Proposed Method for Chemical Detection Using Photoacoustic Spectroscopy and Acoustic Beamforming

Aurelius Graninger, Fow-Sen Choa*

Department of Computer Science & Electrical Engineering, University of Maryland Baltimore County

**Corresponding author: choa@umbc.edu*

ABSTRACT

In recent years many advances have been made in the area of gas detection, especially with the advent of the Quantum Cascade Laser. However, many methods of detection require that the gas be at the location of the sensor, contained in a chamber. Here we propose a new method for standoff chemical detection that combines photoacoustic spectroscopy and acoustic beamforming. Photoacoustic spectroscopy is a proven method for gas detection presently employed in systems such as FTIR that takes advantage of a molecule's excitation via certain light wavelengths to detect its presence. Acoustic beamforming is a technique that allows one to listen in to a specific point in space while cancelling external noise; this will allow us to detect signals from a remote location, rather than a contained location next to the sensor. The system will be comprised of two microphone arrays which will be used to form two acoustic beams aimed at a specific point in space where a molecule's presence is suspected. Then, two Quantum Cascade Lasers will be aimed at this location such that their crosspoint overlaps with that of the acoustic beams. By modulating the QCLs and utilizing beamforming techniques, we can effectively sense chemicals remotely, and by moving the focal point, map the density of a chemical present in an area.

BEAMFORMING THEORY

•Utilize a microphone array to receive the sound source

•DSP is used to "steer" the array to point in a desired location

•Delay and sum beamforming will be used; each microphone is delayed such that the sound source is added constructively, while background white noise is added destructively

•Farfield approximation of sound wave is used due to distance and simplicity

$$b(\boldsymbol{\kappa}, t) = \sum_{m=1}^{M} w_m p_m(t - \Delta_m(\boldsymbol{\kappa}))$$

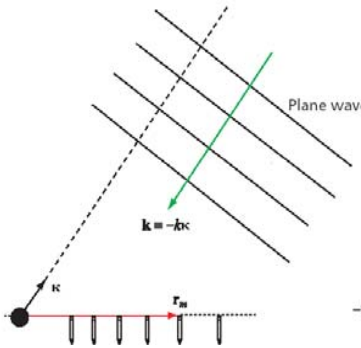
•b is the summed signal at a time t

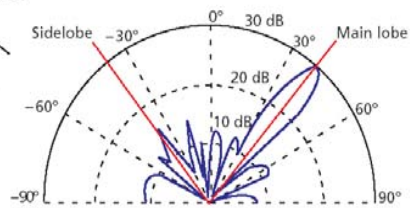
•w_m is weighting coefficient for each microphone

•Δ_m is time delay for each microphone:

$$\Delta_m = \frac{\boldsymbol{\kappa} \cdot \mathbf{r}_m}{c}$$

[1]





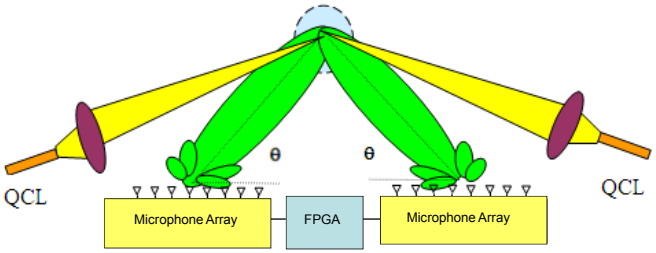
[2]

EXPERIMENTAL SETUP

•Two microphone arrays utilized for single point detection

•Signals obtained are sent to Field Programmable Gate Array for processing and beamforming

•FPGA can dynamically steer microphone arrays to obtain spectra for multiple points



ELECTRICAL SETUP

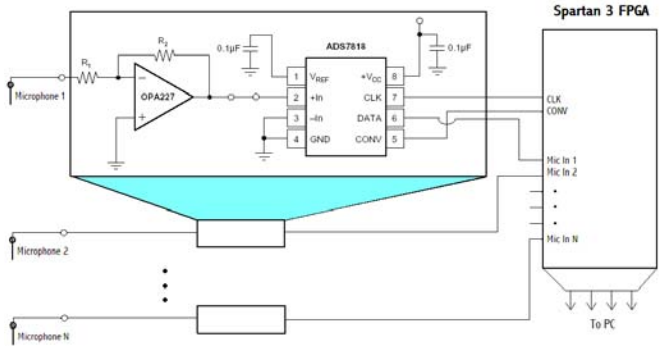
•Output of each microphone is sent through a low noise preamplifier

•The amplified signal is the analog input to an analog-to-digital converter

•The ADC is provided a clock and enable signal by the FPGA

•Serial output for each ADC is simultaneously collected by the FPGA

•FPGA sends processed signals back to LabVIEW for inspection



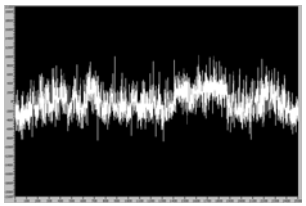
RESULTS

•At the time of presentation, the research is still ongoing

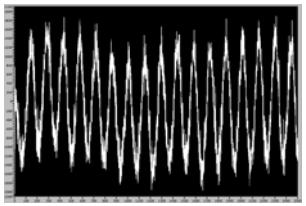
•A single microphone setup has been designed and tested

•Shown below are signals obtained at a 3 MHz sample rate of background white noise, and a person whistling and humming:

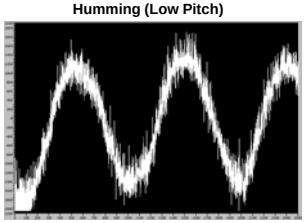
Background White Noise



Whistling (High Pitch)



Humming (Low Pitch)



FUTURE WORK

•Complete microphone array and run tests to ensure external noise cancellation

•Test system with single wavelength QCLs and chemical with absorption peak at that wavelength

•Contribute work on integrated tunable laser

•Test different beamforming approaches and DSP techniques for further optimization

REFERENCES

[1] Johnson D.H. and Dudgeon D.E., *Array Signal Processing: Concepts and Techniques,* Prentice Hall, New Jersey, 1993

[2] Christensen, J.J. and Hald, J., "Beamforming," Brüel & Kjær Technical Review No.1, 2004

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