Beamforming with Collocated Microphone Arrays

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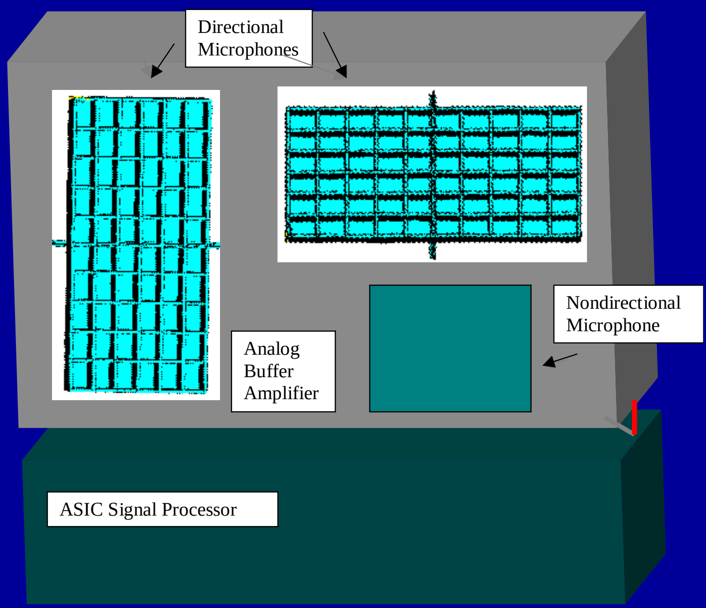
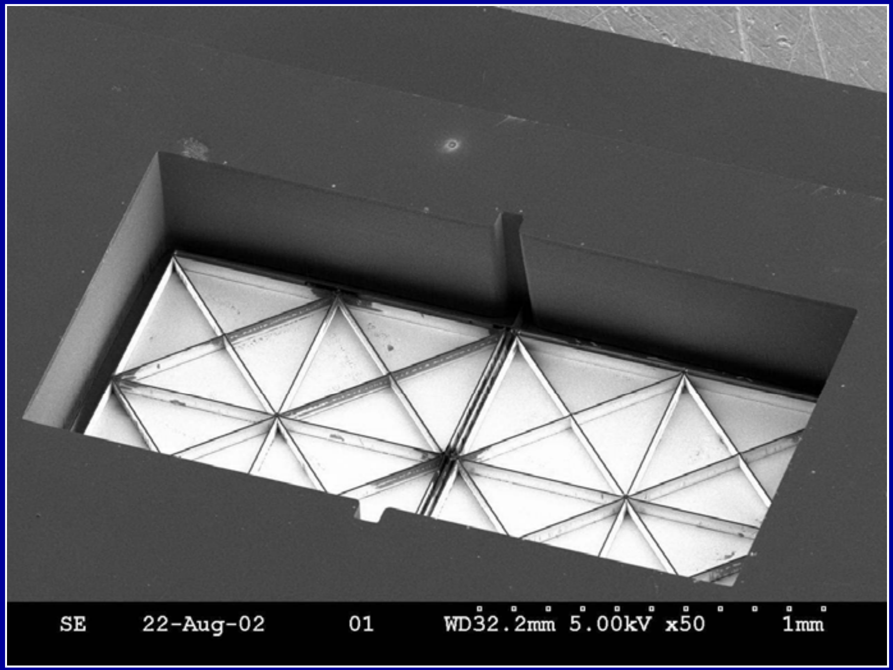
Background

- DARPA Acoustic Microsensors Program
- Goals
  - Development of MEMS microphone technology (~1 cm^3), (SUNY Binghamton)
  - Localization and **extraction** of acoustic sources (UIUC)
- Processing influenced by work with two-sensor frequency-domain beamforming

Sensor Array – MEMS, SUNY

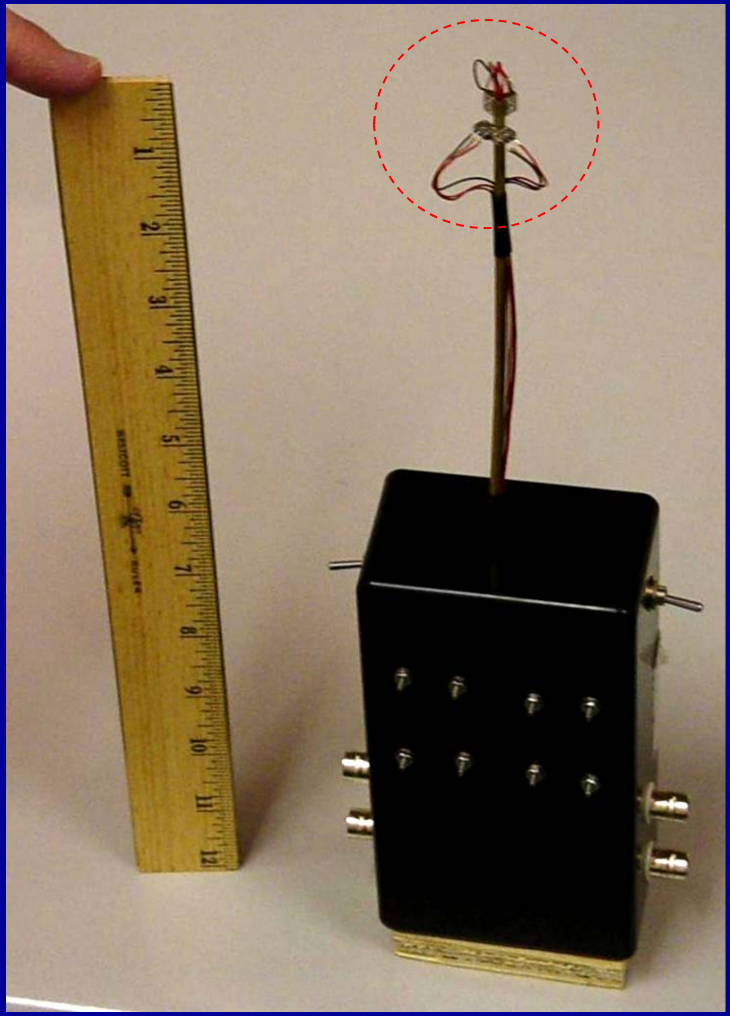
- Very directional, small sensor is desirable
- MEMS array uses a “teeter-totter” type design to sense pressure differences (2 – 3 mm in length)
- They exist, excellent mechanical performance





Sensor Array – non-MEMS

- For proof-of-concept, commercial miniature gradient mics (Knowles NR-3138) were used
  - Each is 6 x 4 x 2 mm
- 1st order, Fig.-8 response
- Arrays of:
  - 2 gradients (X,Y), 1 omni
  - 3 gradients (X,Y,Z), 1 omni (pictured) →



Signal Processing -UIUC

- Conventional techniques
  - *Omnidirectional* sensors, spatially separated
  - **Phase difference** exploited by the processing
- The FMV technique can be used
  - *Directional* sensors, collocated
  - **Amplitude differences** exploited by processing
- Requires:
  - Differently-oriented directional sensors
  - Responses well characterized for θ, φ, and f

FMV Algorithm

- Assumption – relationships between microphones are known for different angles and frequencies
  - Steering vector, impulse response known for direction of target source
  - *f*(azimuth, elevation, frequency)
  - Microphones matched for target direction
- For each frequency band, for a short period of time, find solution that minimizes the output power while maintaining unity response (no distortion) in extraction direction

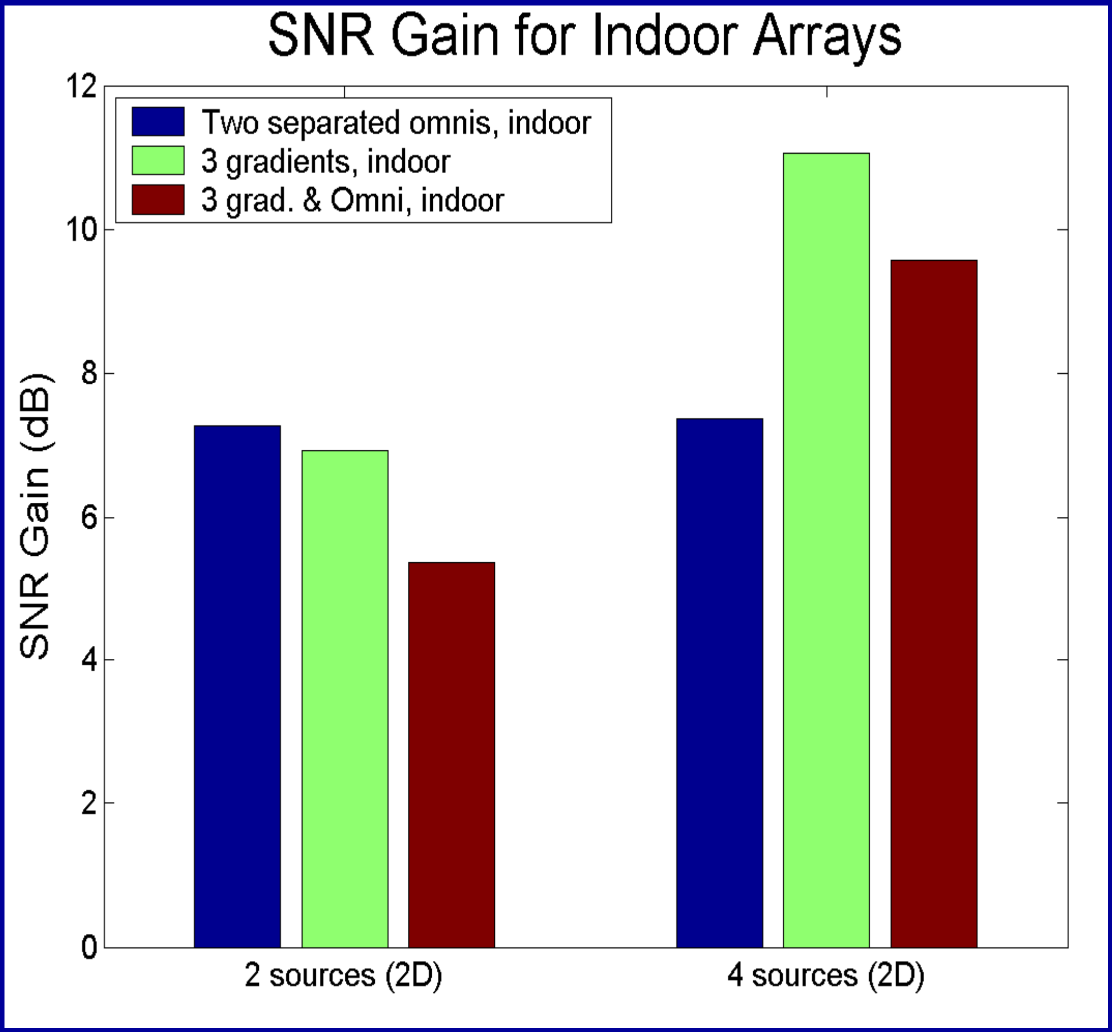
Recordings

- Indoor
  - Sentences (speech) recorded at two elevations (0°, +45°) and eight azimuths (-80° to +60°, every 20°)
  - White noise and MLS sequences
  - Distance = 0.75 m, sound-treated room
- Outdoor
  - Sentences, MLS sequence recorded at 6 elevations, 24 azimuths (full 360°, every 15°)
  - Distance = ~ 3m, grassy field, windscreen used
- Goal
  - Evaluate and compare algorithm performance in both environments, compare to 2-mic. separated array

Tests, Calibration

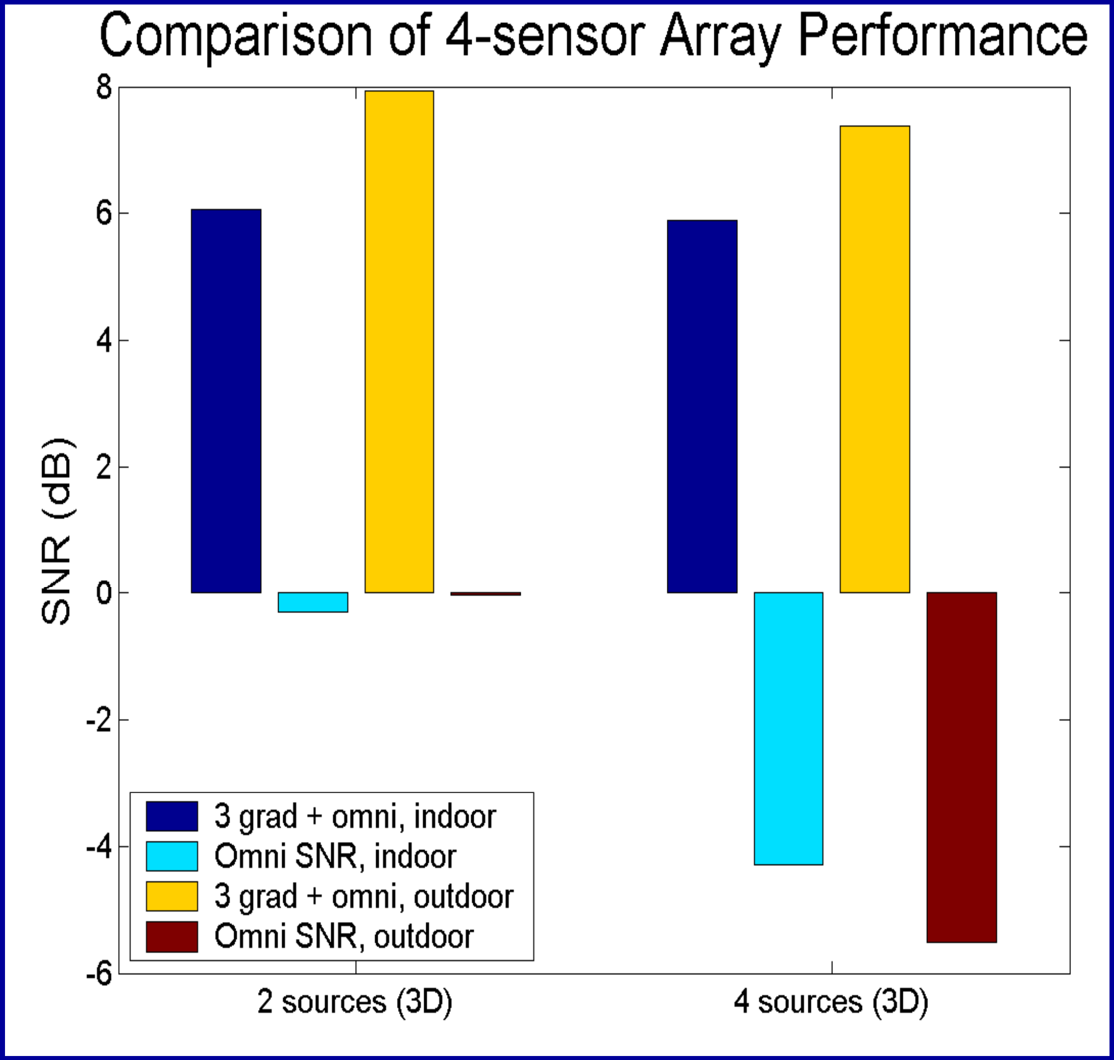
- Interferers 20° from target (indoor), 15° from target (outdoor), across front half plane, to evaluate extraction for “nearby” sources
- One or three interferers, various interferer and target locations varying in azimuth and elevation Some 2D, some 3D.
- Steering vectors obtained from calibration recordings – interpolate for other bearings

Results – Indoor Recordings, 2D



- SNR metric based on signal energy
- Generally comparable to separated sensor array, sometimes better
- 3 grad. array performs better - robustness

Results – Indoor, Outdoor, 3D



- Test signals not identical
- Trends very similar
- High SNR gains for 3D multiple-interferer signals

Conclusion

- Performance is comparable to performance of a separated (~15cm) two-sensor array
- Separates in 3D
- Exciting result, given small size of the array
- More sensitive to microphone mismatch. Effect of significant reverb unknown.
- LF performance - MEMS mics. improve?

- Research made possible by DARPA

Test #	Target Location (Az., El.)	Interferer Locations (Azimuth, Elevation)
1	(60º, 0º)	(40º, 0º)
2	(40º, 0º)	(60º, 0º)
3	(20º, 0º)	(40º, 0º)
4	(0º, 0º)	(20º, 0º)
5	(-20º, 0º)	(0º, 0º)
6	(-40º, 0º)	(-20º, 0º)
7	(-60º, 0º)	(-40º, 0º)
8	(-80º, 0º)	(-60º, 0º)
9	(0º, 0º)	(60º, 0º), (-40º, 0º), (-80º, 0º)
10	(-40º, 0º)	(40º, 0º), (0º, 0º), (-80º, 0º)
11	(0º, 0º)	(0º, 45º)
12	(0º, 0º)	(40º, 0º), (0º, 45º), (-80º, 0º)
13	(0º, 45º)	(0º, 0º)
14	(0º, 45º)	(40º, 0º), (0º, 0º), (-80º, 0º)

Test #	Target Location (Az., El.)	Interferer Locations (Azimuth, Elevation)
1	(60º, 0º)	(45º, 0º)
2	(45º, 0º)	(60º, 0º)
3	(30º, 0º)	(45º, 0º)
4	(0º, 0º)	(15º, 0º)
5	(-15º, 0º)	(0º, 0º)
6	(-30º, 0º)	(-15º, 0º)
7	(-45º, 0º)	(-30º, 0º)
8	(-60º, 0º)	(-45º, 0º)
9	(0º, 0º)	(60º, 0º), (-45º, 0º), (-75º, 0º)
10	(-45º, 0º)	(45º, 0º), (0º, 0º), (-75º, 0º)
11	(0º, 0º)	(0º, 39º)
12	(0º, 0º)	(45º, 0º), (0º, 39º), (-75º, 0º)
13	(0º, 39º)	(0º, 0º)
14	(0º, 39º)	(45º, 0º), (0º, 0º), (-75º, 0º)