Creating virtual receivers from drill-bit noise using seismic interferometry
Motivation

• A data-driven redatuming method
• Can improve migrated images in the presence of velocity errors
• Suitable for deep local imaging

Use drill-bit noise data acquired while drilling for such local imaging?
Outline

• Introduction

• Inter-source seismic interferometry (SI)

• Inter-source SI with non-transient sources

• Synthetic results

• Discussion and conclusion
Seismic interferometry (SI)

- Green’s function retrieval
- Any arbitrary 3D inhomogeneous lossless medium
- Integral (Summation) of crosscorrelation of wavefield observations

• Inter-receiver SI

• Inter-source SI

Data-driven!
for our drill-bit situation:
Simplified form of inter-source SI

\[ G(x_A | x_B) + G^*(x_A | x_B) \propto \int_{\mathcal{E}_D} G^*(x | x_A) G(x | x_B) dx \]
Inter-source SI with non-transient sources

\[ G(x_A \mid x_B) + G^*(x_A \mid x_B) \propto \int_{\partial D} G^*(x \mid x_A) G(x \mid x_B) \, dx \]

• Non-transient source \( S(x_i) \)

\[ Y(x \mid x_i) = G(x \mid x_i) S(x_i) \]

\[ C_{AB}(x) = Y^*(x \mid x_A) Y(x \mid x_B) \]

\[ \int_{\partial D_0} C_{AB}(x) \, dx = S^*(x_A) S(x_B) \int_{\partial D_0} G^*(x \mid x_A) G(x \mid x_B) \, dx \]

\[ \int_{\partial D_0} C_{AB}(x) \, dx \propto S^*(x_A) S(x_B) (G(x_A \mid x_B) + G^*(x_A \mid x_B)) \]
Inter-source SI with non-transient sources

• Same noise signal $s(t)$:

  • SI by crosscorrelation (CC):
    \[
    \int_{\mathcal{D}_0} C_{AB}(\mathbf{x}) d\mathbf{x} \propto |S|^2 \left( G(\mathbf{x}_A | \mathbf{x}_B) + G^*(\mathbf{x}_A | \mathbf{x}_B) \right)
    \]

  • SI by deconvolution (DC):
    \[
    D_{AB}(\mathbf{x}) = \frac{Y(\mathbf{x} | \mathbf{x}_B)}{Y(\mathbf{x} | \mathbf{x}_A)} = \frac{Y^*(\mathbf{x} | \mathbf{x}_A) Y(\mathbf{x} | \mathbf{x}_B)}{|Y(\mathbf{x} | \mathbf{x}_A)|^2} = \frac{G^*(\mathbf{x} | \mathbf{x}_A) G(\mathbf{x} | \mathbf{x}_B)}{|G(\mathbf{x} | \mathbf{x}_A)|^2}
    \]
    \[
    \int_{\mathcal{D}_0} D_{AB}(\mathbf{x}) d\mathbf{x} = \int_{\mathcal{D}_0} \frac{G^*(\mathbf{x} | \mathbf{x}_A) G(\mathbf{x} | \mathbf{x}_B)}{|G(\mathbf{x} | \mathbf{x}_A)|^2} d\mathbf{x}
    \]

  • SI by crosscoherence (CH):
    \[
    H_{AB}(\mathbf{x}) = \frac{Y^*(\mathbf{x} | \mathbf{x}_A) Y(\mathbf{x} | \mathbf{x}_B)}{|Y(\mathbf{x} | \mathbf{x}_A)||Y(\mathbf{x} | \mathbf{x}_B)|} = \frac{G^*(\mathbf{x} | \mathbf{x}_A) G(\mathbf{x} | \mathbf{x}_B)}{|G(\mathbf{x} | \mathbf{x}_A)||G(\mathbf{x} | \mathbf{x}_B)|}
    \]
    \[
    \int_{\mathcal{D}_0} H_{AB}(\mathbf{x}) d\mathbf{x} = \int_{\mathcal{D}_0} \frac{G^*(\mathbf{x} | \mathbf{x}_A) G(\mathbf{x} | \mathbf{x}_B)}{|G(\mathbf{x} | \mathbf{x}_A)||G(\mathbf{x} | \mathbf{x}_B)|} d\mathbf{x}
    \]

• Different $s(t)$:

  \[
  \tilde{G}(\mathbf{x} | \mathbf{x}_A) = \frac{Y(\mathbf{x} | \mathbf{x}_A) \tilde{S}^*(\mathbf{x}_A)}{|	ilde{S}(\mathbf{x}_A)|^2}.
  \]
Synthetic example

Synthetic Vp model. The stars denote drill-bit positions and triangles denote receivers at the surface level. The dots indicate two reference source positions for trace comparison.

nsrc=81, nrcv=121
Same \( s(t) \)

Drill-bit source function and recorded common-source gathers. a) Common-source gather at \( x = 2500 \) m and b) at \( x=3000 \) m. c) Modelled drill-bit source function. d) Power spectrum of the modelled drill-bit function.
Comparison of the retrieved responses with the reference response

The virtual response of the source at x= 2500m retrieved by a) DC, b) CH and c) CC. d) The reference response modelled with a homogeneous overburden.
Comparison of the retrieved responses with the reference response

As the previously, but with the virtual response of the source at \( x = 3000 \text{ m} \).
An example of the modelled drill-bit signals. a) The exact drill-bit source function $s(t)$. b) Estimate of the signal. c) The noise added to the estimated signal, which is up to 5% of the drill-bit signal.
Modelled common-source gather and pilot-deconvolved results.

a) Raw common-source gather from drilling noise at x=3000 m. Pilot-deconvolved common-source gathers using b) the exact source signal and c) the noise-contaminated pilot signal. The arrow indicates the internal multiple from the second layer, which arrives about 0.2 seconds after the direct waves.
a) and c) used $s(t)$ for pilot deconvolution. b) and d) use , and energy normalization is applied afterwards. The arrow indicates the non-physical reflection identified as the crosscorrelation of the direct waves and the internal multiples.
Migration images

a) using retrieved virtual reflection responses at the drill-bit positions, and b) using conventional surface seismic reflection data. The background indicates the true velocity model. Image a) is obtained using a homogeneous velocity model of 2750 m/s (2500 m/s + 10% error), while image b) is obtained using the 10-percent erroneous velocities of the whole model.
Discussion and conclusion

• Create virtual receivers from drill-bit noise using pilot-deconvolved drill-bit data;

• The retrieved responses are useful for imaging as they have been interferometrically redatumed to the borehole level, thus independent of the velocity accuracy of the overburden.

• Information about the drill-bit noise is essential;

• Pilot signals need to have sufficient signal-to-noise ratios;

• Receiver arrays on land or with ocean-bottom stations or cables, with sufficient spacing to avoid aliasing;

• The length of the receiver array also matters.
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