Acoustic Ship Classification

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Maritime Security Domain

USS Cole bombing in 2000 – Killed 17 US Navy sailors
outline

• The acoustic system
• The acoustic signature processing
  – Cross correlation
  – Noise modulation
• The acoustic signature analysis
  – ship classification
• The decision making automated algorithm
  – Decision Tree
• conclusion
Passive Acoustic system

An acoustic system simply listens to its immediate environment.

*Omni-directional hydrophone*

- A pressure sensor designed to sense acoustic pressure
- Equally in every direction
Acoustic Methodology – Maritime Security Lab Architecture

The processing

Ship Noise

1) mechanical noise of the main engine and auxiliary machine
2) propeller cavitations noise
3) Hydrodynamic noise of the moving vessel.
Ship Detection

Cross-correlation

- The noise radiated by a ship propagates underwater and reaches the hydrophones at different times due to different propagation distances.
- This delay depends on the direction of the ship.

Video: F:\Ship Detection\computer\Screen.avi
Noise Modulation

Modulation is the process of taking a signal (voice, ship noise etc) and converting it into some aspect of a sine wave. Then transmitting the sine wave leaving the actual signal behind.

- Ship noise = information signal
- Water = medium
- Sine wave = carrier

Amplitude modulation:
We allow the amplitude of the carrier to change in respond to the information signal
But everything else is kept fixed!
SHIP CLASSIFICATION – final signatures

- Speed Boat
- DEP Boat
- State Police
- Sail Boat

Frequency [Hz]
Ship Classification—Using Attributes

- The general process of classification is placing individual vessels into groups labeled based on quantitative information of its attributes.
- Attributes are: well described categories that are usually denoted by a numerical or alphabetic code.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Attributes subpopulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Peaks</td>
<td>2-3 peaks</td>
</tr>
<tr>
<td></td>
<td>4 peaks</td>
</tr>
<tr>
<td></td>
<td>other</td>
</tr>
<tr>
<td>Main Frequency</td>
<td>10-14 Hz</td>
</tr>
<tr>
<td></td>
<td>41-46 Hz</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>Maximum Frequency</td>
<td>14-41 Hz</td>
</tr>
<tr>
<td></td>
<td>Above 130 Hz</td>
</tr>
<tr>
<td></td>
<td>Other</td>
</tr>
<tr>
<td>Amplitude Ratio</td>
<td>2-4</td>
</tr>
<tr>
<td></td>
<td>other</td>
</tr>
</tbody>
</table>
Ferries on the Hudson River

<table>
<thead>
<tr>
<th>Type</th>
<th># peaks</th>
<th>Main Freq</th>
<th>Max Frequency range</th>
<th>Amp first/sec</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferry_A</td>
<td>3</td>
<td>~11 Hz</td>
<td>20-40 Hz</td>
<td>2&lt;x&lt;4</td>
<td></td>
</tr>
<tr>
<td>Ferry_B</td>
<td>4</td>
<td>~41 Hz</td>
<td>&lt;130 Hz</td>
<td>2&lt;x&lt;4</td>
<td></td>
</tr>
</tbody>
</table>
Classification algorithms

- Objective: automate the process of searching for patterns in the data

- The data set consists of information $x$ and $y$ for each vessel. $x$ denotes a vector of each attribute, $y$ denotes the group label (ferry, not ferry, speed boat etc). $\phi$ - a rule used to evaluate all $x$, that will then declare a range $\hat{y}_j$ that is as close as possible to the real $y_j$ (group label).

- It is the responsibility of the classification algorithm to approximate as closely as possible to the true group labels. Such that:

$$\hat{y}_j = \phi(x_j) \approx y_j$$
Decision Tree algorithm

The process: At each node the algorithm chooses one attribute of the data that most effectively splits its set of samples into subsets.

By measure of homogeneity of the data

Entropy
Information Gain [using entropy]

Information = Entropy of Gain - Sum (entropy of parent table of each subset Si)

Entropy = \( \sum -P_j \log_2 P_j \)

Probability = (# positive instances) / (# total instances)
Conclusion

This case study has demonstrated the effectiveness of utilizing DEMON acoustic signatures for boat identification. Attributes for classification were extracted from the boat signatures and the simplified decision tree was built. Future work is needed in maintaining a catalog for acoustic signatures; developing a library of few hundred boats signatures will allow for more accurate classification of vessels.

Acknowledgment

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Questions?