ED51B-0756: Monitoring seismic waves with school-built seismographs

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Abstract

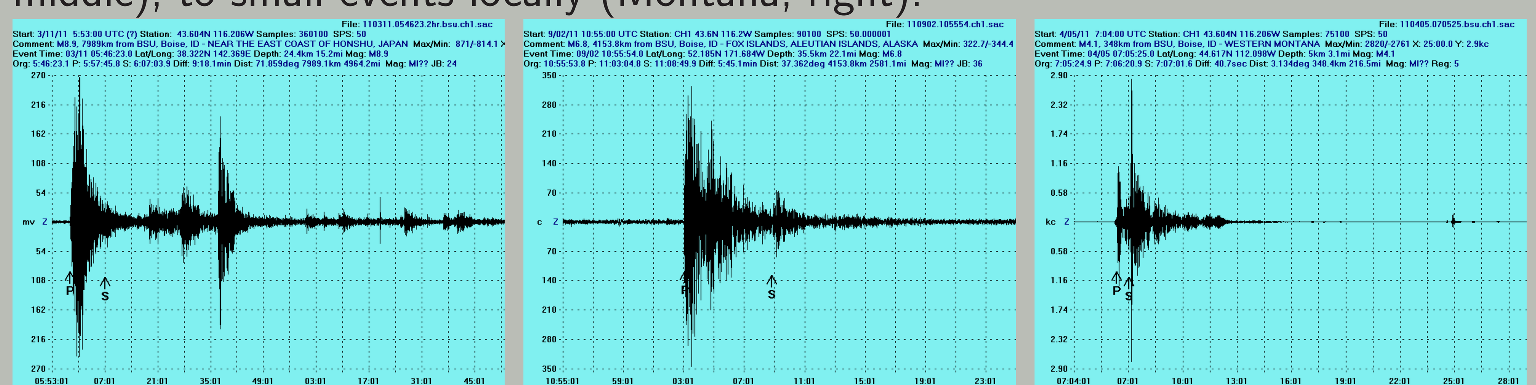
Over the past 5 years, we have developed and refined inexpensive home-built seismometers using a slinky, a magnet and coil. Parts can be obtained from local and on-line hardware stores for less than $100, and construction can be done in one day. The latest developments involve a novel interface between sensor and the data logger: NERdaq (∼$75). The result is a system capable of monitoring regional events $M_0 \geq 3$ and worldwide earthquakes $M_0 \geq 6$. Building one of these seismometers is a highly engaging exercise, and it has been our experience that high school and undergraduate students involved in the process develop a better awareness of worldwide earthquakes, the underlying tectonic processes, and the potential hazard communities face in tectonically active areas.
Here we present the latest hardware, discuss developments in inexpensive analog-to-digital conversion based on an open-source electronics prototyping platform, and report our experiences in the classrooms at Boise State University, as well as the K-16 institutions with which we have partnered thus far.

Introduction

As part of a sophomore geophysics class at Boise State University, we have been building educational seismometers. First, we use these in our own class to help facilitate our learning regarding seismology and tectonic processes. Then, at the end of the semester we partner with institutions of K12 education to place these in their facilities. As of 2012, this final stage is officially a service learning component to the class.
After having experimented with longer period horizontal Lehman designs, we favor a short-period (∼ 1 Hz) vertical sensor based on a toy slinky. The goal is to balance education with performance, with an emphasis on the former.

Events from around the globe, as measured in Boise

Even though emphasis is on education, the slinky seismometers are sensitive enough to record many earthquakes per month. The system is capable of detecting earthquakes from teleseismic (Japan, left), intermediate (Alaska, middle), to small events locally (Montana, right):



Slinky Seismometers in Schools (SSIS)

The goal of the project is to expose K-16 students to the geosciences, and seismology in particular. We now have Slinky seismometers in:

- Barbara Morgan MS in McCall, ID
- Rocky Mountain MS in Idaho Falls, ID
- Kendrick HS in Kendrick, ID
- Boise State University in Boise, ID

We are currently setting slinkies up in Vermont, Delft (NL), and Italy.

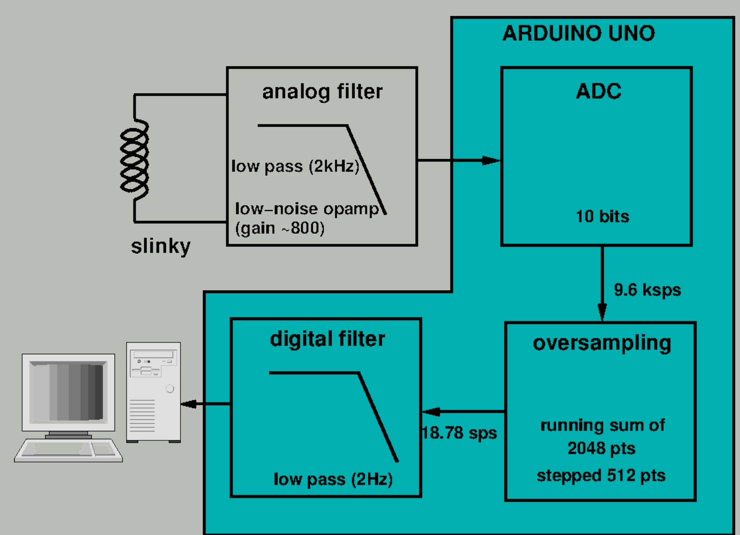
Want more info on how to get a slinky seismometer in your school?

- **visit http://cgiss.boisestate.edu/ssis, or email ssis@cgiss.boisestate.edu**

The website tells you how to build and set up your slinky seismometer. The following sections describe the latest developments in the data acquisition interface, NERdaq.

NERdaq: the interface between sensor and computer

While seismologists can be good at building seismographs, the electronics (Analog-to-Digital Conversion (ADC), filtering and amplification) require a separate set of skills. Here we introduce an open-source, inexpensive and – maybe most importantly – simple unit called the NERdaq. The principal elements of the Data AQquisition system (DAQ) are sketched below:

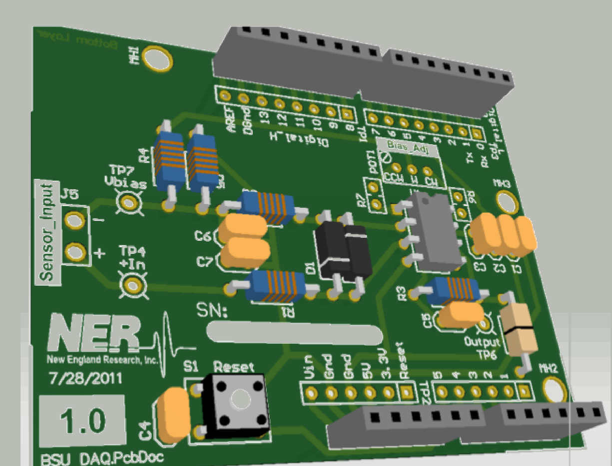


The unusual parts are the high-frequency of the first filter's cutoff (it is a part of the amplifier stage) and of the ADC sample rate. We are using oversampling followed by massive smoothing to achieve most of the effect of a higher-resolution ADC.

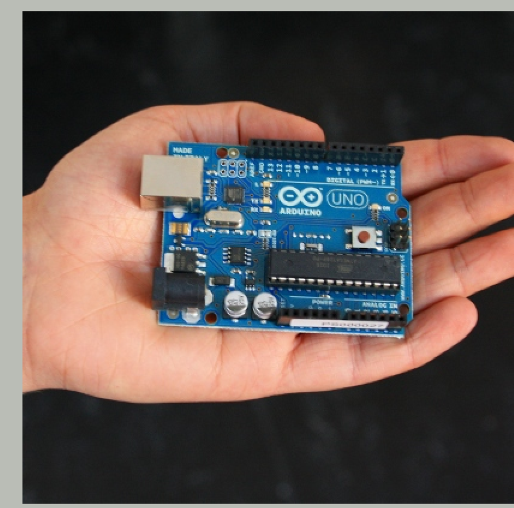
In this instance we get, subject to some qualification, about 16 bits of resolution from a 10-bit ADC. The DAQ is implemented as two units: an analog (opamp) stage and a digital section. The digital section is implemented entirely with a single Arduino Uno. The output, a digital stream at 18.78 sps, is fed over a USB connection to the recording host computer.

Analog filtering and amplification

High-frequency noise out of the slinky seismometer is first minimized with an analog 2kHz low-pass filter, and the signal is amplified 800 times with an Operational Amplifier chip. Our first prototypes were easily soldered on a small breadboard, but for convenience these two steps are now hosted on a Printed Circuit Board (right) with pins to marry the wiring with the Arduino Uno unit described next.



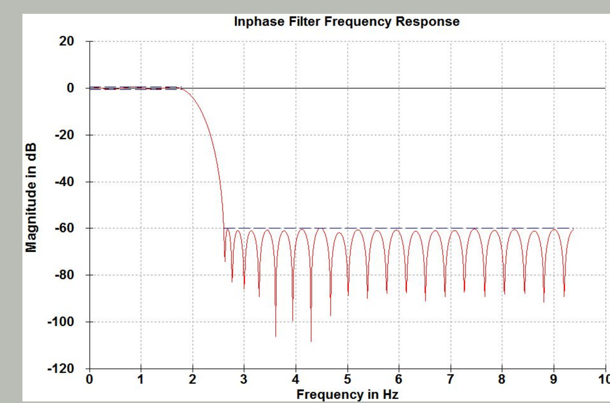
Arduino Uno

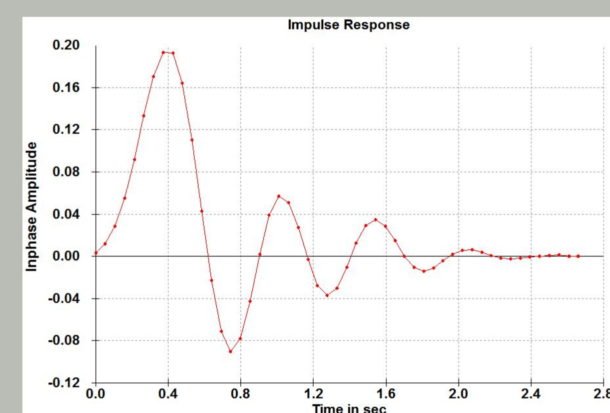


From www.arduino.cc: *Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments.* We use the Arduino Uno, which is cheap ($25), USB powered, 10-bit A/D, sampling rate of 9.6 kHz.

Oversampling and digital filtering on the Arduino Uno

As an example of the benefits of oversampling to the data resolution, consider that we are sampling a value of 14.72 with +-3.0 noise with an ADC whose steps are 1.0. Normally we would just measure 14 no matter how many measurements we made. The noise changes things: because of its presence our measurement of 100 samples has the values 11, 12, 13, 14, 15, 16, and 17 distributed in such a way that the average, say, is 14.68. So because we have noise and we average over many samples we get an effective resolution in this made-up example of about 0.04 instead of 1.0. That is what we are doing in NERdaq: The input noise is fairly large, partly because of direct pickup by the coil, and we are not rigorously fulfilling the conditions oversampling is based on. However, we come close enough to get a good effect once we cast the averaged values to the nearest 16-bit value.





The final filter stage, a low-pass minimum-phase filter at 2.25 Hz, is implemented as a digital filter in the output of the DAQ. On the left (top) is the impulse response of the final (digital) filter. The filter is fairly sharp and we have to pay attention to both ringing and impulse delay. Here the delay is about 0.4 sec which we think is acceptable and the ringing dies away relatively quickly. If the latter proves to be an issue we can decrease the ringing by shortening the length of the filter (currently 51 points) and accepting some degradation in frequency response.

Notice that there is little attenuation below 2 Hz, where our instruments useful sensitivity is located, and 60 dB or more above 2.6 Hz. We indulged in this sharp cutoff to decrease the visible noise in the data stream without requiring the user to configure additional filtering in the acquisition and display program. On the left (bottom) is the frequency response of the final-stage filter.

Acknowledgments

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