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
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.

Diagram:

1. Passive Acoustic Sensor Array → Audio
2. Audio → Energy Detector
3. Energy Detector → Unknown Signal
4. Unknown Signal → Spectral Classifier
   - Whale
   - Not whale
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.

$e(n) > E$ → $e(n) \geq e(n-1)$ → $c > C$ → 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.
Energy Detector Example

Audio signal $x(n)$

- Whale calls

Energy $e(n)$

- Detections

Low SNR call detected.

All calls detected plus some false positives.
Spectral Classifier

Apply filters to increase signal-to-noise ratio.

1. Saved audio signal $x(n)$
2. STFT to generate spectrogram $S(t,f)$ because calls have time-frequency structure.
3. Median filter preserves peaks.
4. Pre-whitening filter subtracts average background spectrum.
5. Binary image after filtering.

Eliminate regions of filtered spectrogram not characteristic of whale calls.

- Bandwidth
- Duration

Regions remaining? Whale Call!
Example Spectral Classifier

Spectrogram

Filtered Spectrogram

Binary Image

Detected call
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 \(\rightarrow\) Detect 100% of whale presence

False alarm rate: 12 false positives per hour \需改进!\n
Use statistics of detections from each dataset to refine classifier.
Whale Call Processing for Localization

Hydrophone 1
Hydrophone 2
Hydrophone 3
Hydrophone 4

Signal conditioner / Amplifier

GPS card

Whale call detector (DSP + FPGA)

Binary waveform s saved to PC

Compute TDOA using cross-correlation

Least square solver or approximate maximum likelihood solver

Array #2 components and data processing steps similar to Array #1

Bearing with respect to Array #1

Bearing with respect to Array #2

Compute the intersection of the two bearings

Location of calling whales
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.
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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