

Analysis of the Intrinsic Noise Spectrum of MEMS Microphones

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Abstract

MEMS microphones are silicon-based devices widely used in consumer electronics due to their small size, low power consumption, and low cost. Their intrinsic noise spectrum depends on environmental parameters such as pressure, temperature, and gas composition. In this study, the noise spectrum of a MEMS microphone was measured from 5–95 kHz in mixtures of nitrogen (N_2), carbon dioxide (CO_2), and methane (CH_4). Principal component analysis (PCA) shows that CO_2 and CH_4 concentrations can be distinguished, indicating the potential for low-cost environmental sensing using noise analysis.

Keywords: Noise analysis, gas sensors, MEMS

Introduction

Micro-electro-mechanical system (MEMS) microphones have evolved into a standard component for consumer electronics products including e.g. mobile phones, smart watches, and tablets with several billion units produced every year. A central goal of manufacturers is to improve signal to noise ratio and sensitivity in the audible range up to 20 kHz [1]. However, the intrinsic noise spectrum of MEMS microphones shows complex dependencies on environmental parameters including temperature and gas composition [2]. This offers means to make use of MEMS microphones as environmental sensors via spectral analysis of its intrinsic noise spectrum, in particular in the non-audible frequency range. While the prominent resonant feature near 20 kHz has been modelled and studied in the past [2], the analysis of the complete spectrum is bound to yield a more reliable classification of the gas composition.

To this end, this contribution presents results on intrinsic noise analysis of a MEMS microphone in a gas matrix composed of three components, i.e. nitrogen (N_2), carbon dioxide (CO_2), and methane (CH_4) by means of a principal component analysis (PCA). The approach could enable low-cost sensing solutions for applications requiring distributed monitoring, for example the detection of methane and carbon dioxide emissions from landfills [3].

Experimental

The experimental setup is shown in Figure 1. To determine the intrinsic noise spectrum the signal of a IDK InvenSense Inc. ICS-40720 microphone that is powered by a supply voltage of $V_{cc} = 3.3$ V is amplified by a factor of 10,000 and then fed to a FSV3013 spectrum analyzer (Rohde-Schwarz GmbH&Co. KG). It determines the signal in a range from 5 kHz – 95 kHz and uses a total of 1001 linearly spaced frequency values. The microphone is embedded into an apparatus to simulate real-world conditions in the laboratory [4] that is able to control the gas composition and temperature.

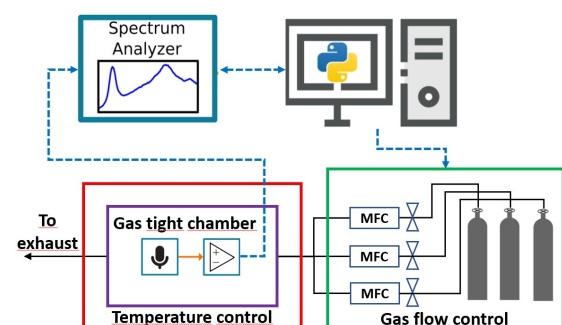


Figure 1: The experimental setup. The microphone and the amplifier sit inside a temperature controlled gas tight chamber. Software controls the Mass Flow Controllers to set a specific atmosphere inside the measurement chamber. The spectral data is sampled by a spectrum analyzer. [2]

Figure 2 shows three exemplary spectra recorded under different conditions.

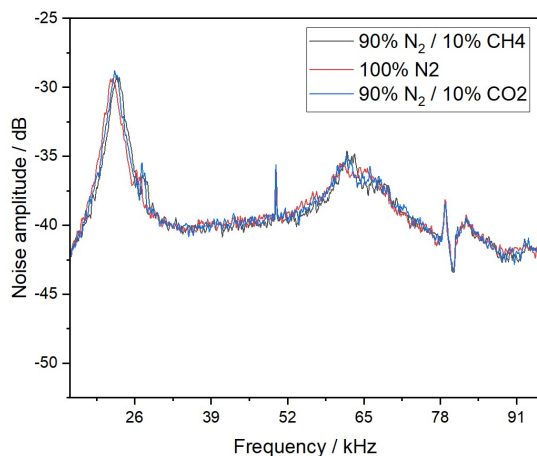


Figure 2: Intrinsic noise spectrum in the frequency range from 15 kHz – 95 kHz under different gas compositions at 23°C and 1 bar pressure.

To analyze the spectra a principal component analysis (PCA) has been employed using 889 frequency values as input features. To analyze each gas composition 140 spectra of each gas composition step were taken to not include spectra where the target gas composition was not reached already. Each of those spectra was then normalized and mean-centered. The PCA was then performed in MATLAB on the spectra between 15 kHz and 95 kHz.

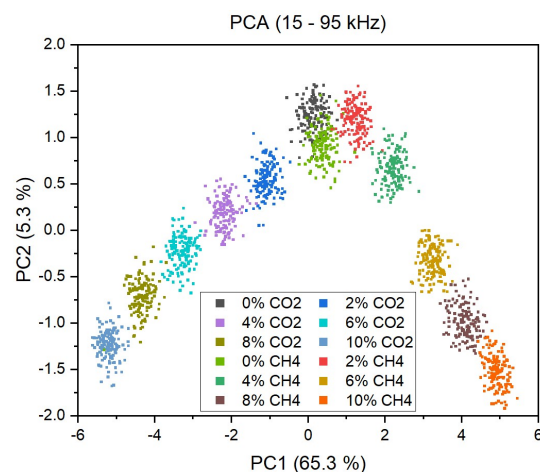


Figure 3: The results of the PCA show a separation of CO₂ and CH₄.

The 0% CO₂ and 0% CH₄ step can be seen almost overlapping in the top center of the figure. From this point it can be seen that with rising concentrations the points move away from the center. CO₂ moves to the third quadrant while CH₄ is moving into the fourth quadrant with rising concentrations.

Conclusion

Gas sensing using intrinsic noise analysis of MEMS microphones, which are mass-produced, inexpensive, low-power, and already integrated into many electronic devices, is feasible. The concept may be used to deploy large-area networks of sensors across landfill sites. Such distributed systems could provide continuous, spatially resolved monitoring of methane and carbon dioxide emissions at significantly lower cost than conventional gas analyzers. Therefore, the results of support the concept that intrinsic noise analysis of MEMS microphones could form the basis of scalable, low-cost landfill gas monitoring systems, capable of detecting methane and carbon dioxide variations in nitrogen-dominated environments.

Future work could extend this approach to measure environmental parameters such as humidity, temperature values using only the intrinsic noise spectrum of MEMS microphones. Such developments could enable compact, low-cost and non-invasive monitoring solutions for atmospheric or industrial applications.

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