Localization of Brake Squeal

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Introduction

This contribution investigates the use of microphone arrays for the detection and localization of brake squeal of a moving vehicle. The advantages of using microphone arrays over other approaches (such as those using vibration sensors, etc.) are: deployment need not be in the immediate vicinity of the brake discs, robustness against individual sensor failures and vehicle-structure independency, to mention a few. Brake squeal occurs as a result of the resonance between the brake disc and the brake shoe, making the acoustic source a distributed one. The squeal is narrow-band in nature, with squeal frequencies typically ranging from 1 kHz to 16 kHz. Also, the squeal frequencies change from event to event and from wheel to wheel. Furthermore, the acoustic environment underneath an auto gives rise to multipath propagation and standing waves. Additionally, the localization algorithm has to cope with the following:

- the sources emit jittered narrowband signals (and, in some cases, one or two higher harmonics),
- the power of the spectral harmonics of the sources are unknown and, further, vary from event to event, and, finally,
- more than once source can contribute to a squeal event.

Under these circumstances detecting and relegating a squeal event to the corresponding wheels is a very demanding task.

Standard source localization algorithms (GCC [1] etc.) fail in this context because of the narrow-band nature of the brake squeal and the complex acoustic environment. Consequently, this paper presents an approach for solving this problem using a weighted cost function, similar in some respects to the steered-response-power approach [2], on a two-dimensional search field. The setup comprises four arrays, with a total of 32 channels for signal input (Figure 1). The arrays are linearly configured, with logarithmic spacing between the elements to take into account the wide range of the squeal signal frequencies.

Further, the detection and localization of the squeal events must be accomplished in real-time, with low latency. For this reason the input signals are analyzed in segments of 200 ms duration, using a windowed discrete Fourier transform (DFT) on overlapping frames in each segment. Note that the finite spectral resolution of the discrete Fourier transform, coupled with the frequency jitter of the sources smears each narrowband acoustic event across more than one frequency bin. The accretion of such adjacent frequency bins builds what we shall denote as frequency *bands*, where each active band characterizes an acoustic event. Consequently, the analysis is on a *band-by-band* basis. We also assume that it is not necessary for each array to have a Line of Sight (LoS) to each source. The algorithm proceeds in two steps: in the first step the active frequency bands are detected using narrowband noise estimates and then the squeal-events are assigned to the active brake(s) using a coherence weighted cost function. The approach has been verified by experiments carried out on a moving vehicle.

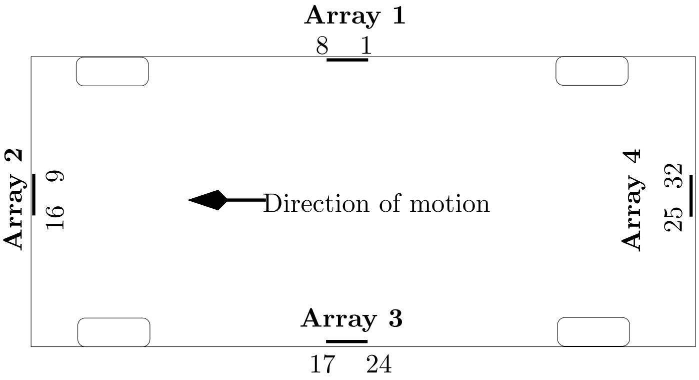


Figure 1: Array positions and microphone indices. The numbers indicate the global channel indices of the first and the last microphone of the respective array.

Localization

As the squeal events are concentrated in the region around the respective wheels, the valid source locations are restricted to the region around the wheels. Furthermore, each array only computes the localization estimates for those brake discs it has a direct line of sight to. The search spaces for array 3 are illustrated in Figure 2. Also, due to the distributed nature of the sources, we do not seek the optimal source location vector $\mathbf{r}_{s,\mathrm{opt}}$; rather, we look for the optimal region. This implies a spatial averaging of the cost function over the search regions. The spectral spread due to jitter and finite time-frequency resolution requires that the time-averaged estimate be further averaged over each frequency band, where the bands

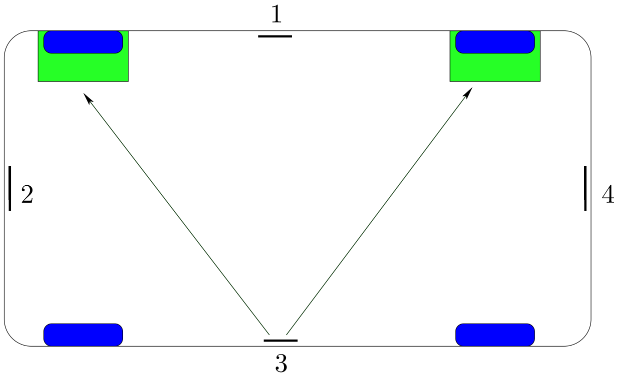


Figure 2: Valid source regions (in green). Each array only calculates the cost function for regions around wheels it has a direct Line of Sight (LoS) to.

are formed by clustering the closest active bins. Further robustness of the algorithm comes from averaging over time and over frequency bands.

Detection

The band-based localization is rooted on the implicit assumption that the band in concern contains a squeal event. Order statistic (OS) [4] approaches can be used to make a robust detection of such active frequency bands. Such approaches also, implicitly, confirm the presence or absence of a squeal event. However, these methods come with a large computational cost. As brake squeal events occur intermittently, the system is accelerated by detecting the presence of brake-squeal in a signal segment using computationally less intensive measures, reserving the OS approaches on segments where brake-squeal is detected – for active frequency estimation. As brake-squeal events are narrowband, with most of the spectral energy being concentrated in the squeal frequencies[1], it gives rise to a rather well-structured spectrum in the presence of brake-squeal. This permits the use of modified information theoretic tools (like entropy) to form an *a priori* decision on the presence of a squeal event [3, 5].

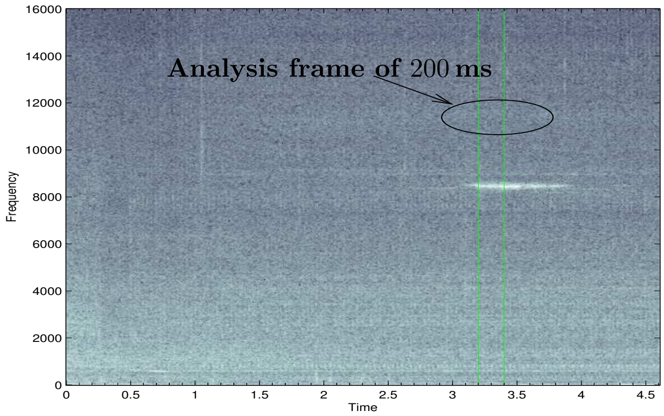
Experimental results

In the following example the localized squeal events are plotted directly upon the spectrogram of the signal. The ordinate of each marker represents the frequency of the squeal event and the horizontal extent defines the length of the event.

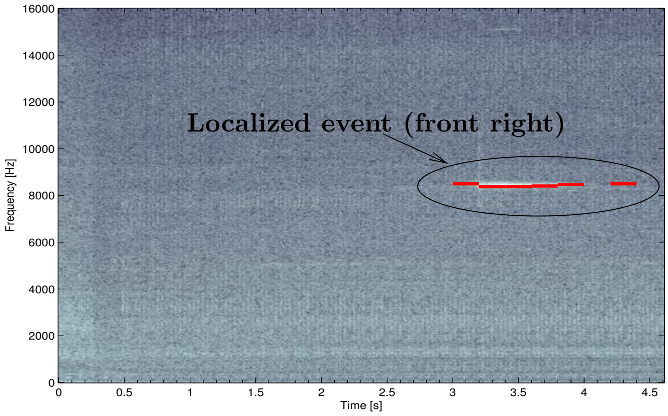
The measurements were made on a moving VW-Touran. The FFT size was 1024, the signals were windowed with a Hann window at an overlap of 75%. The data shown in Figure 3 corresponds to a measurement where only the brake on the front, right wheel was 'active'

Conclusions

The system presented is capable of detecting and localizing multiple narrow-band, possibly overlapping acoustic events. The use of multiple microphone arrays enables the correct mapping of events to their sources. Measurements made in actual conditions of use indicate that the proposed system is robust against disturbing factors such as reverberation and noise.



(a) Spectrogram of single brake event



(b) Detection and localization result

Figure 3: Localization on a moving vehicle

References

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[1] The lower frequencies containing motor noise are neglected in our considerations.