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Controlling temporal factors of aural stimuli for assessment of environmental noise effects on human being

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ABSTRACT

The perception and the human valuation of environmental noise do not only depend on the energy descriptors even if they are improved to take into account effects such as low frequency, tonality or impulsiveness effects. Both, the semantic content of the signals that compose the environmental noise and the interaction of these signals are related to the perceptual organization, grouping and selective attention in turn related to physiological (low level) and cognitive (high level) behaviors. An important factor, at both levels, is the temporal macrostructure of sound. Although effects of impulsive noises have been described and are used to improve energy measurements, the influence of temporal structures on perception is a current research topic. An instrument for controlling the time factors of the stimuli that allows the experimental design aimed for statistical analysis is addressed in this paper. The main block of the proposed instrument is an algorithm that combines sound events from a previously analyzed database by controlling the overall spectrum and the time structure of the output sound. The results are promising for statistical analysis because both the spectral and time factors can be set at different levels.

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1. INTRODUCTION

Effects of noise on the human being such as annoyance, sleep disturbance, and interference in the memory are currently related to factors such as energy, semantic content, tonality, spectrum and temporal envelope. The responses are directly related to these descriptors and also by means of psychoacoustic factors (i.e. loudness, sharpness, fluctuation strength, roughness). Current descriptors used in the legislation of many countries are based on energy, taking into account corrections for specific cases such as tonality, low frequency content and impulsiveness.
On the other hand, effects such as interference in the early memory have been related to the semantic content of the stimulus signal (e.g. irrelevant speech) and no significant $L_{A,eq}$ dependence has been found for two very distant levels [1].
Both, the semantic content of the signals that compose the environmental noise and the interaction of these signals are related to the perceptual organization, grouping and selective attention in turn related to physiological (low level) and cognitive (high level) behaviors [2].
Aural stimulus composed of the combination of sound events are promising for the assessment of the effects of noise in relation to real environments characteristics, in contrast with noise signals with a low degree of processing (i.e. a processing that is not enough to emulate a real sound) [2]. The control of the thus composed sound will allow setting each factor at different levels for using statistical techniques such as experimental design to assess their influence.
A former work describes techniques used to implement the control of the overall spectrum of the composed sound [3] and this article address the control of the temporal factors.

2. METHODS

The main algorithm is implemented in two main steps called semantic and temporal control (STC) and spectral content control (SCC) (see Figure 1).

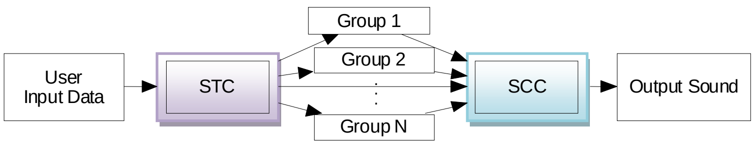

Figure 1. Block diagram of the composer algorithm

The *User Input Data* block holds the required characteristics of the output sound specifying: (I) the semantic content as a vector containing in each element the label of the group of semantically homogeneous sound sources to be included (for instance, speech, birds, traffic), (II) the time data as (II.1) the desired duration of the output signal, (II.2) a vector containing the average events occurrence per second (λ) for each group, (II.3) a vector containing the label of the probability density function (PDF) to be used for generating intervals between consecutive events per group, (II.4) a vector that contains different data per group depending on the chosen PDF (e.g. variance for Gaussian distributions) and (III) the spectrum as (III.1) a vector containing the desired band spectrum levels connected to (III.2) another vector of center frequencies of the bands and (III.3) an argument specifying the kind of bands (octave, third octave or critical bands).

Semantic content and temporal control (STC step)
Some preliminary results of the problem of database creation and semantic content control are reported here in order to introduce the requirements of the temporal control step. A pilot database of events was constructed using audio recordings available in public databases. Each sound event is categorized using the hierarchical structure summarized in Figure 2.

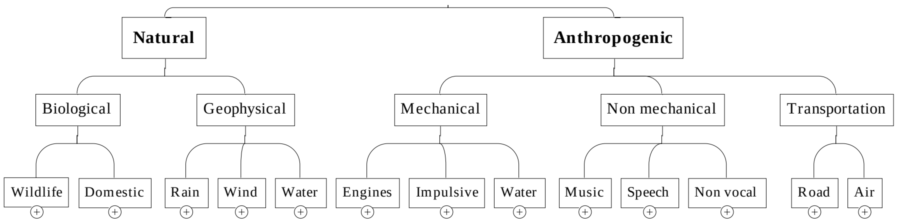

Figure 2. Hierarchical categorization structure (some categories were removed due to space limitations)

The database holds at least three audio files per event. The sound event labels are at the bottom level of the structure. Then the *User Input Data I* is easy specified choosing the events having the same category at an arbitrary level and all the levels above. Even more, the proportion of events from categories at the level just below the arbitrary level can be set (e.g. proportion of light and heavy road vehicles belonging to the same group).

The STC step generates a sound track for each group by placing a random chosen event *i* (from the group) after a random time interval t_i according to the specified PDF *f* (II.3) that has a cumulative density function (CDF) *F*. Assuming a uniform distributed variable *u* in the interval [0, 1], equation (1) can be obtained:

$$P\left[F^{-1}(u) < u_0\right] = F(u_0) \tag{1}$$

which proves that $F^{-1}(u)$ has the same CDF and the same PDF of the previously specified *f*. Then the variable *t* is estimated implementing F^{-1} over a variable *u* from a random number generator. This technique make possible using either theoretic or experimental PDFs.

A theoretical Poisson distribution was implemented because it may explain random intervals between independent events within a class. Actually some correlation does exist in real events and can be incorporated also using experimental PDFs. The correlation frequently is a consequence of the existence of a minimum time between consecutive events. Thus a modification of the Poisson PDF allows taking into account the minimum time distance t_s between events. The elements $t_i \mid (t_i < t_s)$ (i.e. elements lower than t_s) are replaced by $t_s \pm \delta_s$, been δ_s a random Gaussian variable with a little variance in comparison with t_s. It can be shown that a correction term *c* as given in equation (2) must be added to λ in order to maintain the events occurrence rate when using this modification.

$$c = t_s + \lambda^{-1}\left(e^{-\lambda t_s} - 1\right) \tag{2}$$

Spectral content control (SCC step)

The SCC step use the method described in [3] and the *User Input Data III* (see Figure 1). The output of this step is the controlled mix of the groups and is finally saved in a wave file.

3. RESULTS

Tests were carried out using only the modified Poisson distribution (II.3) for all events specifying $\delta_s = 0$ for all the semantic groups. Hereby an arbitrary composition is reported. The desired time of the output sound (II.1) was set to 25 s and the data of λ and t_s as shown in Table 1.

Table 1. Temporal user input data (I and II)

(I) Group	*birds*	*buses*	*cars*	*dogs*	*motorcycle*	*trucks*
(II.2) λ (Hz)	0.4	0.6	0.7	0.5	0.1	0.1
(II.4) t_s (s)	0.1	0.5	0.4	0.3	0.2	0.6

The envelopes of the STC output sounds was estimated as in [3] and are reported in Figure 3 for 3 of the 6 used groups. The overall spectrum of the final output is shown in Figure 4.

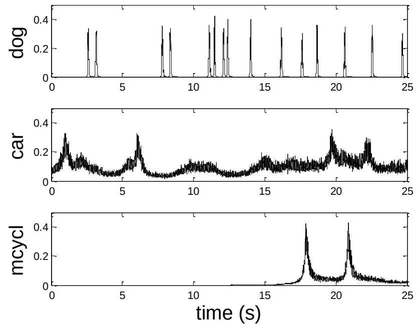

Figure 3. Temporal composition per group (relative amplitude units)

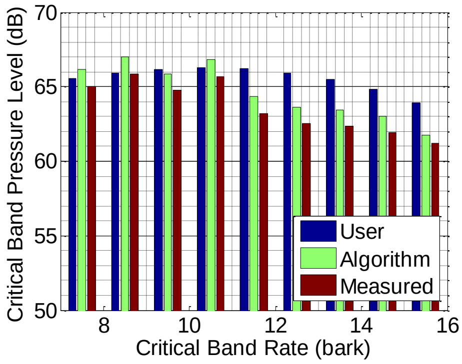

Figure 4. Spectrum of the output sound

The *User* bars in Figure 4 shows the *User Input Data III*, the *Algorithm* bars shows the estimation of the algorithm and the *Measured* bars shows the spectrum measured on the output sound. The differences between *User* and *Algorithm* (about 2 dB in the band of larger difference) depend on the possibility of the groups of achieving the solution and the differences between *Algorithm* and *Measured* (about 1 dB in the band of larger difference) appear because a little coherence between the sound events may exist (see [3]).

4. CONCLUSIONS

An instrument for the strategic generation of sound stimuli for the assessment of effects of noise in the human being in relation to the semantic, temporal and spectral contents has been developed. The strategy is consistent with experimental design techniques for statistical analysis. An improvement on the *User-Algorithm* differences is expected if the database grows in turn increasing the number of categories. Also the *Algorithm-Measured* differences can be improved taking into account the relative phase of the STC outputs.

Further update of this instrument will address the problem of experimental PDF (e.g. bimodal distributions will possibly explain the intervals between footsteps of a person walking). Before experiments to assess the similarity with reality, the localizations cues will be addressed.

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