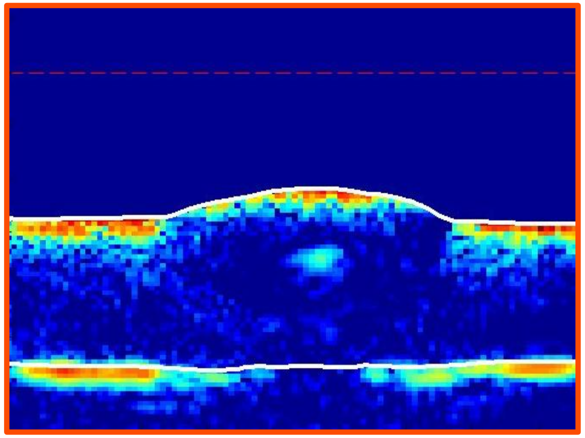
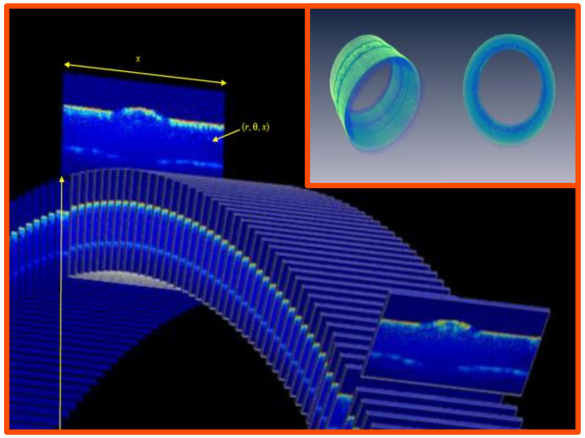
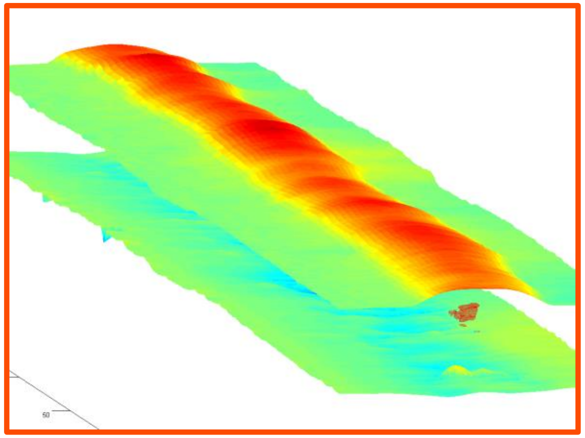
The Ultra-Sound Choice: Ultrasonic Imaging Using MATLAB AND BRAIN

Tom Barber

Anthony Croxford



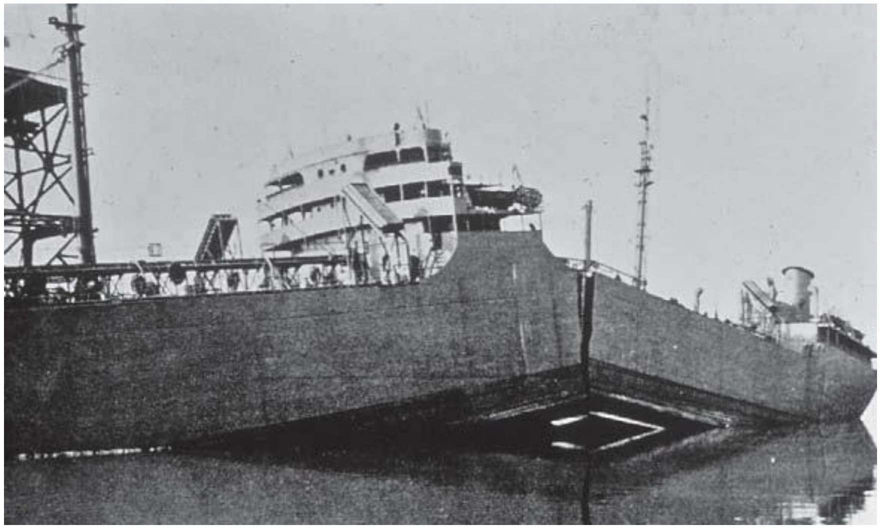




Outline

- **The Engineering Need for Ultrasound**
- BRAIN: Development & Implementation
- Industrial Benefit & Outlook

Structural Engineering
When Things Go Wrong…

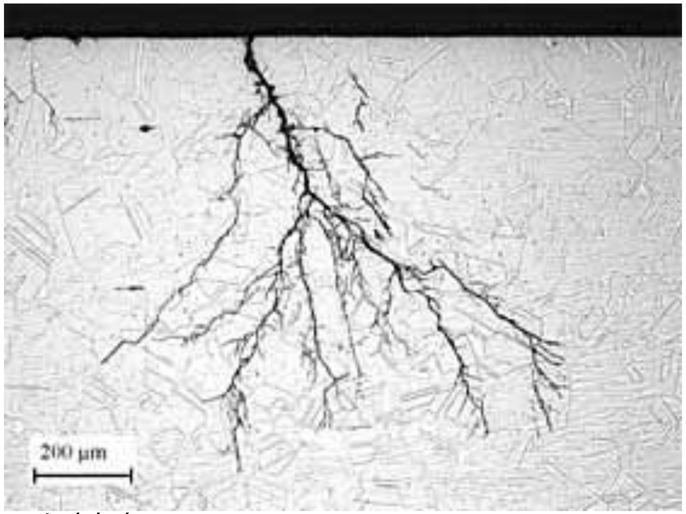


1940s: Liberty Cargo Vessels
Hull-cracking

1988: Aloha Airlines Flight 243
Fatigue-cracking in lap-joint

Structural Engineering
Material Flaws: Causes of failure

Flaws in-service



twi-global.com

Stress-Corrosion Cracking

Flaws at manufacture

Crack in a butt-welded joint

- Cannot be detected reliably by the "Mk 1 Eyeball"
- Can occur sub-surface or in accessible areas
- How are flaws detected or monitored?

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

Non-Destructive Testing (NDT)

Use of sensor and imaging technology to assess the conditions of components, plant and engineering structures during manufacture and in-service

- 25,000 NDT inspections carried in the UK every day
- 120,000 NDT inspections world-wide

Cross-sector:
- Energy, nuclear, aerospace, renewables

Industry Trends:
- Quantitative, data driven inspections
- Automation (robotics and data analysis)
- Probabilistic Risk-Based Inspection

stsgroupuk.co.uk

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

BAE Systems
Maritime

- Naval Ships, Submarines, Maritime Services
- Design, fabrication and in-service support of surface vessels, submarines and combat systems
- ~15,000 employees

University of BRISTOL

RCNDE UK Research Centre in NDE

BAE SYSTEMS

BAE Systems *Maritime*

- Shock-resistant structures and systems
- 100's of sailors on-board
- Welded together
- Submerged and PWR propulsion (submarines)

NDT at manufacture is a vital part of a vessels safety-case

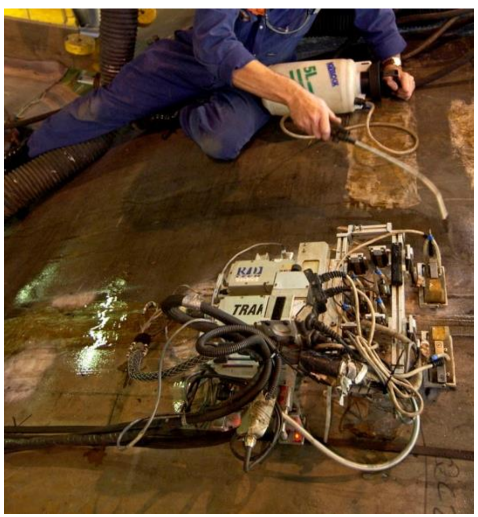
University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

BAE Systems
The Benefit of Ultrasonic Imaging

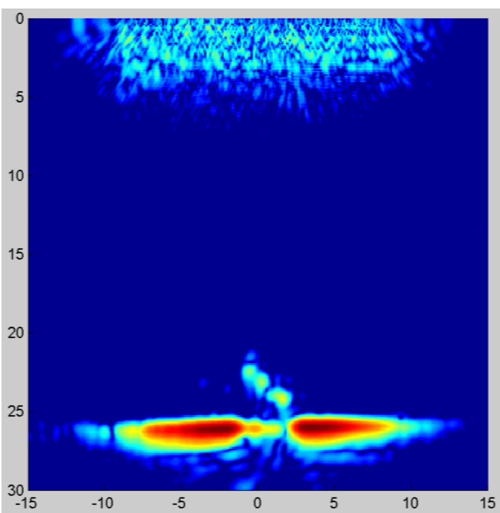
Ultrasonic and Radiographic Imaging are the main methods for sub-surface flaw detection in welded-joints

Ultrasonics is preferred:

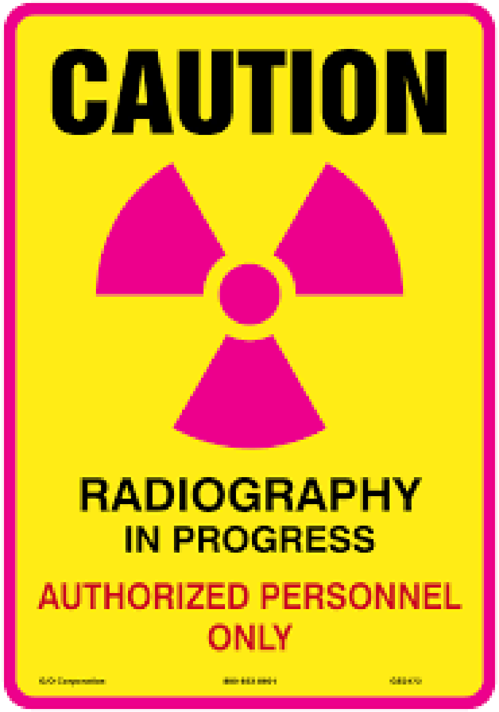
- Industrial radiography is heavily regulated
- Don't have to shut down production to perform



Ultrasonic scanner



Ultrasonic image of flaw



University of BRISTOL

RCNDE UK Research Centre in NDE

BAE SYSTEMS

The Problem
Pipe-welds

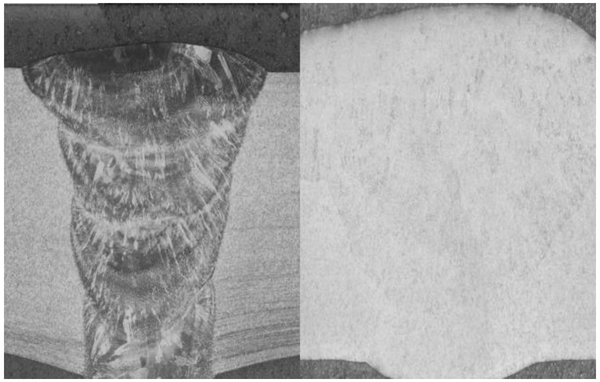
On a typical vessel:

- ~100km of cabling and pipe-work
- ~10,000 welds that require NDT

Small-bore pipe-welds are difficult to inspect using ultrasound

- Geometry
- Material
- Spatial constraints – pipe spools, access to weld (bulk-heads, decks, fittings)

A pipe next to a pen



Micrographs of weld

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

MATLAB: Finding the Solution
Developing and Testing new Imaging Techniques

- End-users of NDT have a reliance on Commercial Off The Shelf equipment (COTS)
- No COTS equipment that meets requirements
- Innovations in ultrasonic imaging are slow to market in the NDT sector

BAE Systems partnered with University of Bristol and the RCNDE to develop and test new imaging techniques and algorithms for pipe welds

Requirements: Pipe Weld Ultrasonic Imaging

- Control, generation and acquisition of ultrasonic data
- Handle large sets of data (10-40GB)
- Real-time signal and image processing
- Rapid testing of new techniques
- Tools to support shop-floor deployment

University of Bristol RCNDE UK Research Centre in NDE BAE SYSTEMS

MATLAB: Finding the Solution
Developing and Testing new Imaging Techniques

- End-users of NDT have a reliance on Commercial Off The Shelf equipment (COTS)
- No COTS equipment that meets requirements
- Innovations in ultrasonic imaging are slow to market in the NDT sector

BAE Systems partnered with University of Bristol and the RCNDE to develop and test new imaging techniques and algorithms for pipe welds

Requirements: Pipe Weld Ultrasonic Imaging
- Control, generation and acquisition of ultrasonic data
- Handle large sets of data (10-40GB)
- Real-time signal and image processing
- Rapid testing of new techniques
- Tools to support shop-floor deployment

MATLAB BRAIN

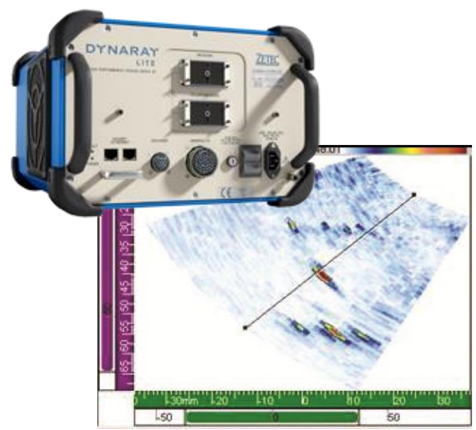
University of Bristol
RCNDE UK Research Centre in NDE
BAE SYSTEMS

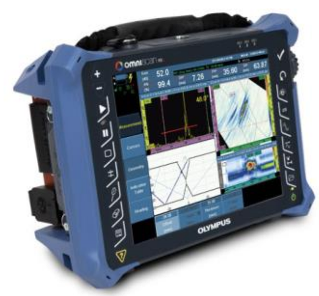
Outline

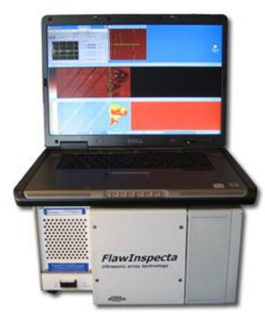
- The Engineering Need for Ultrasound
- **BRAIN: Development & Implementation**
- Industrial Benefit & Outlook

Ultrasonic Phased Arrays
Historical Background

- Sokolov (late 1920s) first use of ultrasound in NDE
- Dussik (late 1930s) first use of ultrasound in medicine
- Wild and Reid[1] (1952) first mechanical imaging in medicine
- Buschmann (1964) first array imaging in medicine
- Lemon and Posakony[2] (1980) first array imaging in NDE








Various contemporary NDE array systems

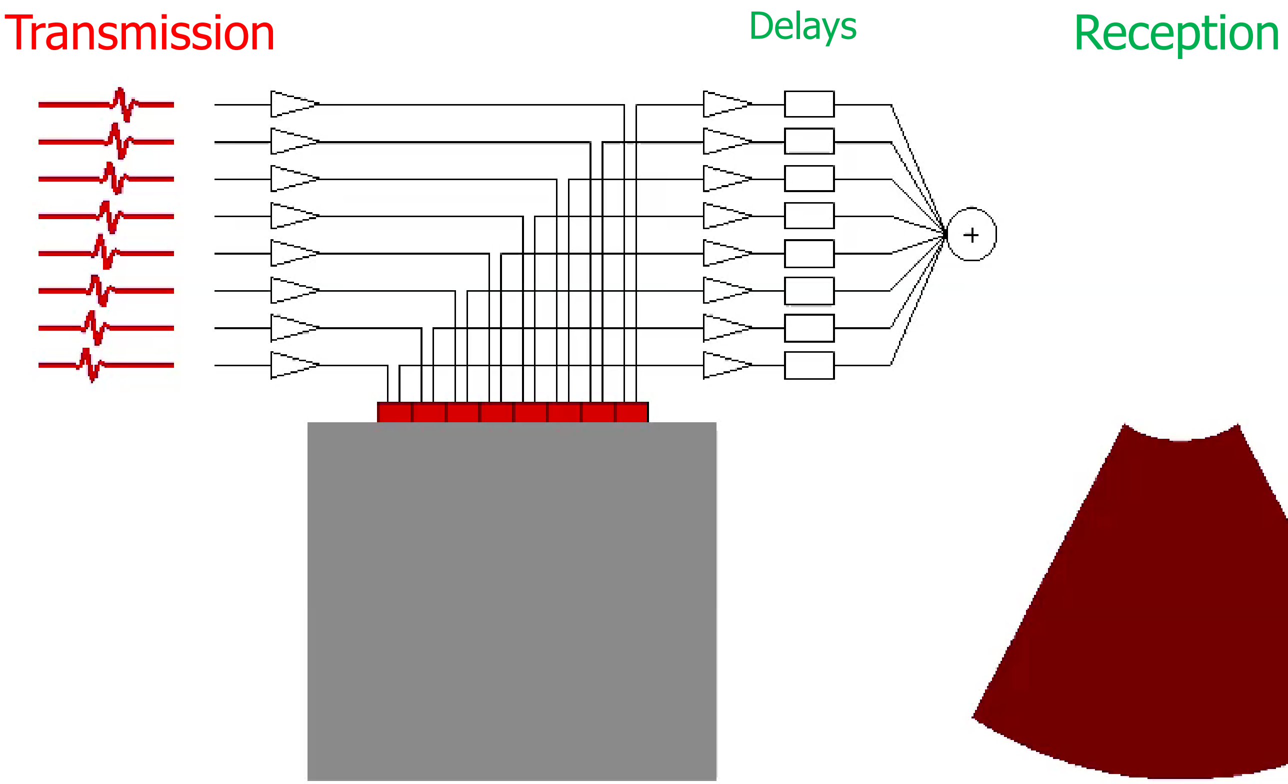
University of BRISTOL

RCNDE UK Research Centre in NDE

BAE SYSTEMS

Ultrasonic Phased Arrays
Classical B-scan

- Use like a radar or lens – Apply delays to focus at a point

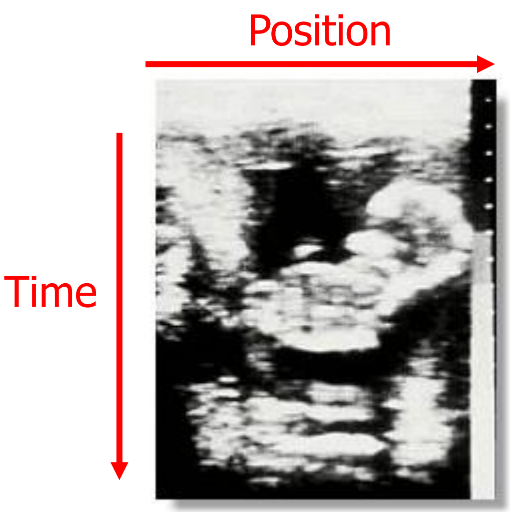


Output image

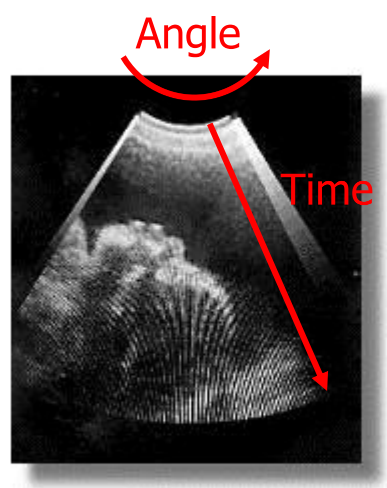
Ultrasonic Phased Arrays
Classical B-scan

- NDT simply applies these medical ideas
- Works well, very useful
- Not flexible
- Not playing to unique features of NDT – Stationary, few scatterers

1975



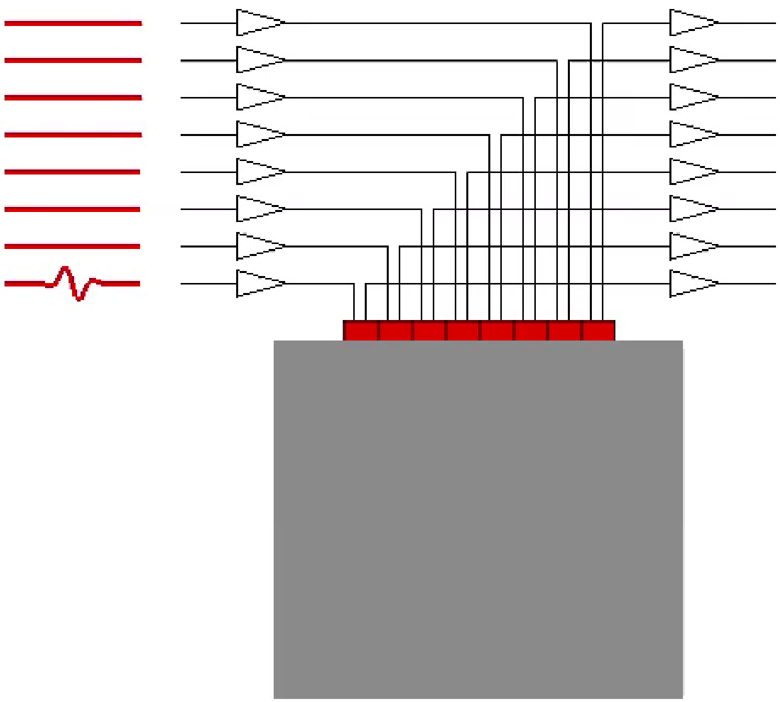
12 weeks fetus imaged with an early ADR



How should we make measurements?
Full Matrix Capture (FMC)

Transmission

Reception



- Fire elements individually
- Focus everywhere in post processing

Output

Full Matrix Capture (FMC)

Why do it?

- Captures all possible data from array
- Allows operations not otherwise feasible (or even possible)
- Moves emphasis from hardware to software
- Improvements in technique can be applied retrospectively

Challenges

- Does not work on classical hardware
- Needs a new way of thinking

Our History

- Doing this since 2003 - Initially took hours to capture and process
- High impact papers
- Slow industrial uptake
- Led to desire to develop tools to take academic research into industry

University of Bristol
RCNDE UK Research Centre in NDE
BAE SYSTEMS

What BRAIN is

BRAIN

- Software platform for array processing based on FMC
  - Demonstrations
  - Initial industrial trials
  - Development of new algorithms
  - Let end users try and develop approaches in a Graphical Environment
- Generic user interface; modular architecture
- Compiled and scripted versions

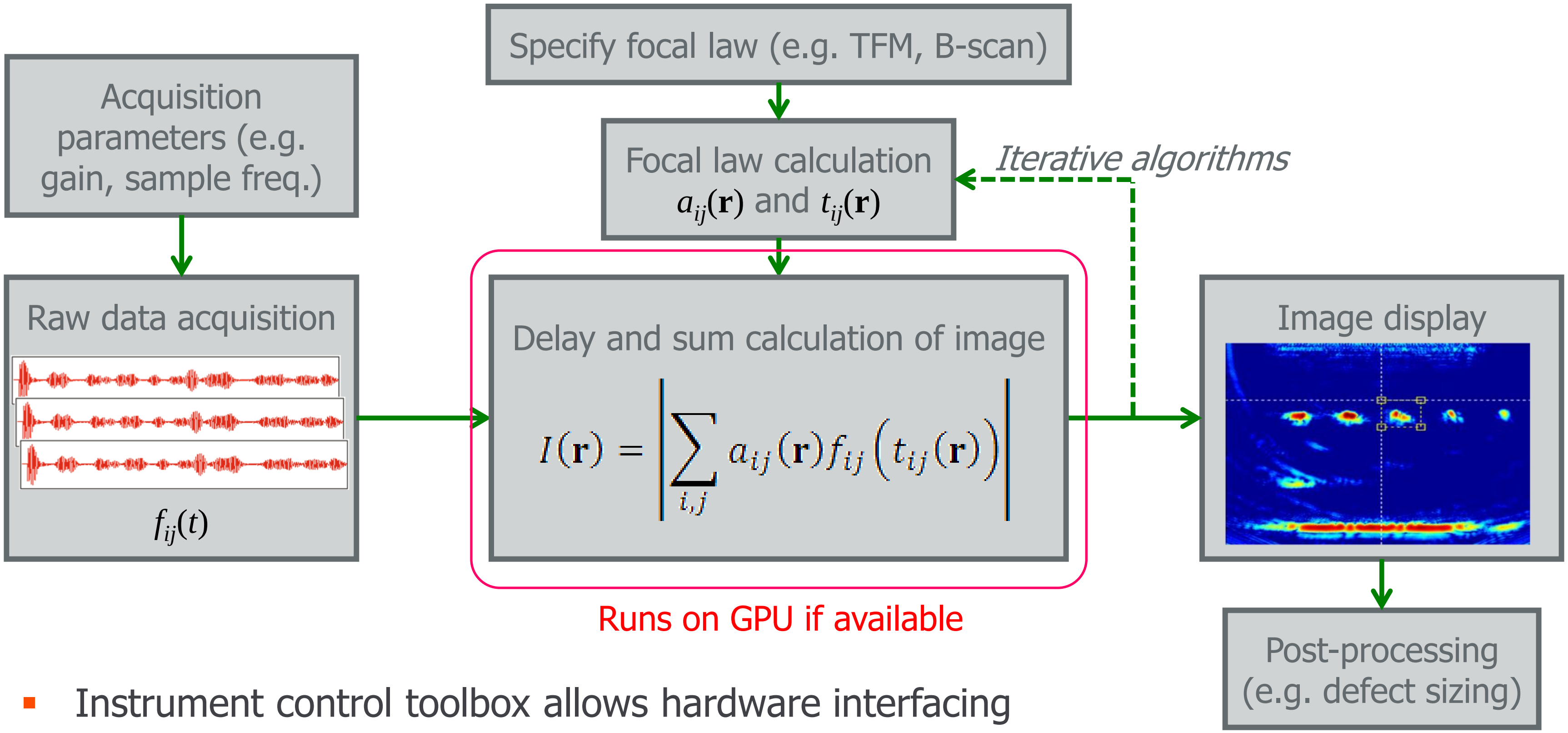
FREE!

Ideally suited to Matlab

- Extensive experience in group – Build on existing code base
- Allows testing of algorithms as scripts first
- Using the Matlab Runtime for compiled use
- Distributing files for scripted version

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

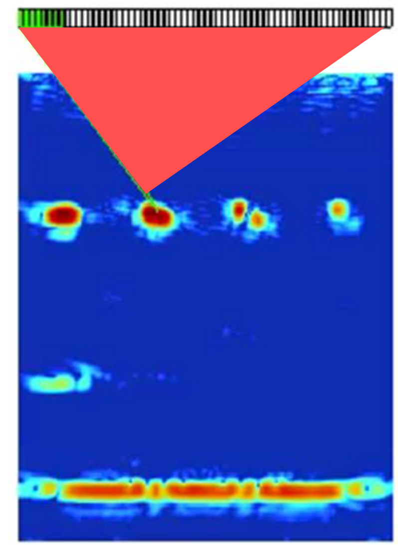
BRAIN
Structural Overview



- Instrument control toolbox allows hardware interfacing
- Good and useful
- However imaging is slow - GPU support is the final step

How we image

- Focus whole array at every image point in transmission and reception
- Close to theoretical image resolution (diffraction limit)

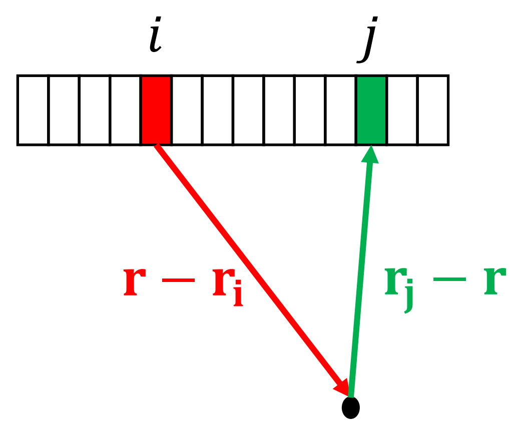


$$I(\mathbf{r}) = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}(\mathbf{r}) f_{ij}(\tau_{ij}(\mathbf{r}))$$

Parameters are:

$$a_{ij}(\mathbf{r}) = 1$$

$$\tau_{ij}(\mathbf{r}) = \frac{|\mathbf{r} - \mathbf{r_i}|}{c} + \frac{|\mathbf{r_j} - \mathbf{r}|}{c}$$



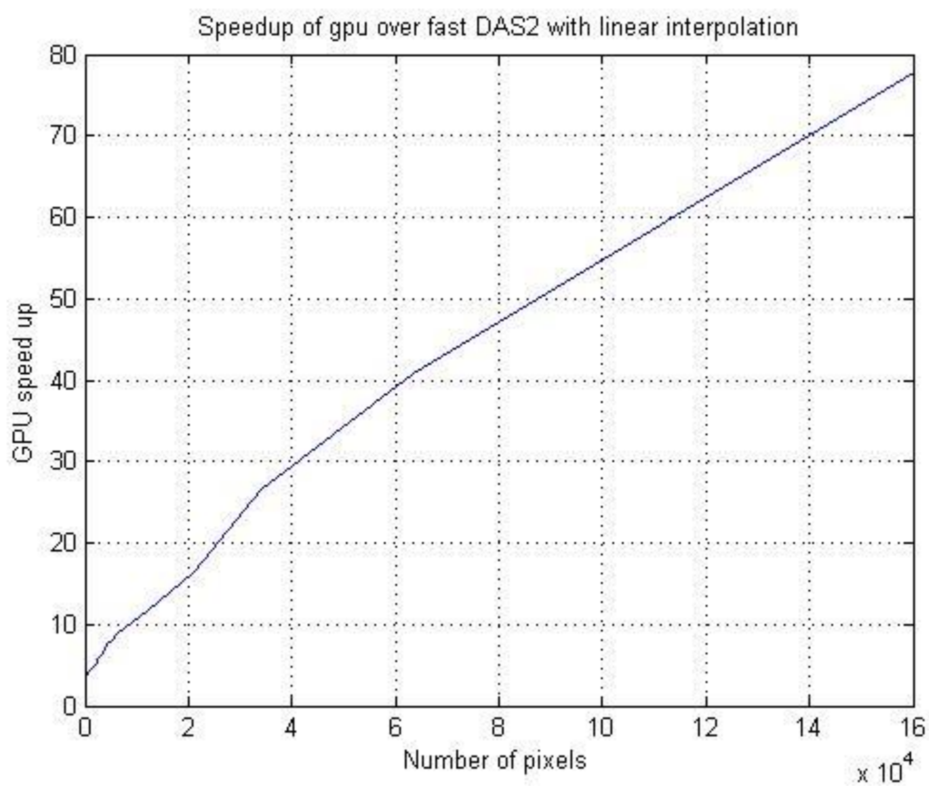
What this means

- Same operation carried out at each pixel - suited to parallelisation
- Many options in Matlab
- Written basic imaging CUDA kernel, good mix of low level code and direct access in Matlab

University of BRISTOL | RCNDE UK Research Centre in NDE | BAE SYSTEMS

Imaging speedup
Comparison of GPU and CPU in Matlab

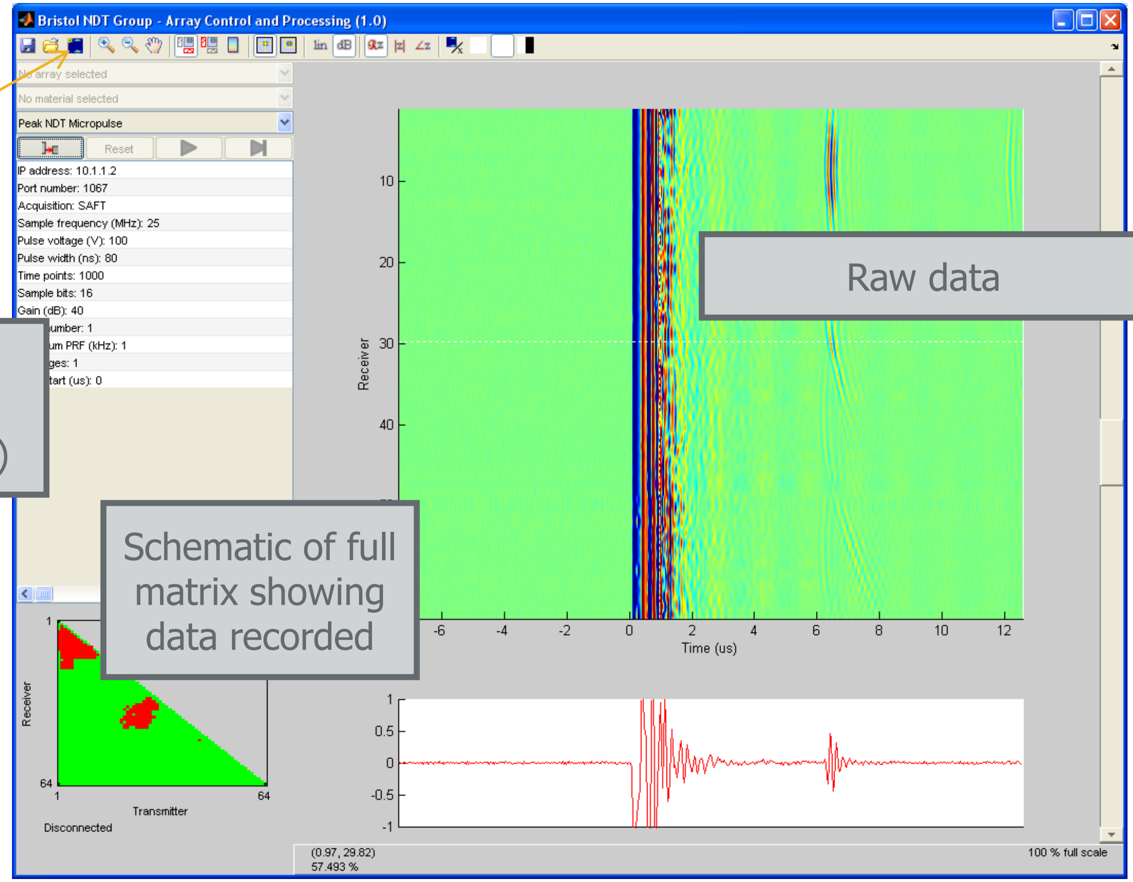
- Order of 100x speedup
- Easy and fast to implement in Matlab
- Lower overhead allows better imaging
  - High resolution
  - Interpolated images
- Makes industrial trials feasible
- Opens up new computationally complex imaging options



BRAIN approach
Data capture

Click here

Acquisition parameters (e.g. gain, sample freq.)

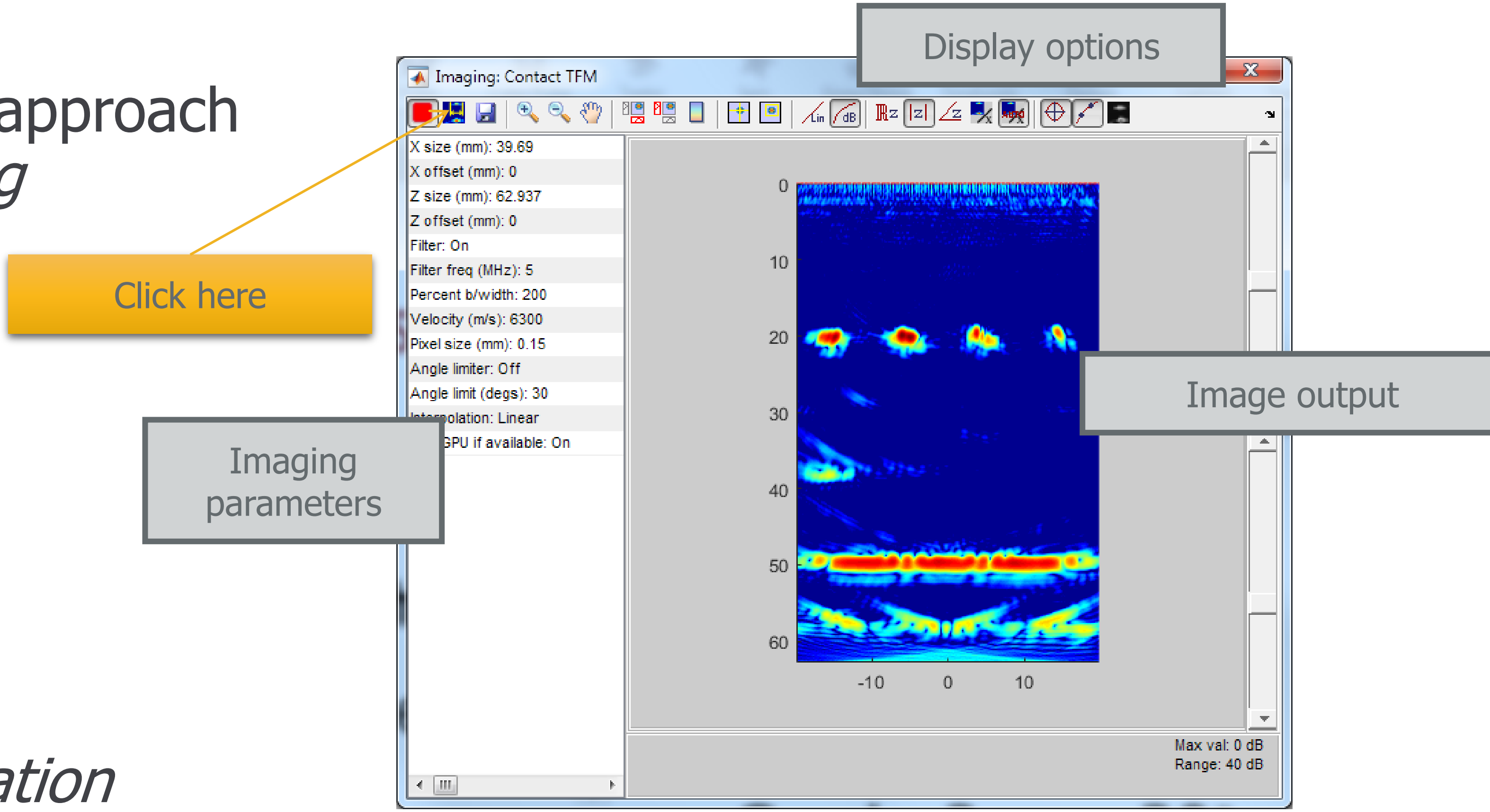


Instrument control

- Allows many different acquisition approaches – FMC, HMC, SAFT, Hadamard
- Acquisition can be tested as scripts, dropped into BRAIN
- Single-shot or continuous operation
- Spawn Imaging windows

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

BRAIN approach
Imaging



Visualisation

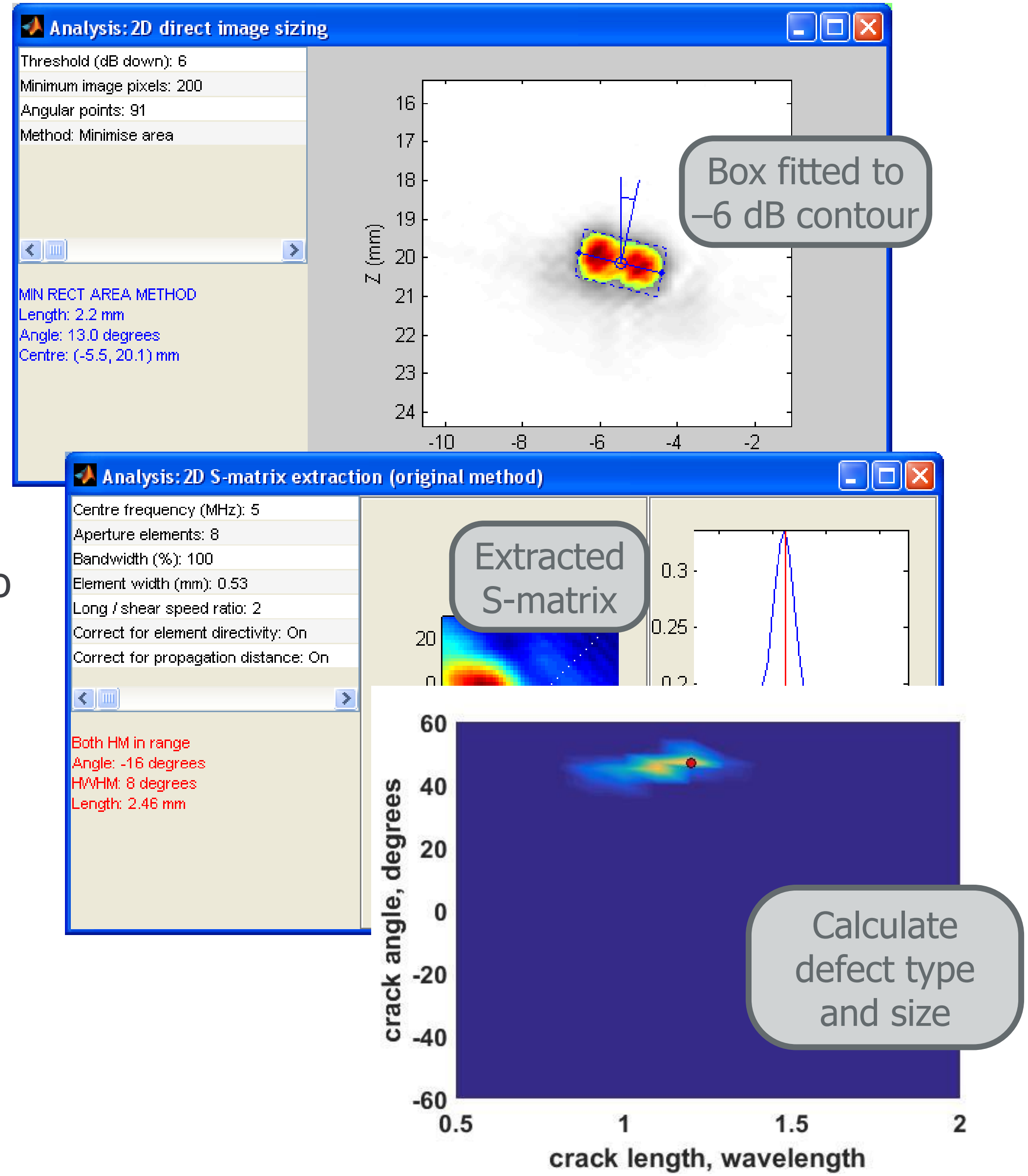
- Completely flexible, built from a standard Matlab script definition
- Many imaging approaches
  - Contact TFM, Contact B-scan, Contact Sector scan, Oblique incidence TFM, Immersion TFM through irregular interface, Contact TFM for composites
  - High computational load, runs fast
- Rapidly produce industrially testable solutions

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

BRAIN approach
Data processing

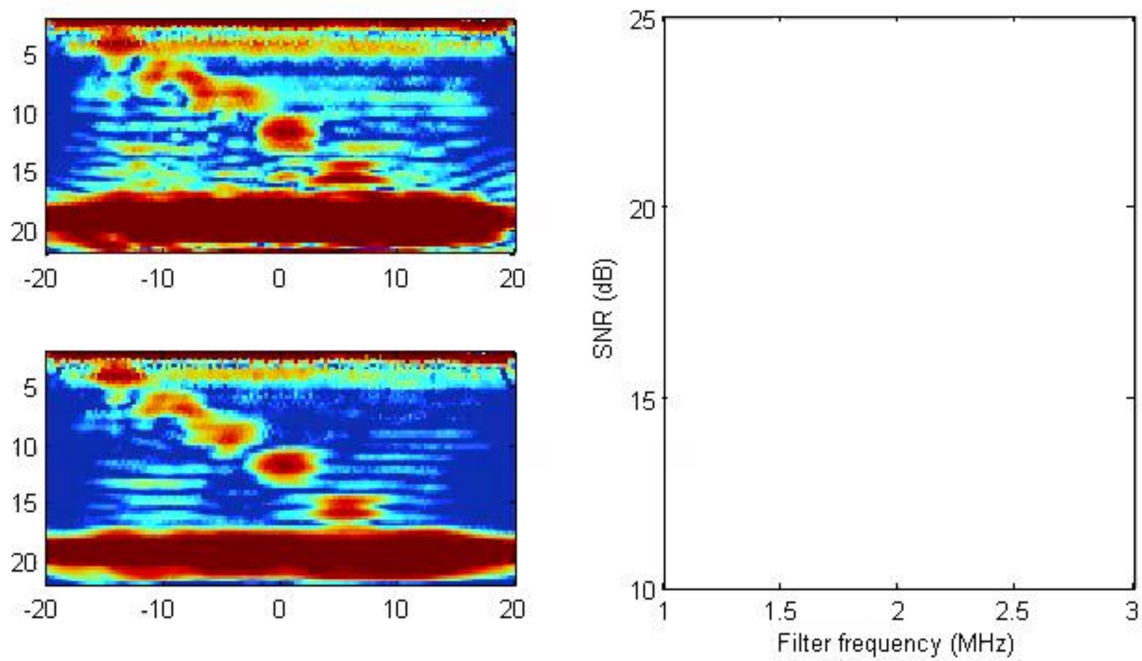
Characterise material and defects

- For industrial relevance this is the next step
- Not widely used
- Papers are good but OEMs want to try techniques
- Characterise defects
- Characterise material
- Low overhead to demonstrate and try these
- Used at multiple tech transfer events
- Carried out several site trials



University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

BRAIN example
Anisotropic material – eg carbon fibre



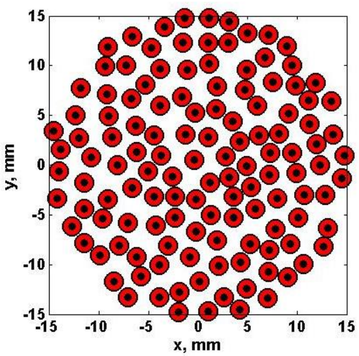
Difficulties

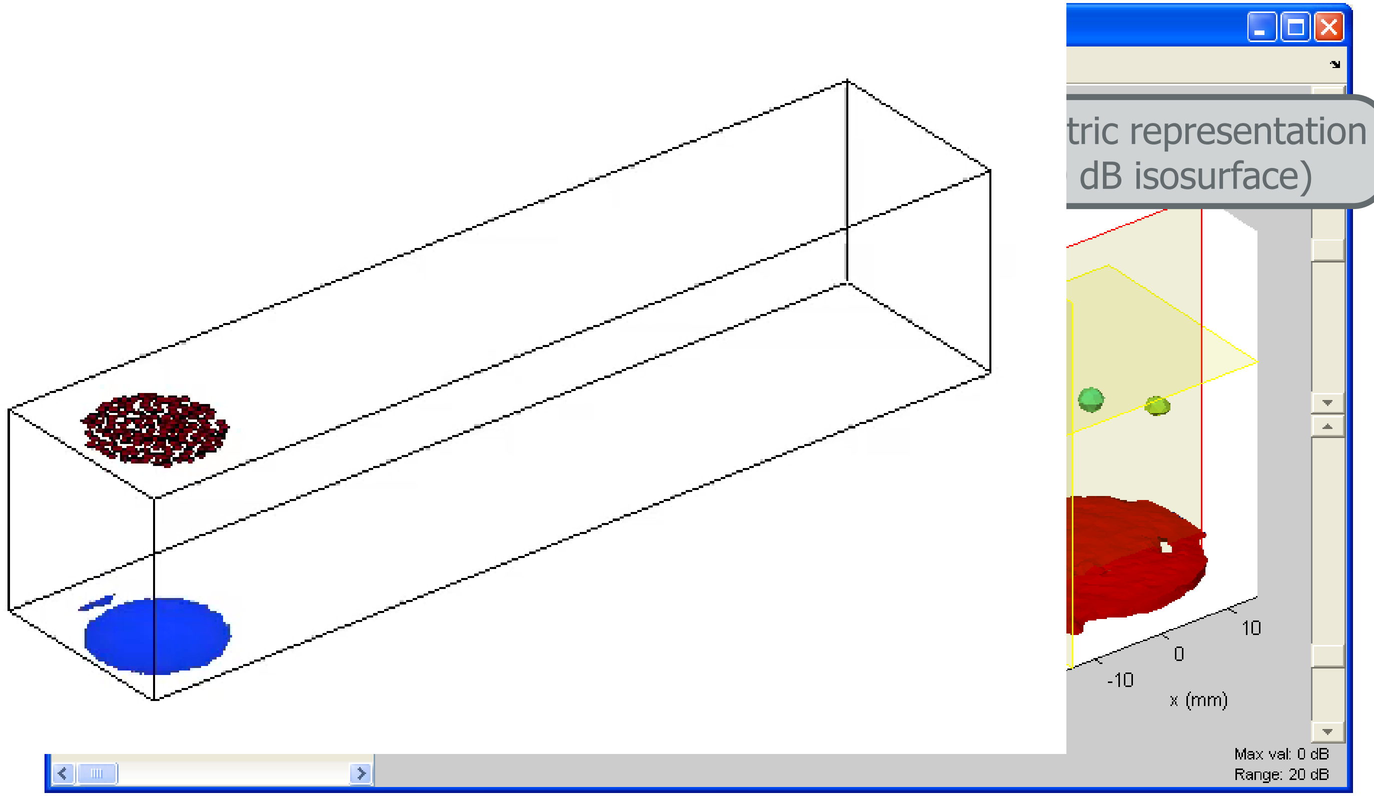
- High attenuation, Angular dependant velocity, Energy steering
- Partners want to try imaging in practise
- Scripts written then converted to BRAIN wrappers

University of BRISTOL
RCNDE UK Research Centre in NDE
BAE SYSTEMS

BRAIN example
3D imaging with 2D array

Array geometry



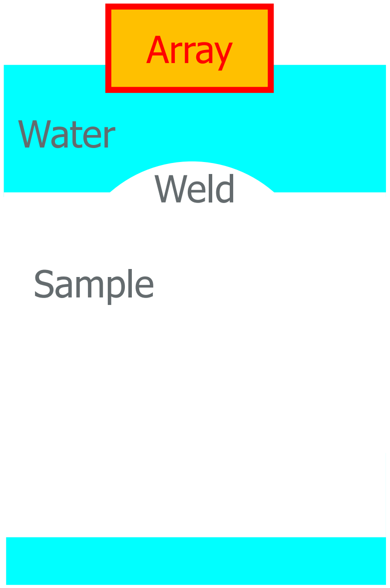


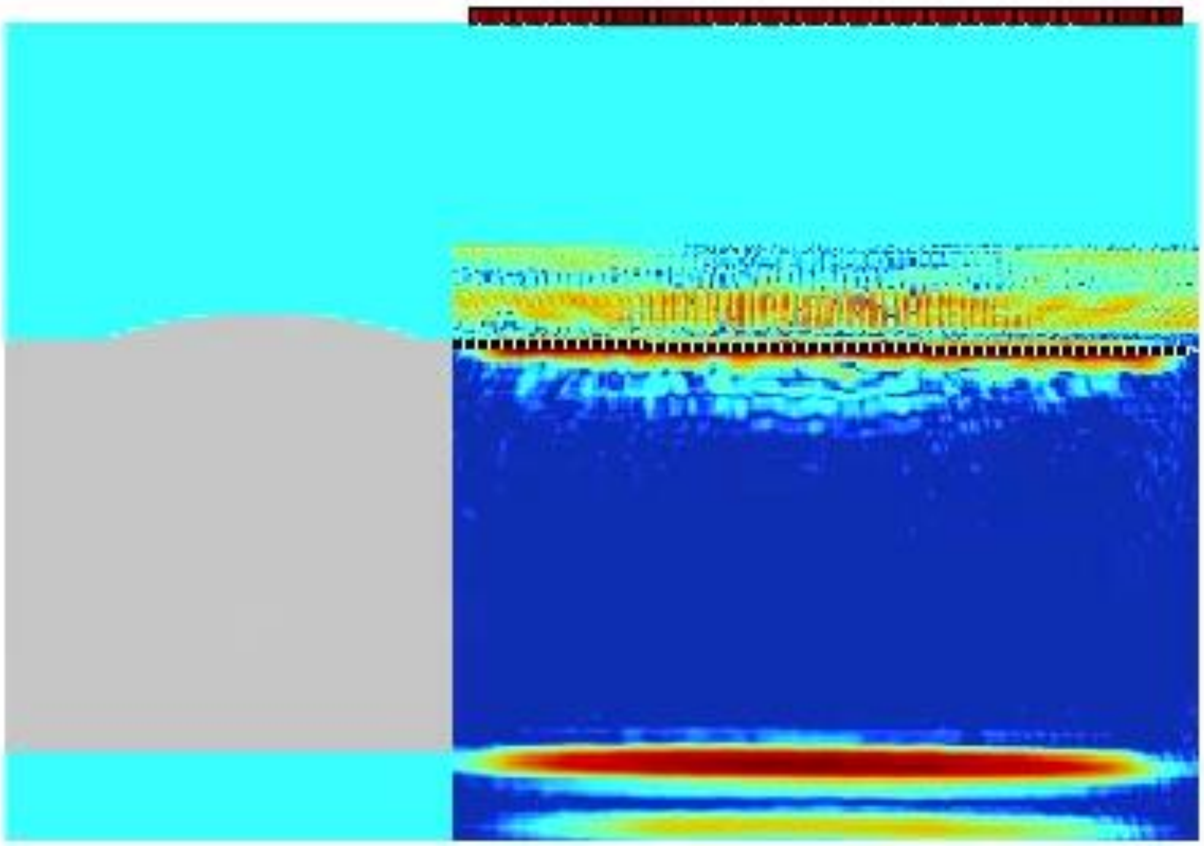
New methods

- Get shape information
- Lots of data and computationally heavy

University of BRISTOL
RCNDE UK Research Centre in NDE
BAE SYSTEMS

BRAIN example
Immersion imaging





Difficulties

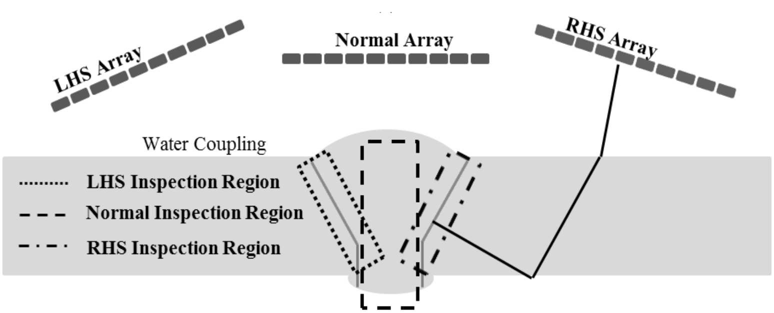
- Computationally heavy, not previously tractable

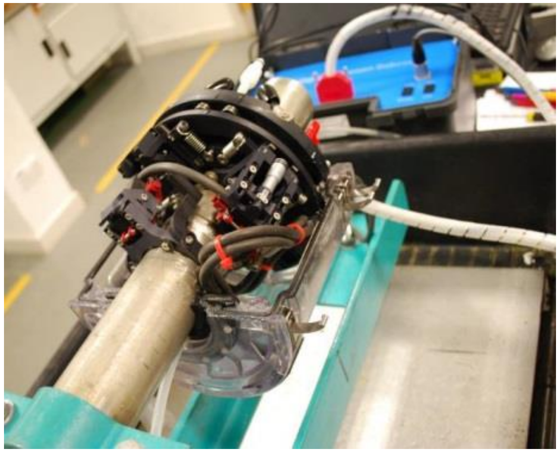
Outline

- The Engineering Need for Ultrasound
- BRAIN: Development & Implementation
- **Industrial Benefit & Outlook**

Benefits
Pipe Welds

- Immersion inspection, 3 arrays scan around weld



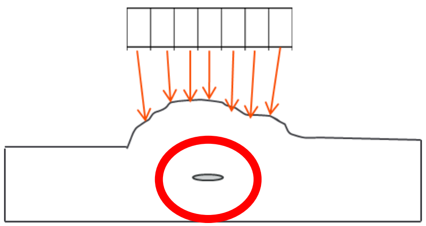


- MATLAB and BRAIN have enabled rapid development and testing of imaging techniques for new inspection methodologies

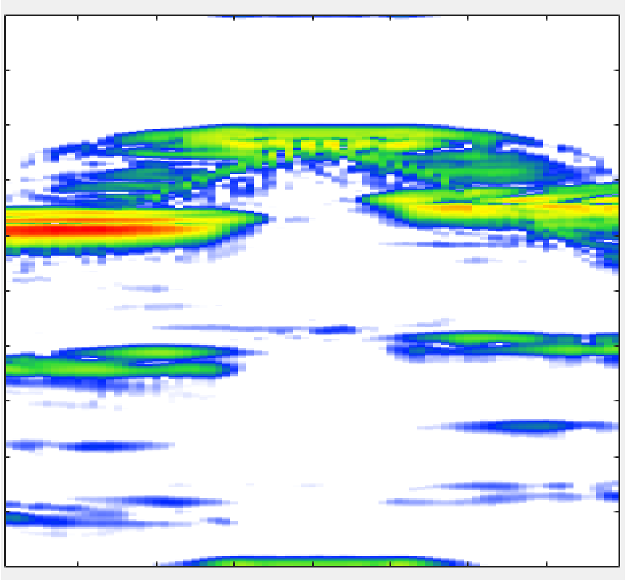
- High level language - <u>effort is spent understanding the problem</u>

Benefits
Novel capability

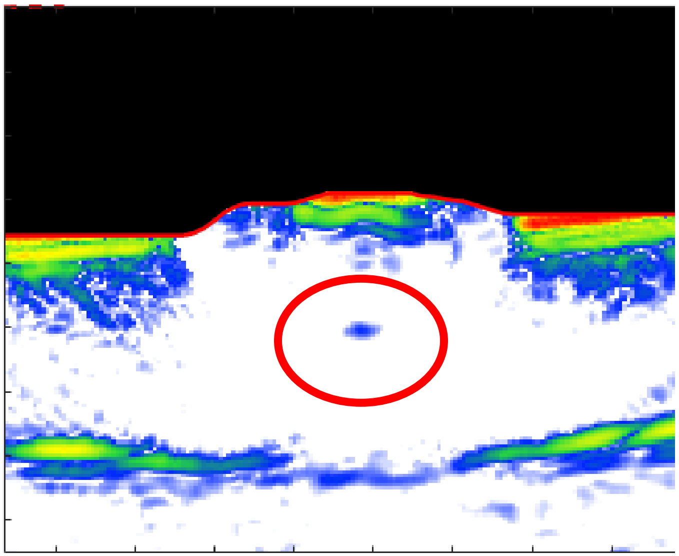
- Through weld-cap adaptive imaging of thin-walled pipes
- Key enabler for ultrasound to replace radiography



Inclusion in weld



"Conventional" imaging capability



Adaptive imaging with BRAIN and MATLAB

University of BRISTOL RCNDE UK Research Centre in NDE BAE SYSTEMS

Benefits
Inspection Speed

- Ultrasonic imaging reduces time NDT inspectors are required on shop-floor – NDT is less disruptive to build activities
- MATLAB GPU support enables practical ultrasonic imaging of pipe-welds practical on a typical desktop workstation

Inspection time (hours)

Process	**Radiography**	**Ultrasonic Imaging (No GPU)**	**Ultrasonic Imaging (GPU)**
Set-up	3	0.5	0.5
Data Collection	1	0.5	0.5
Imaging and Analysis	1	12	1
Time on Shop-Floor	4	1	1
Time in office	1	12	1

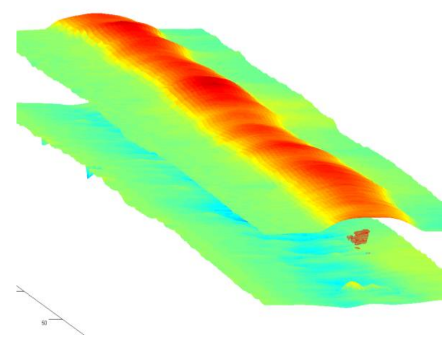
Outlook
Future Plans

Capability has been developed and demonstrated in the lab
Goal is for the technology to be a day-to-day operational activity

- Validation
- Qualification
    - Regulator and customer approval to use the technology
- "Productionisation" - shop-floor ready
    - Mechanical system development
    - Inspector training and in-house certification
    - Integration with other business processes

Developing Image Processing Techniques

Analysis of the ultrasonic images
Automatic sentencing of images (accept/reject weld)
Explore AI opportunities



University of BRISTOL
RCNDE UK Research Centre in NDE
BAE SYSTEMS

Summary