Development of an Infrasound Sensing Array for Atmospheric Studies - Hardware

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Background
Current severe weather radar detection systems are unable to accurately detect a majority of atmospheric activity residing close to the earth's surface. In effort to solve this problem, Collaborative Adaptive Sensing of the Atmosphere (CASA) will be deploying a network of infrasound arrays as a supplement to its dense network of short-wavelength radars located in southwestern Oklahoma. By collocating an infrasound array with a subset of its radars, a synergistic system is obtained where the radars measure the fine scale structure of regions where there is active precipitation while the infrasound arrays point to the general location of energetic wind events such as the circulations associated with tornados. Like CASA's radars, the infrasound array hardware is being designed to be relocatable and remotely operable. This required a custom weatherized system capable of being powered via battery, solar, or line power; GPS for self-location; and WiFi capable 3G modem for internet connectivity. Also required was a mechanical spatial wind filter that both protects the infrasound sensors and filters out small scale wind noise. This poster describes the design and initial operation of this "off-the-grid" infrasound array system.

Barometer Housing and Spatial Wind Filter
Infrasound is defined as pressure waves below the human range of audibility, which is 20Hz. Higher frequency noise caused by wind can distort the desired signal. To obtain a clean signal, spatial wind filters are designed for wind noise suppression. Multiple porous hoses of equal length are attached to the Barometer housing and laid out in a formation as shown in Figure 2. The low frequency sound penetrates the porous hose and travels towards the barometer housing where it is apprehended, while the higher frequency noise is filtered out. The barometer housing is a closed circular container providing the barometers protection from the environment. The housings will be partially buried in the ground in order to minimize any pressure fluctuations caused by changes in temperature.

Data Logger
The data logger box is where all the hardware is housed for each array, excluding the barometers. All the components within the box are secured and the box is weatherproofed and suspended above the ground in order to withstand the surrounding environment for long periods of time. Contained inside the box is the motherboard, the battery charger, the wireless card for close range remote operation, the 3G wireless modem for remote operation via the internet, the USB to RS485 hub for barometer data transfers, the maximum power point tracker (MPPT) for regulating power provided from the solar panel and charging the battery. The GPS receiver is located outside of the box. Figure 1 shows a general layout of the components associated with the data logger. Also extending out from the box are ports for optional ethernet connection and power input via battery and solar panel. The logger box is self-contained and can easily be deployed and relocated due to its small size and portability.

Infrasound Array Design
The barometers will be geometrically arranged in a way that is determined to be most effective for angle-of-arrival estimation. Figure 2 shows an example of a typical array design. This layout allows azimuthal direction and velocity of captured infrasound to be calculated using the least squares algorithm[1]. This algorithm has inputs $\mathbf{f}$ as a vector of time delays, $\mathbf{X}$ is the location matrix of the sensors, and $\mathbf{I}$ is the "slowness vector".

$$f = (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \mathbf{f}$$

From $\mathbf{f}$ we find the estimates for velocity and azimuth of arrival. Refer to “Back-Azimuth Angle Software for Array Processing” of the Software poster for information on the process used for locating infrasonic sources.

Interdisciplinary Connections
Multiple disciplines have collaborated together to help construct and operate the infrasound sensing array. Electrical Engineering knowledge was used to designate and assemble the different device components. The software used to communicate with the different components and to perform the data analysis falls into the field of Computer Science. Also, Collaboration with meteorology specialists will be necessary to interpret the atmospheric data.

References

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Research Objectives

• To design software that will control and read from the Paroscientific Inc. DQQuartz barometers.
• To analyze the pressure readings from the barometers in order to geolocate the source of atmospheric infrasound waves.

Power Spectral Density Software

To complete the Infrasound Sensing process, the pressure data gathered from the data acquisition software must be processed and analyzed. We have developed a power spectral density analyzer, called the DQProcessor to carry out this function. This program takes log files created by the DQlogger and analysis the data. It does this by performing a Discrete Fourier Transform on the data points. A human observer can then view the frequency response graph and determine if there is any power in the graph caused by infrasound frequencies. By observing Figure 3, you can see that there is some energy concentrated around the infrasound range. This proves that the pulses in Figure 2 were occurring 3 times a second.

Back-Azimuth Angle Software for Array Processing

Since the barometers in the infrasound array are spaced 100m apart, an incoming infrasound wave will not arrive at all barometers at the same time. A signal travels over the array at about 340m/s, it arrives at different times at each barometer, by knowing the relative locations of the barometers and the arrival times at each barometer direction of arrival and speed can be estimated. However, to accurately calculate the direction, our Azimuth Angle Software determines a maximum likelihood estimator for the angle of origination. The program sums the pressure readings from the barometers together and shifts the plots of the pressure readings back and forth in time to maximize the power spectral density. When the Power Spectral Density is maxed, the amount of timeshifting done at each barometer allows us to trace a ray which points in the direction of wave origination. Refer to Figure 2 of the Hardware poster for an example of an Infrasound array and further explanation.

Data Acquisition Software

Integral to our infrasound sensing array is the Data Acquisition Software. Called DQlogger for short, this program communicates with and utilizes the functionality of the four barometers. Initially, the DQlogger configures the barometers to the proper setting for detecting infrasound waves. Then, the software begins its operation cycle where it retrieves absolute pressure from the barometers, and records this information in a data log accompanied by the time of sampling. Figure 1 shows an example of the DQlogger live process. Figure 2 graphically displays pressure data collected while a 3Hz test signal was generated.

Sampling/Timestamping via GPS/NTP

A GPS receiver is included in the data logger design. While it will be able to relay location information such as longitude, latitude and altitude, the GPS serves the main purpose of accurately timestamping the collected pressure data. If left unsupervised, the internal clock on the data logger will periodically lose Synchronization with the true time. The GPS calculates location by measuring the propagation delay of transmissions sent from the GPS satellite, and thus maintains an accurate internal clock. We use this GPS time signal to accurately set the logger’s clock, which loses a few hundred milliseconds a day if left unsupervised. If for any reason the GPS should fail, then Network Time Protocol (NTP), which is managed via the 3G modem connection to the internet, will take over the synchronization of the system clock.

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