Title

2D and 3D Acoustic Source Localization Using the AML Algorithm and ENSBox Nodes

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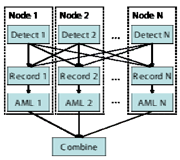
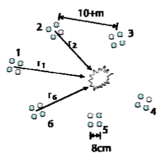
Introduction: Localization by fusing AML bearing estimates from multiple nodes

Deployment Overview

- ENSBox nodes manage themselves and able to perform self node-localization
- Each node records and detects the event, and then run the AML algorithm
- Result is sent to a fusion center to be combined for localization





Approximate Maximum Likelihood (AML)

- Signal Model
  - Time domain: $x_p(t) = s(t-\tau_p) + n(t)$
  - Freq domain: $X(w_k) = S(w_k)e^{-j2\pi k t_p/L} + \eta(t)$
- Optimal under Gaussian noise (approaches CRB)
  - $DOA = \arg\max_{\tilde{r}_k} \sum_{k=1}^{N/2} \| P(w_k, \tilde{r}_k) X(w_k) \|$

  where, $P = DD^+$

  $D = [1 \quad e^{-j2\pi k \tau_{c1}/L} \quad \ldots \quad e^{-j2\pi k \tau_{cp}/L}]^T$

Problem Description: Field deployment can be harsh and the algorithm has to be robust

Deployment Issue

- Large deployment scale
- Rain, fog, sprinklers, mud, dirt and dust
- Setup time and break down time
- Network connectivity in an unknown terrain
- Node positions and orientations ground truth measurements
- System diagnostics, interface, and ease of use

Algorithm Issue

- Performance depends on source signal and array size, position and orientation
  - Closely spaced dominant frequencies is close to *narrowband*
  - Small array size removes ambiguity but has wide main-lobe
- Bearing fuse problem
  - Orientation error and non-uniform signal gain render the *maximum likelihood* (ML) weighting ineffective
- Reverberation
  - Reflection off the trees or buildings introduce *bias*

Proposed Solution: Deploy ENSBox as sub-array and estimate from weighted log-likelihood

ENSBox Architecture

- Packaging
  - A *self-contained* processor and array with an internal battery, weather-resistant packaging and tripod mount ready
- Management
  - A *web-based* management and diagnostic tool to identify problems with individual nodes
- Self-configuration
  - A *multi-hop wireless network* and a sophisticated array *self-calibration system* that can establish precise positions and orientations (within 10 cm and 1.5 degree in a 50 x 80 m field)
- Software API
  - A *synchronized sampling* API that greatly simplifies the development of collaborative sensing application software

Fuse Strategy

- Log-likelihood weight selection
  - Weight maximum based on ML (no weighting)
  - Lower bound minimum based on SNR
- Combining Strategy
  - Create a search map (2D or 3D) and divide into grids
  - Compute functional evaluation at each grid point by summing each node's log-likelihood value that points to the current evaluated position with the appropriate weight

Position & Bearing Estimation Results

- 2D position estimates: (x,y) in meters

Case	Mean	Std. Dev.	RMS Dist.
ICH Marmot	(39.01, 15.59)	(0.03,0.09)	0.78
ICH Noise	(38.27, 15.31)	(0.02,0.04)	0.35
OCH Marmot	(-24.92, 12.30)	(0.47, 0.22)	2.07
OCH Noise	(-27.10, 13.68)	(0.18, 0.08)	0.61

Inside Convex Hull (ICH)
Outside Convex Hull (OCH)

- 3D bearing estimates: (azimuth,elevation) in degrees

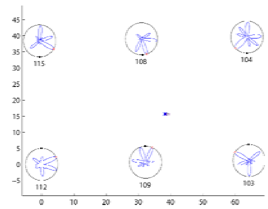
	Angular Error, (Azimuth, Elevation)					
	Mean			SD		
	Node 151	Node 152	Node 153	Node 151	Node 152	Node 153
Acorn Woodpecker	(-1.53,-2.68)	(1.47,1.42)	(-0.09,-0.01)	(1.41,0.74)	(1.18,0.82)	(1.69,1)
Mexican Antthrush	(2.36,-1.26)	(2.69, -1.44)	(-3.21,2.03)	(1.37,1.52)	(2.38,1.82)	(2.8,0.22)

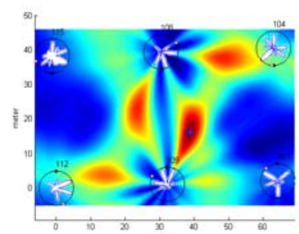
ENSBoxes

Version 1: tetrahedral 4 element array with 6 cm side length from top view

Version 2: tetrahedral 4 element array with 12 cm side length from top view

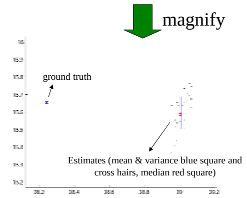
Localization in Action



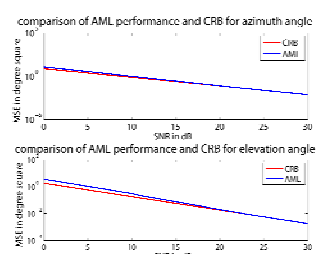


2D weighted log-likelihood

magnify



2D scatter plot of position estimates for ICH case



3D AML performance