APPLICATION OF THE SOTTEK HEARING MODEL FOR ENVIRONMENTAL NOISE ASSESSMENT

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1 INTRODUCTION

Sound quality metrics are often used to analyze complex sound scenarios, e.g., for soundscape applications. Sound quality can also affect the health and well-being of people in a particular environment. Therefore, it is of the utmost importance that the definition of good sound quality in a given context is as precise as possible. In this regard, psychoacoustic indicators are usually used to develop these metrics.

In recent years the Sottek Hearing Model has been developed, which explains and describes many psychoacoustic effects and parameters[1]. **SHM** Loudness (based on the **S**ottek **H**earing **M**odel, standardized in ECMA-418-2)[2] is a new approach to time-varying loudness based on a nonlinear combination of partial tonal loudness and noise loudness (as part of SHM Tonality[3]). This new method better accounts for the fact that the loudness of tonal components, i.e., tonal loudness, can have a stronger influence on the perception of loudness than the loudness caused by the other components, i.e., noise loudness[4]. A brief introduction to psychoacoustic modulation analyses will also be presented: SHM Roughness[5] for evaluating fast modulated sounds and SHM Fluctuation Strength[6], an adapted model for slow modulated sounds (planned to be standardized later this year).

These psychoacoustic parameters are important in the development of sound quality metrics for ambient noise applications. Analyses of complex combinations, such as soundscape applications, often rely on a linear combination of maximum, average, or percentile values of psychoacoustic parameters. But they do not consider the importance of individual events for perception in terms of duration, amplitude and frequency. Single tonal events of a certain duration can have a strong influence on perceived quality, even with low mean tonality values and percentiles[7].

2 SOTTEK HEARING MODEL

The psychoacoustic parameters of the ECMA-418-2 standard are based on the Sottek Hearing Model, whose calculation steps for determining tonality and tonal loudness are shown in Figure 1. The basic idea is to separate the tonal and noise components of sounds using an autocorrelation function and weight them by basis loudness (Figure 1, (3) and (4)). This model considers many aspects of auditory perception[1], such as outer and middle ear filtering, auditory filter bank, half-wave rectification and compression nonlinearity of the human auditory system (Figure 1, (1) and (2)). Tonal loudness and noise loudness (Figure 1, (5)) were added in the most recent edition of the standard[2] and are particularly well suited to handle subcritical bandwidth signals[4].

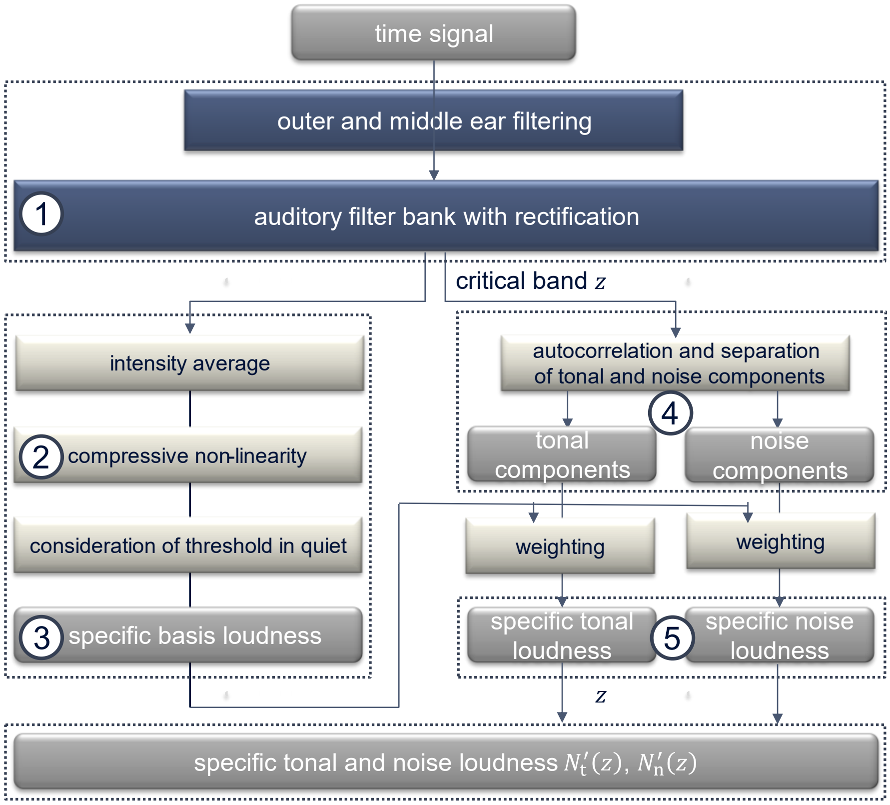

Figure 1: Structure of the Sottek Hearing Model.

2.1 Equal-loudness-level contours

The recent discussion of the alterations to ISO 226:2023[8] from the 2003 version highlighted the primary motivations behind these modifications[9]. Using the new equal-loudness-level contours, we evaluated the efficiency of the three loudness standards ECMA-418-2, ISO 532-1[10] and ISO 532-3[11] in reproducing these curves.

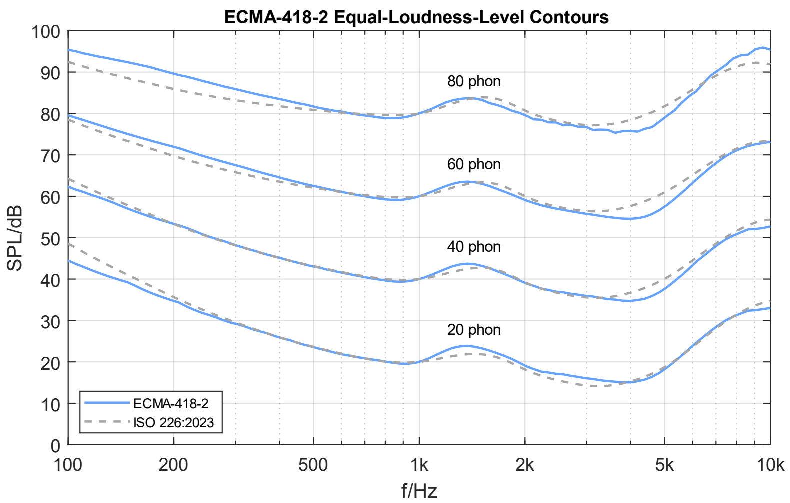

Figure 2: Reproduced equal-loudness-level contours according to the ECMA-418-2 standard compared to ISO 226:2023.

Our results show that the Sottek Hearing Model published in ECMA-418-2, second edition, provides the best performance with a very small RMS error of 1.57 dB, followed by ISO 532-3 with an error of 3.04 dB and ISO 532-1 with an error of 5.55 dB.

2.2 Loudness of sounds with subcritical bandwidth

Several previously published experimental studies show a positive level difference between a subcritical bandwidth noise and a tone perceived as equally loud. The standardized loudness models in ISO 532-1 and ISO 532-3 underestimate the loudness of pure tones.

Based on the concept of tonal loudness, the Sottek Hearing Model (standardized in ECMA-418-2) can overcome these problems by a nonlinear combination of partial tonal loudness and noise loudness.

Figure 3 shows an example of these studies. The loudness of a band-pass filtered (with infinite slope) Gaussian noise centered around 1.5 kHz was matched to a sine wave with a frequency of 1.5 kHz and L = 50 dB SPL. The level of the noise was adjusted in an adaptive two-interval, two-alternative forced-choice procedure, and the total number of subjects was 10. The results of the Sottek Hearing Model are in very good agreement with the listening test and are significantly better than results of the algorithms standardized in ISO 532-1 and ISO 532-3.

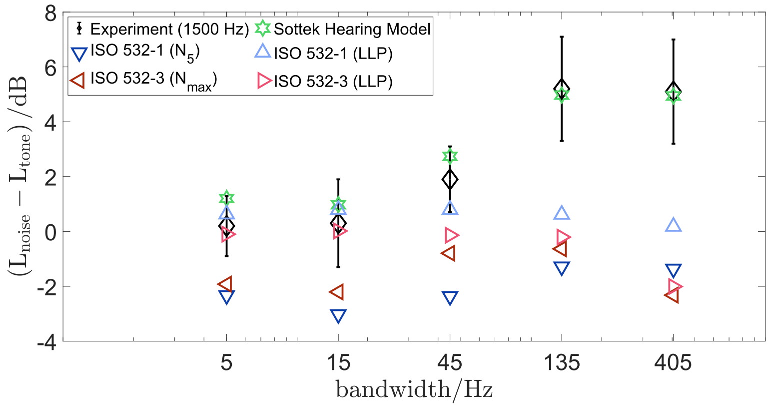

Figure 3: Data of loudness-matching experiment compared to results of standardized loudness models.

Currently, the SHM Loudness defined in ECMA 418-2 has shown equivalent or superior performance in all experiments we have conducted[4,12] and has emerged as the dominant variant in terms of the quality of results.

2.3 Tonality of signals with *multiple* prominent tonal components

However, the SHM Tonality method needs to be modified to account for the influence of signals with multiple prominent tonal components, as it was not designed for this type of signal[12]. A solution is being developed to improve the SHM Tonality method, which would give practically the same single value of tonal loudness for pure tones.

3 PSYCHOACOUSTIC ANALYSES OF MODULATION

Rough and fluctuating sounds are very noticeably perceived and increase annoyance in many environments (but may also be desired in others). They are relevant in various fields (automotive, computer, room acoustics, ...), especially for sound design. The goals of algorithms for calculating roughness and fluctuation strength are:

1) to model the perception of all types of rough and fluctuating sounds (AM/FM, modulated noise, ...) and all dependencies of the perception of roughness and fluctuation strength (volume, frequency, modulation rate, degree of modulation, modulation shape),
2) focus on applicability to technical sounds,
3) to avoid incorrect estimates of non-rough and non-fluctuating sounds (unmodulated noise, sinusoids).

The algorithm for SHM Roughness (standardized in ECMA-418-2) can also be used as the basis for the SHM Fluctuation Strength algorithm, with slight modifications:

1) improvement of frequency estimation for low modulation rates, using **HSA** (**H**igh-Resolution **S**pectral **A**nalysis)[13] patented in 1990,
2) adaptation of spectral weighting of bandpass envelopes[6]**.** Data from the literature on the main dependencies of the perceived roughness and fluctuation strength of AM and FM signals have been examined and modeled very well. The models can adequately predict these parameters for technical sounds as well[5,6].

4 ANALYSIS OF HEAT PUMP SOUNDS

The sound quality of 28 heat pumps was analyzed by psychoacoustic methods. All signals were at the same level, 55 dB(A). The recordings are from Feldmann's doctoral thesis[14]. As examples of the significantly different characteristics, the values of SHM Roughness, Sharpness according to DIN 45692[15] and SHM Impulsiveness[16], based on the 1993 version of the Sottek Hearing Model[1] are shown versus SHM Tonality in Figures 4, 5 and 6.

It can be observed that heat pumps 15 and 17 exhibit nearly identical values of SHM Tonality. However, the SHM Roughness of heat pump 15 is markedly higher, resulting in a greater propensity for disturbances.

All these parameters are ideal for developing metrics. Details of the analyses will be published soon.

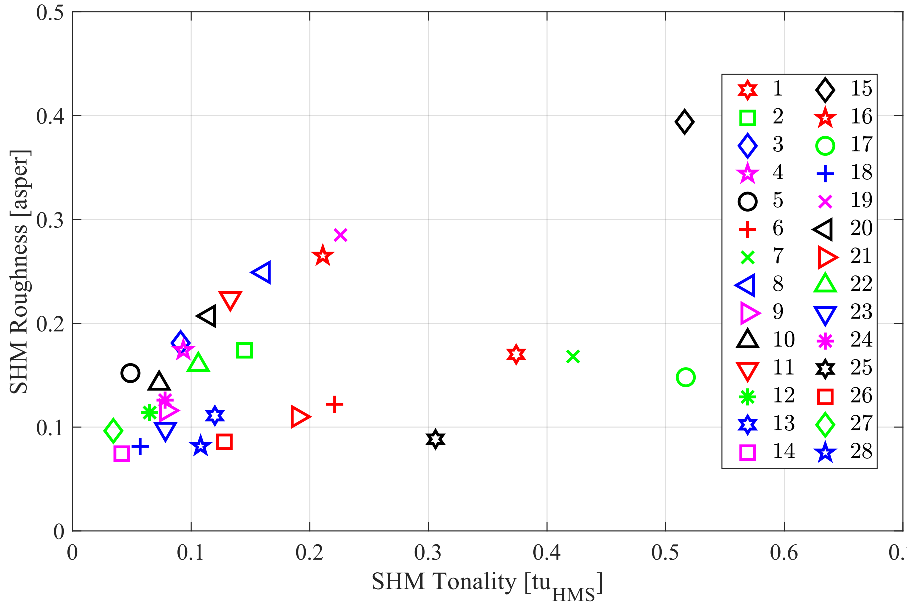

Figure 4: Calculated values of SHM Roughness versus SHM Tonality
for the sounds of 28 heat pumps.

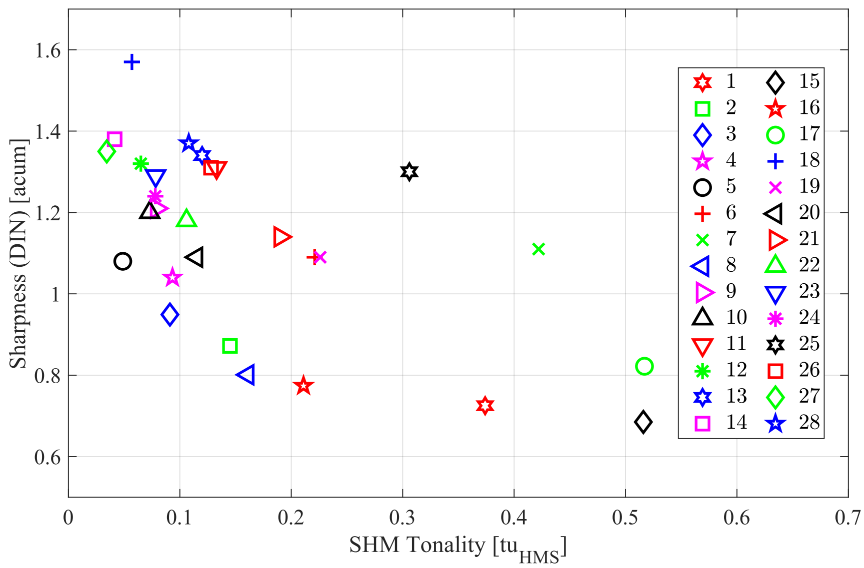

Figure 5: Calculated values of Sharpness according to DIN 45692 versus SHM Tonality
for the sounds of 28 heat pumps.

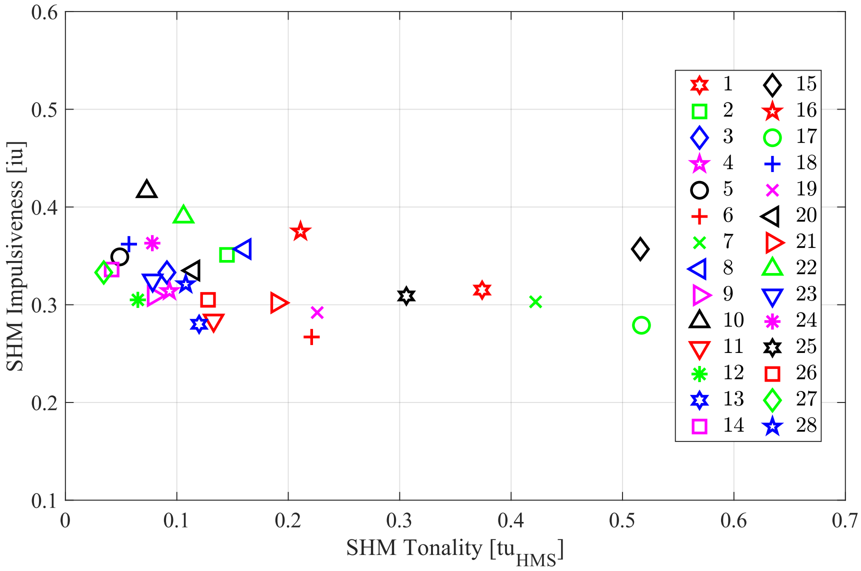

Figure 6: Calculated values of SHM Impulsiveness versus SHM Tonality for the sounds of 28 heat pumps.

5 MEANING OF PSYCHOACOUSTIC VALUES BASED ON THE SOTTEK HEARING MODEL

Figure 7 shows the meaning of the psychoacoustic values based on the Sottek Hearing Model. All parameters have been developed in such a way that, for example, a value of “1” for tonality, roughness and fluctuation strength means strong perception and a value of “0.1” means that the sensation is barely noticeable. As a next step, it is intended to develop an improved calculation of sharpness and impulsiveness, based on the Sottek Hearing Model, whose values allow similar interpretations on a linear scale of perception.

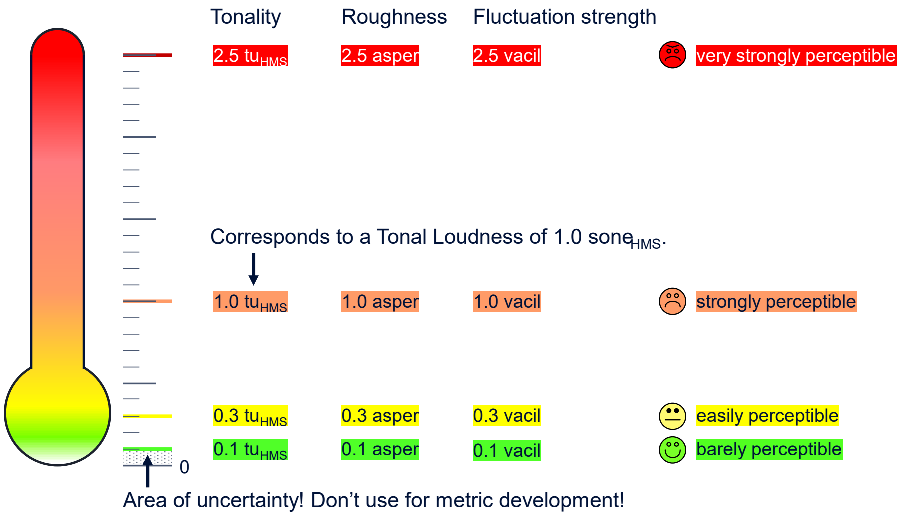

Figure 7: Meaning of psychoacoustic values based on the Sottek Hearing Model.

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