Investigations on the acoustical performance and benefits of a simple three channel microphone-array concept and traditional microphone technologies used for hands-free applications on various placements inside the car cabin

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Introduction

The acoustical performance of three microphone types (omni-, unidirectional and array microphone) is analysed on four different common positions inside car cabins. For this analysis on the one hand omni- and state of the art unidirectional hands-free microphones are used, on the other a sophisticated yet simple three channel microphone-array concept, which can be placed more flexible inside car cabin and has potential for reaching better audio performance than traditional microphone types.

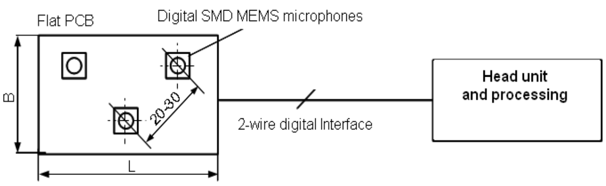

Figure 1: Proposed microphone array (35 x 30 x 5 mm).

The array is designed to capture microphone positions, at which a placement of a standard unidirectional microphone is difficult or even not possible (e.g. a placement hidden behind a headliner). Due to its fully digital interface, low cost MEMS microphones and its undemanding needs to processing power this concept remains cost attractive.

Array Concept

In the following the chosen design of signal processing software, the array geometry and the number of microphones of the array are discussed. In our investigation, the array is seen as a processing block, which must be fully independent from further signal processing components within the signal path like an acoustic echo cancellation or noise reduction. As a consequence the array must have a very low delay, must be fully linear and must be time invariant. We use a fixed beamforming design in time domain without block-processing to fulfil these requirements. The amount of noise reduction is maximized by a superdirective design for a given noise model determined later in this section. The algorithm complexity is reduced by using a general sidelobe structure introduced by [1] and an optimized (reduced) length of involved FIR-Filters.

The number of microphones, their distance and the array geometry have the main influence on the expected performance. There are three independent requirements, which have impact to the proposed array concept: (a) The array should be as small as possible. This allows a flexible placement inside the car cabin. (b) The noise reduction performance should be equal or better than a cardioid microphone. (c) It must be possible, that the array can be focused to the driver and optional also to the passenger for all the investigated positions.

Idealized car noise can be considered as diffuse [2]. As a deviation to that, additional incoherent noise sources are identified. They cause a significant reduced directivity depending on microphone distance and determine in this way the minimum acceptable distance of microphones. We identify quantisation noise and microphone noise as the most significant incoherent noise sources. An omni directional microphone is specified with approximately 60dBA signal to noise ratio (SNR) at 94dBSPL. In a hands-free condition the measured sound pressure of car-noise (130km/h) is about $70dB_{spl(A)}$ (depending on car model and driving condition), which reduces the effective car-noise to incoherent-noise ratio to only 36dB. This value is dominant in comparison to quantisation noise. Taking into account the third requirement above, we specify a worst case "direction of speech arrival" (DOA) for the investigated microphone positions for driver or passenger (following to [3]: A1=20°, A2=40°). Additionally, steering errors are caused by a non exact only sample-wise delay compensation.

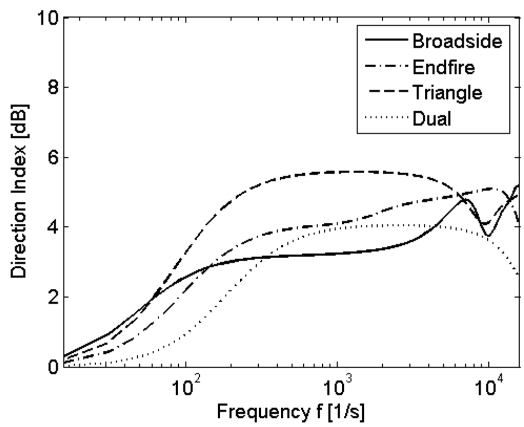

Figure 2: Directivity of different array geometries under non ideal conditions.

Taking into account both deviations, figure 2 shows the directivity of a three channel microphone array in different array arrangements, non ideal DOA and erroneous delay compensation caused by 48kHz sampling frequency. It can be seen, that a triangular arrangement with 25mm microphone distance has in a wide frequency range a directivity of 6dB and has therefore the most potential to outperform a cardioid microphone, which ideally has a directivity of 4.8dB. Under same conditions a dual endfire microphone array does not fulfil our performance expectations.

Theoretical analysis

The performance of the investigated microphone technologies on four positions inside the car cabin is theoretically analysed. Therefore the noise reduction ability and the resulting absolute SNR of the beamformer output are estimated for each investigated microphone position based on free field assumptions and an abstract model of a car cabin, noise and talker-position. This model does not take the enhanced sound pressure on bounding surfaces into account.

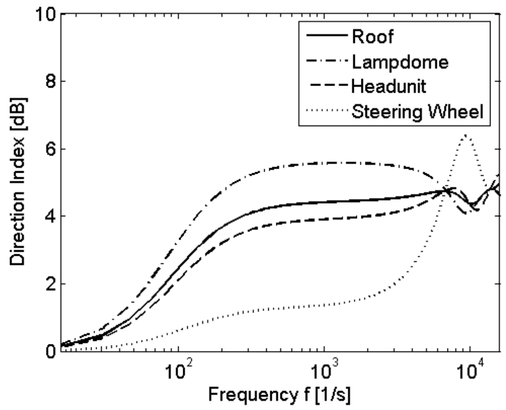

Figure 3: Directivity of proposed beamformer concept on various positions inside car cabin.

The expected SNR-values of the array are compared with the performance of a uni- and omnidirectional microphone on same positions.

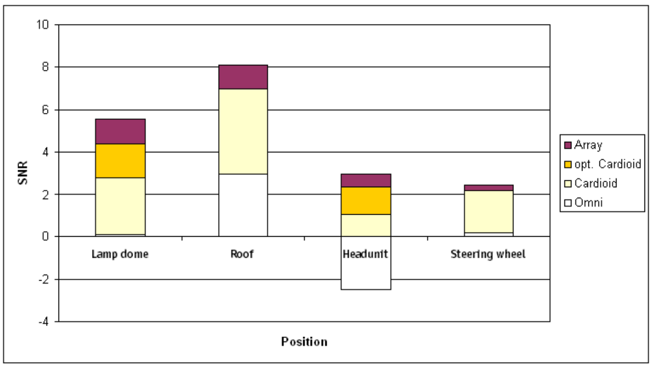

Figure 4: Signal to noise ratio inside car cabin depending on position and microphone technology. As reference (0dB) the omni directional microphone at lamp dome position is used. The optimal directed cardioid is directed to driver. The “normal” cardioid is mounted – as it can often be observed - along symmetry axes of the car**.**

It can be seen, that from theoretical viewpoint the array outperforms the optimal directed unidirectional microphone on all positions by one or two dB. The directivity of the microphones yields to the maximum performance gain on lamp dome position, and to the minimum on steering wheel position. In consideration of the small mouth to microphone distance the roof position yields to the best signal to noise value, while the headunit position results in a very bad SNR value due to its far distance to talker’s mouth.

Measurements in the car

Acoustical measurements for a driver position were conducted in two different cars (Daimler C, Chrysler Voyager) to verify the results of the theoretical analysis. The measurements include sound pressure level of the background noise and SNR of real speech recordings at 130 km/h and frequency responses for the various placements of the microphones in the car.

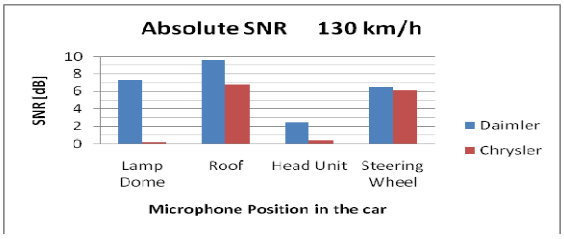

Figure 5: Absolute SNR of an omni-directional microphone inside the car cabin depending on position, derived from speech recordings.

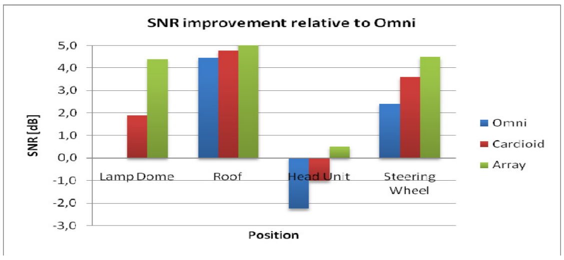

Figure 6: SNR improvement depending on position and microphone technology. As reference (0dB) the omni-directional microphone at lamp dome position is used. The cardioid is mounted along the symmetry axes of the car and therefore not in an optimal position (Especially in the roof, when a relatively small driver is talking, the microphone positioning is important)**.**

Comparing the frequency responses of an omni-directional microphone the roof position has the most flat response followed by the lamp dome, headunit and steering wheel.

Conclusion

Measurements show that the proposed array concept outperforms the omni- and unidirectional microphones in terms of SNR and flexibility in placement and directivity. The optimized placement of the cardioid microphone is a challenging task which has a huge impact on the performance. Due to its good absolute SNR and frequency response the roof seems to be the preferred position for hands-free microphones.

Literature

[1] L. J. Griffiths, C. W. Jim. An Alternative Approach to Linearly Constrained Adaptive Beamforming. In *IEEE Transactions on Antennas and Propagation*, pages 27-34, AP-30, January 1982.

[2] I. McCowan, H. Bourland. Microphone Array Post-Filter for Diffuse Noise Field. *IEEE International Conference on Acoustics, Speech, and Signal Processing*, pages 905-908, 1, 2003.

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