Passive Acoustic Based Compliance Monitoring for Tidal Turbines

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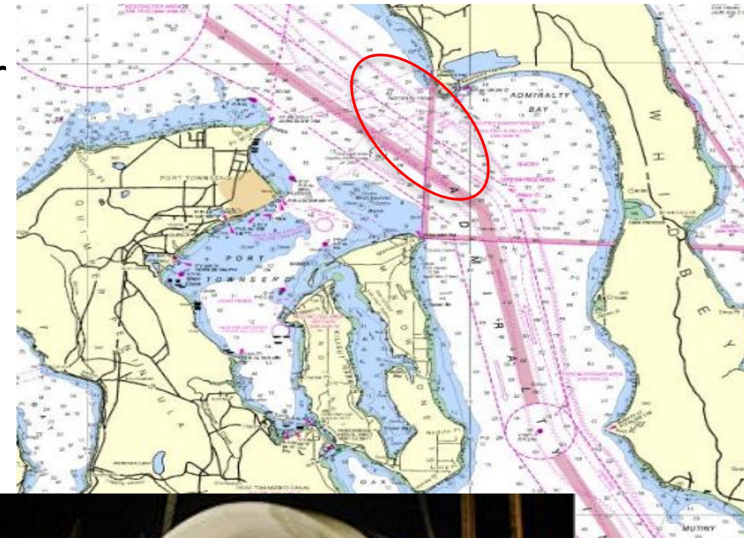
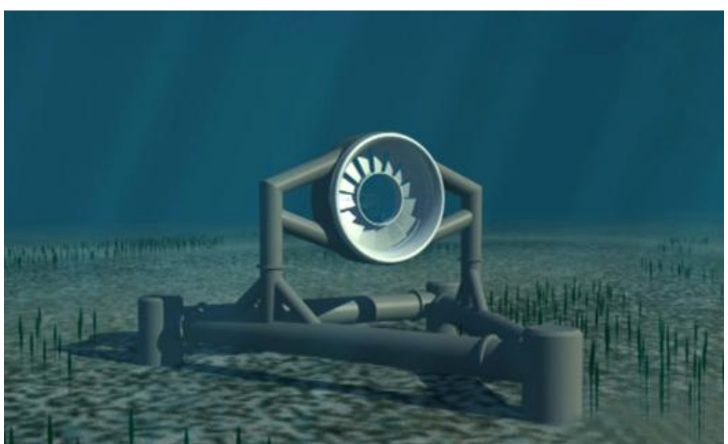
Pilot Tidal Power Project in Admiralty Inlet

Snohomish PUD

- Deployment in Admiralty Inlet, ~60 m water
- FERC pilot-scale license
- < 1-MW OpenHydro
- Migrating marine mammals, salmon (endangered species)
- PNNL role: Environmental assessment, acoustics, peer review of science





Problem

- Short Term – Prototype Stage – Two Turbines
  - Operational compliance at prototype scale
    - Regulators want assurance that endangered species (Southern Resident killer whales) will not be taken by tidal turbines.
      - Primary concern = strike and/or collision
  - Data to aid assessment of the risk of take of protected species by tidal turbines
    - Behavioral response to turbine presence and operation
- Long Term – Utility-Scale Stage – Many Turbines
  - Operational compliance measures and turbine operation flexibility that reflects risk of turbines to protected species

Approach to Problem

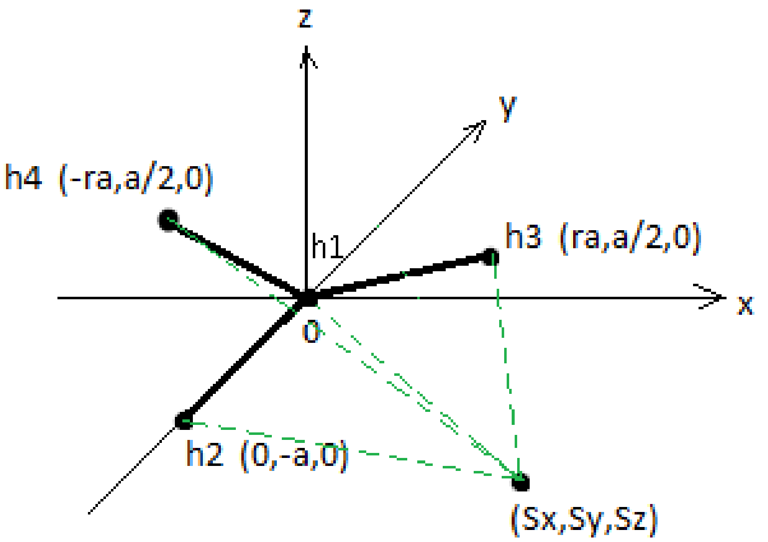
- Goal: Continuous passive acoustic monitoring for detection, classification, and localization (DCL) of killer whales within 200 m of prototype tidal turbines
- Develop means to integrate COTS components into acoustic instrumentation packages to be deployed with prototype tidal turbines
- Develop signal processing (algorithms and real-time processing software) to perform detection, classification, and localization tasks
- Validate system performance and enable competitive procurement of monitoring instrumentation by utilities

Killer Whale (*Orcinus orca*), or Orca

- Southern Resident killer whales
- Adult males 6-8 m long, weigh >6 tons
- Adult females 5-7 m long, weigh 3-4 tons
- Echolocate to find prey
- Very social – vocalize to communicate with others

Passive Array Configuration

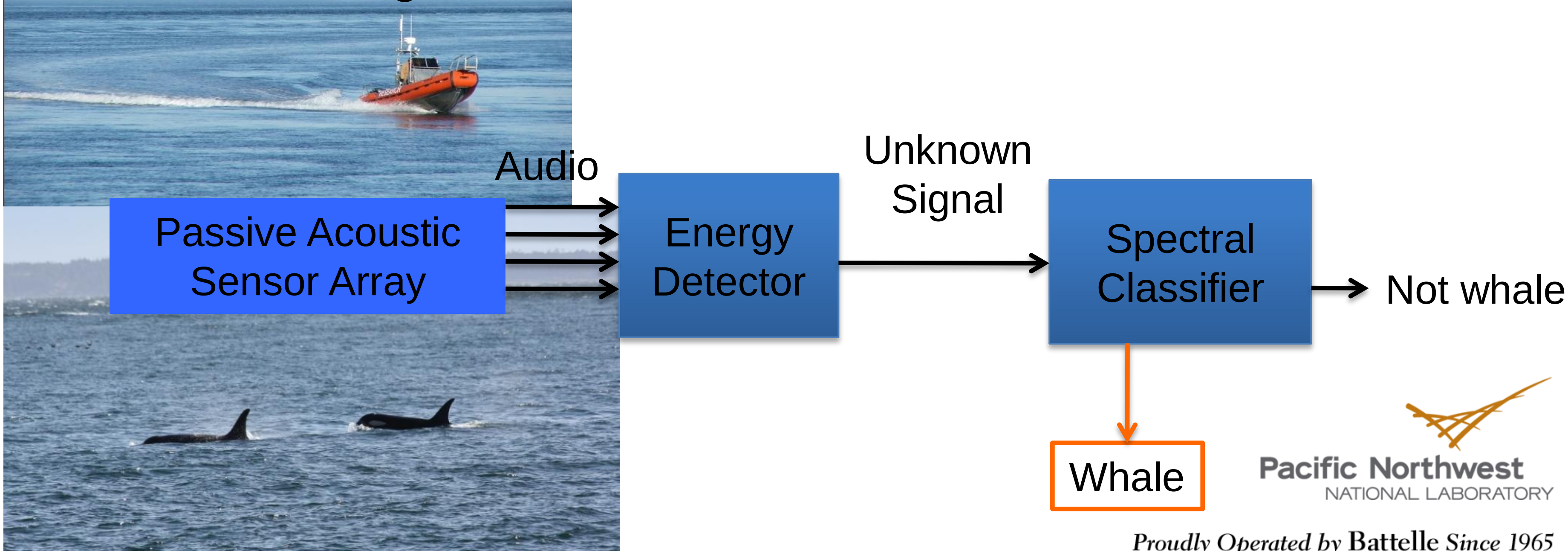
- Arm length = 2 meters
- Four hydrophones per array
- Two arrays, separated by 20 m
- Treat arrays as independent systems: acquire bearing from each array to the sound source, then calculate the source location as the intersection



Detection Approach

Goal: Detect the presence of whales.

- Two-stage detection.
  - Energy detector to identify candidate signals.
  - Spectral classifier to verify signal as whale call.
- First stage reduces data stored and processed.
- Second stage reduces false alarms.



Energy Detector Tuned for Whale Calls

Compute the energy in the time-domain audio signal.

Audio signal $x(n)$ → Bandpass filter 1 – 6 kHz → $x^2(n)$ → $\sum_{i=n-Tf_s}^{n} x^2(i)$ → Energy signal $e(n)$

Frequency band containing most of whale call energy.

Sum energy over time period T that is average duration of whale call.

Detect an increase in energy.

$e(n) > E$ → $e(n) \geq e(n-1)$ → $c = c + 1$ → $c > C$ → Save audio signal.

Compare energy to threshold E that is a multiple of background energy.

While energy is increasing, increment counter.

Compare count to threshold C that is related to duration of whale call.

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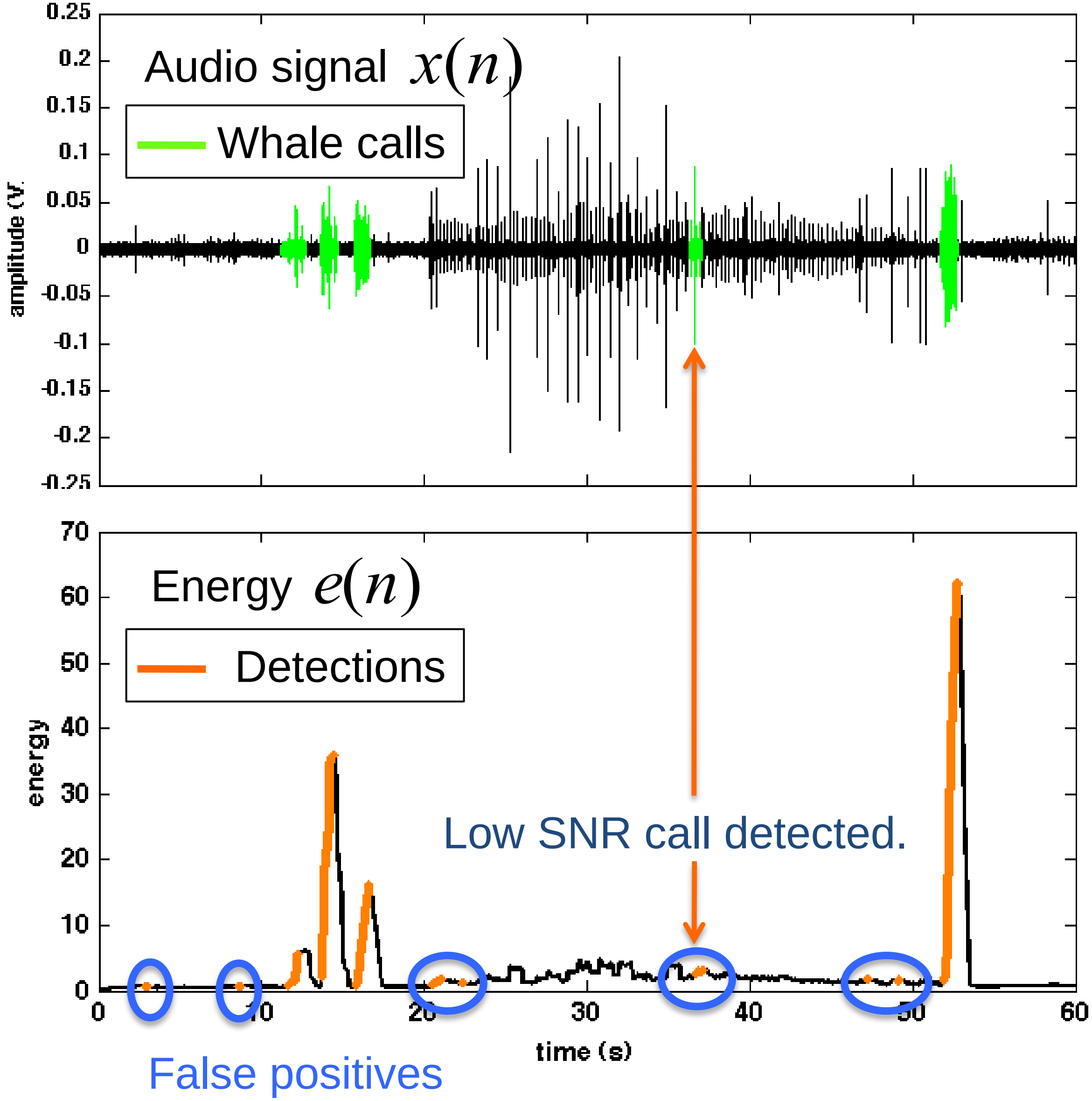
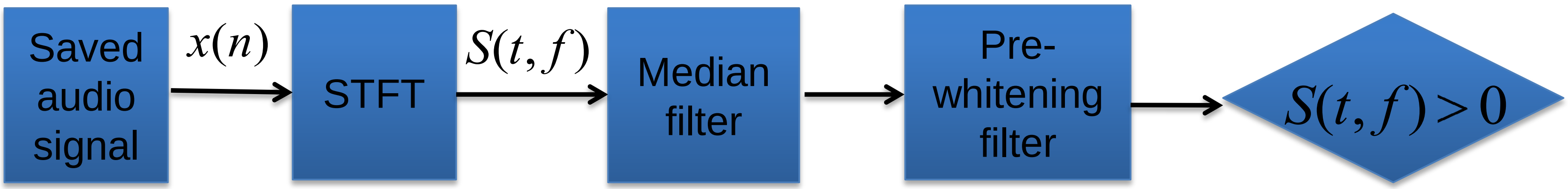
Energy Detector Example



All calls detected plus some false positives.

Spectral Classifier

Apply filters to increase signal-to-noise ratio.



Generate spectrogram because calls have time-frequency structure.

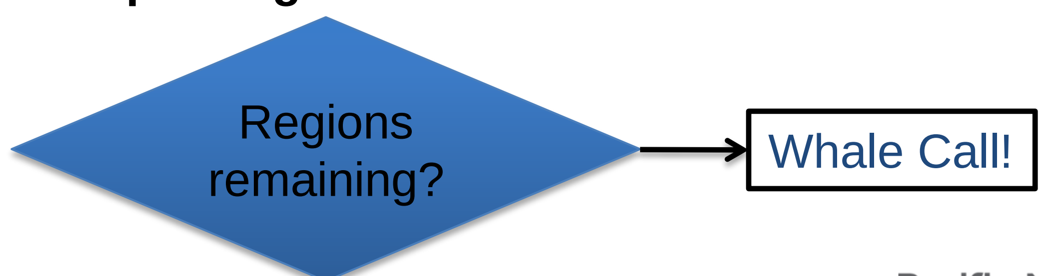
2D low pass filter preserves peaks.

Subtract average background spectrum.

Binary image after filtering.

Eliminate regions of filtered spectrogram not characteristic of whale calls.

✓Bandwidth
✓Duration



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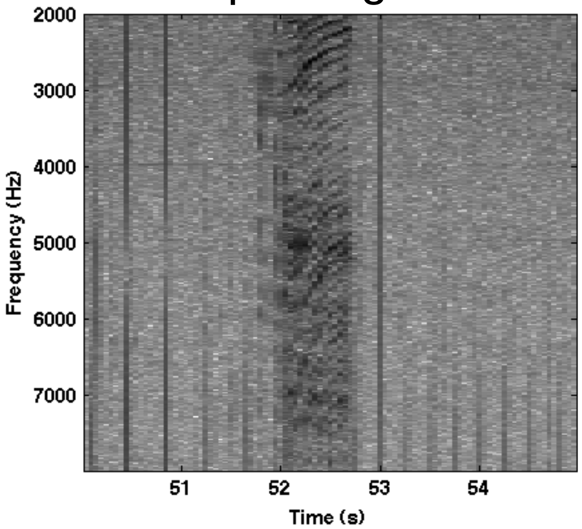
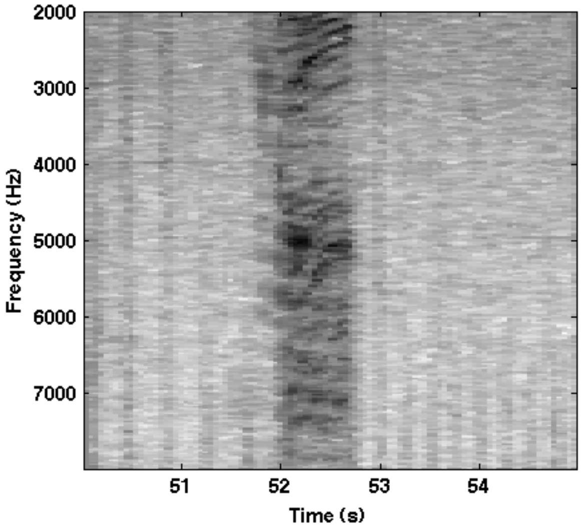
Example Spectral Classifier

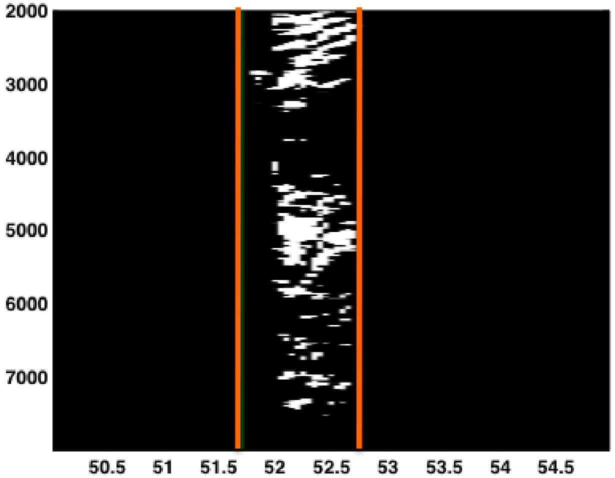
Spectrogram



Filtered Spectrogram



Binary Image



Detected call

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Performance Model

$$P_d = p(d \mid v)\,p(v \mid b)\,p(b)$$

Probability of detecting whales	Probability of detecting vocalization	Probability whales are vocalizing given behavior	Probability of behavior

- Other factors
  - Number of whales vocalizing
  - Vocalizations per time period
  - Speed of travel

Evaluation

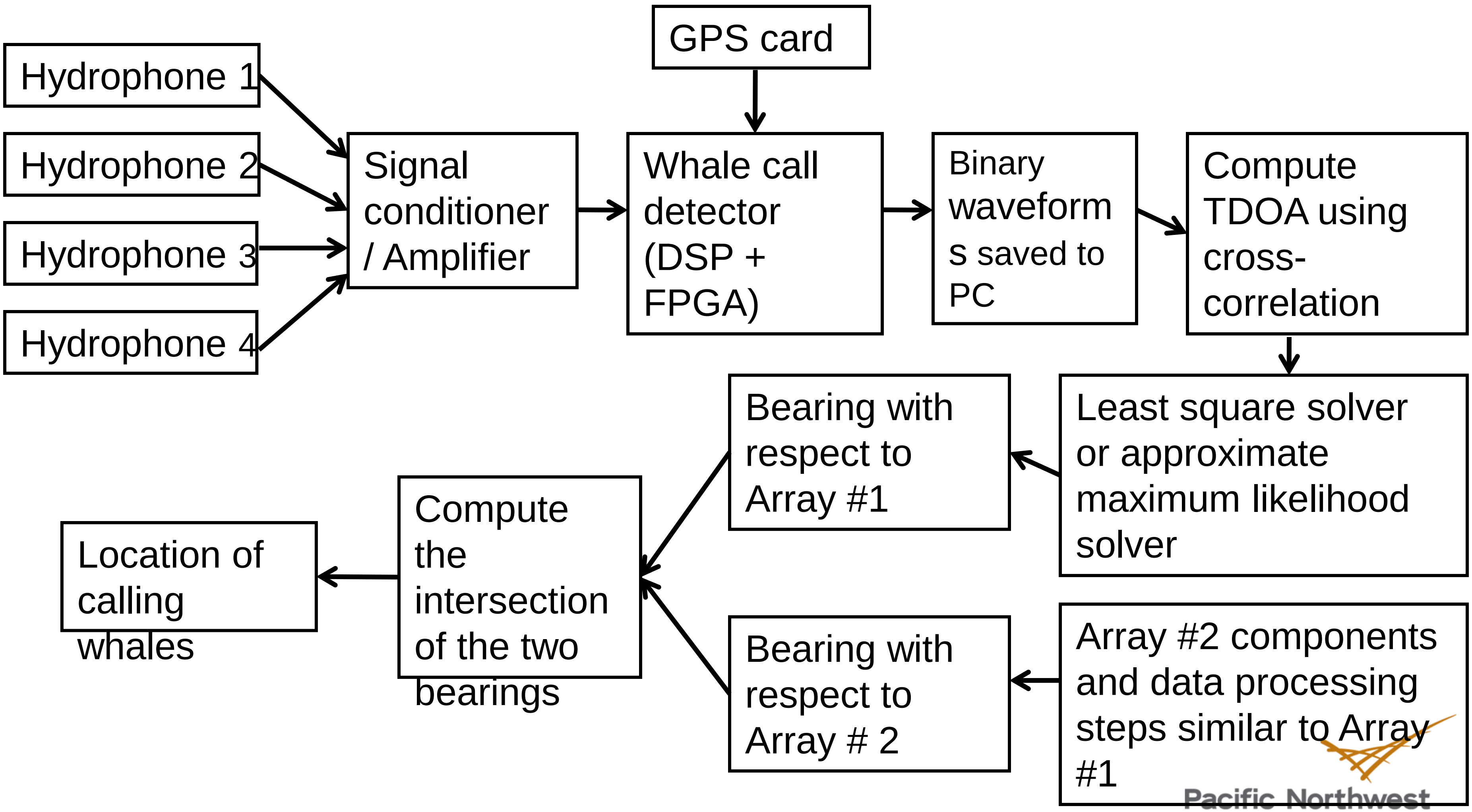
- Datasets
  - Whale calls – annotations
  - Background – no whales
  - Boats
- Performance measures
  - Probability of detection of vocalization
  - Probability of detecting whales
  - False alarm rate (false alarm per minute when no whales)
  - Probability of detecting boat (want this to be zero)

Detect 78% of vocalizations → Detect 100% of whale presence

False alarm rate: 12 false positives per hour **Need to improve!**

Use statistics of detections from each dataset to refine classifier.

Whale Call Processing for Localization



Localization Performance Expectations

- Within 200 m from the star arrays, the bearing error of the estimates on the xy-plane (2D error) should be within 5 degrees.
- The detection range depends on the TDOA errors resulting from different sources of measurement error (hydrophone location, sound speed, and timing).
- If the combined TDOA error is on the order of 10 µs, the detection range is up to 200 m with 15-m accuracy; if the combined TDOA error is on the order of 100 µs, the detection range will be 50-100 m with 15-m accuracy.
- The sampling frequency of MAAS is 1 MHz and the GPS is has 0.4 µs accuracy, we anticipate the TDOA errors to be on the order of 10 µs.

Summary

- An eight channel passive acoustic receiver system has been built which will permit detection, classification, and localization of vocalizing marine mammals within 200 m of tidal turbines
- Performance expectations for the system have been developed
- In-field testing will be conducted in a location where killer whales are likely to be observed to validate system performance expectations

PNNL Contributors

- Permitting and Public Interaction: Kara Blake, Luke Hanna, Simon Geerlofs, Laura Zdanski, Andrea Copping, and Brie Van Cleve
- Active Sonar : Jinshan Xu , Jayson Martinez, Bob Mueller, Mark Weiland, and Josh Meyers
- Noise Measurements: Jinshan Xu, Jayson Martinez, Josh Meyers, and Bob Mueller
- Target Strength Modeling: Jinshan Xu, Jayson Martinez, and Graysen Squeochs
- Passive Detector Algorithm Development: Tao Fu, Huiying Ren, Shari Matzner, and Yannan Sun
- Detector Hardware/Implementation Development: Eric Choi, Tao Fu, and Jayson Martinez
- Design Array Design and Simulation: Yannan Sun, May Chandler, and Andrew Stevens
- Array Mechanical Design: Jayson Martinez and Josh Meyers.
- Deployment Site Survey and Array Installation: John Vavrinec, Rhonda Karls, Susan Southard, Kathleen Hall, Josh Myers and Jennifer Elster

Collaborators

- University of Washington
  - Broadband Noise Measurement
  - Noise Sample Processing and Metric Standardization
  - Passive and Active Acoustic System Deployment Strategies
  - Power and Data Transmission Cable Specifications
- Sea Mammal Research Unit (SMRU)
  - Killer Whale Behavior (Vocalization and Movement)
  - Detection and Classification Algorithm Development
  - Lime Kiln Passive System Assessment
- BioSonics Inc.
  - Active Acoustic “Sideband” Sound Evaluation
  - Killer Whale Target Strength Model Validation
- NMFS
  - Time-Depth Recorder (TDR) and Dtag Data Sets
- Others
  - Dr. Brandon Southall – Marine Mammal Noise Exposure
  - Dr. Jennifer Miksis-Olds – Ecological Acoustics