A Correlation-Maximization Denoising Filter Used as An Enhancement Frontend for Noise Robust Bird Call Classification

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Outline

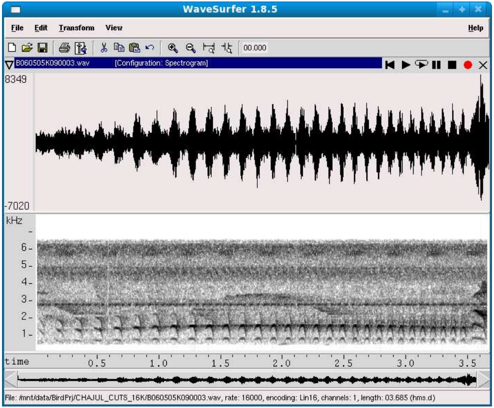
- Motivation
- Bird Call Analysis
- Bird Call Classifier Design
- Denoising Filter Design
- Experiments

Motivation of noise robust bird call classification

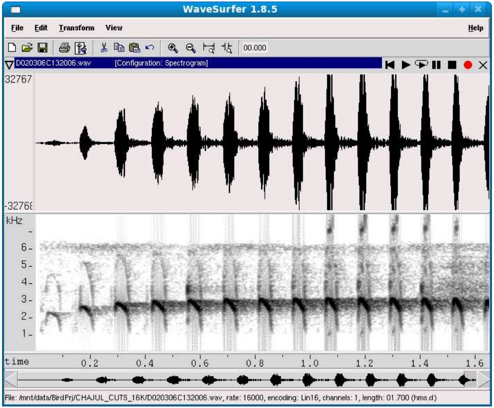
- Songs are important in the communication between birds of specific species.
- Behavioral and ecological studies could benefit from automatically detecting and identifying species from acoustic recordings.
- It is a challenge to correctly classify the bird calls under noisy conditions.
- In this work, we analyze 5 types of Antbirds.

Now let us listen to several examples of Antbird calls:

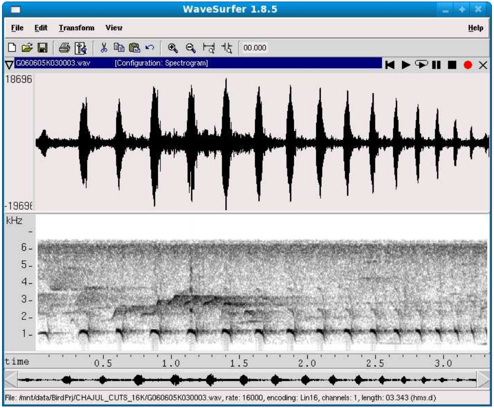
Waveform and spectrogram of a Barred Antshrike (BAS) call



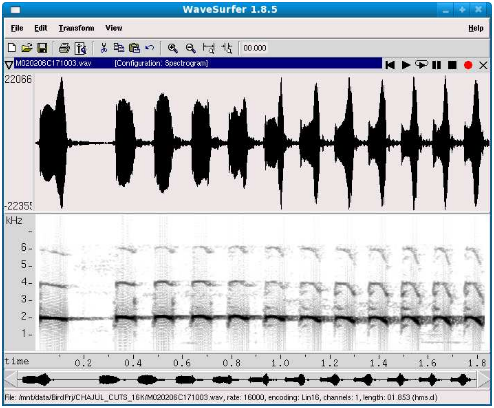
Waveform and spectrogram of a Dusky Antbird (DAB) call



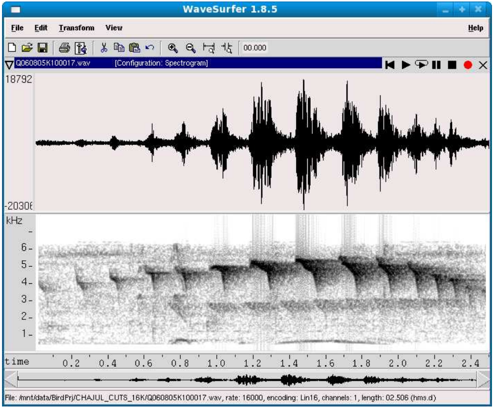
Waveform and spectrogram of a Great Antshrike (GAS) call



Waveform and spectrogram of a Mexican Antthrush (MAT) call

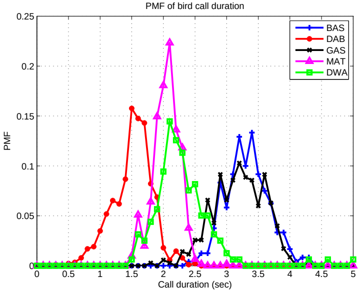


Waveform and spectrogram of a Dot-winged Antwren (DWA) call



Antbird Call Properties

- A bird call consists of a sequence of chirps.
- The interval between chirps and the chirp intensity gradually decrease over time.



A histogram of bird call duration of 2246 samples from 5 bird species. The duration ranges from 0.5 to 5 seconds.

Automatic bird call classification involves several aspects:

- Waveform denoising: the focus of this paper
- Feature extraction: Mel-Frequency Cepstral Coefficients (MFCCs)
- Acoustic modelling: Gaussian Mixture Model (GMM) and Hidden Markov Model (HMM)
- Learning model parameters from observations
- Decoding observations

Why denoising is needed?

Different kinds of background noise can be observed in the recordings:

- Other bird chirps
- Insect sounds
- Sounds of other animals

We propose a Correlation-Maximization based filter to suppress background noise existed in the bird calls.

A prevailing denoising approach: Wiener filtering

Clean $X(f)$ is corrupted by an additive noise $\Rightarrow$ noisy $Y(f)$.
$\widehat{\mathrm{SNR}}(f)$: an estimation of $\mathrm{SNR}(f)$:

$$\widehat{\mathrm{SNR}}(f) = \frac{|\hat{X}(f)|^2}{|\hat{N}(f)|^2} \quad (1)$$

The estimated clean spectrum is :

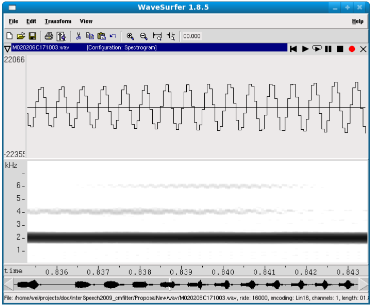
$$|\hat{X}(f)|^2 = H(f)|Y(f)|^2 = \frac{\widehat{\mathrm{SNR}}(f)}{1+\widehat{\mathrm{SNR}}(f)}|Y(f)|^2 \quad (2)$$

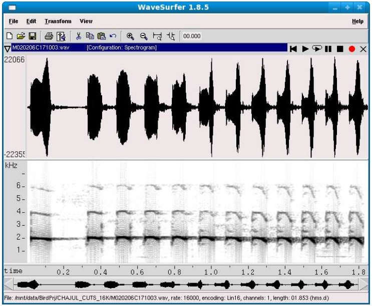
The noncausal Wiener filter converts the denoising problem into an SNR estimation problem [1].

Futher Analysis of the Bird Call

Two Levels of Bird Call Periodicity

1. Short phonation period (Left): ranges from 0.2 - 1.0 ms
2. Interval between chirps (Right): ranges from 0.06 - 0.3 sec, slowly decreases with time. ⇒ instruct the denoising!





Correlation-Maximization Filter

Suppose an FIR filter with L taps:

$$\mathbf{h} = [h[1], h[2], \cdots, h[L]]^T \tag{3}$$

is used for denoising the noisy bird call $y[n]$.
The output of the filter is the estimated clean signal $\hat{x}[n]$:

$$\hat{x}[n] = \sum_{k=1}^{L} h[k]y[n-k] \tag{4}$$

$y[n]$ and $\hat{x}[n]$ is then segmented into frames.

Correlation-Maximization Filter (cont.)

Two Assumptions

1. $y[n]$ and $\hat{x}[n]$ are wide sense stationary: The bird chirps are repeating periodically.
2. A single $\mathbf{h}$ for each bird call: The spectral distributions of different frames in a bird call are similar.

The cross correlation function of $\hat{x}[n]$ at lag k of frame m:

$$\phi_{\hat{x}}^{m}[0,k] = \mathbf{h}^T \Phi_y^m[0,k]\mathbf{h} \tag{5}$$

$\mathbf{h} = [h[0], h[1], \cdots, h[L]]^T$: coefficients of the FIR filter.
$\Phi_y^m[0,k]$: cross correlation function of $y[n]$ (independent of $\mathbf{h}$)

Use Dynamic Programming (DP) to Search the Chirp Interval

Searching the chirp interval in each frame over $\hat{x}[n]$.

DP: minimizing the distortion induced by background noise

- Local cost at lag k of frame m: $-\bar{\phi}_{\hat{x}}^{m}[0, k]$
- Transition cost of from lag k_i at to k_j:

$$d(k_i, k_j) = e^{\alpha|k_i - \delta - k_j|} - 1 \tag{6}$$

Purpose: prevent chirp intervals from greatly varying in two consecutive frames.

A trellis structure of $K \times M$ for dynamic programming is built.

Correlation-Maximization Filter (cont.)

The effect of an optimal filter **h**

Removing the additive noise in the corrupted signal so that the minimum accumulative cost is achieved in chirp interval searching:

$$\mathbf{h}^* = \arg\min_{\mathbf{h}} \mathcal{F}(\mathbf{h}, \mathbf{s}) \quad (7)$$

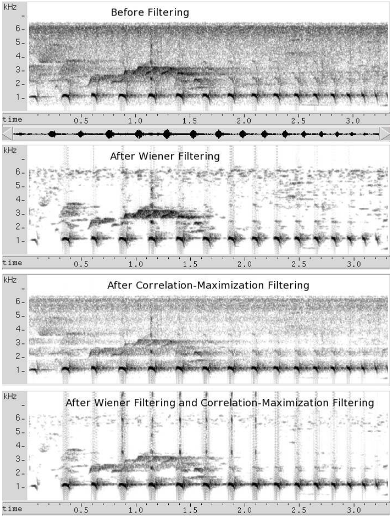
$\mathbf{s}$: an valid path in the trellis: $\mathbf{s} = s_1, s_2, \cdots, s_M$,
$\mathbf{h}^*$: the optimal denoising filter.
the accumulative cost $\mathcal{F}(\mathbf{h}, \mathbf{s}) = \Psi(\mathbf{h}, \mathbf{s}) + \Theta(\mathbf{h}, \mathbf{s})$.
$\Psi(\mathbf{h}, \mathbf{s})$: accumulative local cost;
$\Theta(\mathbf{h}, \mathbf{s})$: accumulative transition cost.

Speed Up: From Brute Force to N-Best

- There are K^M possible paths in a $K \times M$ trellis. Suppose the average iteration times of the gradient search is $\bar{I}$, this brute-force approach needs $K^M \times \bar{I}$ iterations which is computationally unacceptable.
- We can assume that $\mathbf{s}^*$ is within a path subset denoted by $\mathcal{S}(\mathbf{h})$ in each iteration. The subset is composed of the top N-best paths from the dynamic programming using the trellis.
- That means the gradient descent search is only needed to be applied to the N-best paths, not all the paths at each iteration.
- Let J denotes the size of N-best search, the total gradient search iterations is reduced to $J^2 \times \bar{I}$.
- Typically, for Antbird calls, $K = 49$, $1 \leq M \leq 50$, $J = 20$.

The spectrograms of a GAS call before and after filtering

- (a) other non-target bird chirps: 0.6 - 1.6 seconds
- (b) both target and non-target bird chirps are enhanced after Wiener filtering
- (c) Correlation-Maximization filter suppressed the non-target chirps while enhancing the target chirps
- (d) non-target chirps and background noise are suppressed when cascading two filters



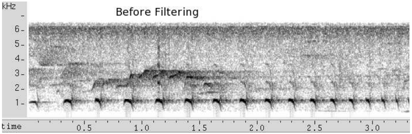
Correlation-Maximization Filter

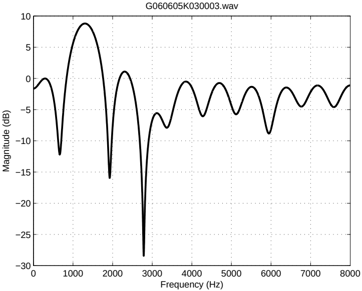
The frequency response of the CM filter for a GAS call

- enhanced the the target bird call;
- minimized the interference introduced by background noise and other bird.

filter h's characteristic

- pass-band: 800 - 1750 Hz
- stop-band: 2600 - 8000 Hz
- dip: around 2800 Hz





Data Set

Researchers from UCLA Ecology and Evolutionary Biology department collected 2 hours of bird calls (3366 calls) from 5 species. We split the corpus into a training and testing set with a ratio of 2:1.

Table: 2.1 The number of bird calls in the training and test sets. BAS: Barred Antshrike; DAB: Dusky Antbird; GAS: Great Antshrike; MAT: Mexican Antthrush; DWA: Dot-winged Antwren.

	BAS	DAB	GAS	MAT	DWA	Total
Training	240	888	350	609	159	2246
Testing	120	444	175	304	77	1120

The training set has 85 minutes of recordings; the testing set is 42 minutes long.

Setting

- A band-pass filter with cutoff frequencies at 360 Hz and 6500 Hz is used to remove the irrelevant frequency components.
- Downsamped from 44.1 kHz to 16 kHz.
- The taps of the filter $L = 20$.
- The frame length $N = 600ms = 9600samples$.
- The dimensions of MFCC features is 39.
- GMM: 256 Gaussians; HMM: 6 states, 256 Gaussians / state.

Classification Results Analysis

Table: 2.2 The classification error rate using the bird call test set. **W+/CM+**: feature extraction using the output of the Wiener/Correlation-Maximization based denoising filter

	GMM	HMM
MFCC	8.7%	5.4%
W+MFCC	5.9%	4.9%
CM+MFCC	5.3%	4.6%
CM+W+MFCC	**4.7%**	**4.1%**

- HMM based classifier is better than the GMM classifier when using the same features.
- Correlation-Maximization based denoising filter is effective before extracting MFCC features.
- Cascading the CM filter and Wiener filter is most effective.

Conclusions and Future Work

The Correlation-Maximization based denoising filter is effective in reducing the classification errors of the bird call which has a quasi-periodic structure in the time domain and an invariant power spectral density across frames.

Future work

- Extract better features for classification, such as long-term features and the modulation frequency features;
- Detect the bird call in an audio stream.
- Use Dynamic Bayesian Network to represent the probabilistic relationships between the observed bird calls and the bird species.

Thank you!

Q & A?

S. Boll,
“Suppression of acoustic noise in speech using spectral subtraction,”
IEEE Trans. on Acoustics, Speech and Signal Processing, vol. 27, no. 2, pp. 113–120, 1979.