Acoustic Event Localization by Means of Passive Transducer Arrays in Environmental Monitoring

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A system for localizing acoustic event sources by means of an array of microphones is described in this paper. For signal detection, a statistical coherency method, successfully applied to infrasonic transducer arrays, is proposed and its connection with the other elements of the system is described.

1. INTRODUCTION

The localization of acoustic sources in the atmosphere has had a long history and in the last decade great progress has been made, as its potentialities, particularly in its military applications, have been appreciated. Much of this progress is due to the availability of powerful digital processing and the development of low power Digital Signal Processors (DPS) and fast high resolution Analogue to Digital (AD) converters which makes it possible to design portable real-time devices in these applications.

The principal idea in acoustic event localization using passive transducer arrays, is that by analyzing the multitude of signals from each transducer one can reconstruct the bearing (and in some cases, angle of elevation) from which coherent acoustic waves appear to be arriving. In effect, unless a wave propagation model which takes into account the local meteorological information is taken into account one should refere to this as apparent source bearing. Furthermore, there may be an inherent indetermination characteristic to the placement of the transducers, e.g. if omnidirectional ones are used and they are all aligned it is not possible to determine on which side of the alignment axis the actual source is placed.

The essential feature in these system, the acoustic receiving transducer, has evolved from a single highly directional microphone, to an array of omnidirectional ones allowing not only the simultaneous localization of several sources, but also improves the capability of the system to remove extraneous noise. In a microphone array the signal’s wave front impinges on each element of the array with a time delay which is determined by the array configuration and the bearing of the wave front with respect to the array. One difficulty that must tackled in the design of practical arrays is that sounds, travelling through turbulent air, tend to breakup into multiple paths and as a consequence of this, the coherency of the wave front is maintained only across a small portion of the original one. If the array elements are spread too widely apart, in terms of the signals wavelength, its performance will rapidly be degraded.

The principle techniques used in determining the bearing of a sound source are that of beamforming, coherency detection and acoustic tomography. Beamforming is widely used in wireless telecommunications systems were multiple beam paths dramatically reduce signal reception. In the field of acoustic localization it is successfully used in underwater applications as well as in the atmosphere. Essentially, this technique performs the reconstruction of the signal over multiple paths and relies behaves, in its most simple form, as a spatial extension of a
matched filter [1] by combining the data collected by the transducers in the array with suitable weighting factors, so that a coherently enhanced estimate of the signal of each source is obtained. Acoustic tomography, on the other hand attempts to model the propagation of the wave through the medium by characterizing the field’s local sound velocity (and sometimes its attenuation) and therefore the signals travel time to each transducer; this results in the possibility of obtaining other information related to the medium, such as temperature profiles [2]. Unlike beamforming, acoustic tomography benefits from widely spaced transducers as the loss in coherency is the element which enables the characterization of the field’s parameters. In this paper a third technique, coherency detection will be discussed.

2. COHERENCY DETECTION

The detection of coherent acoustic energy impinging on an array of transducers has been successfully applied in the field of infrasound monitoring since the early 1970’s [3]. In this technique, the data from the microphone array is analyzed probing bearing angles for statistically significant signal coherency at each frequency. Data is processed in the frequency domain determining the Fisher value, a measure of signal coherency, to detect when coherent waves travel over the array. This Fisher statistic for a signal received from an N-element array, is defined as [4]

\[
S_F(\omega,k) = \frac{E(\omega,k)}{E(\omega)-E(\omega,k)} (N-1)
\]

where

\[
E(\omega,k) = \frac{1}{N} \sum_{j=1}^{N} A_j(\omega) \exp(-ik \cdot r_j)^2
\]

with \(A_j(\omega)\) as the Fourier coefficient of the \(j\)-th array and \(r_j\) its position vector, and

\[
E(\omega) = \frac{1}{N} \sum_{j=1}^{N} |A_j(\omega)|^2
\]

Essentially, equation 1 expresses the ratio of the power at a given point in frequency (\(\omega\)) – wavenumber (\(k\)) space to this and the total power at the specified frequency enabling its statistical significance to be determined.
3. SYSTEM DESCRIPTION

The problem of determining the localization of an acoustic event’s source can be divided into several tasks. The logical schematic diagram in figure 1 shows the breakdown of these. Signals from the Transducer Array (TA) are analyzed by the Acoustic Event Profiler (AEP) whose first action is to detect the signal and to determine its (SDB). The relevant information regarding the detected signal (including strength, frequency, bearing, coherency) are logged to the Detected Events Acquisition Log (DEAL), while at the same time the detected signal is forwarded to the next stage. The Signal Tracking Over a Period of time (STOP) stage attempts to follow the event (say through a Kalman filter); again this result is logged and the signal is sent to the last stage. Here in the Apparent Source Localization (ASL) stage, data regarding the instrument’s position as determined by a GPS system are integrated with the information determined by the STOP stage so that the source’s apparent position can be determined; this result is also logged. Until meteorological information has been taken into account this will remain an apparent position; the propagation model task follows the AEP stage so that this can turned into the actual position estimate. For this task meteorological data is used to establish the models parameters and from the DEAL an acoustic event (green arrows) is extracted with its relevant signal characteristics are then backtracked so that the apparent position is transformed into its actual estimate and sent to the Actual Position Log (APL). If an “in situ” measurement is made near a reference source its local acoustic “signature” can be had and this (blue box) can also be processed through the propagation model, so that an Expected Signal Log (ESL) will be generated. By analyzing the information from, DEAL APL and ESL (dashed arrows) the investigating team can modify (red dashed arrow) the propagation model so as to enable it to determine a more appropriate one.

REFERENCES

