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PARAMETERS INFLUENCING NOISE ESTIMATION

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Abstract. *Noise estimation is one of the main issues regarding user products development. However, as the unique correlation between physical parameters and corresponding sound perception does not exist, the psychoacustic methods for relation determination are very delicate and sensitive and still not completely defined. This paper, by taking into account available data, shows some noise parameters that can be of significant relevance regarding noise estimation. Parameters like sharpness, roughness, pleasantness and fluctuation strength, which have been used more often recently for elementary psychoacoustic sound quality signal analysis estimation are described first. Paper also indicates their profound influence on humans and shows semantic differential technique for connotative and denotative meanings of the set of natural sound properties.*

Key Words: *Noise, Loudness, Pitch, Timbre, Sharpness, Roughness, Fluctuation Strength, Pleasantness*

1. INTRODUCTION

Sudden production processes and traffic developments have led to a significant increase of sound energy in everyday human life environment. Noise is becoming a very important factor regarding various professional diseases disturbing the comfort of both working and living conditions, causing productivity decrease and many other unpleasant things.

In the past several decades there has been an ongoing multidisciplinary research whose goal is to decrease the noise level. Big efforts are especially made to define quantities and procedures of their determination in order to establish apropriate subjective impression correlation with a purpose of predicting the sound quality and finding apropriate procedures for protection.

However, an important difference can be found between objectively determined noise characteristics and subjectively estimated values of the same noise. Namely, using objective

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based noise analysis and optimization methods and standards is common nowadays. A human, however, estimates noise on the basis of what he hears and thus different sound treatment can lead to different estimates of the same noise. Therefore, the knowledge of psychoacustic quantities is necessary; this is something, unfortunetaly, not developed enough. Nor is it related sufficiently enough to the respective objective quantities.

It is common knowledge that the sound has three basic physical characteristics: intensity, frequency and amplitude spectrum. Regarding perceptive domain these characteristics have correlating psychoacoustic quantities of people' sense of hearing, loudness, pitch and timbre. Since we can directly measure these quantities the psychoacoustic are more susceptible to various changes [1-3].

Namely, it is not enough to characterize noise just along the scale between loud and silent, the way it is usually done. One can describe sound as powerful, metal, pleasant, or to judge it as smooth or rough, sharp or not, variable or constant, describing it with various more or less disturbant properties. Also, it should be mentioned that hearing sense receives information at real time, and thus the temporal distribution of sound energy has significant effect on hearing [2-4]. It has been established that many other factors also influence noise estimation. For example, a significant factor regarding noise estimation of a car is the appearance of it, seat vibration, landscape seen from the car etc. [5].

Noise is usually estimated on the basis of L_{Aeq} i.e. using the "A" characteristic of sound measurment equipment, which represents the effort to include psychoacoustics characteristics of hearing sense in estimation. There is relatively good accordance between the equal loudness contures and this characteristic on low levels. However, on higher levels, differences occur regarding lower frequencies, which cause different estimation of the sound with distinctive low frequency components. Taking into account some of the other numerous psychoacoustic quantities, apart from the familiar noise level or loudness is the necessary reason for detalied noise description.

Unfortunately, appropriate correlation between human experience and defined physical characteristics is still not determined and thus only technical measurements can give objective and reusable measurements. However, nowadays basic psychoacoustic quantities such as loudness, sharpness and roughness can be calculated using analysis signal software (digital signal processing) [2]. As sound quality contains more than these basic attributes, additional assessments are needed to get the whole sound quality picture. Also, since sound perception depends on experience and emotional factors, additional research is needed. This paper therefore defines some of these sound properties, like sharpness, fluctuation strength, roughness, pleasantness, etc. Their influence on man is indicated and semantic differential technique is presented for exploring connotative and denotative meanings of the properties of a set of natural sounds.

2. PSYCHOACOUSTIC SOUND SENSATIONS

The well known psychoacoustic sound properties are loudness, pitch and timbre, and it is necessary to describe additional, and nowadays more often used, quantities which describe sound quality in the way the human senses it.

The basic property of the sound timbre reception is **sharpness**. It mostly depends on central frequency of the narrowband noise. According to the definition narrowband noise on 1 kHz, 60 dB level has sharpness of 1 acum (from "acer", latin for sharp). Sharpness increases with factor of 20 at the change of frequency from low to high, and we can observe significant increase at high frequencies. For wideband noise sharpness depends on frontier frequencies, especially influenced by the upper one, Figure 1 [2].

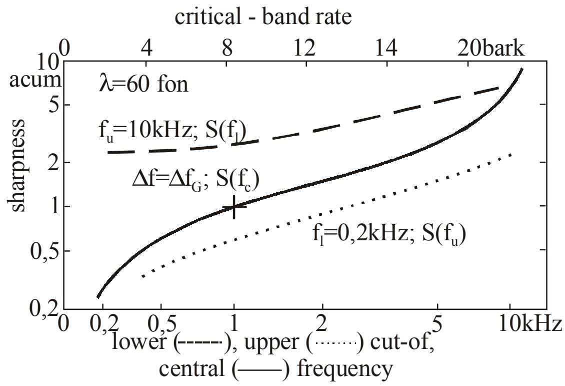

Fig. 1. Sharpness of different sounds;
narrow band noise (solid), highpass noise (dashed), lowpass noise (dotted) [2]

On the basis of this noise effect knowledge one can conclude that the sharpness of some sound can be lowered either by decrease of high or addition of low components. However, regarding other possibilities we must take into account that the overall loudness of the sound will increase. This solution can be used as compromise regarding design of noisy products.

It was experimentally determined that L_{Aeq} has good correlation with impression of the power of noise when it has wide frequency bandwidth. However, when sound contains only high frequency components it provokes sharp and a metallic impression. In this case, the metallic impression can be estimated by calculating sharpness [3].

Subjective sound sharpness impression depends also on its duration. It has been established that the shorter duration of sound the sharper the sound estimates. For example, temporal changes of calculated sound sharpness are different when you hit a golf ball with various rods. High correlation exists between subjective impression, during every repeated hit, and temporal change of sound sharpness, which indicates that temporal change has significant effects on subjective impression. One of the interesting facts is that time interval between short sounds also has significant influence on hearing estimating those kinds of signals [3].

Sharpness estimation model was proposed by Bismarck in 1974. Later, in the year of 1984, Aures proposed a new model which contained combination of sound timbre and loudness effects. In the year of 1990, Zwicker and Fast announced a method based on spectral weighted first momentum of the specific loudness pattern which is used in many laboratories today.

Sensation of **roughness** occurs in the case of modulated sound with frequencies higher than 20 Hz. Reference roughness sound is a tone of 1 kHz and 60 dB level which is amplitude modulated by 70 Hz frequency with degree of modulation $m = 1$. Roughness of this reference sound is 1 asper (from "vox aspera" – latin for rough voice). It is experimentally established that roughness increases proportionally to the second power of the degree of modulation and that the increase of roughness is relatively small with increase of the noise level. For example, for the 40 dB level difference factor 3 increase of roughness occurs.

Roughness is of importance mainly for sound quality improvement. Thus for example, motor of the sport car must have sound with certain roughness, while this roughness can demage the sound quality inside the luxury car.

A psychoacoustic roughness model was first announced by Fastl in the year of 1977, on the basis of psychoacoustic measured temporally variable masking patterns. Recently, an algorithm based on the specific loudness samples was introduced analyzing temporal changes in each of the channel of specific loudness [2].

In the case of temporal noise **fluctuation strength** two different senses should be considered. For low frequencies all power changes are very clearly observed as loudness changes. However, for high frequencies, loudness practically achieves stationary values so any change of strength causes sound roughness sensation.

Frequency tone of 1 KHz and 60 dB level, which is amplitude modulated by frequency of 4 Hz with degree of modulation $m = 1$ represents reference sound for fluctuation strength of 1 vacil (from "vacilare" - latin for verb *to change*).

This sound fluctuation strength sensation could have special and important meaning for alarm signals, which must be loud, sharp, with various tones and variable. It is experimentally established that if the sound level temporally and sistematicaly changes one has an impression that the loudest is the sound with the biggest primordial loudness level.

The fluctuation strength model was first proposed by Fastl in the year of 1982, and was later inovated by Zwicker and Fastl and is still in use nowadays. A recent proposal was published by Widmann (1992).

Pleasantness factor is, however, connected with knowledge and cultural factors as well as with psychic sound properties. It is hard to predict sound pleasantness knowing only his physical properties. However, in limited situations, physical properties showing good correlation with subjective impression could be found [3].

3. PSYCHOACOUSTIC DISTURBANCE

In order to model estimates on the basis of hearing noise parameters, combination of different hearing sensations was adopted and psychoacoustic disturbance was defined [2]. Application of this disturbance model gave good results regarding sound quality and noise control problems. This disturbance PA [au] was derived based on the knowledge of sound loudness N [son], sharpness S [acum], fluctuation strength F [vacil] and roughness R [asper], and can be presented as:

$$PA = N_5\left(1+\sqrt{a_S^2 + a_{FR}^2}\right). \tag{4}$$

where member a_S includes sharpnes contribution that depends on loudness, i.e.

$$a_S = 0{,}25(S - 175)\log(N_5 + 10) \text{ for } S > 1.75\text{acum}\ , \tag{5}$$

and member a_{FR} represents fluctuation strength and roughness contribution,

$$a_{FR} = \frac{2.18}{(N_5)^{0,4}}(0{,}4F + 0{,}6R). \quad (6)$$

If there is no additional contribution of other hearing senses, then psychoacoustic disturbance is determined only by loudness quantity. The fact that the estimate of temporally dependent sounds can be well simulated by measurement of percentage values is reason that the N_5 was taken for psychoacoustic disturbance calculation. Percentage sound loudness value N_5 means, for example, that the given sound loudness value was achieved or surpassed for 5% of the measured time. Loudness, in general, has dominant role in psychoacoustic disturbance estimation, because all other quantities have significantly lower estimation impact. This model does not include tone components because they are very critical regarding the sound quality and thus it is easier not to take them into consideration than discuss algorithms for their calculation.

Inner niose of a car estimation can be presented as an example of this sound quality measurement application. Reduction of noise inside car was achieved by improving the door closing system.The results of the noise estimate show that the noise reduction in total loudness was 20%. However, it changed sound timbre, i.e. roughness was decreased by 27%, which in turn decreased psychoacoustic disturbance by 33%.

By examining the passing car sounds, a dependence of the percentile loudness N_5 can be easily derived:

$$N_5/\text{sone} \approx 11 + 0{,}29 \cdot v/\text{km/h}$$

This simple function can be used for the moving traffic noise emission assessment gained speed limit. 27% percentile loudness N_5 reduction is achieved by reducing the driving speed from 150km/h to 100km/h. [2].

4. SEMANTIC TECHNIQUES

Already developed semantic differential techniques for emotional meaning identification have been extended to a large variety of different concepts including sound properties as well [5]. Thus this technique is used for connotative and denotative meaning research of the set of natural sounds. Denotative scales refer to acoustic or psychoacoustic sound properties like, i.e. loudness. Connotative scales are intended for emotional meaning measurement which is contained in the sound on the scale such as calming – exciting. Denotative scales have shown relatively high correlation with psychoacoustic properties like loudness, sharpness and roughness. In given example these scales are unified and applied to the set of everyday noise patterns like, for example: musical instruments sounds, home appliances, natural environment, tools etc. Semantic differential contains large number of opposite sound properties pairs, which constitute the poles on the bipolar scales, and estimation was done in 7 values [4].

Audience estimated in sound which was reproduced over headphones and each sound was repeated until the whole scale was filled in. Results of the compared test and retest characteristics are shown in Figure 2.

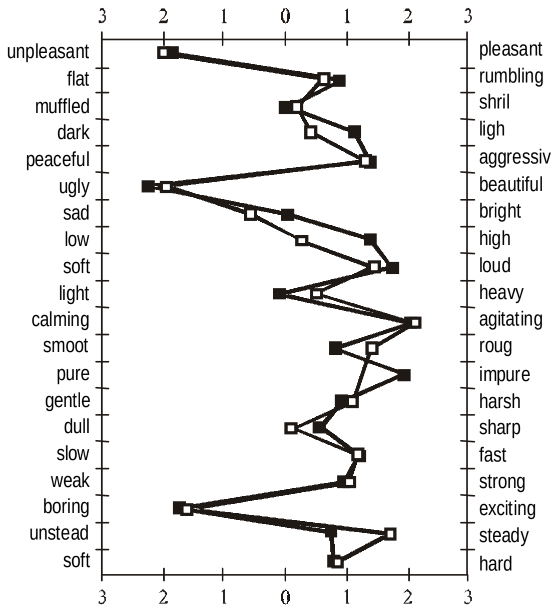

Fig. 2. "Hair dryer" estimated sound quality test and retest mean values [4]

Queried test and retest reliability indicates relatively good precision of this technique. Consideration of these scales revealed 4 factors covering 70% of total variance and can be interpreted regarding "evaluation", "timbre", "power", and "temporal change". Thus we have:

- factor "evaluation": ugly-beautiful, pleasant-unpleasant, calming-agitating, boring-exciting, gentle-harsh, pure-impure, soft-hard.
- factor "timbre": dark-light, low-high, muffled-shrill, light-heavy.
- factor "power": weak-strong, soft-loud, flat-rumbling
- factor "temporal change": steady-unsteady, smooth-rough.

These bipolar scales with only 7 levels give much better correlation for loudness then the 10 level where loudness can be described as low, middle and high…

5. Influence of other factors

Sound quality estimate is under influence of other factors besides sound. For example, car noise estimate is under influence of car appearance, seat and floor vibration, quality of cars interior equipment, landscape seen from the car etc.

Visual image effect decreases negative sound quality impression where the effect can be even 10 dB. Seat and floor vibration enhances unpleasantness while landscape environment decreases it [5].

Cars with diesel engine, unlike the cars with gasoline engine, show typical sound property caled "dieselness". There is a proven hypothesis that this characteristic sound is significant for car sound quality estimate and that it is in correlation with psychoacoustic properties.

Comparing estimated noise quantities for gas engines with diesel car noise quantities we have come to conclusion that gas engine produces 65% of loudness, 50% sharpness, 60% roughness, 30% fluctuation strength and only 10% of dieselness related to lowest noise estimate of the car with diesel engine[6].

6. RESULT ANALYSIS AND CONCLUSION

Subjective sound estimate according to different hearing sensations could be hard and painful. The object of this paper was an attempt to summarize some hearing sense based parameters that can be applied to sound quality design and noise control and which are available in present literature.

Possibilities of using different methods for computer supported sound quality estimate of elementary psychoacoustic properties, like loudness, sharpness, roughness, etc. This analysis can be very useful for designing technological processes, especially for the initial stages of design project. Procedures based on audience impression are suitable for realization of significant and cost efective noise control because we can now fight just components that affect user audience.

However, as sound perception depends also on knowledge and emotional factors, additional research are needed to get the whole sound quality picture. Denotative techniques have shown high correlation with given psychoacoustic quantities.

In past decade hearing sense based models have been used and they have proven to be very succsesful in the sound quality and noise control. However, better and faster progress in procedure standardization for quantities calculation is needed to ensure necessary compatibility demanded by generalized application of these quantities.

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PARAMETRI KOJI UTIČU NA VREDNOVANJE BUKE

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Vrednovanje buke je jedno od glavnih pitanja u okviru razvoja korisničkih proizvoda. Kako ne postoji jednoznačna korespondendencija izmedju fizičkih parametara i percepcije odgovarajućeg zvuka, to su psihoakustičke metode odredjivanja ovih relacija vrlo komplikovane i osetljive, tako da još uvek nisu u potpunosti definisane. U ovom radu su na osnovu podataka u dostupnoj literaturi prikazani neki od brojnih parametara buke koji mogu bitno da utiču pri njenom vrednovanju. Najpre su opisani parametri koji se sve češće koriste pri analizi signala za procenu elementarnih psihoakustičkih osobina zvuka, kao što su oštrina, fluktuacija snage, hrapavost, prijatnost i dr. Ukazano je i na njihov uticaj na čoveka. Pokazana je i semantička diferencijalna tehnika za istraživanje konotativnih i denotativnih značenja osobina prirodnih zvukova.

Ključne reči: *buka, jačina, visina, boja zvuka. oštrina, hrapavost, fluktuacija snage, prijatnost*