Ultrasonic Phased Arrays and Interactive Reflectivity Tomography for Nondestructive Inspection of Injection and Production Wells in Geothermal Energy Systems

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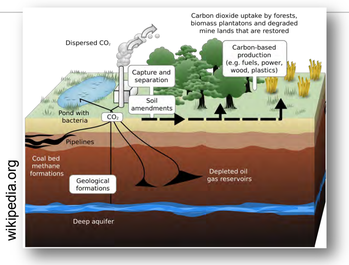
Objective

Develop a ***highly integrated and optimized*** ultrasonic phased array imaging system and reconstruction algorithm to provide new ***wellbore characterization*** capabilities that will significantly improve wellbore integrity evaluation and ***near wellbore region characterization including fracture network mapping***.

- **Project Start Date:** Late December 2015
- **Expected Benefits:**
  - More detailed structural characterization of wellbore and near wellbore region
  - Improved capability for identifying wellbore integrity compromises
  - Provide critical data that can be used to improve stimulation design
  - Provide ability to measure evolution of the fracture network to support long term management of reservoir operations

Motivation

- **Current logging instruments**
  - Expedited inspection of the integrity of steel-to-grout bond; further penetration is not typically done
  - Poor transverse lateral resolution (15.2 cm)
  - Expert interprets sonic/ultrasonic signals/images
- **Techniques from other fields**
  - Ultrasound imaging could leverage from advances in X-ray imaging, in particular computational tomography
  - Pioneering implementation of Model-Based Iterative Reconstruction (MBIR) for ultrasonic signals
  - Develop reconstruction technique that can applied across applications (e.g., CO2 Storage, Oil and Gas, Geothermal, etc.) and that is adaptable to different acoustic sources



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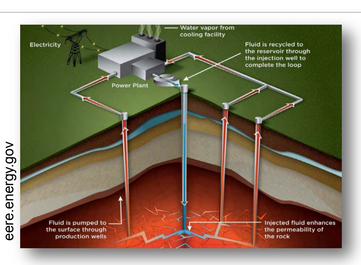

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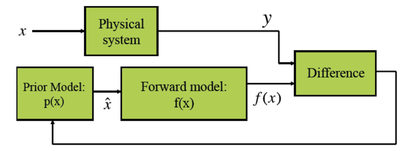
System Performance Goals

- **Acoustic System**
  - 16-element phased array
  - Broadband 100KHz central frequency
  - Control system for dynamic adjustment for phased array focal laws
- **Reconstruction Algorithm**
  - MBIR reconstruction assuming acoustic propagation
  - Two-dimensional reconstruction (i.e., cross-section slice)
- **Overall system**
  - Depth range of 1m or greater
  - Transverse spatial and axial resolution of 10cm or greater
  - Image quality superior to Synthetic Aperture Focusing Technique (SAFT) reconstructions

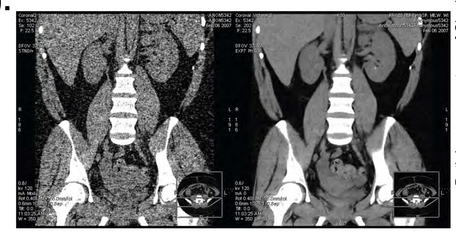
Model-Based Iterative Reconstruction (MBIR)

- **The Framework**
  - p(y/x) models the response of the system given an estimate of the media
  - p(x) models the media
  - p(y/x) and p(x) are application and system dependent
- **For X-Ray Computed Tomography (CT):**
  - First FDA approved X-ray medical CT iterative reconstruction technique
  - Dramatic reduction in X-ray dosage
    - Lung cancer screening ~80%
    - Pediatric imaging 30-50%
  - Superior in the presence of noise and sparse information

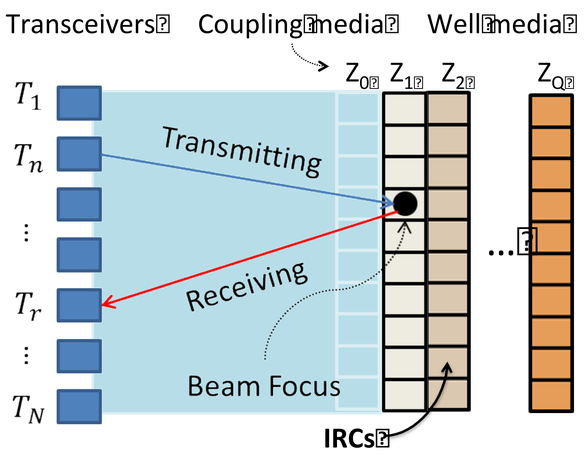


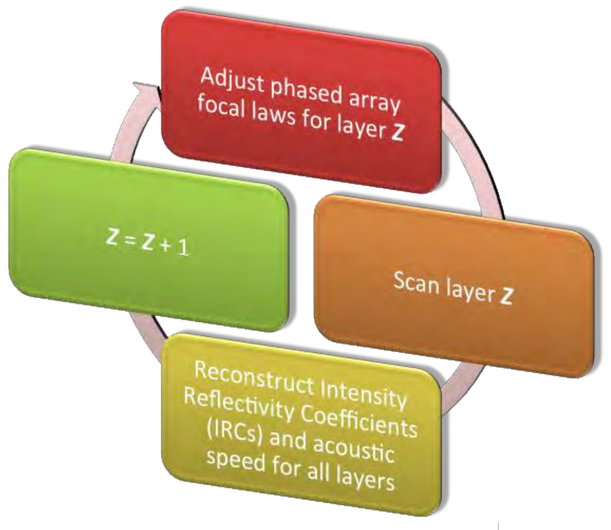
$$\hat{x} \leftarrow \arg\max_{x} \{\underbrace{\log p(y \mid x)}_{\text{forward model}} + \underbrace{\log p(x)}_{\text{prior model}}\}$$

$\hat{x}$ – Reconstructed object
y – Measurements from physical system


Both images courtesy of Charlie Bouman, Purdue University

Technical Approach





- **Research plan:**
  - Development of ultrasound phased array with adaptive focal laws
  - MBIR implementation for 2D reconstructions
    - Define forward models
    - Invert and discretized forward model
    - Wrap forward model in convergence algorithm
  - Test of reconstruction algorithm with synthetic data
  - Laboratory proof-of-concept demo
  - Compare MBIR performance against state of the art SAFT

Key Accomplishments and Progress

- **Requirements for transducer performance and phased array control have been developed based on the imaging goals of the project**
  - System hardware performance specification developed
  - All hardware components have been received and are in the process of assembly
  - System commissioning planned for June
- **MBIR**
  - Inverted forward model assuming homogenous media, born approximation, and coherent integration
  - Initial Matlab implementation of iteration algorithm
  - Currently working on discretization of forward model

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