A Monitoring System for the Detection, Identification, and Localization of Acoustical Transient Events in National Parks

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Introduction and Problems Statement:

The natural sounds program of the NPS was established to help parks manage their acoustical environments in a way that balances park access with the expectations of park visitors and the protection of park resources. This program addresses acoustical issues raised by congress, NPS management policies, and NPS director’s orders. The program also provides technical assistance to parks in the form of acoustical monitoring, data processing, park planning support, and comparative analyses of acoustical environments throughout the national park system. This research project seeks to improve acoustical monitoring efforts that provide a scientific basis for assessing the current status of acoustical resources. In particular, these efforts help to identify trends in resource conditions, quantify impacts from other actions, assess consistency with park management objectives and standards, and provide a basis for management decisions regarding desired future conditions.

Presently, acoustical monitoring stations have been deployed for extended periods of time in various backcountry sites in several national parks recording data that can be used for eventual characterization of their soundscapes. These monitoring stations capture acoustical environments using a single microphone and record data in two different formats. Due to the extremely large quantity of data, automated methods are needed for detection, identification, and localization of sources of intrinsic and extrinsic sound, since manual inspection of this entire database would be a tedious and impractical task. However, these are challenging tasks owing to the presence of competing sources of interference, highly variable operating and environmental conditions, and limitations on the storage capacity of deployed monitoring stations. Some specific tasks in this research focuses on in order realize a system capable of automatic characterization of national park soundscapes include:

a) Development of algorithms and software that automatically estimate natural ambient sound levels, removing the effects of transportation and other noise sources. This includes exploration of new methods of characterizing natural ambient sound levels, possibly separating biological, transient physical, and background baseline levels.

b) Investigation of methods that can automatically identify various types of transportation sound sources. This may include options for estimating the speed of the vehicle, the slant range of its closest point of approach, and possibly its altitude (for aircraft).

c) Investigation of options for separating sound source signatures, to parse recordings of composites of sounds into representations of what each source would sound like in isolation.

d) Develop a public display system that can indicate the noise level generated by passing vehicles, with a flashing indication when the noise level exceeds current NPS regulations (like a radar trailer).

e) Deploy new environmental sound monitoring systems at NPS park units to assess their performance, reliability, and ease of use, while collecting data that can support air tour management plans, resource management plans, and park technical assistance requests.

f) Develop a hardware/software implementation of an ultrasonic bat sound recording system that leverages capabilities of existing inexpensive handheld audio recorders to capture bat calls for several different species of
bats. The low unit cost allows extended field monitoring that would be too expensive with the currently available ultrasonic recording devices.

Approach:

As can be seen, there is large variety of tasks to accomplish for this research project, and therefore the approaches taken will be just as varied. A new subspace tracking method has recently been developed to simultaneously solve the first three tasks, namely autonomous detection, identification (task (b)), and estimation of natural and manmade acoustic sources. Using this method, estimation of signal sources (i.e. manmade transportation sounds) can be performed even when interference sources (i.e. natural sounds such as birdsong and rain) are simultaneously present, hence providing separation (task(c)) of the two sources and further yielding an estimate of natural ambient sound levels (task (a)). The proposed method is applicable to any sequential vector data where each sample generally represents characteristics of the acoustic scene captured over a certain time interval. Currently, the monitoring system collects and operates on 33-dimensional vectors, where each element of a vector is the sound pressure level obtained by integrating the energy over a different 1/3 octave frequency subband in a one second time window.

The idea behind the proposed transient source detection, identification, and estimation framework is to first perform detection on a window of data vectors using an undersampled log likelihood ratio test (LLRT) [1], where the sample data covariance is compared to a model noise covariance. Assuming a positive detection has been encountered, eigenvectors are then extracted from the data matrix and a weighted subspace distance measure [2] is calculated between the data and each set of basis vectors within libraries of signal and interference basis vectors that represent each source. While these steps perform initial source detection and identification, the composition of the data in terms of signal and interference is still not clear at this point. Therefore, the next step is to establish a series of state equations for both single source and duel source hypotheses, where the state vector in each case represents the basis coefficients for the source(s) assumed to be present. A standard Kalman filter is used to estimate the source basis coefficients, at which point a second LLRT is established to determine which of the sources are present based on the distribution of the estimated observation in each case. The coefficients of the accepted hypothesis can then be used to find estimate(s) of the source(s) thought to be present, where source identity information is obtained from the subspace distance measure(s) calculated earlier in the process. Preliminary results indicate this method is able to provide excellent detection and identification performance when applied to real 1/3 octave data obtained from national parks.

Prototypes for the new aforementioned multi-channel acoustic monitoring station and public display systems have also been designed and built. The new monitoring system provides the ability to continuously monitor the audible environment, similar to weather stations. Each unit (or node) consists of five microphones, high fidelity analog channels and a FPGA processing board to allow on-board generation of one-third octave sound pressure levels from all channels for man-made and natural sources. This system supports forming a sparse wireless sensor network of several nodes via the high performance radio links. The system also has the capability of sending daily feature summaries or immediate alerts wirelessly to park headquarters. The multi-channel processing ability of the system allows for separation, classification and localization of sound sources; capabilities that were lacking in the previous systems. Additionally, the new system will be of substantially lower cost and more compact, hence allowing for large scale deployment in national parks. The system can be easily integrated into the National Ecological Observatory Network (NEON).

Current Results:

Fig. 1 shows the results of applying the proposed subspace tracking method for detecting, identifying, and estimating vector transient sources to a two hour snippet of 1/3 octave data obtained from a remote backcountry site in Kenai Fjords National Park, AK. The bottom image is a graphical representation of the 1/3 octave data snippet to which the proposed framework was applied. Directly above the raw data image are detection/identification strips for the true signal (top), estimated signal (middle), and estimated interference (bottom) sources. Colored portions of these strips indicate time intervals where a source has been declared whose
label depends on the color. Ideally, the strip for the estimated signal sources would match exactly with the strip for the true signal sources. This is indeed the case most of the time, with the exception of a few missed detections toward the beginning and end of the snippet. Fig. 1 also shows a plot of the measure used for initial detection of sources, and the LLR used to determine the number of sources. When the detection measure falls below the threshold indicated by the black line, the presence of a source is declared. When the LLR exceed its own threshold, also shown by a black line, the presence of two sources (both signal and interference), rather than just one, is declared.

Fig. 2 shows more explicit detection and source quantity results for the data segment shown in Fig. 1, in the form of receiver operator characteristic (ROC) curves. Specifically, Fig. 2(a) shows the detection ROC curve, and the relationship between correct detections (P_D) and false alarms (P_FA). As can be seen, the knee point of the detection ROC curve (where P_D + P_FA = 1) is at P_D = 98.4% and P_FA = 1.6%, indicating excellent detection performance. Fig. 2(b), on the other hand, shows the source quantity ROC curve, i.e. it shows the ability of the system to correctly determine the presence of multiple sources (signal and interference). As can be seen, the knee point of the source quantity ROC curve is at P_D = 94.0% and P_FA = 6.0%, indicating that the system is indeed capable of recognizing the presence of signal and interference sources even when their signatures are superimposed, which in turn has a drastic positive impact on the overall signal detection and identification performance of the system.

**Figure 1.** Demonstration of results obtained using the proposed method for detection, identification, and estimation of vector transient sources.

**References:**


Figure 2. ROC curves generated by the proposed method for the data segment shown in Fig. 1.