

# Synthetic test for moving source

*Kaiwen Wang and Jon Claerbout*

## ABSTRACT

Migrating tremor source is observed at the San Andreas Fault. To test the possibility of applying PEF on the moving source problem, we generate a synthetic example using a moving source model and estimate the source migration velocity.

## A SYNTHETIC EXAMPLE

We set the source depth to be 40km and moves along a horizontal line at 0.5km/s. The location of the source is  $sloc = [0, 0.5t, 40]$ . Two stations ( $sta1 = [2, 0, 0]$ ,  $sta2 = [5, 3, 0]$ ) record signals of repeating low frequency earthquakes. We use a homogenous velocity 3km/s.

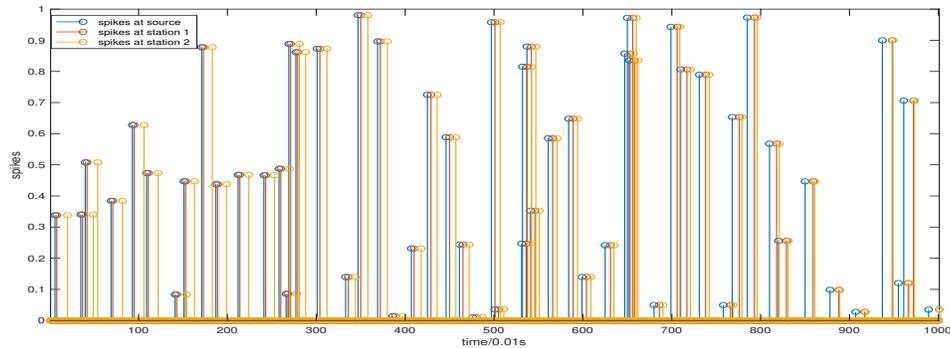


Figure 1: Spike train at different locations. The spike train generated at source location is in blue. Red and yellow spikes are the blue spikes delayed by its travel time.

Figure 1 show the spike train at different locations. We see the time difference between the spikes at the two stations changes as the source migrates. Figure 2 show the repeating earthquake template. To mimic the real tremor signal, we use a template found in [Shelly, 2017].

The spike trains at the two stations are convolved with the template to generate seismic recordings in Figure 3.

The tremors at two stations are inputs to the prediction error analysis. We assume stationary template and the two station share the same template. The recovered template is plotted in Figure 4.

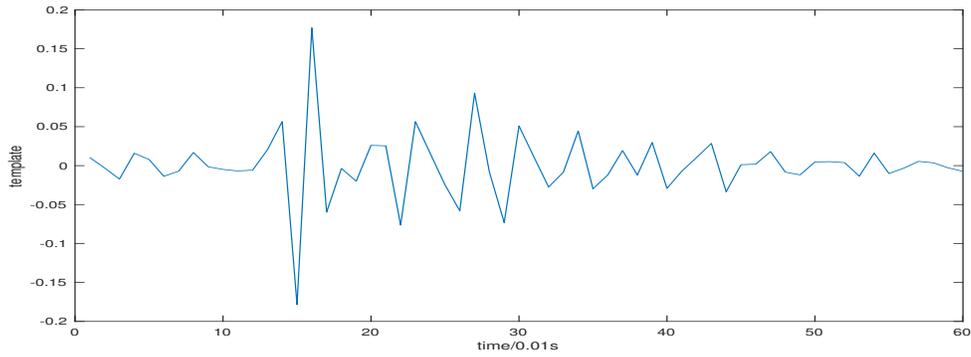


Figure 2: Tremor template, downsampled from a real low frequency earthquake. The template shrink in length to reduce computation cost.

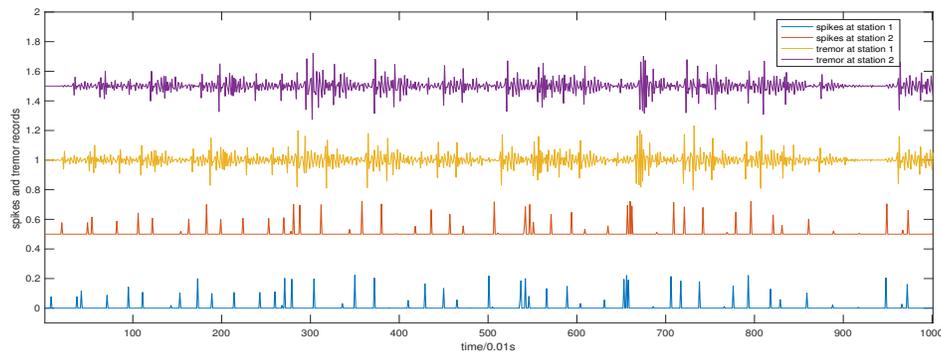


Figure 3: Bottom two traces: spikes at the two stations. Top two traces: tremors at the two stations.

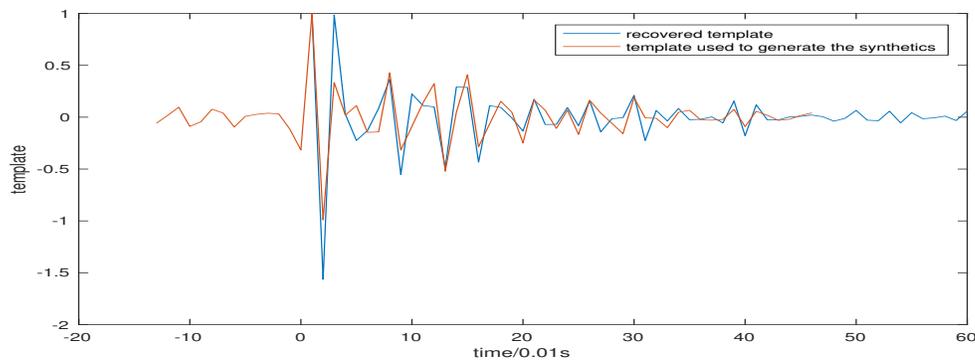


Figure 4: Blue: recovered template by calculating the impulse response of the learned filter. Red: the template used to generate the synthetics. The two curves are aligned and scaled for display.

The recovered spike train at two stations are shown in Figure 5. We see that the recovered spikes agree with the ground truth spikes.

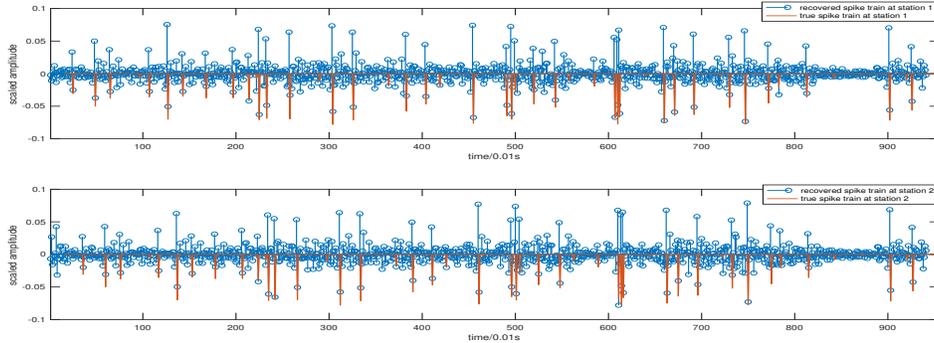


Figure 5: Top panel: Blue: recovered spike train at station 1 by calculating the prediction error. Red: ground truth spikes at station1. Bottom panel: Blue: recovered spike train at station2 by calculating the prediction error. Red: ground truth spikes at station2. The curves are scaled for display.

The following shows how we estimate the source moving velocity by cross-correlating moving windows. We chose the window size 40 ms and compute cross-correlation of each window pair. The lag (Figure 6) corresponding to the maximum correlation coefficient is recorded at each time step. The time lag is then smoothed and compared with the ground truth lag (Figure 7). Here, the ground truth lag is calculated by  $\sqrt{\text{sta2} - \text{sloc}} - \sqrt{\text{sta1} - \text{sloc}} = \sqrt{5^2 + (3 - v_s t)^2 + 40^2} - \sqrt{2^2 + (v_s t)^2 + 40^2}$ , where  $v_s = 0.5\text{km/s}$ . We can fit the lag curve to estimate the source migration velocity.

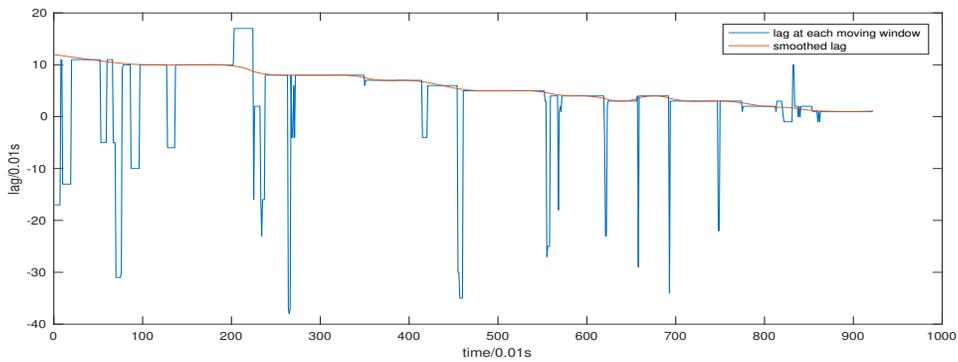


Figure 6: Time lag at each moving window.

In each window, we shift the recovered spike train at station 2 by smoothed time lag, and plot the shifted curve with the recovered spike train at station 2. The two agrees well both in spike location and amplitude, suggesting that the prediction error estimation of spike train could preserve both the spike location and amplitude information.

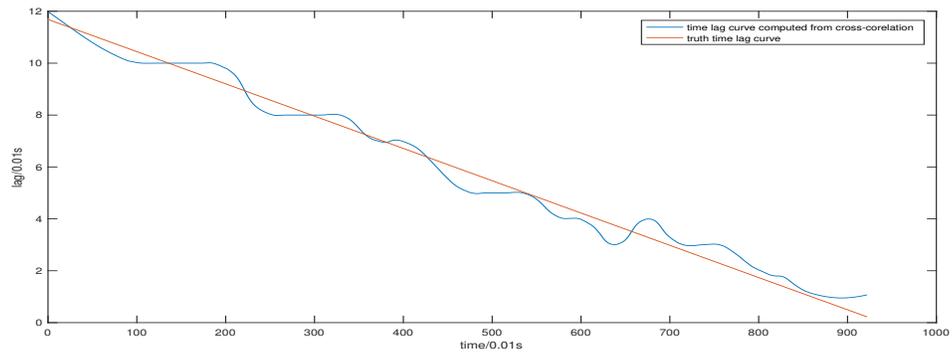


Figure 7: Calculated time lag curve compared with ground truth

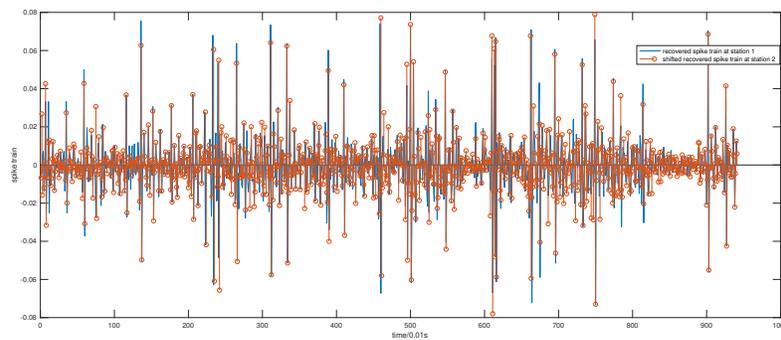


Figure 8: Blue: recovered spike train at station 1. Red: shifted recovered spike train at station 2.