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Prediction of Psychoacoustic Parameters

Klaus Genuit
HEAD acoustics GmbH
Ebertstrasse 30a
52134 Herzogenrath
Germany
klaus.genuit@head-acoustics.de

André Fiebig
HEAD acoustics GmbH
Ebertstrasse 30a
52134 Herzogenrath
Germany

ABSTRACT

Noise is defined as an audible sound which either disturbs the silence or an intentional sound listening or leads to annoyance. Thus, it is clearly defined that an assignment of noise can not be reduced to simple determining objective parameters like the A-weighted SPL. The question whether a sound is judged as noise can only be made after the transformation from the sound event into an hearing event has been accomplished. The evaluation of noise depends on the physical characteristics of the sound event, on the psychoacoustical features of the human ear as well as on the psychological aspects of men. The subjectively felt noise quality does not only depend on the A-weighted sound pressure level, but also on other psychoacoustical parameters such as loudness, roughness, sharpness, etc. The known methods for the prediction of the spatial A-weighted SPL distribution in dependence on the propagation are not suitable to predict psychoacoustic parameters in an adequate way. Especially the roughness provoked by modulation or the sharpness generated by an accumulation of high frequent sound energy cannot offhanded be predicted distance-dependent.

1. INTRODUCTION

Our daily life experience may suggest that perception is simple and automatic, but it isn't. We are so familiar with the act of perceiving that the complexity of the process emerges only when we deliberately turn our perceptual talents back on themselves to observe what is going on as we see, hear, smell, taste and touch the world. Perception of the everyday world is an exceedingly complicated phenomenon¹. Particularly, sound is omnipresent in the perceptual world. Thus, this sensory dimension influences greatly the quality of life, since apart from the omnipresence of sound the human ear cannot be easily switched off in order to avoid acoustic input. Although sound can be analyzed and measured in physical terms and numbers, the complete analysis of sound depends on the psychoacoustic attributes of human hearing. For example, an assignment of noise can only be retraced with the help of a multidimensional approach, which takes into consideration the physical aspects of the sound, the frequency composition, psychoacoustic parameters (loudness, sharpness, roughness, fluctuation strength) as well as the attitude of the listener, the informative character of the sound, and the cultural background. Noisiness and annoyance are more (than energy of sound) sensitive to subjectivity, thus the social and cultural backgrounds have important influence on the subjective attitudes of people to the noise². This means that the evaluation of noise depends on the physical characteristics of the sound event, on the psycho-acoustical features of the human ear as well as on the psychological and social aspects of human being.

The idea of noise-mapping is an approach to predict noise contribution at different places and to ascertain the standard of accommodation with regard to the environmental noise situation. But, up to now only noise-mapping based on A-weighted sound pressure level is available, which does not consider the multidimensionality of perception and evaluation mentioned above. But, it is almost common knowledge that the assignment of noise cannot be reduced to simple determining objective parameters, such as the A-weighted sound pressure level or the equivalent continuous sound pressure level offhand³. In fact, it depends on the spectrum's structure and the pattern in time domain. Thus, changes of the short time spectrum with respect to the frequency and time domain have an influence on the classification of sound. Therefore, the application of psychoacoustics in the context of noise-mapping is inevitable. But, noise-mapping with respect to psychoacoustic parameters is unknown and undeveloped so far.

2. ENVIRONMENTAL SOUND AND NOISE MAPPING

Typically, environmental noise situations result from a number of spatially distributed sound sources, and those situations consist of complex superposition of natural and technical sounds caused by different sources. But, the subjective evaluation of sound is context dependent and influenced by the attitude and expectation of the listener. This means that the prediction of the sound quality in a complex situation arising from the superposition of a number of diverse sound sources is very complicated unless the signal processing involved in human hearing is taken into account^{4, 5}.

All in all, sound could be modified by adding or removing of sound sources. It could be observed that two sound sources, which are causing both a high degree of annoyance, the superposition of the two sound sources again results in a situation of high annoyance. However, the total of perceived annoyance depends on the location of the two sound sources relative to the listener. On the other hand, it is possible for an existing sound source of high annoyance to be masked by a second sound source of preferred sound quality⁶. For example, the subjective perceived impulsiveness of individual sound sources can be reduced by adding noise of a comfortable sound quality⁷. Therefore, the following questions with respect to the prediction of the evaluation of sound and the noise-mapping have to be answered: which sound source of the superposition is responsible for the annoyance, which signal attributes like modulation or specific patterns in the time and frequency domain are creating annoyance, and what kind of attitude and expectation has the listener?

Comprising, beside the distribution of the A-weighted SPL the engineer needs a mapping with psychoacoustic parameters to predict adequately the sound quality or the annoyance at different places. While it is possible to precisely predict A-weighted sound pressure related to the distance from the noise, such methods of calculation are not applicable for psychoacoustic parameters such as loudness, and particularly sharpness, roughness, and fluctuation strength⁸. These psychoacoustic parameters are non linear and the influence of distance is not simple predictable.

3. THE SUPERPOSITION OF SOUNDS

In order to comprehend the complex interactions and connections between the human sensation and psychoacoustic parameters, the following experiments should exemplify how the perception with respect to the known psychoacoustic parameters is generally working. For that purpose, two sounds are superposed. In the first experiment two sounds are added; the first sound is white noise with 80 dB(A) and the second sound is 1000 Hz narrow noise band with the same A-weighted level. Then, the following questions inevitable arise: What happens with respect to A-weighted level, loudness, sharpness and roughness by adding these two sounds?

The sum of the A-weighted level constitutes a level of 83,5 dB(A) SPL, when the two described sounds are added. In contrast to the 40% increased A-weighted level, the sum of the loudness is only 12% higher. This means that the same level results in a different loudness. Particularly, it can be remarked that the comparable A-weighted levels of the white noise and of the 1000 Hz narrow band noise result in two complete different loudness values, because of the different spectrum. Moreover, the sum of the sharpness is lower than the sharpness of the white noise. Finally, the sum of roughness is much lesser than the roughness of the narrow band noise. (Figure 1)

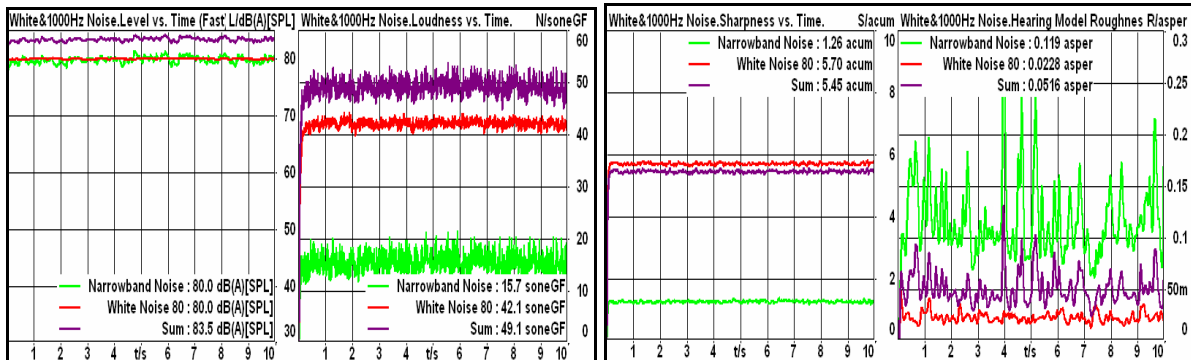


Figure 1: The superposition of white noise and 1000 Hz narrow band noise; the A-weighted level vs. time, loudness vs. time, sharpness vs. time, and roughness vs. time .

Different consequences can be found, if two tonal sounds are added. Generally, the resulting loudness depends on the spectral distance of the two tones. Partly, masking effects, which can influence the loudness, have to be considered. Moreover, the resulting sharpness depends on the spectral contribution and the resulting roughness depends on the spectral distance of the used tones. The next experiment contains the superposition of two tones, which are close to each other; 1000 Hz and 1070 Hz and both with 80 dB(A) SPL. There is an excitation of the same critical band. It can be stated that the characteristics of the A-weighted level and the loudness are not comparable. Although in both cases an increased value could be observed, the loudness increases only 3,0 sone, because of the small difference in frequency of the stimuli (simultaneous masking). The sharpness is nearly unchanged. The value of the sharpness is almost constant in all cases. The curve progression of the roughness points out an extreme increase. (Figure 2)

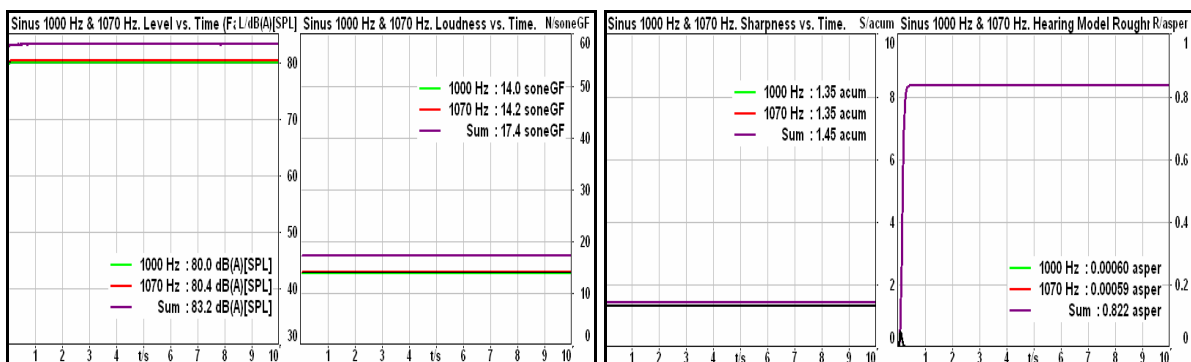


Figure 2: The superposition of two tones with 1000 Hz and 1070 Hz; A-weighted level vs. time, loudness vs. time, sharpness vs. time, and roughness vs. time.

Another experiment is the superposition of two tones, which are not close to each other and excite different critical bands. There, tones with 1000 Hz and 1400 Hz are superposed. The linear

sound pressure level of both tones constitutes 80 dB(A) SPL. The following changes with respect to the psychoacoustic parameters could be detected. The characteristics of the A-weighted level and the loudness can be compared. The A-weighted level increased of 40%, the sum of the loudness is 50% higher. Contrary to these parameters, the sharpness decrease after the superposition of the two tones and the roughness is nearly nonexistent. (Figure 3)

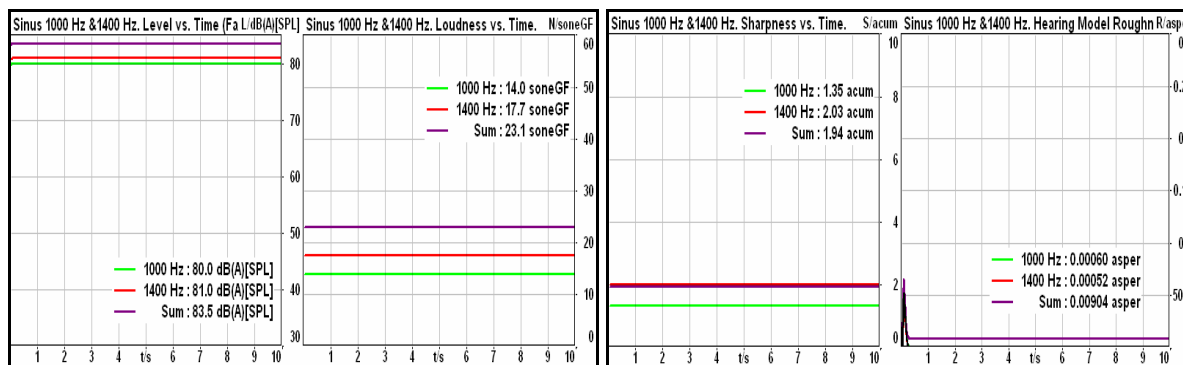


Figure 3: Figure 2: The superposition of two tones with 1000 Hz and 1400 Hz; A-weighted level vs. time, loudness vs. time, sharpness vs. time, and roughness vs. time.

The experiments above mentioned have clearly shown that the characteristics of psychoacoustic parameters depend on the nature of the different sounds, which contribute to the overall sound.

4. DEPENDENCY OF DISTANCE

The principle of the A-weighted level dependency of distance in the free field is known; doubling the distance to a point-source yields half the level. The characteristic of the loudness in dependency of the distance depends on the level because of the frequency weighting, which is necessary to determine the loudness. The sharpness shows only minor changes as the relationship between power of higher frequencies to the total loudness is nearby constant. The roughness displays only minor changes as the modulation frequency and the degree of the modulation are constant.

The first experiment shows white noise and the changes of the psychoacoustic parameters, when the A-weighted SPL decrease 6 dB(A). In contrast to the A-weighted level, the decrease of the loudness is not similar. It can be stated that the reduction of the loudness depends on the level. Therefore the decrease of the loudness, when the A-weighted level declines from 80 dB(A) to 74 dB(A), should decrease half the initial value. But the value decline only 13 sone from the initial value of 42,1 sone. This means that the value of the loudness does not halve as the A-weighted level. The same phenomenon can be observed in the decrease of the loudness, when the A-weighted level decreases from 74 dB(A) to 68 dB(A) or decline from 68 dB(A) to 64 dB(A).

In contrast to the characteristic of the loudness it can be ascertained that the roughness does not changed in a simple way. The variation of the roughness value with the change of the A-weighted level of the white noise is nearly constant. The characteristic of the sharpness shows only minor changes. All in all, the reduction of the level leads not to a comparable reduction of the sharpness. (Figure 4)

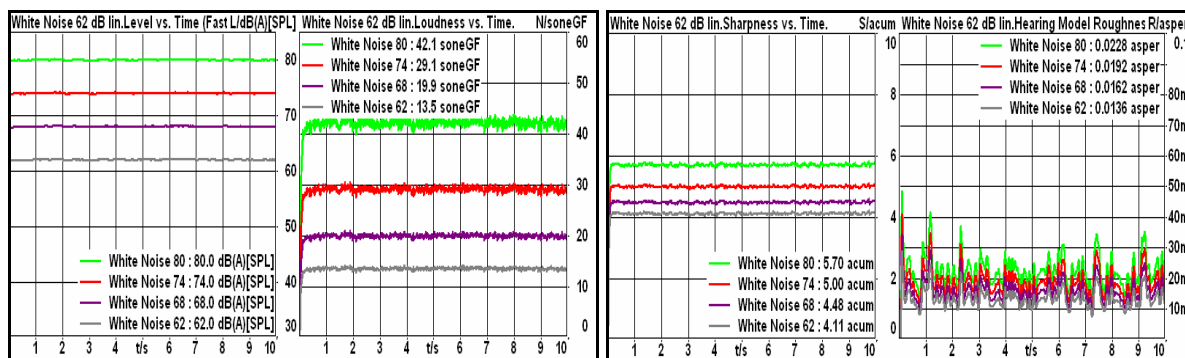


Figure 4: White noise with 80dB(A), 74 dB(A), 68 dB(A), and 62 dB(A); A-weighted level vs. time, loudness vs. time, sharpness vs. time, and roughness vs. time.

The next experiment examines the behavior of psychoacoustic parameters in context of real and complex sounds. Therefore, a vehicle at a constant speed of 30 mph was recorded and measured at different distances (7m, 25m, 50m, and 100m). The characteristics of the A-weighted level and the loudness can be compared. According to the rule of distance, the value of A-weighted level approximately halves as distance doubles. But, as noted above the loudness depends on the level of noise, and therefore the similarities are only valid for small level differences. In contrast to these parameters, the sharpness shows another characteristic. The sharpness differs greatly only in the near field; at a greater distance the effect is nearly not observable. The sharpness of a pass by vehicle in great distance is almost constant and the differences observable for 25m, 50m, and 100m positions are virtually zero. The variation of the roughness curve with the change of distance is nearly constant. The roughness only decreases very slowly with distance. (Figure 5)

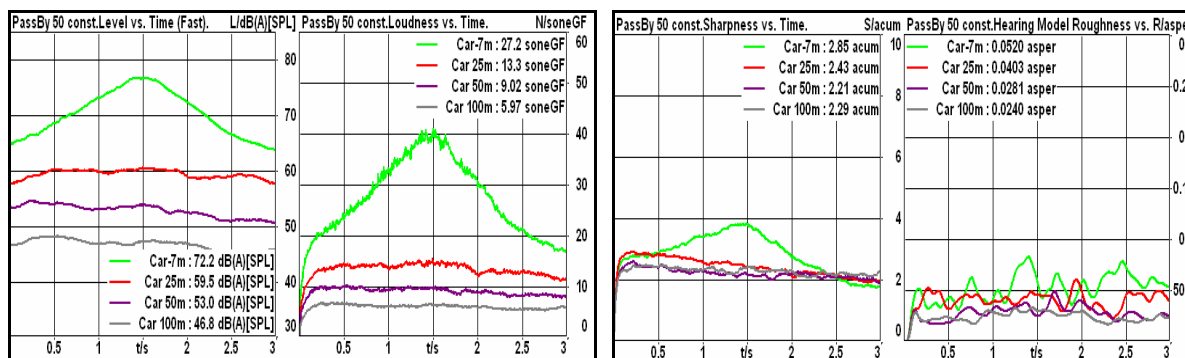


Figure 5: A pass by of a vehicle at a speed of 50km/h, measured at a distance of 7m, 25m, 50m, 100m; A-weighted level vs. time, loudness vs. time, sharpness vs. time, and roughness vs. time.

The presented experiments make clear that the simple measurement of the A-weighted level does not take into account the character of the sound, which can be determined with psychoacoustic parameters, and therefore, the A-weighted level cannot sufficiently describe the human process of perception and evaluation. The A-weighting allows no differences regarding frequency, and all time structures are eliminated through the integration in the time domain. Particularly, the known methods for the prediction of the spatial A-weighted SPL distribution in dependence on the propagation are not suitable to predict adequately psychoacoustic parameters⁹. Furthermore, the experiments have clearly shown that the connections between the sound and the psychoacoustic parameters are mainly dependent on the character of the sound. Therefore, the sound source and its characteristic sound have to be scrutinized in order to collect valid data for noise-mapping.

5. CONCLUSIONS

Altogether, in contrast to the level, the psychoacoustic characteristics of a sound source regarding roughness and sharpness are relatively independent from the distance. The different relations, which are used to determine the sharpness and roughness, do not change due to the level and thus, are not due to the distance of a sound source. This means that the human ear can adapt to the change of the level and on the other hand is able to detect the same pattern in the time domain and in the spectrum's structure, although the level decreases with the distance. Therefore, the reduction of the sound pressure level in case of a greater distance to the source does not mean that a reduction of the annoyance can be automatically expected. Different psychoacoustic phenomena can force identical evaluations in spite of a perceivable decrease of the loudness. Thus, noise mapping merely based on the A-weighted level does not represent the factual perceptions and evaluations of exposed subjects.

New measurement categories could be introduced, like the *Relative Approach*¹⁰. The calculation method of the *Relative Approach* takes the human hearing abilities into account, since human hearing is particularly sensitive to time changes in acoustic signals, or spectral structures which contain characteristic peaks and troughs. There, the difference between the estimated value and the current value is determined. This consideration represents the signal change, which is a relevant parameter with respect to noise annoyance. Further calculation parameters, which for example were introduced in this paper, have to be additionally integrated into the noise maps.

Altogether, the presented experiments have shown that a complex consideration of the psychoacoustic aspects of sound is necessary in order to comprehend the impact of sound on the human ear and its perception. The A-weighted level and the loudness are not sufficient in describing sounds.

Comprising, a multidimensional approach is necessary, which detects adequately the relevant psychoacoustic parameters and allows the description of environmental noise situations. Nevertheless, the analysis should not be taken the sound out of context and reduced to unquestioned singular numbers, because when a soundscape is reduced to the sum of its pieces, it is easy to lose sight of the complexity of the puzzle¹¹.

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