Autonomous & Adaptive Inspection Technologies

NDE Research Horizons

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Faculty of Engineering
Sectors Implementing NDT&E

- Nuclear
- Petrochemical
- Aerospace
- Defence
- Manufacturing

Energy

Inspection is critical to safe operation across many sectors
Sectors Implementing NDT&E

- Nuclear
- Energy
- Petrochemical
- Aerospace
- Defence
- Manufacturing

Many common inspection challenges
Common Inspection Challenges

Manufacturing
- Economic Factors
- Production Rate
- Reliable & Accurate
- Challenging Conditions

In-service
- Coverage & Speed
- Access & Environment
- Ease of use
- Reliable & Accurate
- Safe
- Human factors
- Permanent installation
- On-line measurement
Common Inspection Challenges

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Industrial Vision for Inspection Technologies

Vision 5
Applying technology

Currently at ~TRL 3 or above.
Principles are well understood & estimate of capability.
Match found with business need.

Vision 10
The next generation

Issues that known technologies could address if they were more advanced.

Vision 20
Exploring new ideas

Where we want to be in the ideal world.
Includes issues with no current solution identified from known technology streams.

Thayer P, “Enabling the Fourth Industrial Revolution (4IR) and the role of NDE and monitoring”, Insight, Vol 59 (9), 2017, pp 469-472
## Key Strategic Topics: Vision 5

<table>
<thead>
<tr>
<th>NDE Technology</th>
<th>Infrastructure NDE</th>
<th>Manufacturing NDE</th>
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<tbody>
<tr>
<td>Using <strong>material knowledge</strong> to improve inspection</td>
<td>Minimised manual inspection</td>
<td>Trend to <strong>in-process inspection</strong></td>
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<td>Coping with <strong>complex geometries</strong></td>
<td>Widely used <strong>robots</strong> and manipulators for field inspection and for <strong>difficult access/harsh environments</strong></td>
<td>Inspection of <strong>3D printed components</strong></td>
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<tr>
<td>Wider use of <strong>robotics</strong> and manipulators</td>
<td></td>
<td>High-accuracy <strong>robotic NDE</strong> for large <strong>complex-shaped components</strong></td>
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<tr>
<td>Wider use of embedded sensors (SHM)</td>
<td>Long-life, reliable permanent sensor networks</td>
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<td><strong>Real-time data fusion</strong></td>
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<tr>
<td>Robust <strong>automated data interpretation</strong></td>
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**Autonomous and Adaptive Inspection Solutions**
## Key Strategic Topics: Vision 10

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<tr>
<td>“Connected” sensor networks</td>
<td>Wider use of monitoring for large-area screening and SHM</td>
<td>Online inspection of <strong>3D printed components</strong></td>
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<tr>
<td>Targeted NDE with remote and automated NDE</td>
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<td>Fast, online tomographic inspection</td>
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<tr>
<td>Automated adaption for material properties</td>
<td>Self-calibrating sensors</td>
<td>In-process inspection matching post-manufacturing inspection performance</td>
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<tr>
<td>Suite of modelling tools and experimental validation</td>
<td>NDE Targeted by monitoring</td>
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<tr>
<td>Universal remote autonomous NDE tools</td>
<td>Wide range of platforms for remote and automated NDE for <strong>ultrafast inspection</strong></td>
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<td>Real-time data processing and decision making</td>
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<td>Common file formats</td>
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<td>Physical model based POD</td>
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*Autonomous and Adaptive Inspection Solutions*
### Key Strategic Topics: Vision 20

<table>
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<th>NDE Technology</th>
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<tbody>
<tr>
<td>Material-independent, high-sensitivity NDE</td>
<td>Fully-instrumented plant on scales of 10-100 km</td>
<td>“Inspection-assured” tailored materials</td>
</tr>
<tr>
<td>Rapid, long-range and wide-area non-contact inspection</td>
<td>Field-ready methods for self-monitoring and smart structures</td>
<td>“Design for inspection” implemented</td>
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<tr>
<td>Interoperability of NDE and SHM</td>
<td></td>
<td>Holistic estimation of component quality to predict in-service performance</td>
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<tr>
<td>Fully automated data analysis</td>
<td>Fully-informed integrity assurance and plant optimisation</td>
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<tr>
<td>AI in systems</td>
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<td>Processes fully monitored from raw materials to customer</td>
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<td>Integration of NDE models with materials engineering</td>
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<tr>
<td>“Digital Twin” capability</td>
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<td>Inspection processes not impacting on cycle rates</td>
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**Autonomous and Adaptive Inspection Solutions**
Non-Destructive Evaluation

- Transduction
- Deployment
- Instrumentation
- Data/Image Processing
- Data Interpretation and Visualisation

Inverted pump casing showing location of phased array transducer and scan geometry.

Internal crack penetration and depth visualisation.
Non-Destructive Evaluation

Transduction

Deployment

Instrumentation

Data/Image Processing

Data Interpretation and Visualisation
Transduction: Laser Induced Phased Array

- Aluminium AM sample (40 x 20 mm) on aluminium baseplate (10 mm)
- 6 included defects: Ø0.7 mm and 0.2 mm
- Nd:YVO pulsed laser; 500 averages

Non-Destructive Evaluation

Transduction

Deployment

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Data Interpretation and Visualisation

Inverted pump casing showing location of phased array transducer and scan geometry

Internal crack penetration and depth visualisation

Note crack face separation higher at deepest point in crack
Autonomous Inspection: Optimising Inspection Time

- Autonomous inspection based on Bayesian optimisation
Non-Destructive Evaluation

Transduction

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Data Interpretation and Visualisation

Inverted pump casing showing location of phased array transducer and scan geometry.

Internal crack penetration and depth visualisation.
State of the Art:
• Eddyfi Scorpion 2 manually performing a tank shell inspection.
• Only inspects point under the UT probe. It is both manual and brute force in its approach to data collection.
Autonomous Inspection: Intelligent Structure Mapping

Concept:
• Step 1: Automatically map the structure’s geometry
• Step 2: Highlight areas of significant wall loss, and if required inspect them in more detail.

Objectives:
• Smarter NDE acquisition to reduce inspection data
• Understand inspection results to ‘close the loop’.
Autonomous Inspection: Intelligent Structure Mapping

Implementation of 2D occupancy grid mapping
Non-Destructive Evaluation

Transduction

Deployment

Instrumentation

Data/Image Processing

Data Interpretation and Visualisation
Adaptive Weld Imaging: Mapping Material Media

- Phased Array Based Time of Flight Tomography

Homogeneous, isotropic, constant wave speed assumption

Use map constructed using rj-MCMC

Use coarse known map (taken from EBSD measurements)
Final Thoughts.....

• Multi-disciplinary, cross-sector solutions
• Inevitable advances in supportive technologies
  – Computer processing speed, electronics miniaturisation, data storage capacity, battery longevity, etc
• Application and interpretation of sensor networks will be integral to inspection of future smart infrastructure
• Convergence of operational, environmental, inspection and monitoring data will require integration of previously discrete disciplines
• Research is underway working towards the long-term goal of fully adaptive, autonomous inspection