EcoEARS
Ecological & Environmental Acoustic Remote Sensor Application for Long-Term Monitoring and Assessment of Wildlife

Technical Symposium & Workshop Threatened, Endangered, and At-Risk Species on DoD and Adjacent Lands
June 7-9, 2005

- Stuart H Gage – Michigan State University
- Rob Maher – Montana State University
- Gonzalo Sanchez – Sanchez Industrial Design Inc.
Areas of Collaboration

Stuart H Gage
Monitoring and Interpretation of Environmental Acoustics

Rob Maher
Acoustical Detection of Birds on Airport Environments

Gonzalo Sanchez
Design and Implementation of Real-Time Data Acquisition Hardware
The ability to hear and to interpret sound is one of our basic senses. Acoustic signals produced by the environment is an untapped resource to assess the dynamics and health of the Earth’s ecosystems within which we live and extract resources.
Sound as an Ecological Indicator and a Stressor

Ecological Indicator

Biophony

Stressor

Anthrophony

Hay Marsh, MI
05/22/2002
10:50 am

Chippewa River, MI
07/01/2002
10:55 am
Soundscape
Acoustic Spectrum from 40 Hz to 11.050 kHz

Geophony
Diffuse Across the Spectrum

Anthrophony
40 Hz to 2 kHz

Biophony
2.5 kHz to 8 kHz

Stationary
Consistent or Periodic

Temporal
Non-periodic or Brief

Mechanical
Industrial and Mechanical

Oral
Communication

Intentional
Communication Among Organisms

Incidental
Signals Caused by Organisms

Spectrogram
Slicing

Anthrophony (< 2 kHz)

Biophony (2.5 ~ 8 kHz)
These formulae are mathematical derivations of the acoustic activity within the three primary spectral regions. The variables are used in analyses. The automation system rapidly calculates the values necessary to derive these variables for multiple samples.

<table>
<thead>
<tr>
<th>Index</th>
<th>Ratio</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthrophony</strong></td>
<td>$\alpha_r = \left( \frac{\alpha}{\sigma} \right)$</td>
<td>$\alpha_p = \left( \frac{L_1 + L_2}{\sum_{11\text{Levels}}} \right) \times 100$</td>
</tr>
<tr>
<td>$\alpha$ = Mean from 0 to 2 kHz</td>
<td>$\alpha_p$ = Percentage of activity in the anthropophony band</td>
<td></td>
</tr>
<tr>
<td>$\alpha_r$ = Ratio of anthropogenic activity mean to grand mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_r$ = Ratio of biological activity mean to grand mean</td>
<td>$\beta_p$ = Percentage of activity in the biophony band</td>
<td></td>
</tr>
<tr>
<td><strong>Biophony</strong></td>
<td>$\beta_r = \left( \frac{\beta}{\sigma} \right)$</td>
<td>$\beta_p = \left( \frac{\sum_{L_3\text{to}L_{11}}}{\sum_{11\text{Levels}}} \right) \times 100$</td>
</tr>
<tr>
<td>$\beta$ = Mean from 2 to 11 kHz</td>
<td>$\beta_p$ = Percentage of activity in the biophony band</td>
<td></td>
</tr>
<tr>
<td>$\beta_r$ = Ratio of biological activity mean to grand mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Geophony</strong></td>
<td>$\gamma_r = \left( \frac{\gamma}{\sigma} \right)$</td>
<td>$\gamma_p = \left( \frac{\sum_{L_8\text{to}L_{11}}}{\sum_{11\text{Levels}}} \right) \times 100$</td>
</tr>
<tr>
<td>$\gamma$ = Mean from 8 to 11 kHz</td>
<td>$\gamma_p$ = Percentage of activity in the geophony band</td>
<td></td>
</tr>
<tr>
<td>$\gamma_r$ = Ratio of geological activity mean to grand mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Activity</strong></td>
<td>$\rho = \left( \frac{\beta}{\alpha} \right)$</td>
<td>Global Variables</td>
</tr>
<tr>
<td>$\rho$ = Ratio of biological to anthropogenic activity</td>
<td>$L = 1$ kHz level</td>
<td></td>
</tr>
<tr>
<td>$\sigma$ = Mean value of entire signal (Grand Mean)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Framework for Environmental Acoustic Monitoring

- Weather Station
- Digital Camera
- Microphone
- Monitoring Computer
- Satellite Uplink
- Server and Digital Library

Clickables:
- Clickable Ecosystem
- Internet Community
- Environmental Acoustics Analysis System
- Clickable Ecosystem Website
Automated Acoustic Monitoring Locations

(Sample rate: 30 seconds every ½ hour and transmitted to MSU server)
**Gordon Trutes Residence Site Characteristics**

**Audio File Characteristics**

- **Recording Time**: 6/3/2004 7:30:30 AM
- **Recording Location**: Gordon Trutes Residence
- **Coordinates (Lat, Lon)**: (43.74876, -85.39826)
- **Land Use Class**: Forest Wetlands
- **County, Twp, State**: Big Rapids, Mecosta, MI
- **System Date/Time**: 6/11/2004 9:26:24 AM

**Site Location**

**Audio File Analysis**

- **Sonogram**: Click on image (sonogram) to hear sound
- **Sonic Amplitude in each Frequency Slice**: Click here to view the data

**Glossary of Terms**
Summary

- **Standardized measurements** and methods permits comparison within and between soundscapes.

- Dividing a spectrogram into **frequency domains** provides ability to develop ecosystem stressor and indicator indices.

- **Quantify environmental acoustics** for interpretation of soundscape meaning.
Summary (cont.)

- **Automation** provides an ability to analyze and interpret soundscapes at times not usually monitored.

- Linking *soundscapes and landscapes* via remote sensing provides mechanism to scale to region

- **Developing soundscape** system demonstrates potential for other sensors
Acoustical Detection

- Time-Variant Spectral Analysis
  - Short-time Fourier transform (STFT)
  - Separate acoustic signal into a sequence of overlapping sections, or frames
  - Typical frame length: 20-40 ms
  - View result as amplitude & frequency vs. time (spectrogram), or find spectral peak tracks

- After detection, need to classify
Short-Time Fourier Transform

Time

Amplitude

Frame 0
Compute FFT Magnitude

Frame 1
Compute FFT Magnitude

Frame 2
Compute FFT Magnitude

...etc...

Compute FFT Magnitude
STFT Spectrogram

- Spectral energy as a function of time
Peak Track Analysis

- Follow only spectral peaks frame to frame
Acoustical Classification

- Pattern matching between measured time-variant spectrum and reference templates
- Easy for human brain, hard for computers
- Approaches:
  - Segmentation and warping
  - Model-based analysis
  - Peak track similarity measures
  - Map-seeking circuits
  - etc.
**Example Application: Bird Strikes**

- Bird strikes are estimated to cost US $300 million in damage and downtime.
- Various means are available to detect the presence of birds, but classifying the threat requires identifying the species.
- One approach: classification of bird vocalizations.
Bird Vocalization Identification

- Requirements:
  - Achieve high accuracy with small database
  - Reasonable computational complexity
  - Capable of near real-time classification
  - Reliable even in noisy airport environment
Peak Track Matching Strategy
Spectral Peak Track Method

- Spectral peak track search:
  - Coarse search (McAulay and Quatieri procedure)
  - 1st fine search (Discontinuous, short or inconsistent)
  - 2nd fine search (Peak track number and order)

- Feature extraction: 12 parameters for every track
  - Frequencies and Frequency differences
  - Shape and Trend
  - Relative intensity
  - Duration

- Target and classification:
  - Represents the desired syllable in the best possible manner
  - Compares an unknown bird sound with targets of bird species
Syllable Identification Experiment

- **Bird Species**
  - 12 natural bird species (crow, goose, swan, gull, bluejay, etc.)
  - 16 synthesized bird species (tonal, harmonic, inharmonic)

- **Bird Sound Format**
  - Single channel
  - Sampling frequency: 16 KHz
  - Quantization: 16 bits

- **Syllable Format**
  - *Manual* syllable extraction from the bird sound
  - Silent onset and release at syllable boundaries
## Classification Results

<table>
<thead>
<tr>
<th>S/ N (dB)</th>
<th>Natural Sounds (10 instances of 12 species)</th>
<th>Natural + Synthetic Sounds (10 instances of 28 sound classes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Error Tally:</strong></td>
<td><strong>Error Tally:</strong></td>
</tr>
<tr>
<td>Clean</td>
<td>1 / 120</td>
<td>2 / 280</td>
</tr>
<tr>
<td>30</td>
<td>1 / 120</td>
<td>2 / 280</td>
</tr>
<tr>
<td>24</td>
<td>1 / 120</td>
<td>2 / 280</td>
</tr>
<tr>
<td>18</td>
<td>1 / 120</td>
<td>2 / 280</td>
</tr>
<tr>
<td>12</td>
<td>0 / 120</td>
<td>1 / 280</td>
</tr>
<tr>
<td>9</td>
<td>2 / 120</td>
<td>3 / 280</td>
</tr>
<tr>
<td>6</td>
<td>3 / 120</td>
<td>4 / 280</td>
</tr>
<tr>
<td>3</td>
<td>5 / 120</td>
<td>5 / 280</td>
</tr>
</tbody>
</table>
EcoEars
Ecological & Environmental
Acoustic Remote Sensor
Grand Teton National Park – Permanent Monitors
Semi-Permanent Monitor
Permanent & Portable Equipment Types

DataLogger and RF modem

MP3 Recorder
### Typical Sound Level Report

The graph above illustrates the hourly sound levels at **Site # 2**. The data shows the **Leq (equivalent sound level)**, **Lmax (maximum sound level)**, and **Lmin (minimum sound level)** over the course of 24 hours. The x-axis represents the time of day, while the y-axis indicates the sound pressure level in dBA.

#### Key Observations:
- **Leq** (black line) represents the average sound level throughout the day.
- **Lmax** (red line) indicates the highest sound level recorded.
- **Lmin** (green line) shows the lowest sound level.

The graph suggests that sound levels vary significantly throughout the day, with peaks occurring at certain times. Monitoring these levels helps in understanding noise trends and identifying potential noise sources.
Grand Canyon National Park
Automated Identification of Mechanical/Repetitive Sounds

- Jet aircraft
- Propeller aircraft
- Helicopter
EcoEars System Specifications

- Low power data acquisition device capable of collecting and transmitting the following information:
  - Audio data (WAV or MP3 file format)
  - Environmental data (wind speed & direction, air & soil temperature, solar radiation and rain)
  - On-board GPS for precise timing of data and location of sensor
  - Data storage to hard drive and/or compact flash
EcoEars System Specifications (cont.)

- Wireless communication
- Real-time tracking/identification of mechanical sounds
- Low cost - about $1000 per unit without the sensors
- Real-time identification of animal sounds (some is done currently and more in the FUTURE)
Benefits of the EcoEars System

- Acoustic signals provide information on wildlife and habitat trends/changes
- Allows the users to document current conditions
- Weather information provides additional insight
- Monitors noise levels in real-time
- Tool to remotely detect and monitor the presence/absence of animal species
- Ability to monitor noise impact from sources like military equipment/aircraft/vehicles/etc
- Non-invasive type of monitoring (minimizes biased measurements and reduces labor)
- Long term acoustic recordings can be used for post-processing by other scientists (if properly documented and calibrated)
Thank You