Results from a prototype tetrahedral array for tracking sound sources in shallow water

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Motivation

• Use passive acoustics in a near shore environment to detect sources by their characteristic sound (signature)
  – No environmental impact
  – Sources don’t know they are being detected
  – Broadband, mid- to high frequency sources (1kHz to 40 kHz)

• Goals
  – Detect, classify and track underwater broadband sources
  – Robustness over accuracy
  – Develop a computational inexpensive model
  – “Small scale” (few hydrophones)
  – TDOA, Likelihood function*, Beamforming

* 5aEA12. Diver Monitoring using the Hawaii Experimental Acoustic Range
Hydrophone Configuration

• 4 hydrophones for each Array
  – 3 in the horizontal plane
  – 1 raised from the center
  – Can be steered both vertically and horizontally

• Phase center is center of spherical coordinate system
  – Azimuth: Theta [0-360] deg
  – Elevation: Phi [0-180] deg
Model Validation

- Linear up-chirp from 20-40 kHz @ 192 kHz
- Length: 0.015 s duration

- Source Location: \( \theta = 40^\circ, \phi = 70^\circ, d = 100 \text{ m} \)
  - Plane wave assumption* (radius = 0.9 m)

- \( \lambda/2 \) frequency: 850 Hz
  - General problem with grating lobes

* Array Signal Processing by Don H. Johnson: \( \approx 60 \times \text{radius} \)
Model Results
Beamformer Output

Scaled Image Plot

Theta [deg]
0 50 100 150 200 250 300 350

Phi [deg]
0 20 40 60 80 100 120 140 160

Scaled Image Plot

Theta [deg]
25 30 35 40 45 50 55

Phi [deg]
95 100 105 110 115 120 125

dB
-64 -62 -60 -58 -56 -54 -52
Model Results
Directivity Plot
Source with white Noise

Scaled Image Plot, Source at Theta = 40.0 deg, Phi = 70.0 deg, SNR = 10.0 dB

Theta Location (Source as 40 Deg) versus SNR

Phi Location (Source as 70 Deg) versus SNR
HPW - Resolution

Horizontal HPW
Original Range: 0-12 deg

Vertical HPW
Original Range: 0-16 deg
Experimental Setup

- **Location:** Makai Research Pier
- **2 Arrays (5 phones each)**
  - Reson omnidirectional TC4032 Hydrophones, Frequency Response +/- 1 dB
  - Flexible configuration
  - 192 kHz digitized at 24 bit
  - Anti aliasing filter
  - 10 Hz high pass filter

- **Source:**
  - Depth: 1 m
  - SL: ~ 90 dB re. 1 μPa
  - Chirp Length: 0.150 s
  - Sweep: 20 to 40 kHz
Results – Makai Exp.

• Source 1 (-93 deg) – 1 deg search: -89 deg – ¼ deg search: -92.5 deg

• Source 2 (-93.6 deg) – 1 deg search: -93 deg – ¼ deg search: -93.5 deg

• Source 3 (-94.7 deg) – Any search: -100 deg

• Source 4 (-36 deg) – 1 deg search: -42 – ¼ deg search: -36°

$\theta = 271°$

$\Phi = 78°$

$\theta = 267.5°$

$\Phi = 79.9°$
Conclusions

• Beamformer is accurate as long as there are no side reflections
  – Horizontal source location can be determined with bottom or surface reflections (subject to environmental conditions)

• Change array configuration to a circular array (Application dependent)
  – triangulation
  – Reduce computational cost
  – Increase horizontal resolution

• Experiment with 3 arrays in an open shallow water environment
  – Location: South Shore Oahu, Kilo Nalu Ocean Observatory
  – Goal: Identify likely multipath models and construct a model utilizing a Likelihood function along with TDOA and focused beamforming

• Noisy environments
  – Energy Detectors (Teager-Kaiser Operator)
  – Edge detector in Spectrograms (e.g. Laplacian)