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Environmental noise assessment:

Psychophysical background

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Abstract

In this paper, some aspects of the psychophysical background of environmental noise assessment are touched. Psychophysical methods useful for the measurement of environmental noise are mentioned. The simulation of the loudness perception for normal hearing and hearing impaired persons is illustrated. Moreover, the influence of the meaning of sound as well as of additional modalities on noise assessment is discussed.

1. Introduction

Psychophysics can contribute substantially to the assessment of environmental noise. The goal of psychoacoustics is to establish firm relations between the physical magnitudes of sounds and the correlated perceptual magnitudes. Since other modalities like visual or tactile senses can have an influence on noise evaluation, these days we can see a transition from psychoacoustics to multimodal psychophysics. Nevertheless, in order to tackle acoustic problems, still a solid background in psychoacoustics is of advantage. Therefore, this paper mainly deals with psychoacoustic aspects, and multimodal aspects are only briefly touched.

2. Methods

For the evaluation of noise emissions, the procedure of magnitude estimation has proven successful to tackle questions of environmental noise. On the other hand, in order to assess noise immissions, psychophysical procedures have to be used, by which a magnitude can be scaled as a function of time. The basics for such a procedure were laid down by Namba and Kuwano with the procedure of continuous judgement by category (Kuwano and Namba 1985). Usually a seven point category scale is used, and the task of the subject, while listening to a noise immission, is to indicate the instantaneous loudness of a sound by choosing the appropriate category from extremely soft (1) to extremely loud (7). The advantage of the method of continuous judgement by category is that it enables an evaluation of sounds as a function of time. On the other hand, the resolution of only seven categories sometimes may be too coarse. Therefore, the method of line length was developed (Namba et al. 1988, Fastl et al. 1989), where the subjects varies the length of the line, displayed on a monitor, corresponding to the actually perceived loudness. Variants of these procedures were proposed by Weber (1992) and Hellbrück et al (1997).

A pertinent feature of results obtained by these methods is that the overall loudness is larger than the average of the instantaneous loudnesses (Kuwano and Namba 1985, Fastl 1991). This means that loud events have a definite influence on the overall judgement. The well proven discrepancy between the average of instantaneous loudness and overall loudness suggests that memory effects are involved.

In an engineering approach, these effects are modelled by an exponential decay. The corresponding reasoning is illustrated in figure 1. The length BL of a line on a monitor is given by the dotted curve for a noise immission of 15 minutes duration. All data are normalised relative to the maximum length of the line. For eight passby sounds, the line length (dotted) reaches values above 60 % whereas the background noise is in the order of only 10 %. To simulate in a rough first engineering approach memory effects, from each peak starts an exponential decay with a time constant of 5 minutes. The average value of this modified function is indicated by the horizontal dashed line. The subjective evaluation of overall loudness is given by the small arrow at the right ordinate. As can be seen, the average of the modified line length (dashed) is close to the subjectively evaluated overall loudness (arrow).

Similar calculations were done for a multitude of scenarios, and always the average of the modified line length was rather close to the psychoacoustically measured overall loudness (e.g. Fastl 1997). This means that for an engineering approach, the rather simple assessment of memory effects by an exponential decay may be useful.

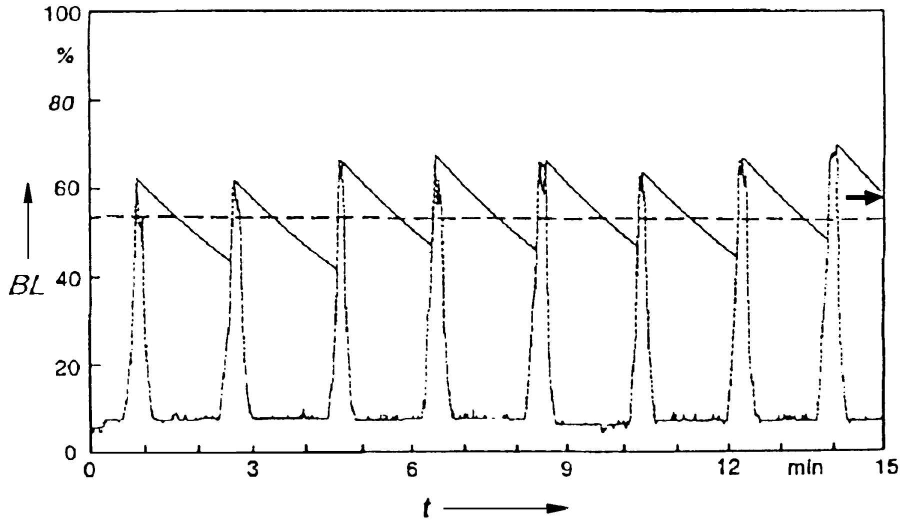

Figure 1: Loudness evaluation for a noise immission of 15 minutes duration. The perceived instantaneous loudness is tracked by the subjects by the length of a line displayed on a monitor. Eight passby sounds are clearly visible (dotted) over a background pedestal. The exponential decays from the peaks hint to memory effects. The overall loudness predicted from the instantaneous loudness (dashed horizontal line) is close to the psychoacoustically measured overall loudness (arrow at right ordinate).

In summary, we believe that the discrepancy between the average of instantaneous loudness ratings versus overall loudness rating of noise immissions is due to memory effects. If the coarse engineering approach by an exponential decay is further refined by psychoacoustic knowledge on memory, the accuracy of predictions of overall loudness from instantaneous loudness scalings could even improve.

3. Simulations

Since simulations of hearing sensations in psychoacoustic models have been described in detail in the literature (e.g. Zwicker and Fastl 1999), in this paper only a new loudness model should be briefly mentioned. This model has the advantage that it can account for the loudness perception of normal hearing as well as hearing impaired subjects (Chalupper and Fastl 2002).

In figure 2, the block diagram of the Dynamic Loudness Model (DLM) is sketched. The model has many features of the classic loudness model by Zwicker for stationary sounds like the spectral analysis by critical band wide filters, upward spread of masking, and spectral summation. Also temporal features of later implementations (see e.g. Zwicker and Fastl 1999) like the effects of post-masking (forward masking) and temporal integration are included.

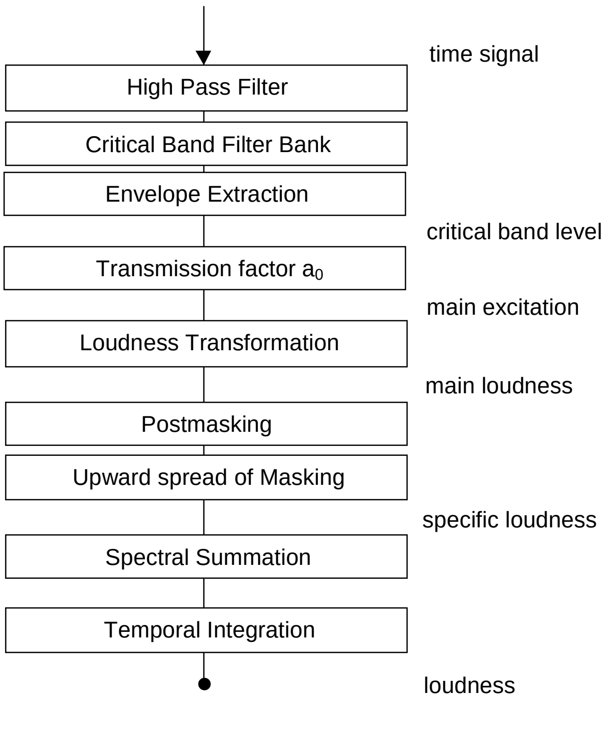

Figure 2: Block diagram of the Dynamic Loudness Model (DLM) proposed by Chalupper and Fastl 2002.

The important new feature of the DLM can be characterized as follows: just by modifying the transformation from level into specific loudness, the model can account for the loudness perception of normal hearing and hearing impaired subjects. This single modification “automatically” accounts for the differences in spectral and temporal resolution between normal hearing and hearing impaired subjects! Therefore it is not necessary to simulate the shallower spectral and temporal masking patterns of hearing impaired subjects separately.

The possibility to simulate with the same type of model loudness perception by normal hearing and hearing impaired subjects with different degrees of hearing deficits is of relevance in many highly industrialized countries with an ageing population.

4. Meaning of sound

In the assessment of environmental noise, the meaning of a sound may play a relevant part. In addition, when comparing the results of international studies, also the cultural background of the subjects may be of importance. For example, cross cultural studies with subjects from Japan and Germany (Kuwano et al. 1997) showed that sometimes one and the same sound can be rated differently: the sound of a bell was interpreted by German subjects as sound of a church bell leading to connotations of ”pleasant” or “not dangerous”. On the contrary, Japanese subjects were reminded by the bell sounds to sounds of a fire engine or a railroad crossing leading to feelings of “dangerous” or “unpleasant”.

While in the scientific community there is agreement about possible influences of the meaning of a sound on its rating in environmental noise assessment, the magnitude of such influences compared to e.g. variations in sound pressure level is not yet clear.

In order to be able to realize sounds for this type of experiments, a procedure was proposed, which allows to largely remove the meaning from a sound (Fastl 2001), i.e. to “neutralize” its meaning. In essence, the procedure contains the following steps: the sound signal is analyzed by FTT and - after spectral broadening - resynthesized by IFTT. This processing is illustrated in figure 3.

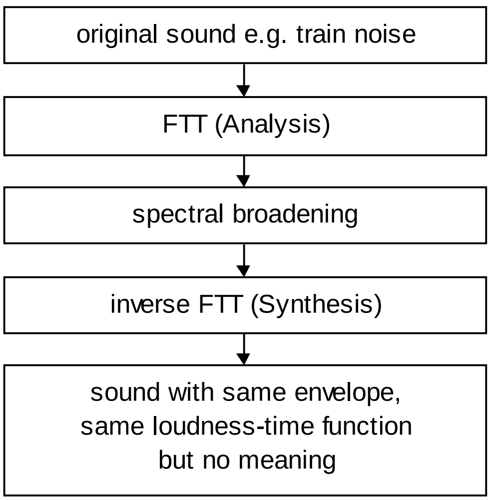

Figure 3: Block diagram illustrating the procedure to neutralize the meaning of sound.

With the procedure mentioned, many signals can be deprived of their meaning. However, some signals like for example “neutralized” speech - although it sounds pretty awkward - still can be recognized as human speech.

When applying the procedure outlined in figure 3, the loudness-time function is kept in such detail that it is not easy to distinguish original sound and “neutralized” sound. An example is given in figure 4, where the upper trace represents the loudness-time function of original sounds and the lower trace the loudness-time functions of the corresponding “neutralized” sounds.

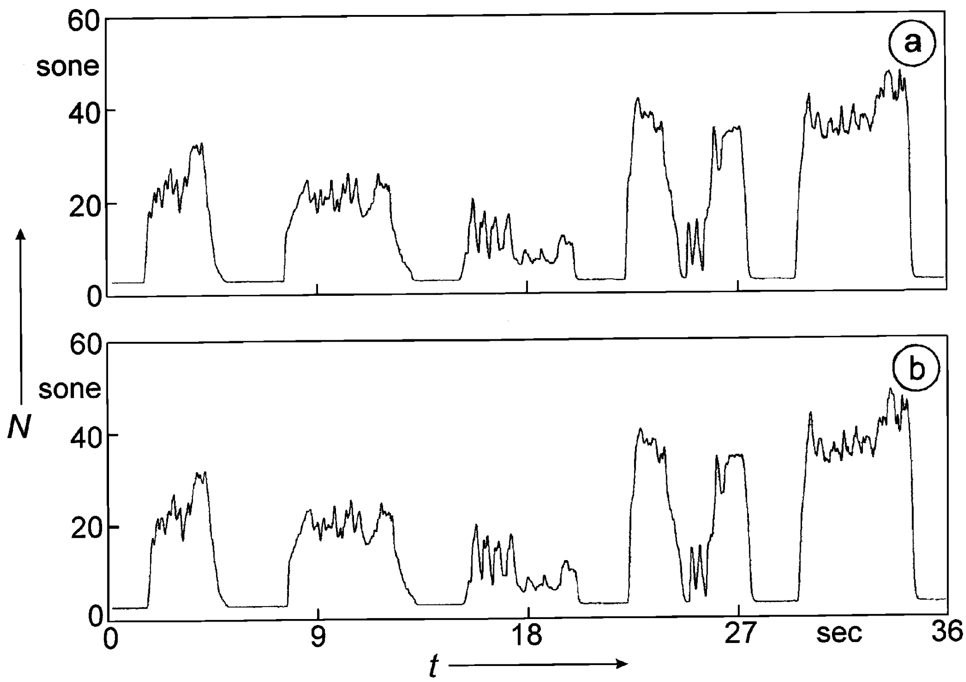

Figure 4: Loudness-time function of original sounds (upper panel) and of corresponding „neutralized“ sounds (lower panel).

It should be mentioned that - because of the spectral broadening – original sounds and “neutralized” sounds differ somewhat in temporal structure and hence in fluctuation strength and roughness (Fastl 2002).

5. Combined modalities

The assessment of environmental noise may depend not solely on acoustic features, but additional inputs from other modalities, like e.g. visual input may play an important part. For example, Suzuki et al.(2000), presented evidence that the sound of white noise, when combined with the image of a waterfall, significantly increases its pleasantness. Despite identical acoustic stimuli, the rating of acoustic magnitudes can be modified by additional visual inputs.

Another example from Suzuki et al.(2000) shows that when the sound of a product is accompanied by a corresponding visual image, the loudness rating frequently decreases.

Hashimoto and Hatano (2001) compared the rating of sounds with and without visual image. In many cases, the addition of the visual image to the acoustic signal was equivalent to a decrease of the original soundpressure level by as much as 10 dB.

Patsouras et al. (2002) showed that the color of the image of a railway car - despite identical acoustical stimulus - can influence loudness rating.

Strong effects of combined modalities were also reported for the interaction of acoustic and tactile input (e.g. Quehl et al. 2000).

6. Conclusion

Results from psychoacoustic experiments can form a solid basis for the assessment of environmental noise. For the evaluation of noise immissions, memory effects seem to play an important part. When simulating results of psychophysical experiments by algorithms, it seems useful - regarding the demographic factor in most industrialised countries - to simulate not only the hearing ability of young persons, but to take also into account hearing deficits of elder persons. When looking for engineering solutions of noise problems, effects of the meaning of sound as well as multimodal components should be taken into account.

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