Zero-Power Seismic Sensors for Discrimination of Foot and Vehicle Traffic

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Abstract

Modern approaches to signal discrimination typically depend on digitizing an analog signal, and analyzing it with digital techniques, often in the frequency domain. This approach is untenable in severely power-limited applications such as Distributed Sensor Networks. We will attempt to design a completely analog sensor capable of receiving and analyzing seismic signals, delivering an output that is proportional to the amplitude of the vibration generated by nearby foot or vehicle traffic. Our goal is to develop a sensor that operates at extremely low power (0-1mW), making it suitable for long-term battery-powered operation. The sensor will be field-tested to determine its operational characteristics and compared to published results obtained via digital processing.

Outline

Tracking of vehicle and foot traffic is important for various national security applications, including protection of chemical or nuclear facilities and monitoring of the US borders against nuclear smuggling. These applications require instrumenting large areas- perhaps thousands of square kilometers for effective border monitoring. A large-scale Distributed Sensor Network (DSN) makes an attractive concept for solving these sorts of problems, as a DSN should require little or no infrastructure and can be designed around simple, inexpensive, and possibly covert sensor nodes. A DSN node designed for long-term, unattended deployment can be expected to be severely power-limited. The processing and communications systems of the sensor node can be made power-efficient simply by controlling their duty cycle. The node may not have this luxury where its sensor is concerned, especially if the sensing modality is the first line of a defense-in-depth scenario: the sensor may have to operate at 100% duty cycle. Therefore, development of zero-power (or extremely low power) sensors is vital for the successful implementation of DSNs in many applications. Our efforts in developing a tracking DSN application have so far centered on an agent-based simulation of a multi-phenomenology DSN for autonomously locating a person on foot attempting to smuggle fissile material across a border [Nemzek et al., 2007]. While the various parts of our system-level model are based on simple yet accurate physics, none of them have been demonstrated as actual hardware with the proper characteristics for use in a deployable DSN.

In this project, we will attempt to develop a very-low-power sensor to demonstrate that a DSN-based approach to tracking vehicle or foot traffic is feasible. We will use seismic sensing, a tried and true approach. The sensor will not only detect ground vibration; it will also run a simple discrimination algorithm in analog electronics to deliver a signal that is (in a rough sense) proportional to the distance between the sensor and the source.

Seismic detection of foot traffic dates back at least to the Viet Nam War, when air-dropped sensors were used to measure activity along the Ho Chi Minh Trail. More modern demonstrations have shown that foot traffic can be detected with 50% probability at distances of ~80m by the use of standard geophones [Houston and McGaffigan, 2003; Richman et al., 2001]. Geophones are highly appropriate for this application because of their low noise floor, high sensitivity, and simple operation. Basically a spring-mounted magnet moving through a wire coil, geophones generate a voltage signal with no external power source required. However, they are relatively bulky. The first task of the experiment will be to compare geophone characteristics

(both on paper and in use) to those of piezoelectric and MEMs sensors. The most appropriate sensor type for the task will be selected for use in field measurements and hardware development.

Our first experimental goal will be to duplicate the results of Houston and McGaffigan [2003] by acquiring field data and analyzing it with their algorithm (Fourier transform, followed by split-window normalization to determine relative power in the 2-3 Hz "walking" band). We will also acquire data for vehicle traffic, to determine whether we can develop a similar algorithm to discriminate vehicles from background. Our work here will be guided by Rutledge et al. [2003].

A sensor-network implementation of the Houston and McGaffigan [2003] algorithm would require digitization of the analog signal, followed by digital processing (an FFT) to discriminate the signal of interest in the frequency domain. This is exactly what we would like to avoid, for power consumption reasons. Therefore, the bulk of our work will be geared toward developing an analog version of the algorithm. We will use filters to extract the signal and the background level. Active filters may have to be used. An analog divider can be used for normalization. Achieving the low power levels needed, will be a challenge. If COTS parts are not sufficiently low-power, we will have to demonstrate the concept with greater power consumption than desired, and do sufficient research to show the existence of a reasonable path to low power operation through custom circuitry.

The final product of the project will be a breadboard version of a low-power seismic sensor. The sensor will deliver an analog signal proportional to the Signal-to-Noise Ratio (SNR) of the power present in the ~few Hz ground vibration band typical of foot traffic. The SNR preferably will be expressed in terms of dB. Our metrics of success will be power consumption and probability of detection as a function of range, where detection is defined by a particular SNR.

Bibliography & Suggested Reading

- Houston, K.M., and D.P. McGaffigan, Spectrum analysis techniques for personnel detection using seismic sensors. Proc. SPIE, 5090, 162-173, 2003.
- Nemzek, R., G. Kenyon, A. Koehler, D.M. Lee, W. Priedhorsky, and E.Y. Raby, SNM-DAT: simulation of a heterogeneous network for nuclear border security, Nuc. Inst. Meth.-A, in press, 2007.
- Richman, M.S., D.S. Deadrick, R.J. Nation, and S.L. Whitney, Personnel tracking using seismic sensors, Proc. SPIE, 4393, 14-21, 2001.
- Rutledge, J.T., C.M. Aprea, S.S. Giandoni, and R.J. Nemzek, Seismic tracking of vehicles by determining direction to source, Los Alamos Report LA-UR-03-7511, 14pp., Los Alamos National Laboratory, Los Alamos, NM, 2003.

- General understanding of Fourier Transforms, Signal-to-Noise Ratio, Passive and Active filtering, dB scales

Weekly Plan:

Week 1: Training and system-level introduction
Week 2: Comparison of Geophones, Piezoelectric, and MEMs detectors
Week 3: Collection of field data (foot and vehicle); comparison to published results
Week 4: Design of analog filtering circuitry
Week 5: Design of split-window normalizing circuitry

Week 6: Integration and test
Week 7: Finish analysis and begin presentation
Week 8: Complete and deliver presentation

Real-world design:

As the hands-on parts of the project are completed, any time remaining will be used for developing concepts for a deployable system. This will include considerations of robust packaging, covert operation, ground coupling, and simple emplacement.

Equipment requirements:

Data acquisition system capable of digitizing at rates of up to ~10 kHz (may be available from ISR-2), standard electronics instrumentation (voltmeter, oscilloscope), spectrum analyzer (available from ISR-2).

Software requirements: Standard tools for statistical analysis and visualization such as MatLab, IDL, or other plotting packages.