Robust Automatic Detector And Feature Extractor For Dolphin Whistles

Joel Bud and Guy Shkury
Supervised by Dr. Roee Diamant

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Agenda

• Background
• Previous works
• Goals
• Main Challenges
• Our solution - ECV
• Results discussion
• Conclusions
Background

- Two endangered species
- Underwater desert
- Human interaction
- Whistles (and Clicks)

Short-beaked common dolphin, Delphinus delphis; http://marinebio.org

Common Bottlenose Dolphins, Tursiops truncatus; Yotam Zuriel, Ashdod, Israel
Previous Work

• Semi-automatic detection, manual feature extraction
  [Song et al. 2015]

• Naïve Scenarios to increase SNR:
  hydrophone arrays
  suction cups on dolphins
  [Oswald et al. 2003, Erbs et al. 2017]
  [Esfahanian et al. 2013]

• Consensus of features needed for classification
  [Esfahanian et al. 2014]
  [Oswald et al. 2003]
  [Erbs et al. 2017]
Model and Assumptions

- Single hydrophone
- Surveying vessel
- Dolphin whistle and Additive noise:
  - i.i.d Gaussian noise
  - Noise transient
  - Low frequency artificial noise

\[
y(t) = d(t) + n(t), \\
n(t) = n_g(t) + n_h(t) + n_u(t)
\]
Dolphin Whistles

Bottlenose dolphin

Common dolphin
Goals

- Automatic detection
- Automatic feature extraction

* Dolphin whistle recordings in the presentation were provided by Yotam Zuriel, Morris Kahn Marine Research Station, University of Haifa, Israel
Main Challenges

- Underwater noise
- Keeping it simple and robust
- Contour tracing
- Lack of data sets for the region
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- Underwater noise
- Keeping it simple and robust
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Believe it or not, there's a whistle here.
ECV - Entropy, Correlation and Viterbi
Entropy Detector

- Dolphin whistles are narrow-banded → reducing entropy
- Adapts to environment entropy level

Entropy – commonly regarded as a measure of disorder
Entropy Detector

- Dolphin whistles are narrow-banded → reducing entropy
- Adapts to environment entropy level

\[ P(t, m) = \frac{S(t, m)}{\sum_f S(t, f)} \]

\[ H(t) = \sum_{m=1}^{N} P(t, m) \log_2(P(t, m)) \]
Temporal Correlation Detector

- Adjacent time segments ~ stationary
- Accurate whistle start
Temporal Correlation Detector

- Adjacent time segments ~ stationary
- Accurate whistle start
Constrained Viterbi Algorithm

- Most likely sequence of hidden states
- Spectrogram → Emission matrix
- Time space → Observation space
- Frequency bin → Hidden Markov states
- Confidence level
Constrained Viterbi Algorithm

- Most likely sequence of hidden states
- Spectrogram $\rightarrow$ Emission matrix
- Time space $\rightarrow$ Observation space
- Frequency bin $\rightarrow$ Hidden Markov states
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Constrained Viterbi Algorithm

- Markov process

\[ P(S_{t+1,f_y} \mid S_{t,f_x}) = P(S_{t+1} \mid S_t, S_{t-1}, S_{t-2} \ldots) \]

**States of \( \{\text{time, frequency}\} \)**
Constrained Viterbi Algorithm

- Markov process

\[ P(S_{t+1,f_y} | S_{t,f_x}) = P(S_{t+1} | S_t, S_{t-1}, S_{t-2} \ldots) \]

\[ P(S_{t,f}) = \frac{\hat{x}(t,f)}{\sum_{n=f}^{\kappa} \hat{x}(t,f)} \]

\( \hat{x}(t,f) \) represents spectral matrix

\[ P(S_{t+1,f_j} | S_{t,f_i}) = \begin{cases} 
1/\kappa & \text{for } i - \kappa/2 < j < i + \kappa/2 \\
0 & \text{o.w}
\end{cases} \]
Constrained Viterbi Algorithm
Illustration of ECV operation
Illustration of ECV operation
Simulation vs Real

Simulated whistle

Real whistle of Bottlenose dolphin

Power/frequency (dB/Hz)
Simulation

SNR = 3 dB

SNR = 0 dB

SNR = -3 dB

Frequency (kHz)

Time (s)

Power/frequency (dB/Hz)
Parameters selection

- Total of 4 system parameters:
  - Correlator
  - Viterbi
  - Viterbi transitions
  - Entropy
- Tradeoff: detection and false alarms

<table>
<thead>
<tr>
<th>Parameter / Error</th>
<th>Mean</th>
<th>STD</th>
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</thead>
<tbody>
<tr>
<td>Start time [sec]</td>
<td>0.03</td>
<td>0.02</td>
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<tr>
<td>End time [sec]</td>
<td>0.9</td>
<td>0.07</td>
</tr>
<tr>
<td>Start Frequency [kHz]</td>
<td>1</td>
<td>0.8</td>
</tr>
<tr>
<td>End Frequency [kHz]</td>
<td>6</td>
<td>4.5</td>
</tr>
<tr>
<td>Max Frequency [kHz]</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Min Frequency [kHz]</td>
<td>3.2</td>
<td>3.1</td>
</tr>
</tbody>
</table>
Parameters selection

Start time sensitivity

Viterbi transitions – Contour

Confidence in the contour

First filter
PAMGuard
Results

- Compares to PAMGuard
- Feature Accuracy:
  - Accurate start
  - Not as accurate for the rest

<table>
<thead>
<tr>
<th>Evaluation over real tagged whistles</th>
<th>ECV</th>
<th>PAMGUARD + Rocca</th>
</tr>
</thead>
<tbody>
<tr>
<td>True detection [%]</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>False alarms per minute</td>
<td>$10^{-1}$</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>

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<th>Feature extraction accuracy evaluation over real tagged whistles</th>
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Conclusions

• Robust
• Automatic
• Small number of system parameters
• Easily modified to extract new features
• Potential in non-causal implementation
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Conclusions

• Robust – Same parameters for different environments
• Automatic – Produces list of spectral features
• Small number of system parameters – Easily configured if needed
• Easily modified to extract new features – Outputs the whistle contour
• Potential in non-causal implementation
Conclusions

- **Robust** – Same parameters for different environments
- **Automatic** – Produces list of spectral features
- **Small number of system parameters** – Easily configured if needed
- **Easily modified to extract new features** – Outputs the whistle contour
- **Potential in non-causal implementation** – Start times have higher accuracy
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