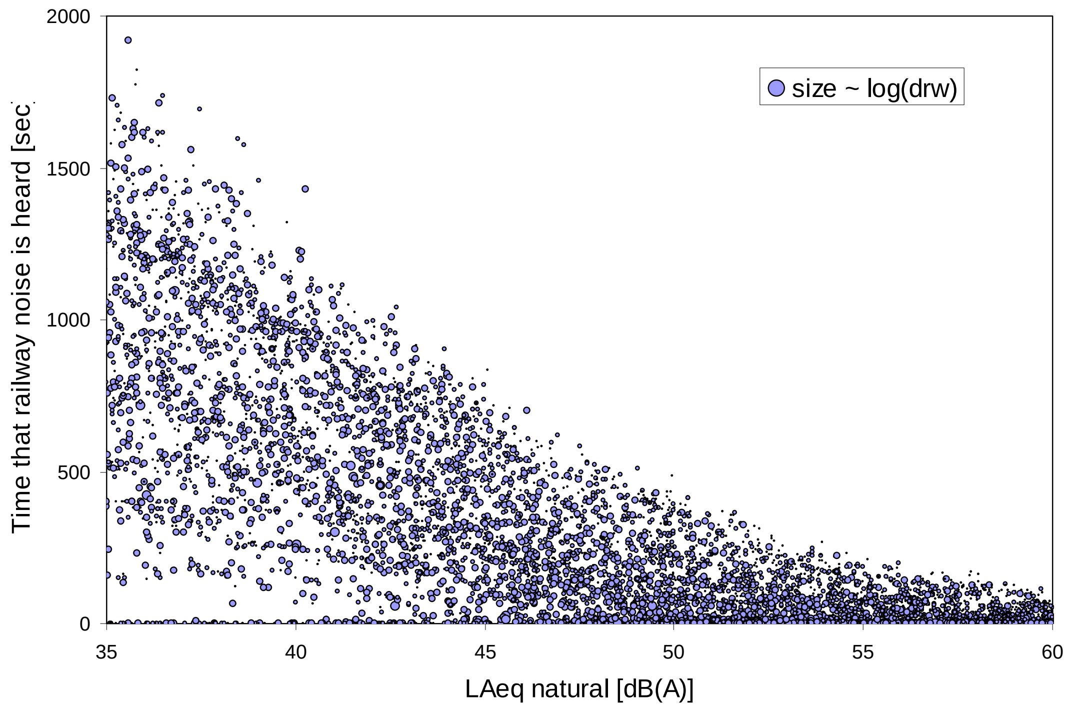

Figure 5:Time that rail traffic noise is heard within one hour (size of dots indicates distance to railway)

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