Application of a psychoacoustic model for the determination of the psychoacoustic roughness of interior car sounds

Carsten Zerbs, Otto Martner

Müller-BBM GmbH, Robert-Koch-Str. 11, D-82152 Planegg bei München, Germany, Email: zb@mbbm.de

Introduction

Beside the design and the optical appearance of a car also the interior sound is important for its perceived character. In order to quantify and to characterise the different factors contributing to the sound perception of a car and to explore the differences in the perceived image between listeners from a different origin, a hearing test was designed and carried out in Central Europe and North America. In the course of the statistical evaluation of the test it was found that the subjectively judged roughness and the predicted roughness showed practically no correlation.

Study

Test sounds from three driving modes (acceleration, cruising and idle) had to be compared according to 12 different attributes within a paired tournament test. Altogether 30 test subjects took part in the test for each driving conditions and in each country. Test persons were of both genders and mostly lay persons. For each driving condition 16 test sound samples had to be evaluated.

Concerning the accuracy of the results, a complete paired comparison test would be appropriate. But for the large number of sound samples a complete test is not practical. For that reason, a paired comparison tournament test was choosen as test procedure. The test starts with 8 pairs of sound samples which are randomly selected from the 16 sounds. A comparison judgement has to be made, and only the "winner" is compared with the winner of another pair. So the number of comparisons is reduced to 15 for one attribute. The test persons had to make a decisions about the relative "markedness" of a pair within twelve categories. These were (among others):

- loud
- booming
- *smooth*
- sharp
- powerful
- luxury
- fun to drive
- sporty
- ...

Test results were checked for concordance and inter-individual reliability. A factor analysis (PCA) was performed on the average scale values within one driving condition. A multivariate analysis was performed to relate sensory attributes (like "luxury" or "sporty") with objective psychoacoustic parameters.

Roughness of the sound samples

A comparison of subjective judgements and objective psychoacoustic parameters showed that the correlation between subjective roughness and the psychoacoustic parameter objective roughness [4] was quite poor. An example for this behavior of the predicted roughness vs. the subjective judgements is given in Figure 1.

In the hearing test the verbal attribute "smooth" as the antonym of "rough" was employed. In the following figures the predicted roughness is plotted vs. subjective roughness which is calculated as the negative scale value of the "smoothness" attribute. Subsequently, the scale is shifted toward positive values.

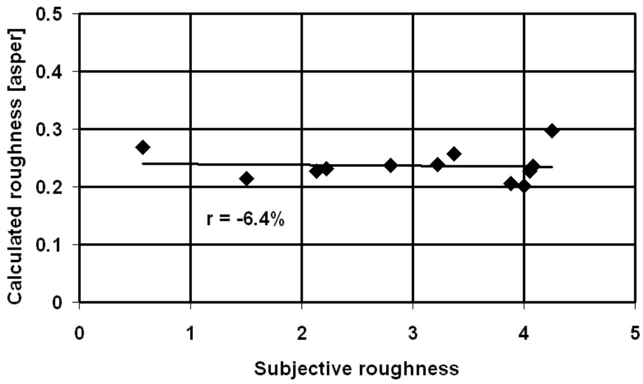

Figure 1: Predicted roughness (classical roughness model) and the subjective results for the German test persons from the paired comparison test. Results are for the acceleration configuration.

A recently presented model [1, 2, 3], which considers the order structure of car sounds (or, more generally of sounds which depend on rotational speed) was employed to improve the correlation between subjective and objective psychoacoustic roughness. The spectral decomposition of the sample sounds is controlled by the rotational speed. So the centre frequencies of the filter bank are not fixed, e. g. on a Bark scale but placed on the main orders of the engine sound. A block diagram of the model's signal processing is shown in Figure 4 on the next page. Since the model requires an rpm-signal, which was not available for all sound recordings employed in the hearing test, evaluation was restricted to these 12 sounds for which an rpm-signal was measured.

This model improves the correlation of predicted and subjective roughness. An example is given in Figure 2 for the same subjective results as in Figure 1. The correlation between both data sets increases from -0.06 to 0.68.

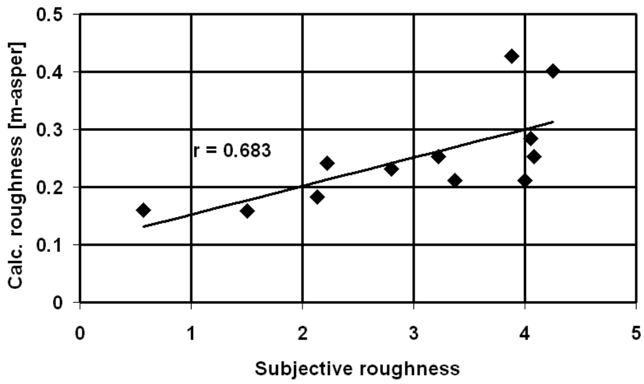

Figure 2: Comparison of the predicted roughness originating from the new roughness model with the same subjective results as in Figure 1.

Figure 3 shows the comparison of subjective and objective roughness for the idle configuration. It could be observed that the correlation of the predicted values with the subjective results improves when the modulations of the signal are evaluated with a modulation filter which is centered at a frequency lower than 70 Hz which was employed for the higher rotational speeds. The better performance of the model for low rotationals speeds with a 40 Hz filter can be explained with the fact that at these speeds the engine orders are spaced closer which results in lower modulation frequencies of the total signal.

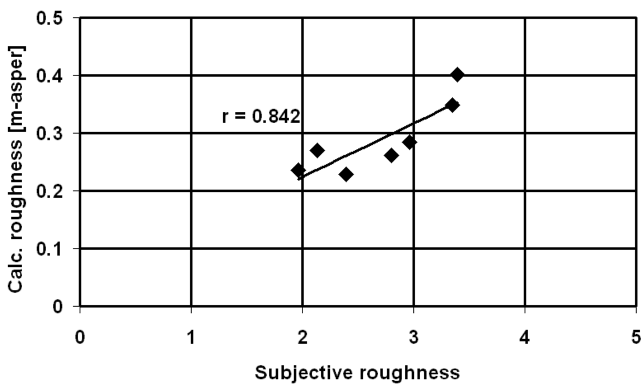

Figure 3: Comparison of the predicted roughness (new roughness model) and the subjective results for the idle configuration. For this configuration (rotational speeds) the fluctuations in the signal envelope are evaluated employing a modulation filter with a centre frequency at 40 Hz.

Conclusion

A recently developed model can improve the quality of the prediction of the roughness of interior car sounds. For low rpm's the model's behavior can be improved employing a modulation filter with a centre frequency at 40 Hz.

References

[1] Martner, O. et al.: Neues psychoakustisches Modell zur objektiven Bestimmung der Rauigkeit bei Verbrennungsmotoren. MTZ Motortechnische Zeitschrift 62 (2000) 10, 678–685.

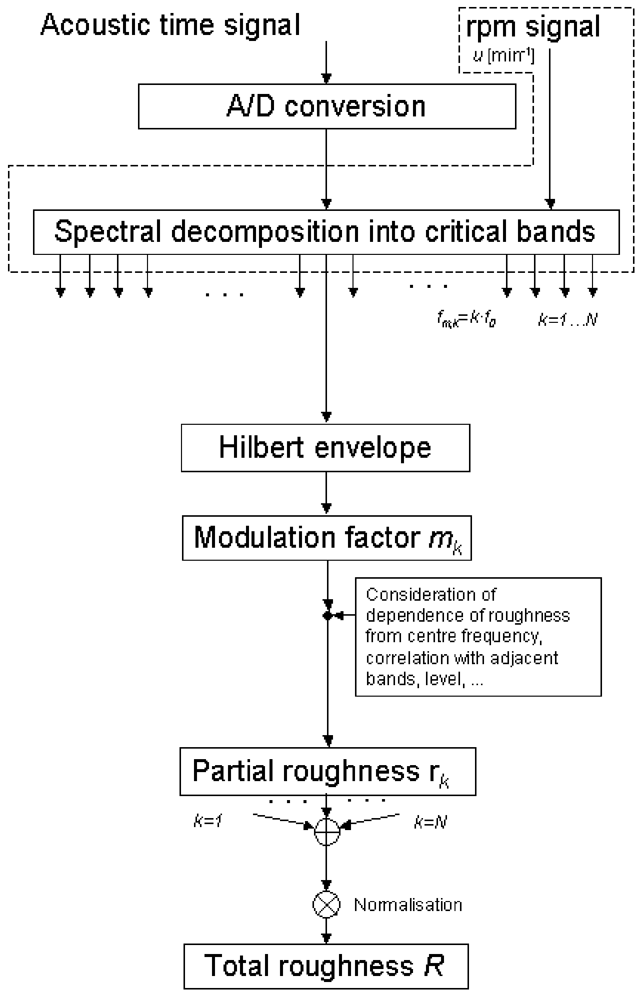

Figure 4: Block diagram of the model for calculation of the rpm-dependent psychoacoustic roughness. The centre frequency of the critical-band filters is controlled by the rpm-signal. Apart from that fact the structure of the signal processing is quite similar to that of standard roughness models. In addition to the total roughness the partial roughness can be be displayed. It is specified in m-asper/order.

[2] Martner, O. et al.: Psychoacoustic model for the objective determination of engine roughness. Sound Quality Symposium, Dearborn, Michigan, August 2002.

[3] Zerbs, C. et al.: Modell zur Berechnung der subjektiven Rauhigkeit von drehzahlabhängigen Geräuschen. DAGA 2001.

[4] Zwicker, E.; Fastl, H.: Psychoacoustics. Facts and models. Springer, 1999.