Prediction of perceptibility of vehicle exterior noise in background noise

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Introduction

In recent years the warning effect of vehicle exterior noise for other road users, especially pedestrians, has been widely recognized. Previously we showed experimental results on perceptibility of different vehicle exterior noises in urban traffic, and demonstrated that a qualitative prediction of perceptibility is possible by just considering noise levels [2]. The present paper aims at extending this approach so that correct quantitative predictions become possible. This can be achieved by considering masked thresholds and vehicles' exterior noise levels. The present article explains this calculation and compares the results with those from earlier experiments.

Algorithm

Figure 1 shows the basic process for the calculation of the perception-distance of an arbitrary vehicle.

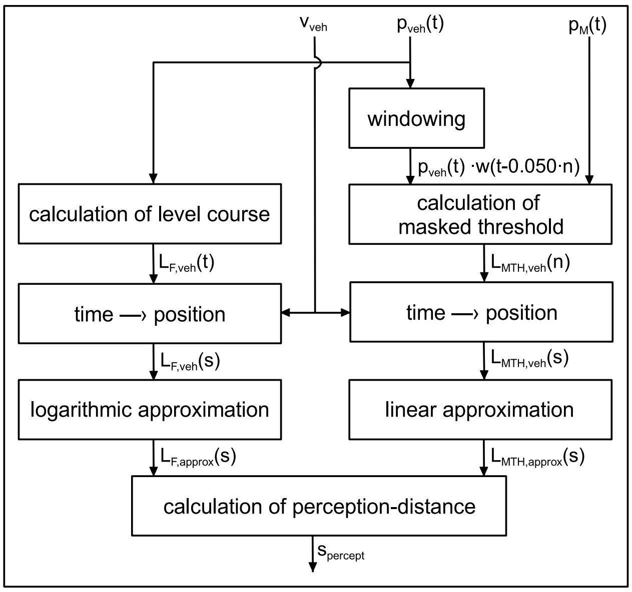

Figure 1: Flow chart of the algorithm for the calculation of the perception distance of an arbitrary vehicle.

The algorithm uses three input parameters for the calculation. The properties of the car are defined by its time varying sound-pressure $p_{veh}(t)$ and the speed v_{veh} of the approach. Additionally the sound-pressure-level $p_M(t)$ of the masking noise or alternatively its third octave spectra is needed. In a first step the vehicle sound p_{veh} is split in n chunks of 200 ms using a rectengular window with gaussian ramps of 10 ms and an overlap of 75 %. For all of these n timesteps the masked thresholds in the given background noise $p_M(t)$ are calculated using a procedure to calculate energetic masking proposed by Fastl and Zwicker [1]. This procedure was adapted to use third octave filters rather than critical band filters, since these filterbanks are more commonly used in vehicle acoustics. Along with the known speed of the vehicle, the course of masked thresholds over time are then converted into masked thresholds as a function of the actual position s of the vehicle, which is then expressed as linear function $L_{MTH,approx}(s)$. In parallel to this calculation of masked thresholds the level of the approaching vehicle is measured with a standard sound-level-meter (unweighted, timeconstant FAST). This level is also expressed as a function of the actual vehicle position and approximated by a logarithmic function $L_{F,approx}(s)$. The perception-distance $s_{percept}$ can now be estimated as the intersection point between $L_{F,approx}(s)$ and $L_{MTH,approx}(s)$ additionally taking into account the average reaction time of a person, which was estimated in an earlier experiment to 0.56 seconds. Figure 2 shows masked threshold and level course along with the approximations as a function of the vehicle position. It also indicates the calculation of the perception-distance $s_{percept}$.

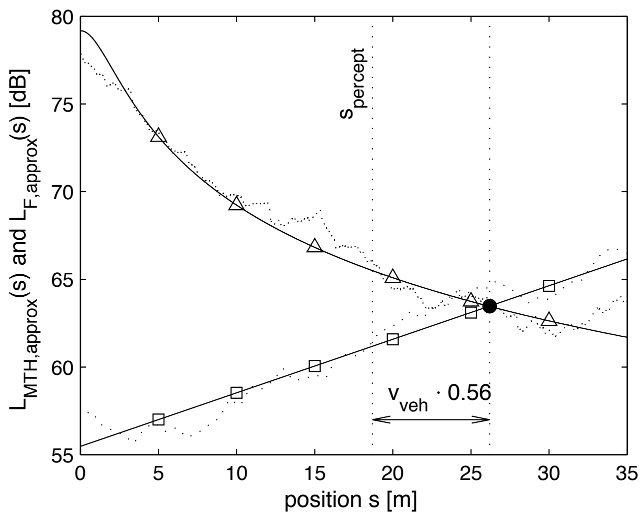

Figure 2: Principle of calculating the perception-distance $s_{percept}$ out of the approximation for level course (triangles) and masked thresholds (rectangles) for a selected car. The dotted lines indicate the real signal courses.

Evaluation

To evaluate the algorithm data derived experimentally was considered. In these experiments subjects had to indicate when they hear an approaching vehicle in a background noise (speech - like noise, approx. 62 dB(A)) by pressing a button. For this the recordings of the last three seconds of approaching vehicles before a hypothetical collision were used. A more detailed description of these experiments can be found elsewhere ([2, 3]). Figure 3 shows the predictions of the algorithm along with the experimentally derived data for perception-distances.

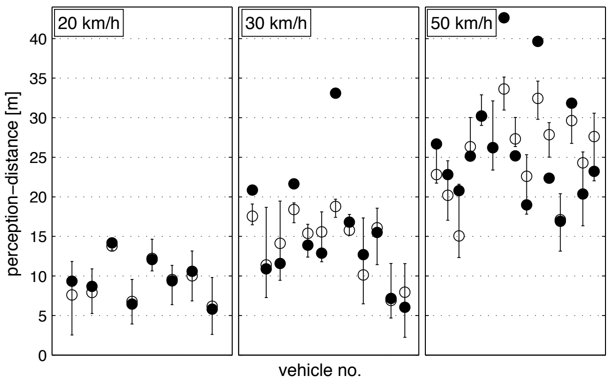

Figure 3: Medians and interquartiles of experimentally derived (unfilled circles) and calculated (filled circles) perception distance for 35 vehicles at three different speeds.

Figure 3 depicts perception-distances for 35 middle and upperclass vehicles approaching at speeds of 20, 30 and 50 km/h. Unfilled circles give medians and interquartiles for the experimentally collected data of 12 normal hearing persons. Additionally the calculation of the before described algorithm is shown as filled circles.

As can be seen 28 of 35 calculated perception-distances (i.e. 80 %) fall within the interquartile ranges of the experimental data. It is also obvious that the algorithm performs better for vehicles which approach with slower speeds, i.e. vehicles which become audible at shorter distances from an observer. The reason for this is that the recordings of the vehicle sounds have a better signal-to-noise ratio when the vehicles are closer to the microphone, which was for the recordings placed at the point of the observer. The smaller signal-to-noise ratios influence the calculation of masked thresholds, and thus the estimation of perception distances in a negative way.

For speeds of 30 and 50 km/h there are also some vehicles for which perception distances get highly overestimated by the algorithm. These are vehicles which are driven in low gears, which results in a high level sound with a lot of energy at high frequencies. It is very likely that due to the experimental design (i.e. only three seconds of the recordings before the collision were played back in the experiment) most of our listening test subjects highly underestimated perception distances for these vehicles.

Figure 4 gives a more direct comparison of experimentally derived and calculated perception distances. The graphic shows again the better predictions for slower speeds. This is also confirmed by the Pearson correlations, which are listed in Table 1.

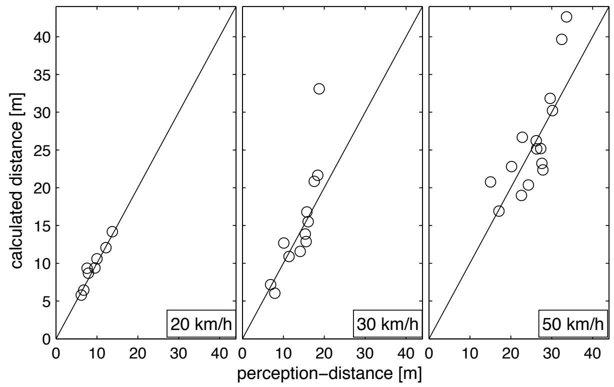

Figure 4: Experimentally derived vs. calculated perception distances for 35 vehicles at three different speeds. Diagonal lines indicate a perfect prediction.

Table 1: Pearson - correlations of experimentally derived and calculated data for the three speeds. All values are significant on a 0.1 % level.

20 km/h	30 km/h	50 km/h
0.965	0.823	0.799

Summary

The paper describes an algorithm to predict the perceptibility of vehicles in different background noises. Comparison of the calculated with previously collected experimental data confirms, that the algorithm is capable of making very accurate predictions, especially for vehicles driving at slow speeds. It can serve as a tool to design vehicle exterior noises in a way to maximise vehicle perceptibility without raising the overall level to unnecessarily high values, and thus to improve traffic safety.

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