Locating and monitoring hydraulic fracture and earthquake rupture using elastic reverse-time migration

Jidong Yang & Hejun Zhu, The University of Texas at Dallas

Abstract

- Locating and monitoring passive seismic sources provides us important information for studying hydraulic fracturing and earthquake rupture.
- We present a novel passive-source monitoring approach using elastic reverse-time migration (ERTM) based on a fast vector wavefield separation.
- We compare three imaging conditions: waveform dot-product, energy, and power. Numerical experiments demonstrate that the power imaging condition gives us the highest resolution and is less sensitive to noise.
- To capture the propagation of hydraulic fracture and earthquake rupture, we implement the zero-lag cross-correlation imaging condition within local time windows.
- The application for the 2014 South Napa earthquake demonstrates that the elastic time-reversal imaging method can provide reliable 3D constraints for earthquake rupture.

Theory

   \[ \mathbf{u} = \nabla (\nabla \cdot \mathbf{u}) - \nabla \times (\nabla \times \mathbf{u}) \] where \( \Delta \mathbf{u} = \mathbf{u} \)

2. Imaging conditions for separated vector wavefield
   - Waveform: \( I_1(t) = \int \mathbf{u}(x,t) \cdot \mathbf{u}(x,t) \, dt \)
   - Energy: \( I_2(t) = \int \mathbf{u}(x,t) \cdot \mathbf{u}(x,t) \, dt \)
   - Power: \( I_3(t) = \int |\mathbf{u}(x,t)|^2 \, dt \)

3. Dynamic imaging conditions for separated vector wavefield
   - Waveform: \( I_1(t) = \int \mathbf{u}(x,t) \cdot \mathbf{u}(x,t) \, dt \)
   - Energy: \( I_2(t) = \int |\mathbf{u}(x,t)|^2 \, dt \)
   - Power: \( I_3(t) = \int |\mathbf{u}(x,t)|^2 \, dt \)

4. Comparison between reflection and transmission RTM schemes

Earthquake rupture example

- Dynamic source signature: 0.3 s
- Dynamic source signature: 0.4 s
- Dynamic source signature: 0.6 s

Hydraulic fracture example

- Velocity model
- Static source signature
- Dynamic source signature: 0.3 s
- Dynamic source signature: 0.4 s
- Dynamic source signature: 0.5 s

Conclusion

- We introduce the vector Helmholtz decomposition into elastic time-reversal imaging and develop an efficient and accurate passive-source locating and monitoring method.
- Three implementations, i.e., dot-product, energy and power, are used in the cross-correlation imaging condition for the separated vector P- and S-wavefields.
- This method can be used to image hydraulic fracture and earthquake rupture, and monitoring their dynamic propagations.
- Numerical examples for synthetic data and 2014 South Napa earthquake demonstrate its feasibility and adaptability.

Acknowledgements

This research is supported by the Geosciences Department Ph.D. program. We are grateful to the computational resources provided by the Texas Advanced Computing Center.

Email: jyy160930@utdallas.edu