IMPACT SOUND QUALITY OF CONSUMER PRODUCTS
EVALUATION BY SOUND QUALITY-METRICS AND
WAVELET TIME-FREQUENCY ANALYSIS

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ABSTRACT

The sound quality of impacts generated in consumer products is part of the attributes that communicate the total product quality to the customers. Known examples are door closing sounds for cars and sound and tactile quality of knobs, levers and other controls for handling the product. The sound quality aspect is not necessarily received consciously.

Sound quality metrics for impacts are not yet standardized and are probably hard to generalize for any type of sound and product. This paper gives some examples of practical sound quality (SQ) development of typical impact sounds. It also discusses the "sensitivity" of some standard SQ-metrics developed for continuous sounds like loudness, sharpness etc. to the sound quality of short impacts.

The pragmatic use of wavelet time-frequency analysis for SQ-evaluation and development is discussed and demonstrated together with some audio illustrations. A combined use of wavelet analysis and simple time history analysis is shown to be quite useful for comparing and designing specific impact sounds for similar products.
1 INTRODUCTION

The total product quality is consciously or subconsciously judged by the customer e.g. before a purchase decision and the price a customer is willing to pay is a complicated result of the perceived product quality, experience, the brand image and the economic means of the customer. It is therefore often hard to estimate for product developers what the customer value of an increased sound quality is and how much cost can be accepted due to any specific SQ improvement. Cross-brand comparisons, jury testing and objective data are needed.

The objective evaluation of sound quality for continuous sounds is rather well known and will not be discussed here. Objective analysis and judgement of sound quality for impulsive (short transients) sounds are however less researched, but yet important as these sounds are especially frequent during product comparisons on the shop-floor. Most consumer products are not available for “test driving” like cars, and often the shop-floor impression is the only one that finally has to decide what to purchase.

2 PRODUCT SOUND QUALITY IN PERSPECTIVE

Let us put sound quality in its larger context. The broader concept of total product quality is illustrated in figure 1.

![Figure 1. Sound Quality attribute as part of the total product quality. The parts where sound quality appears are marked with an ellipse.](image-url)

The functional quality (e.g. how long it performs well without malfunctioning and repair) may not be affected at all by product SQ, which is mainly one part of the perceived quality, both at purchase and during ownership. The sound quality is part of the impression at the shop-floor, comparing products side-by-side. Opinions from friends, family and testing in mass-media may also influence the buying decision. Good SQ is of course also of importance during the use of the product and increases brand loyalty when the product is replaced.
3 Objective Evaluation of Sound Quality

3.1 Objective analysis of continuous product sounds

A number of measurable single-figure quantities exist for continuous sounds that correlate more or less well with subjective, perceived sound quality. The main advantage of objective metrics is that they can be used by simulation models for design comparisons and to validate product changes by measurements. The problem with using simple objective quantities is that they do not always correlate sufficiently with subjective perception. In addition, far from all aspects of the quality of sounds are measurable.

We can divide quality attributes of sound into classes, an example is the following:

1) loudness related (L_A, Stevens’ or Zwicker’s loudness)
2) sound character related (Sharpness, Roughness, Pitch etc)
3) time character related (e.g. how often)
4) pleasing aspects and
5) information content

Loudness is generally much better correlated with perceived loudness (“How loud?”) of continuous sound than L_A and is obtained with e.g. the Zwicker’s method.

It is more complicated to measure the sound character although some established metrics exist. Some of these are more general (sharpness, fluctuation strength and pitch) while some have been developed for specific noises (e.g. roughness).

So far no good objective methods exist to describe how the pleasing a sound is or if it has better or worse information content. Probably there will be no generic metrics since this depends very much on the context (product, customer type and expectations etc).

3.2 Objective analysis of impulsive product sounds

While there are many objective quantities for evaluation of sound character of continuous sounds, few exist for short transient events. University research activities are also rather recent. The transient sound evaluation is harder and also even less generic, and a temporal dimension of prime importance is added. Most established single-figure metrics are found to be much over-simplified when attempted to be applied to impulsive sounds. For example, how do we define an unambiguous “loudness” metric for a short transient? Shall it take the peak amplitude or the energy of the impulse into account or a suitable mix of those? Is there any relevance of a sharpness or pitch metric and how shall it then be defined? What about roughness, etc?

We have found that the sound quality of impulses involve much more than can be described by a few simple single-figure metrics. Especially when focussed on engineering changes for improvement, and more detailed benchmarking, objective evaluation has to be more detailed to be meaningful. The sound events need to be evaluated simultaneously in the time and frequency domain with sufficient resolution. Time-frequency wavelet analysis in conjunction with simple time history analysis has been effective from the engineering perspective.


### 4 WAVELET ANALYSIS, A SHORT INTRODUCTION

Wavelet transforms provide more optimal resolution in both time and frequency domain for rapidly changing signals, e.g. short transients. The theoretical background is covered elsewhere [1]-[4]. Many commercial analysis systems also support wavelet analysis with slightly different implementation [5]-[7], and MATLAB toolboxes are also available.

Fourier transforms effectively decompose a time signal into a set (finite or infinite) of orthogonal sinusoidal basis functions that represent the frequency content of the signal. The main drawback is that the transformation into the frequency domain has no time information.

One way of providing time information is to apply the Short Time Fourier Transform (STFT) where the signal is chopped into short sections that are windowed and Fourier transformed separately. Due to the Heisenberg uncertainty principle, the frequency resolution will be determined by

\[ \Delta f \approx \frac{1}{T} \]  

where \( T \) is the time-window used for the FFT. For sufficient frequency resolution, one has to use long time windows resulting in low resolution in the time domain or vice versa.

Wavelet transforms use a set of short time-limited basis functions created from a “mother” wavelet that is scaled and repositioned in time. We then obtain a time-frequency transformation with varying time and frequency resolution. A basis function may look like Figure 2b compared to the continuous sine wave (Figure 2a) used by Fourier transforms.

![Figure 2. a and b) Comparison between the basis functions used by Fourier transforms and Wavelet transforms. Observe that many different “mother” wavelet functions exist with different properties. c) The resolution is good for sampling in the time domain as well as the frequency resolution in the frequency domain (via Fourier transforms). The STFT provides relatively low resolution in time and frequency as a compromise. Wavelet analysis provides a varying resolution with better time resolution for higher frequencies. It is analogue with a filter bank with constant relative bandwidth compared to the FFT filter bank with constant absolute bandwidth.](image)

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5 EXAMPLES OF PRODUCT SOUND ANALYSIS USING WAVELETS

5.1 Car door opening and closure, a classic sound quality example

The most well known impulse sound quality example is probably the car door opening and closure sounds. We select to use this example to illustrate the use of wavelets for the analysis and use three existing cars used by people in our company. Data for products under development are classified and can not be published. Figure 3 shows the three cars and there respective objective analysis. First transients are due to opening and the last is closure.

![Car Images]

Figure 3. Door opening/closure sounds for cars in three different product segments (luxury, premium, economy). Time histories and wavelet time-frequency colour plots. The scales are identical in all cases and the sound is recorded at the same distance outside the car. The wavelet plots have time on the x-axis and logarithmic frequency on the y-axis.

Both the time histories and the wavelet plots use A-weighted signals. One can determine some attributes easily from the simple time history, e.g. the peak A-weighted amplitude and decay. The wavelet plot shows the frequency content with quite good time resolution. It is clear that the BMW has the lowest overall level for the closure, also reflected in the spectral content, which is similar to the closure sound of the SAAB. The Citroën Berlingo has the highest peaks and also the “sharpest” sound (much high frequency content) as well and a lot of reverberation and a strong double impulse. This is an unfair cross-brand comparison since the price difference is a factor of five between the cheapest and the most expensive of these cars but exemplifies the benchmarking idea.

5.2 Dishwasher door opening, an example of typical shop-floor experience

The next example is a dishwasher door opening, and is presented to illustrate the need for resolution in both time and frequency in order to be able to investigate and verify the impact of different possible design modifications. The measured time history as well as subjective
listening reveals that the opening sound consists of a series of individual transient events. In order to improve the sound, some of these have to be addressed by separate modifications. Influence of these, also on the frequency content has to be documented and used as basis for alternative design decisions.

Figure 4. Dishwasher door opening. Upper left is the time history. Lower left is the corresponding wavelet plot. The four other plots show: Mid upper - Wavelet, mid lower – STFT with 512 frequency points, right upper - STFT with 2048 frequency points and right lower - STFT with 128 frequency points.

The figure demonstrates the superiority of the wavelet presentation regarding time and frequency resolution. The 512 point frequency resolution is a fair compromise but some secondary events do not show up correctly and smearing of energy is present for the main events.

6 CONCLUSIONS

Wavelet analysis is very useful for design of the quality of transient sounds from the engineering perspective, if used together with time data and parallel subjective evaluation.

REFERENCES

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