Autonomous Monitoring of Wellbore Integrity Applying Time-Reverse Nonlinear-Elastic Wave Spectroscopy and Fiber Optic Sensing and Communication
Project Number (FWP-FE-853-17-FY17)

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U.S. Department of Energy
National Energy Technology Laboratory
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 TRIAD Property
Outline

• Collaborators and Background
• Approach
• Impact
• Technical status
• Accomplishments to date
• Lessons learned
• Synergy opportunities
• Project summary
Collaborators and Background

Team

Los Alamos National Lab (project lead)
- P. Johnson (PI), C. Donahue (Co-Pi), M. Remillieux, B. Carey, E. Dauson, L. Beardslee, L. Frash, S. Boyce, and E. Rougier
- Acoustics (nonlinearity, time reversal, signals from noise); machine learning; wellbore integrity; lab-scale experiments; project integration; DAS

Lawrence Berkeley National Lab
- S. Nakagawa
- Acoustics; fiber optics

Clemson University
- L. Murdoch, L. Hua, H. Xiao, S. DeWolf
- Fiber optics, geomechanics, acoustics

Chevron, ETC
- H. Goodman
- Field application needs

Background to Approach

Our previous work has demonstrated:
- Nonlinear acoustical methods probe mechanical damage in complex earth materials;
- Acoustic time-reversal methods used to focus energy (including within earth materials);
- Machine-learning algorithms can extract small seismo-acoustic signatures from noisy backgrounds;
- Fiber optic sensors can be used to monitor strain at high resolution;
- Microwave photonics can measure distributed strain with optical fiber using non-proprietary methods.
Goals and Objective: Development of an autonomous system that can be deployed in wells for unattended long-term (e.g., decades) to monitor both wellbore integrity and stress changes near wellbore

- Need: affordable, robust, autonomous system for monitoring wellbore integrity, especially post closure
- Need: detect leakage signatures for long term CO$_2$ monitoring

Innovation: Combination of:

(i) Fiber optic sensing to track near-borehole anomalous stress evolution associated with damage and to detect acoustic signals

(ii) Supervised machine learning to extract passive seismo-acoustic signals for long term monitoring of associated with leakage;

(iii) Active acoustics using embedded sensors and Time Reverse Nonlinear Elastic Wave Spectroscopy (TR-NEWS) to probe for localized damage
Approach

A. **Listen for leakage** in near-wellbore region using passive acoustic methods (specific objective 1; task 3)
   i. Identify/discover signatures
   ii. Evaluate ability of embedded acoustic sensors to detect signature(s)
   iii. Develop machine-learning algorithms to extract signature(s) autonomously, including the extraction of signal from noise

B. **Interrogate and locate** damage regions with *time-reversal nonlinear elastic wave spectroscopy* (TR-NEWS)
   i. Demonstrate the ability to focus acoustic energy at specific points along a wellbore using time reversal (specific objective 2; task 4)
   ii. Identify/discover nonlinear elastic signatures associated with damage zones and leakage pathways (specific objective 3; task 5)

C. **Monitor strain/stress evolution** in near-wellbore region using fiber optic sensing
   i. Demonstrate the ability of an embedded fiber optic cable to detect strain tied to loss of integrity in the near-wellbore region (specific objective 4; task 6)
   ii. Evaluate the feasibility of measuring distributed strain and acoustic spectra using non-proprietary fiber optic techniques
Half Pipe to Inspect and ground-truth Damage

- Create local damage
- Use Time Reversal to look for local signs of nonlinearity

Half cased wellbore in 1 ton of Berea
Product Specifications
Sensing Capabilities
Range: 0 - 40km
Frequency Range: 0.01Hz - 50kHz
Spatial Resolution: down to 1m*
Monitoring Acoustic Signals

- Listen to flow through a cracked rock
- Use machine learning to look for signatures
Time Reversal Simulations

Bending mode
Torsional mode
Longitudinal mode
Accomplishments to Date

- Performed TR in open hole and exposed cased half-pipe with laser vibrometer and fiber optics
- Simulated TR in open hole and cased hole
- Tested two optical fiber systems with TR on large sandstone block and in half-pipe
- Acquired iDAS system
- Gathered data and applying Machine Learning to acoustic signal generated by flow through a cracked rock in pressure vessel
- Simulation of TR-NEWS system show many sources are needed
Lessons Learned

- DAS shows promise
- Need sufficient reflectors and/or sources in open hole for time reversal
- Difficult to create damage for evaluation in case wellbore
- Anticipate pieces will be in place at end of project to move to prototype development
Synergy Opportunities

– **Leak Detection over large areas** – Youzuo Lin. Some signatures discovered and algorithms developed in this effort may be relevant to our project—lessons learned will be shared.

– **Monitoring Reservoir Displacements** – Paul Johnson. Particularly looking at the State of Stress.

– **Monitoring Seismicity** – Ting Chen

– **Ground Base Nuclear Explosion Monitoring** – Michael Begnaud. Interest in applying DAS

– **Global Security** – Emily Schulze-Fellenz. Interest in applying DAS.
Key Findings:
- TR NEWS computer simulations show the procedure in full
- The TR Experiments work reasonably in a laboratory borehole and will require optimization
- iDAS System has been delivered, developments in iDAS show a low cost method for leakage monitoring

Next Steps:
- Advance ‘leak listening’ studies applying machine learning. Laboratory and simulation.
- Planning field test using iDAS
- Continue simulations of listening and state of stress
- Publish tests of TR NEWS
Appendix
Benefit to the Program

- GOAL: development of autonomous system that can be deployed in wells for long-term (e.g., decades), unattended monitoring both wellbore integrity and associated stress changes (Topic Area 2).

- If successful in achieving the overarching R&D goal, the outcome would be a cost-effective option (hardware and software) for long-term autonomous monitoring of wells.

- This technology would have broad application in subsurface operations, where maintaining and monitoring wellbore integrity is central to reservoir management strategies (including geothermal operations, oil/gas operations, injection operations). However, the largest benefit to national subsurface energy interest likely lies in post-closure monitoring of wellbore integrity, as needed for CO2 storage operations. This system would be a cost-effective autonomous option to provide the data necessary to ensure that wellbore integrity is being maintained, targeting a central need in any CO2 storage.
Goals and Objective: Development of an autonomous system that can be deployed in wells for unattended long-term (e.g., decades) to monitor both wellbore integrity and stress changes around the borehole.

- Need: affordable, robust, autonomous system for monitoring wellbore integrity, especially post closure.
- Need: detect leakage signatures for long term CO₂ monitoring.

Innovation: Combination of:

(i) Machine learning to extract passive seismo-acoustic signals for long term monitoring of associated with leakage;

(ii) Active acoustics using embedded sensors and Time Reverse Nonlinear Elastic Wave Spectroscopy (TR-NEWS) to probe for localized damage

(iii) Fiber optic sensing to track near-borehole anomalous stress evolution associated with damage.
LANL: overall lead
LANL and LBL: TR NEWS simulation and experiment
LANL: DAS and Machine learning applied to leak signals, experiment and simulation
Clemson: consultation on Fiber Optics
Chevron: consultation on R and D, and application
# Gantt Chart

(project initiated late Q1 FY18)

Table 1. Timeline for project by task and project year (PY), with two go/no-go (G/NG) decision points.

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<th>Task Description</th>
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- Go: Project continues as planned.
- No-go: Project is terminated.

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Bibliography

• In Progress