A Novel Full Matrix Capture Ultrasonic Imaging System for Non-Radioisotopic Inspections

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Outline

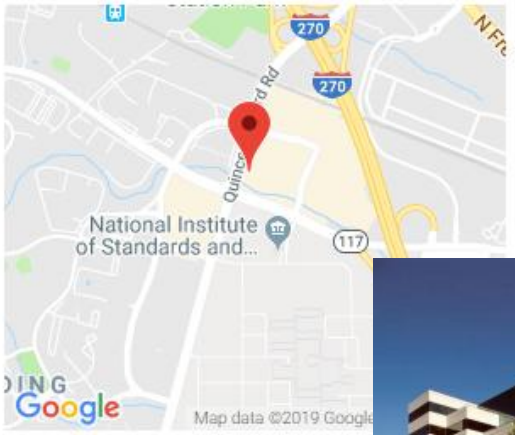
- XII Introduction
- Challenge Target for Radiographic Source Usage
- Proposed Solution for Alternative Technology Adoption
- Overview of Volumetric Focusing Imaging Technology
- Technology Development Status and Next Steps
- Discussion

X-WAVE INNOVATIONS, INC.

Make state-of-the-art obsolete

Company Overview

- Woman-owned small business (WOSB)
- Founded in 2009
- Located in Gaithersburg, Maryland
- 16 professional staff: 10 Ph.D., 3 M.S., 3 B.S.
- Diverse background including ME, EE, MS, CS, CE, and Physics



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Core Technologies

Sensor Technology
- New sensing technologies & systems
- Sensor network & data fusion

NDT and SHM
- Acoustics / Ultrasonics, Vibration
- Guided / Defused waves
- Electromagnetic, microwave / RF

Signal & Image Processing
- Machine learning, pattern recognition
- Fault detection, identification, classification
- Digital image correlation

Data Analysis and Management Services
- Custom data modeling & analysis
- App development; Database Management

Power Electronic Systems and Controls
- Battery state of charge and health monitoring
- Battery management and control
- DC/DC and DC/AC Converters

Advanced Materials and Processing
- Additive Manufacturing,
- Surface material processing; Residual stress relief
- Nanomaterials process and test

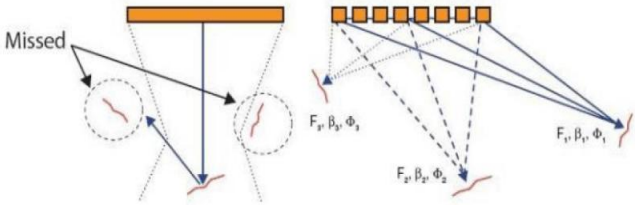
Challenge Target

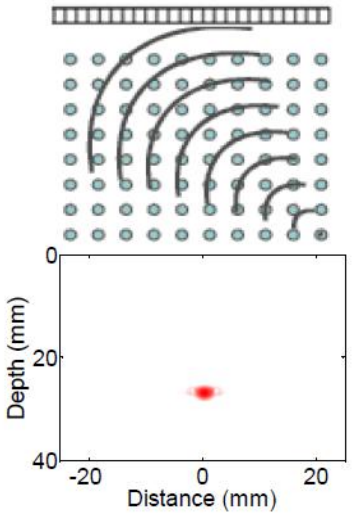
- Radiographic techniques:
  - widely used in NDE applications for inspections and flaw detection
  - operational safety and security risks due to use of radio-isotopic materials
- Technology development goals:
  - Reduce dependence on commercial and industrial radioactive materials for nuclear non-proliferation
  - Develop alternative technology solutions to perform inspections in a reliable, cost-effective and safe manner
  - Improve upon deficiencies of currently available technology
- Alternative Technology Solution Premise:
  - Replace radiographic techniques with ultrasonic inspection methods

Ultrasonic Array Inspections and Full Matrix Capture

- Ultrasonic Phased Array:
  - Use several ultrasonic sensors in combination instead of single transducers in isolation
  - Multiple transducers used simultaneously as transmitters and receivers
  - Interaction of traveling ultrasonic signals produces better resolution of flaws
- Full Matrix Capture
  - Special implementation case of ultrasonic phased array sensor system
  - Use each transducer successively as transmitter; acquire all signals received at all transducers
  - Numerically combine and analyze acquired signals
- Most common numerical technique:

  Total Focusing Method

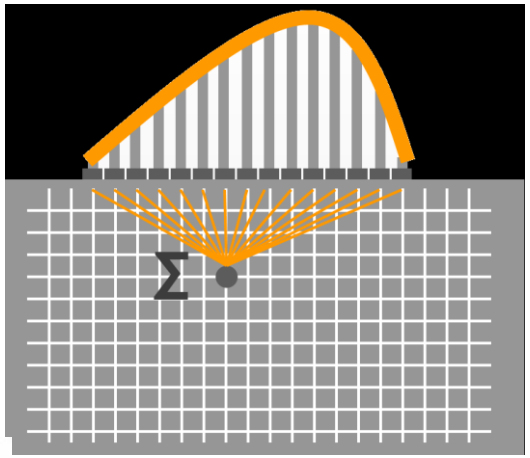




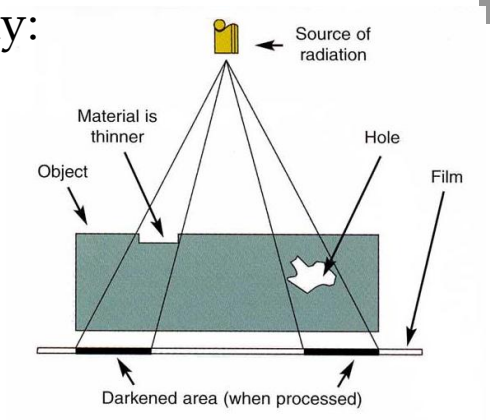
Source: Minghui Li and Gordon Hayward, Sensors 2012, I2, 2-54, doi: 10.3390/s120100042

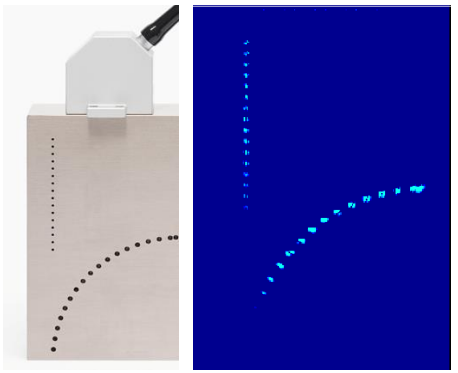
Total Focusing Method (TFM) and Comparison with Radiography

- For each ultrasonic array scan, TFM algorithm creates a vertical cross sectional image
  - FMC data 'focused' at different specimen locations
  - Vertical view (B-scan) images are created
  - New images produced as sensor array moves across surface



- In comparison, in radiography:
  - Imaging is performed on an entire test surface
  - Plan view images (C-scan) are created
  - Radiography images saved for later analysis





Source: https://www.nde-ed.org/GeneralResources/MethodSummary/MethodSummary.htm

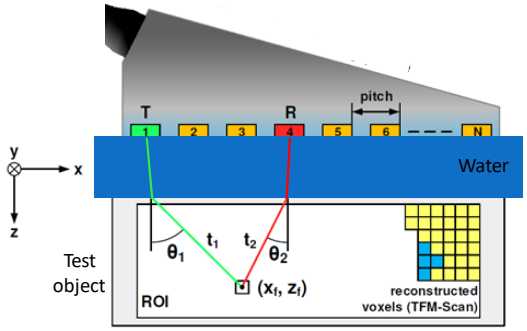
Source: https://www.karldeutsch.de/PDF/Konferenztexte/Mo_1_A_3_Deutsch.pdf

Proposed Solution for Alternative Technology Development

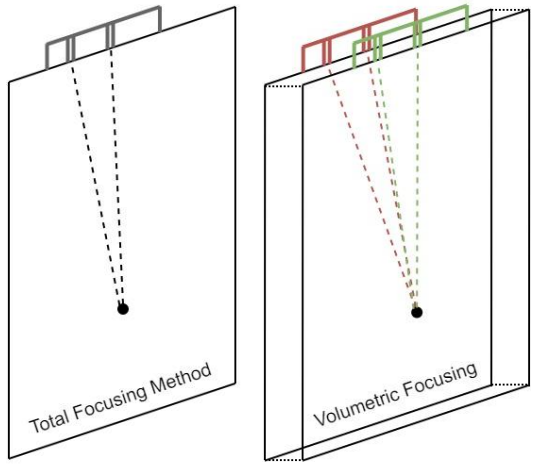
- Ultrasonic array based volumetric inspection
  - Full matrix capture (FMC) data acquisition; retain all ultrasonic signals
  - Numerically combine all acquired signals to identify flaws present
  - Improve upon currently available Total Focusing Method (TFM) by performing volumetric analysis instead of vertical planar analysis
- Volumetric Focusing Imaging (patent pending):
  - Experimentally acquire full matrix ultrasonic array signal data from multiple adjacent planes using custom 2-D ultrasonic array probe
  - Combine all acquired data to perform volumetric analysis using synthetic aperture focusing algorithms to combine signals
  - Create plan view (C-scan) images of test specimen by performing volumetric focusing analysis with combined volumetric signal data
  - Enable creation of custom planar views at any specified plane/region

Total Focusing Method vs. Volumetric Focusing (Patent Pending)

- Total Focusing Method
  - Current state of the art
  - Numerically superpose individual ultrasonic signals to recreate beam-forming within specimen region
  - Reconstruct single vertical planes at a time
  - Multiple planes can be 'stacked' together to approximate image over a volume
- Volumetric Focusing Imaging
  - Currently under development at XII
  - Implement 'neighborhood' focusing by considering ultrasonic data from multiple adjacent vertical planes
  - Two-fold advantage:
    - Include more data for superposition, improving SNR
    - Create true volumetric imaging, capturing 'intermediate' vertical planes between successive vertical experimental scans
  - Custom 2-D ultrasonic array probe for dedicated implementation; capture signals from multiple planes



FMC + TFM imaging method.
Schematic created based on
Grager et al. 2016, http://ndt.net/?id=19483



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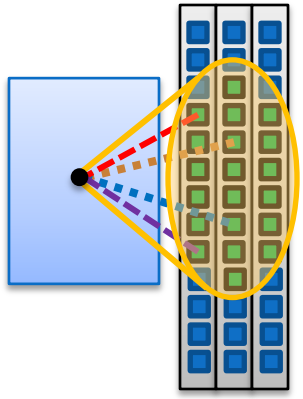
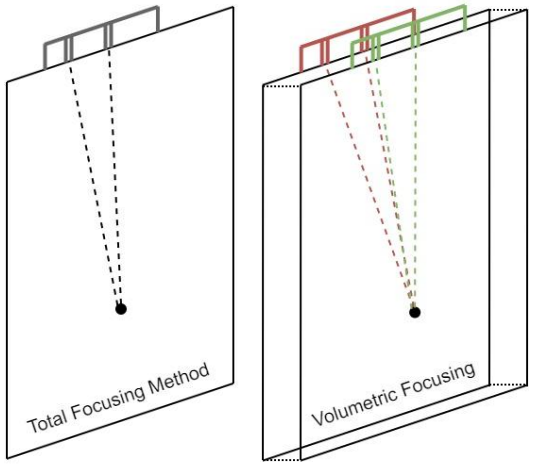
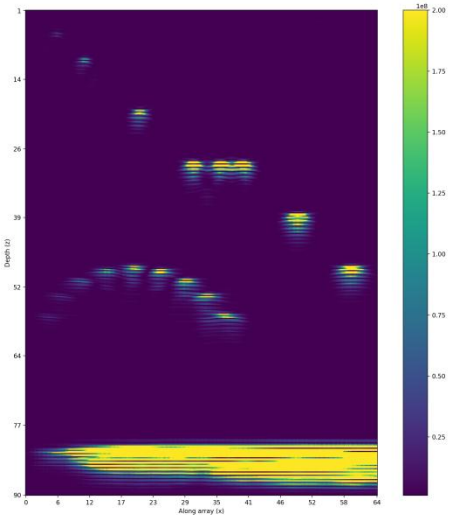


'Neighborhood' region for each volumetric point



Technology Development Status and Next Steps

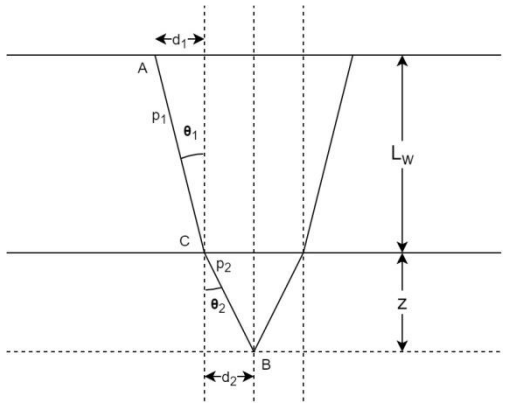
- Current status of technology development
  - Successfully completed SBIR Phase I project and demonstrated proof of concept of our volumetric imaging approach
  - Developed preliminary algorithms for volumetric focusing
  - Experimentally acquired preliminary ultrasonic data, from in-house sensor hardware and from commercial partner
  - Performed preliminary simulations to model ultrasonic waves
  - Performed preliminary image reconstruction
- Next steps to continue technology development
  - Continue development through SBIR Phase II program (we will submit Phase II proposal in the upcoming cycle)
  - Develop and build fully functional prototype device
  - Design and build custom ultrasonic array sensor hardware
  - Update, augment and improve algorithms and software
  - Evaluate and validate performance of the prototype system
  - Work on technology transitioning to build integrated product



Preliminary image reconstruction using VFI

XII Preliminary Ultrasonic Sensor for Proof of Concept

- XII wheel probe sensor system
  - Olympus RollerFORM ultrasonic array sensor + AOS array controller hardware
  - Can be operated in phased array mode (currently available) which can be used as benchmark for the system
  - Can be used for FMC data capture (volumetric focusing under development)
- Olympus RollerFORM system:
  - 64 element 3.5 MHz sensors array in a wheel probe
  - Sensor array is installed in a special 'tire' which is water filled. Tire material closely matches impedance of water.
  - Signal acquisition is triggered by encoder attached to rear roller.



Delay law calculation for water layer

Summary and Advantages of XII's Volumetric Focusing Imaging

- Current radiographic methods are popular and widely used
  - Includes disadvantages due to use of radio-isotopic materials
- VFI technology improves upon current implementations of FMC and TFM technique of ultrasonic phased array inspections
  - Current TFM technique provides B-scan images as inspection proceeds
  - Material volume is approximated by stacking multiple images
  - No image reconstruction in intermediate points
- VFI technology is of great interest in the inspection community. Advantages of the our technology:
  - True volumetric reconstruction, including points in intermediate planes
  - Creates C-scan images of the test material, similar to radiography
  - Allows generation of plan view images at depths of user choice
  - Allows generation of planar images from custom viewing planes

Discussion

Questions / Comments?

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