Filtering Seismic Timeseries Data in Passive-source Seismic-Processing (PsSp)

Implementation details of the filters provided for isolating seismic signals

Alexander R. Blanchette*

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Abstract

Seismic data—whether it is ground motion (displacement), velocity, or acceleration—is recorded as a function of time (timeseries). Seismic timeseries recordings contain information from a plethora of sources—natural and anthropogenic. Typically, an analysis task is focused on processing/analyzing signals from a specific target *source*[1]. Generally, seismometers record and are sensitive to a frequency range that is significantly larger than that which any given analytical method/goal requires. Filtering is a critically important tool for isolating signals of interest. In this document I give a brief overview of timeseries filtering in general and provide the specific details of the filters implemented in Passive-source Seismic-processing (PsSp).

*arbCoding@gmail.com

[1] *Source* is being used in the generic sense here; it could refer to the nucleation point of the seismic signals (earthquakes, explosions, etc.) or to structural sources (reflections, refractions, conversions).

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1 Introduction

Filtering of time-dependent recordings (timeseries data) is a task common among a wide range of different scientific/engineering disciplines. While great advances have been made to analyze as much of the seismic timeseries as possible—such as the extraction of approximate Green's functions from the ambient seismic noise field—virtually all seismic analysis first requires the seismic timeseries to be filtered in order to isolate the portion of the recorded data that is most compatible with the intended analysis. In the fairly distant past this was less important due to the limitations of: 1) the available seismographic instruments, and 2) the available computational infrastructure. At present, relatively inexpensive seismometers can record broadband seismic timeseries with the flat-sensitivity range of a high-quality instrument being between a period of 1000 seconds (s) at the low end (a frequency of 0.001 Hz) up to a high of 100 Hz. Such a large dynamic range of frequencies—containing signals from numerous stationary and non-stationary sources—results in a rather complicated timeseries. This excess information convolutes the analysis of the signal(s) of interest. Filtering is the solution to this problem; it allows the analyst to isolate the signal(s) of interest by removing the *noise*[2] from the recorded timeseries. Fortunately—thanks to the many technological advancements over the last few decades—personal computers are sufficiently capable of handling most modern seismic workflows (all except particularly large or high throughput workflows that require more specialized computing infrastructure).

Filtering is a tremendously wide topic of study itself, with a rich history across many otherwise disparate fields of study, well beyond the scope of this simple document. Therefore, I will restrict myself to—at most—provide a brief discussion on the fundamentals of filtering, while leaving many of the details up for the intrepid reader to research on their own. Afterward, I will provide a detailed description of the implementation of filters specific to PsSp. This is not meant to provide a detailed derivation from first principles of the filters employed, but is instead intended to serve as a pragmatic guide on their internal implementation. This is intended as much as a guide to any reader as it is to myself.

[2] *Noise* is a bit of a misunderstood term in seismology, especially with the advances in the last few decades in ambient noise seismology. The word 'noise' is used here to mean 'any signal that is not of interest for a specific analysis' and does not provide any suggestion to the source of the noise.

2 Background

2.1 Historical Background

2.2 Mathematical Background

2.2.1 The Temporal (Time) Domain

2.2.2 The Spectral (Frequency) Domain

2.2.3 The Laplace (Complex-Frequency) Domain

3 The Fast Fourier Transform

4 The Butterworth Filter

4.1 Lowpass

$$H(s) = \frac{G_0}{B_n(a)}; a = \frac{s}{w_c} \tag{1}$$

4.2 Highpass

$$B_n(s) = \sum_{k=0}^{n} a_k s^k \tag{2}$$

4.3 Bandpass

4.4 Bandreject

$$a_{k+1} = a_k \frac{cos\,(k\gamma)}{sin((k+1)\gamma)}; a_0 = 1; \gamma = \frac{\pi}{2n}; a_k = a_{n-k} \tag{3}$$

5 References