Audibility of resolved tonal components of gear meshing noise in passenger car cabins by trained listeners

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Introduction

The designing of a pleasant acoustic ambience in passenger car cabins is an increasing factor in quality assessment of cars. Although gears usually do not belong to sound design, sounds originating from the transmission should remain almost inaudible. Occasionally inevitable tonal components may appear at specific frequencies due to structural resonance, being extremely low in level compared to the total ambience noise. As a result from pilot studies it was found that the different characteristics in fluctuation strength of genuine motor noise and tonal components arising from gears are clearly distinguishable. Partial masking and unmasking by motor noise, air stream and additional acoustic emissions in an automobile determine the detection of gear noise components. Nevertheless they are perceptually resolved because of their distinct frequency location and different modulation characteristics. .A psychoacoustic test procedure of gear sounds is in development in order to predict subjective quality judgments on the parameters of acoustic measurements.

To obtain subjective quality judgments of gear sounds up to now a 10 point quality assessment scale has been used ranging from unacceptable to acceptable The comparison of individual scores shows large interindividual variance. One reason for the interindividual variance observed may be due to the complexity of the sound signal, exhibiting a large amount of partials simultaneously in dependence of the driving speed and change of gears. This results in a perceptual ambiguity among different test drivers focusing on different pitches. Moreover in the course of a test run continuity effects have to be taken into account, which let a tonal component, slowly rising or falling in pitch, appear to be present uninterrupted even when temporally masked or inaudible. This phenomenon can be compared to the well known picket fence effect.

Spectrographic analysis as well as measurements of spectral band levels showed quite different modulation patterns of motor noise and tonal components from gears. Whereas motor noise exhibits a large amount of spectral components with fluctuations equal or faster than 4 Hz, gear tones appear isolated in the higher frequency range and show almost no modulation. As the time structure of gear tones is uncorrelated with motor noise, the listener is enabled to resolve gear tones in a separate auditory stream. That's the reason why weak but resolved tonal components are audible even in the presence of strong broadband motor noise. Auditory streaming is known as the main psychoacoustic function to distinguish different voices in multipart music. Fusion and fission of simultaneously sounding spectral components depends on the frequency range and difference between the participating tones as well as from their common envelope and temporal fine structure.

The basic mathematical model consists of the computation of simultaneous masking according to the algorithm published in [4], which provides the separation of audible and inaudible spectral components. Additionally order tracking of gear orders and modulation analysis of gear orders in comparison to motor orders is performed. The model primarily differentiates between sound segments containing gear tones and segments with motor noise alone.

Scores from subjective quality measures are cross checked against the ranking order of audibility of gear tones. It is expected that the ranking corresponds to the existing Product Rating System (PRS), derived from the traditional ATZ scale. Additional tests with acoustic experts are performed to evaluate the parameters computed and to obtain appropriate weighting functions for the simulation of the PRS scale.

Test material and procedure

Calibrated sound recordings have been performed during conventional test runs with passenger cars. Omnidirectional measurement microphones as well as an artificial head were positioned at the front passenger seat. Additional to mono and stereo sound recordings the gear revolution was stored simultaneously on a separate soundtrack. The continuous reference to the revolution track allows a simple and exact derivation of gear orders used in throughout the test evaluation. The recording of each run was partitioned into a sequence of sound segments of 7s duration. This segment duration was chosen, because individual segments have to be long enough to capture typical lengths of gear generated tones as well as to enable a reasonable response of the listeners on the PRS scale. Test sounds were presented via headphones.

The subjects were seated in front of a computer screen showing a graphical outline of the recording as a whole as well as the segments in chronological order. Subjects were instructed first to listen to the complete test run, then to judge the quality of gear noise segment by segment on a scale ranging from 1 to 10. The sound presentation of a segment was controlled by the subjects by mouse click. The test persons were allowed to listen to any sound segment in arbitrary order repetitively.

Subjects were asked to perform a second ranking task on the same sound material. In an AB/X comparison task rank orders have been obtained additionally.

Preliminary Results

One of the main problems reported by the subjects was the difficulty to separate reliably gear tones from other noise components in the listening test. In “real life” situation, driving the car, the separation is done by changing intentionally the conditions in the power train and listening to the corresponding changes of the gear tones. This step is not possible in an offline test mode.

It was argued by the test persons that several further limitations of the design may have an influence on the quality assessment

- As described above, the possibility to interact with the car in order to verify gear data was not given.
- A number of ambiguous sensations due to tones originating from different sound sources made the assessment difficult. In some cases the listeners argued that a “wrong” order might have been evaluated. Nevertheless, as long as the judgements are bound to properly annotated sound segments the results are still valid.
- The presentation of the test sounds via headphones is not appropriate enough in view to the real life listening condition.
- The position of the microphones had to be fixed during the recording. A human listener in contrary, is capable to find maxima of standing waves by head movements. This limitation was initially known, and has to be taken into account.

The signals produced with an artificial head were suggested to sound better in quality than those done with measurement microphones. Alternatively a binaural recording technique, such as ORTF may be suggested.

Statistical evaluation

8 highly experienced test persons listened to approximately 100 sound segments (items) recorded during experimental test runs as described above.

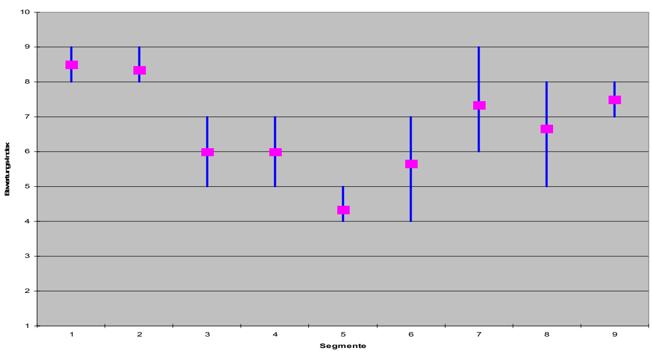

Fig. 1 typical response pattern for a test run. Abscissa: sound segments of the test run (each of 7s duration). Ordinate: PRS scale ranging from 1 to 10. Values are arithmetic means over 8 subjects. Bars indicate min/max score on each sound segment..

Subjects judged the contribution of gear tones if present or not as well as on the PRS scale. High scores represent no presence of gear noise. The arithmetic means of different sound segments vary in the range from 4.7 to 10. Variance between subjects in high scores is considerable reduced in cases unambiguously no gear tones were present or at low scores when gear tones could distinctively perceived.

Extended Model

The present model computes the simultaneous masking and applies the irrelevance threshold to the sound material. For the identification of gear tones an order tracking has to be implemented. The individual modulation characteristics are analysed on the orders under consideration and the overall amplitude of gear orders is determined. Amplitude envelopes of gear orders have to be evaluated in terms of psychoacoustic parameters such as frequency resolution, location on the frequency axis (sharpness) and duration in order obtain appropriate weighting functions for the simulation of the PRS scale.

Conclusion

The audibility of gear tones in the presence of interior car noise is primarily dependent on a) the relative magnitude of the tone, b) the background masking noise. Although the amplitude of gear tones is low in comparison to the level of the background noise, gear tones can become audible due to their distinct time structure. Whereas engine noise usually shows amplitude modulation, gear tones can remain stable over several seconds. As a large number of engine orders and only few gear tones can appear simultaneously the construction of an automated quality assessment model has to deal with proper separation between both. In view of the variance in the experimental results the model has to account moreover for the perceptual ambiguity, in the midrange of audibility and inaudibility.

References

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