Sonification Experiments with the Seismic Signature of Ocean Surf

Prepared by

William Tang
Smithtown High School
Smithtown, NY

for the

School of Marine and Atmospheric Sciences
Stony Brook University
Stony Brook, NY

2013

Stony Brook University’s COAST Institute

Coastal Ocean Action Strategies Institute

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COAST has been called upon to assist in resolving coastal problems at home on Long Island, throughout the U.S. and in many parts of the world. COAST also provides a real world, action-learning laboratory for graduate students at MSRC. Each year students who are interested in coastal management and policy take part in gathering and analyzing data, in transforming data into information, and in synthesizing information-all targeted at identifying and evaluating management alternatives to attack the problems that COAST is helping to solve.

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Introduction

Ocean surf conditions are particularly difficult to measure. Harsh conditions and energetic waves take a toll on instrumentation in the surf zone. Seismometers have the advantage of being a reliable and robust technology safely installed on dry land. The interpretation of seismic records in terms of surf conditions, however, requires considerable data processing and analysis. In this project, I explored the potential of sonification of seismic records as an aid to data assimilation.

Sonfication involves transforming the seismograph into audible sound. The process compresses the data so that an hour's record translates into a few minutes of audible signal. Sonification might be used, for example, as a new technique for recognizing dangerous surf conditions at the beach. Slattery (2010) used a seismograph to detect the wave conditions thought to cause rip currents. If these seismographs can be converted into audio data, hazardous conditions might be quickly recognized by the discriminating human ear.

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Previous Work

The technique of sonification has found recent application in many diverse fields, for example, in the search for ETI involves looking for extrasolar planets and biomarkers of life in the universe. After researchers at CERN discovered the Higgs Boson, they immediately began sonification of the experimental data. Analysis of the data could be done through listening to the sonification, In the field of ecology, soundscape ecology consists of biophony, sounds created by organisms, geophony, sounds from the environment like a river flowing, and anthrophony, human generated sounds. Soundscape ecology allows us to understand the relationship between humans, organisms, and the environment through the recordings of ambient sounds. For example, songbirds have a circadian pattern for singing that is influenced by the climate and timing of the environment. The arrival of an invasive species could change the biophony between the native species. Therefore, studies use recordings of the soundscape to learn the harmful effects of human activities or perhaps the detrimental arrival of an invasive species. Changes in the soundscape signal a change in the ecosystem.

Seismographs record vibrations of the ground due to earthquakes, explosions, vuklcanism, construction activity as well as ocean waves. Because both seismograms and audio files are stored as numbers in a computer, it is possible to convert seismograms into audio. But the frequency of ground motion is too low for the human ear, so by speeding up the time series, that is, increasing the frequency, the signal can be rendered audible to humans to. The Earthquake Quartet, a musical piece for voice, trombone, cello, and seismograms, is composed to the ground shaking during earthquakes. Tidal patterns have also been converted into music. The sound traces the time and heights of high and low tides through maxima and minima points in Venice and Ancona, Italy. Scientists have also translated volcanic behavior into sound waves. The "Enabling Grids for E-sciencE" (EGEE) and the "E-Infrastructure shared between Europe and Latin America" (EELA) projects have been transposing seismic activities of volcanoes into sound waves to analyze volcanic behaviors and eruption patterns. They have been working on Mount Etna, in Europe, and Tungurahua, in Latin America, and hope to predict future eruptions by using data sonification to detect eruption patterns.

Standing on the beach, you can often feel strong surf pounding sand. Indeed, reports of feeling vibrations caused by waves are not uncommon. Residents of the California coast (Benumof and Griggs 1999), for example, report feeling buildings vibrate when there are storm waves affecting nearby coastal regions. Seismologists often find their records contaminated by noise, called microseisms, some of which is generated by ocean waves. Large storms can generate standing sea-waves (Tabulevich 2002), and even remote seismic station, detect microseisms so produced. Seismic signals were detected in New Mexico from the “Perfect Storm” off the Massachusetts coast in 1992 **(**Bromirski 2001**)** and microseism caused by Hurricane Katrina in the Gulf of Mexico in 2005 were detected at sites as far away as California (Gerstoft et al. 2006). Such a signal can be used to estimate wave climate (Beach and Sternberg 1988). Shoaling water-wave energy dissipated along sea cliffs in California, possibly due to standing waves set up by the reflections of incident waves at the shoreline, have been detected by nearby seismometers (Adams et al. 2002). Talman’s Sea of Curves (2012) new sound installation is used to record oceanic waves and the oscillation sounds of the Earth created by the impact of oceanic waves on the seafloor.

My research was to apply principles of Sonification to the discrimination of surf conditions at an ocean beach in east Hampton, NY.

Methods

Seismic readings of the surf are collected with a Guralp Systems Limited CMG-3TD digitizer stationed at the Maidstone Golf Club in East Hampton, NY. These readings are recorded with *Scream! 4.3* and stored in hour-long segments. The files collected in the years 2007 and 2008 recorded data at 20 Hertz. The files collected in the year 2011 recorded data at 40 Hertz. MATLAB is used to convert the stored .gcf files into .dat files, displaying the seismic readings as a string of numbers that represent the amplitude of the vibrations recorded by the digitizer. In Microsoft Excel, a positive amplitude shift is applied to the data so that each data point is a positive integer. Figure 1 shows a visual graph of Data hour 20110828_1100z's amplitude values after being shifted.

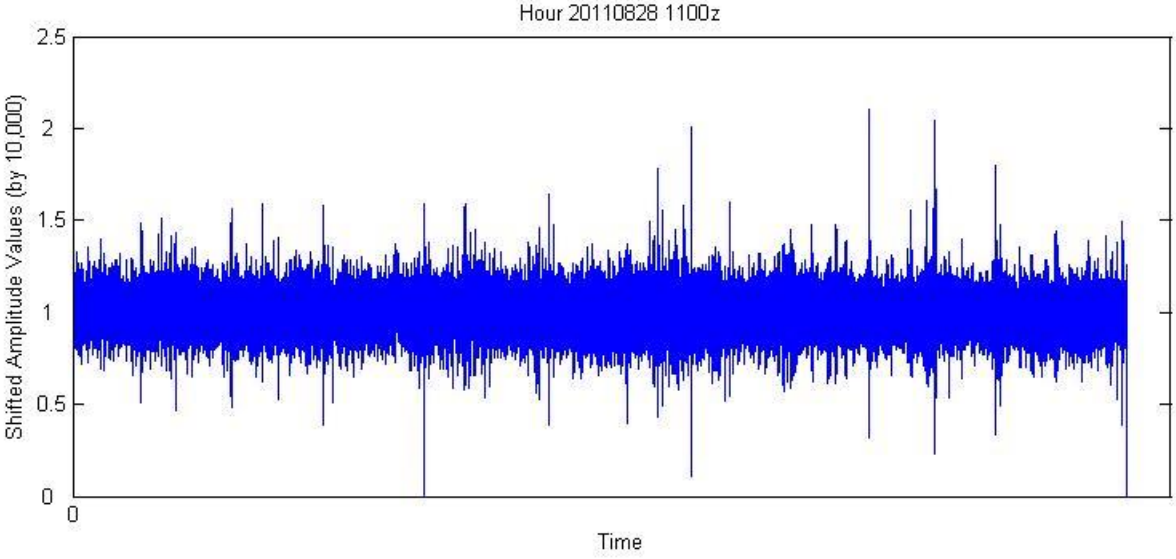

Figure 1. A plot of amplitude values of Hour 20110828_1100z over time

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The sonification is completed with the program Max/MSP. With this software, the data is compressed in time so that it may be interpreted as literal measurements of pitch, using a comfortable listening range of 600-1200 Hz. In my case, the data was compressed from a frequency of 20 Hertz to a frequency at 1,000 Hertz. A hour's seismograph was compressed to approximately 1 to 3 minutes of audio. It is the sonification of an hour's worth of seismic data, allowing amplitude to be reinterpreted and observed as pitch.

After the sonifying the data, it became apparent that it was difficult to distinguish extremes and anomalies because of the lack of distinguishable sounds for interesting data points that fell outside the normal range of values. The sonifier was programmed in Max/MSP with a filter system with a high pass and low pass, each representing the upper and lower boundaries of the average range of data values. Values higher than the high pass limit would be converted into audio signals of high frequency, resulting in a high pitch. Values lower than the low pass limit would be transposed to signals of low frequency, resulting in a low pitch that gives a deep sound (Figure 2).

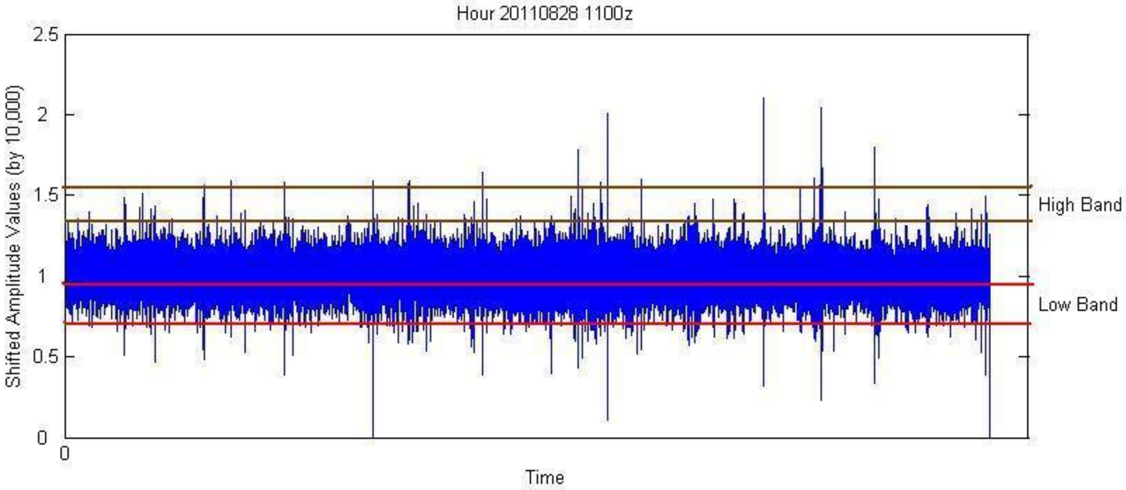

Figure 2. Band-pass filters. The brown lines represent the boundaries of the high band while the red lines represent the boundaries of the low band. Data points falling in the low band would be converted to lower frequencies to emit the pops while data points falling in the high band would be assigned to higher frequencies to emit the high chirps.

MAX/Msp filters took in the original time-series through inlets represented by the number rectangles and the square knobs (Figure 3). Values were then be scaled to a new frequency range, and in Figure 3B, it would be from 440 – 14000 Hertz. This accounted for either the low-frequency “pops” or high-frequency high “chirps”.

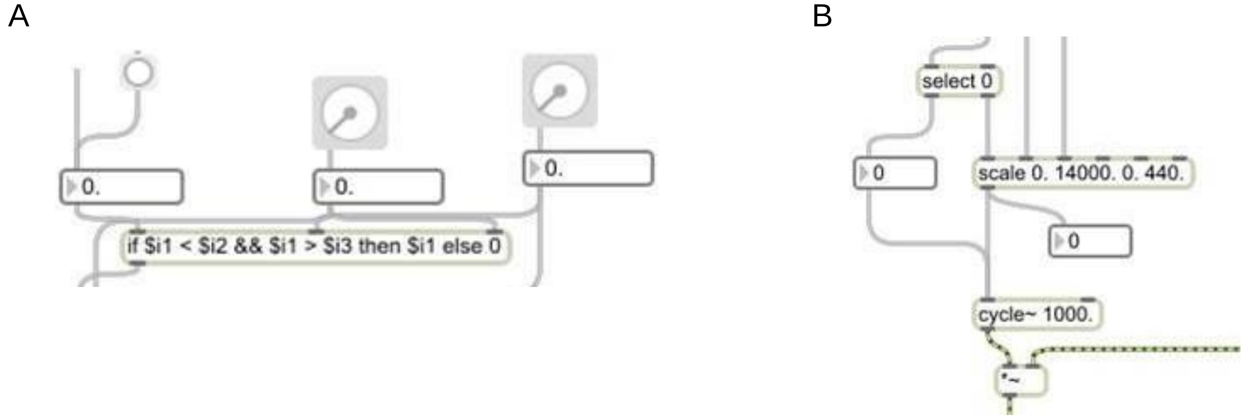

Figure 3. A: An if object in MAX/Msp filters inputted data values that only takes values within a certain band range. B: The filtered data values are scaled to lower or higher frequencies in the scale object.

Different sets of data sets had different ranges of amplitude values, making it difficult to compare values because there was no defined reference point of control group. A system of different filters was created to address this problem. For the filter settings from band to band, the boundary values of the previous band were increased by approximately 10,000. Generally, the lower and higher band boundaries were between 5000 and 7000 higher or lower than the "normal" range (Figure 4). Each hour of seismic data was run through each filter setting, which resulted in 10 different audio files for each set of data.

Filter Settings	Low Band	Normal Band	High Band
1	40000 - 55000	60000 - 90000	95000 - 115000
2	45000 - 65000	70000 - 100000	105000 - 125000
3	55000 - 75000	80000 - 110000	115000 - 135000
4	65000 - 85000	90000 - 120000	125000 - 145000
5	74000 - 94000	100000 - 130000	136000 - 156000
6	84000 - 104000	110000 - 140000	146000 - 166000
7	94000 - 114000	120000 - 150000	156000 - 176000
8	104000 - 124000	130000 - 160000	166000 - 186000
9	113000 - 133000	140000 - 170000	177000 - 197000
10	123000 - 143000	150000 - 180000	187000 - 207000

Figure 4. The different filter settings applied to each set of data. If values fall in the high band, high chirps will be emitted while if values fall in the low band, low pops will be emitted.

To compare the different time series, a reference point had to be established. A function of halving, or reducing the set of values by any fraction, was added to the sonifier by multiplying data values by the desired fraction, and this compressed the range of data values. A gate function in MAX/Msp allowed the user to choose between two or more different options, such as using the original values or halving the data values. This function was added to simulate what a control time series representing wave amplitudes during a calm day. The original values, taken from Hurricane Irene, would represent wave amplitudes during stormy and turbulent conditions. The halved audio files would be compared to the original audio files to hear the differences between the two conditions. However, halving the values also shifted the data values to a much lower range of values. A better comparison was accomplished by keeping the two sets of data in the same range by making sure the halved values have the same average value as the original. After determining the average value of the original values, the halved set of data was shifted up to that average value so both would be in comparable ranges.

Results

All of these sonified samples share two distinctive features. As expected, they were dominated by a high-frequency chirping created by the incident surf with periods of 5 or 6 seconds. There are also audible lower frequency waves that create a popping sound, like a percolating coffee pot, that is lower in pitch and is clearly distinguishable from the higher frequency, continuous noise band. These lower-frequency sounds represented the infragravity waves with approximately 20-second periods. Audible distinctions could be heard in the sonified seismic data.

Examples of particular filter settings were chosen in order to compare storm and calm conditions. All examples were process using the same methods. For seismograph “20110828_1100z”, a storm hour. The peak value was 210801 and the lowest value was 38989. The recordings vary greatly under different filters. Some were characterized by “pops”, the sounds associated with a low-frequency storm waves. Other records were characterized by “beeps”, and still others by continous high-frequency "chirping". These higher-frequency sounds were interpreted as the short-period, incident water waves. The lack of specific reference point, however, made it hard to determine which set of band settings was the best to use.

After halving the values, comparing the halved and original values of the same set of data yielded more noticeable and sensible differences and made for better comparisons. After shifting the halved values back to the same average value of the original values to account for errors, the desired anomalies to be heard became more distinguishable in the audio files. Though both would have similar sounds, the original file, which represented storm conditions, had greater isolated sounds of sharp “chirps” or low “pops” than the halved file. The points where the halved file lacked a distinct sound but the original had a sharp “chirp or low pop are areas of interest because they represent the deviations.

Discussion and Conclusions

My study focused on finding the suitable filter setting with the right high and low band values to serve as a point of reference for sonifying data values because the lack of such a point for comparison made it difficult to distinguish storm from calm conditions. Comparisons of different hours with the filter system did not yield conclusive results because was hard to compare the different hours since each had drastically different amplitude values. The lack of data during calm and normal conditions led to the halving function, which was needed to simulate calm days. The shifting of halved values to the same average value of the original allowed the two data sets to be compared without inaccuracies. While this did yield audio files with reasonable differences and similarities in "chirps" and "pops", there are still problems to be solved. First, a point of reference or preferred filter setting still could not be determined. Second, the "chirps" and "pops" were still not obvious enough to determine the desired points of interests. However, the data sonification yields an interesting method of analyzing data and different methods of data sonification could be pursued to perhaps give other results.

Acknowledgements

This study could not have been accomplished without the help and direction of Dr. Henry Bokuniewicz, distinguished service professor of Stony Brook University's School or Marine and Atmospheric Sciences, and of Timothy Vallier for his help and guidance.

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