Inspection of composite structures

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Aerospace Non-Destructive Testing Laboratory

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Faculty of Aerospace Engineering

Technische Universiteit Delft

Abstract

- Introduction of the latest developments in NDT/SHM technology and advances in signal processing of big data. This new technology and software could solve some of today's and tomorrow challenges in the inspection of composite structures

Global Challenges for Society

- **Transport**: Developing green, safe, efficient and accessible transport networks
- *Our Contribution: KET – Advanced measurement techniques for materials and structures in structural design, composite manufacture and aircraft maintenance and repair*

What are the big challenges in NDT/SHM?

1. Efficient and cost-effective operation
2. Automation & measurement speed
3. Flexibility for measuring complex structures
4. Measuring hard to access structures $\rightarrow$ SHM
5. Improvements in detectability of damage

Aerospace NDT Lab Research Topics

KET Topic Areas

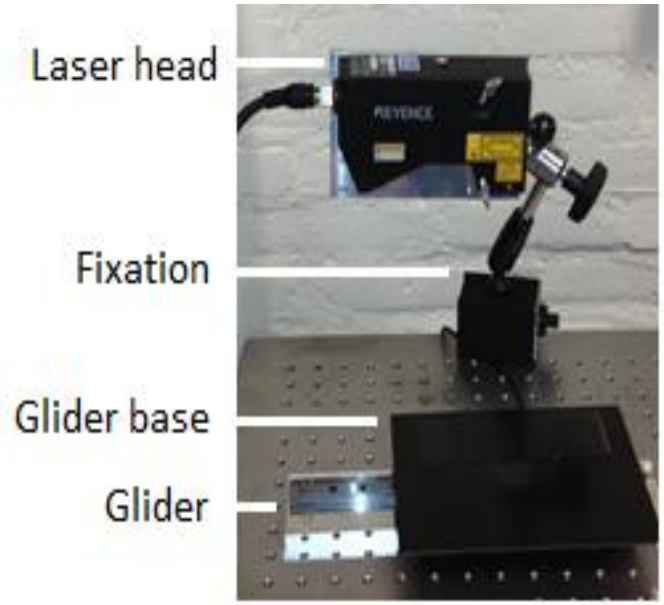
1. **Optical Metrology:** *Dr Andrey Anisimov*
   - Shearography, Fringe projection, Dimensional measurement
2. **Fibre Optic Sensors**: *Ping Liu, MSc*
   - Optical coherence tomography, Fibre Bragg gratings (FBGs)
3. **Spectral Imaging**: *Dr Vassilis Papadakis*
   - Hyperspectral imaging, Fibre optic reflectance spectroscopy
4. **Ultrasonics:** *Dr Roger Groves*
   - Phase-array ultrasound, Guided Lamb waves

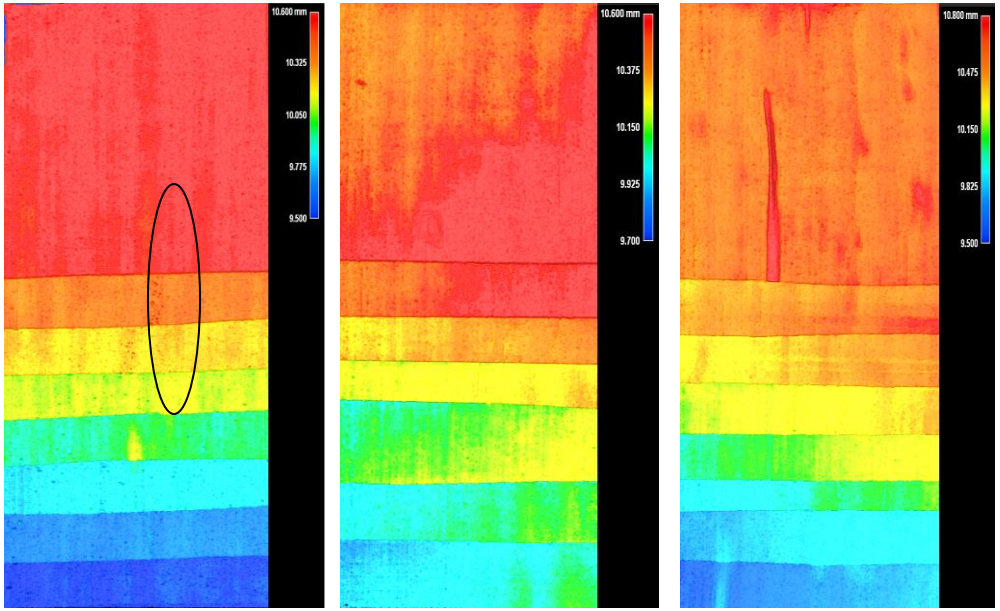
1. Optical Metrology Research Topics

Dr Andrei Anisimov (A.Anisimov@tudelft.nl)

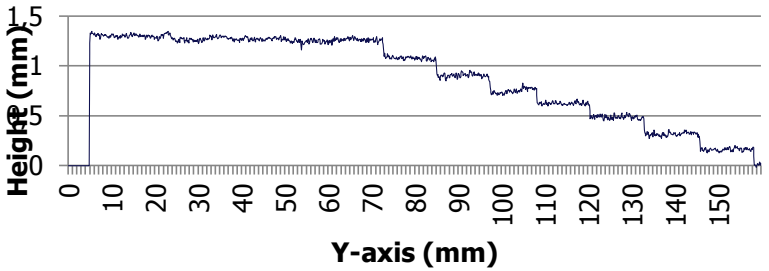
a. Linescan & point shape sensors
   i. Shape measurement (scanning sensors)
b. Fringe projection
   i. Shape measurement (camera-based)
c. Shearography
   i. Non-destructive testing
   ii. Displacement gradient & strain measurement
   iii. Vibration characteristion (full-field)

Linescan/Point Shape Sensors





Application: manufacturing layup of composite materials
Accuracy to 2,6 µm



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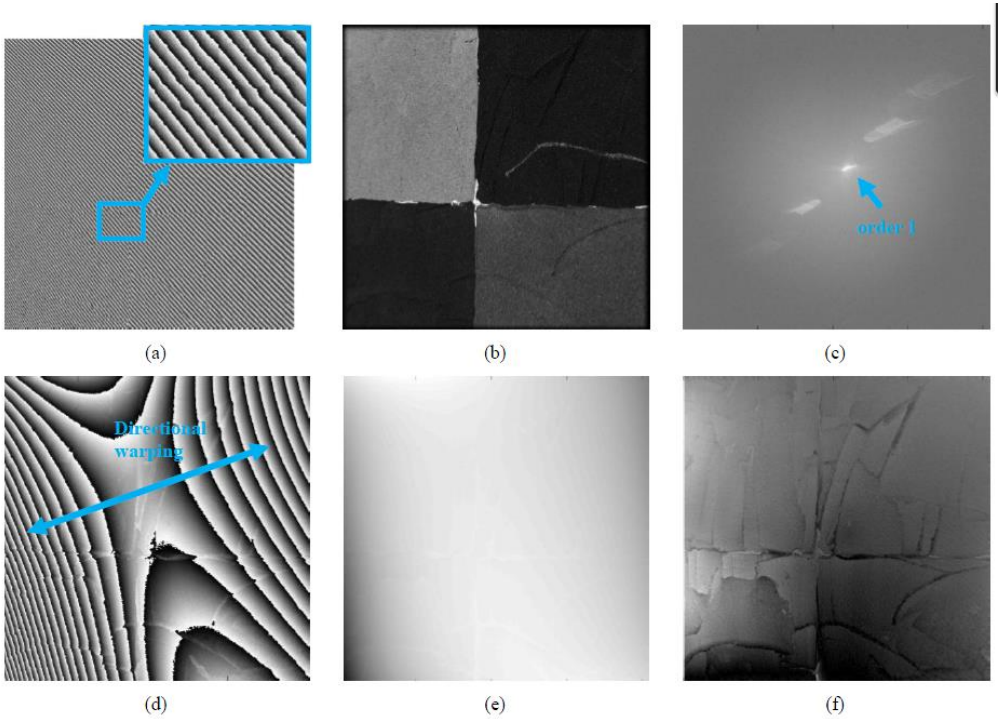
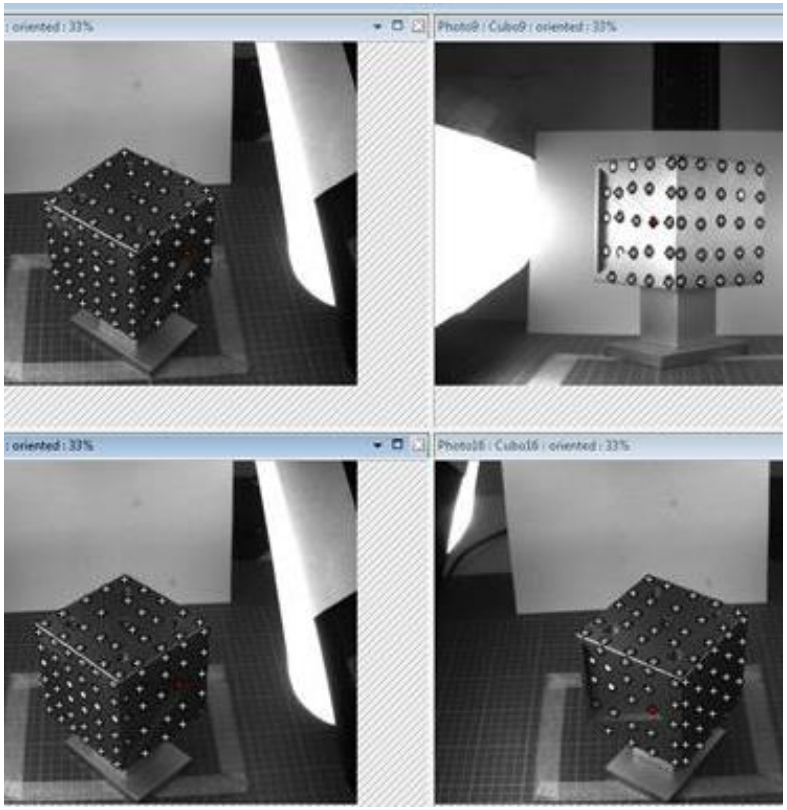
Shape: Fringe Projection





Application: Artworks in FP7 Syddarta Project
Accuracy to 50 µm

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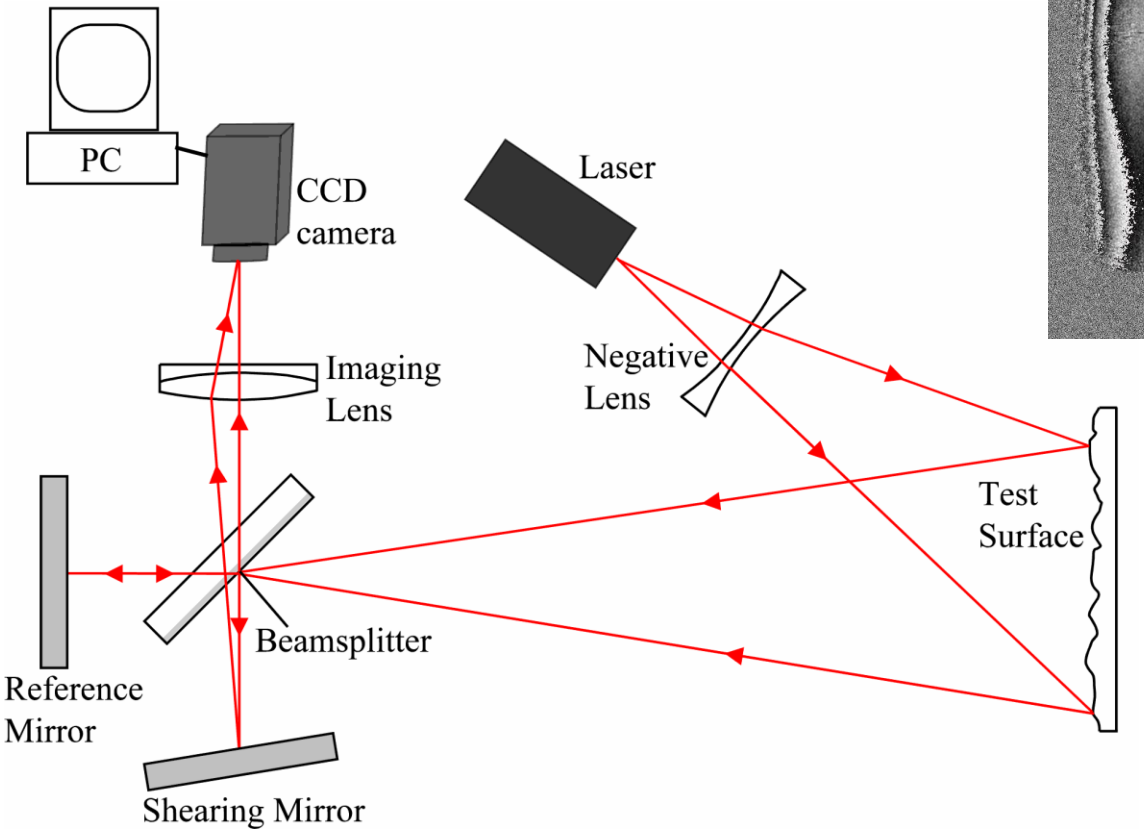
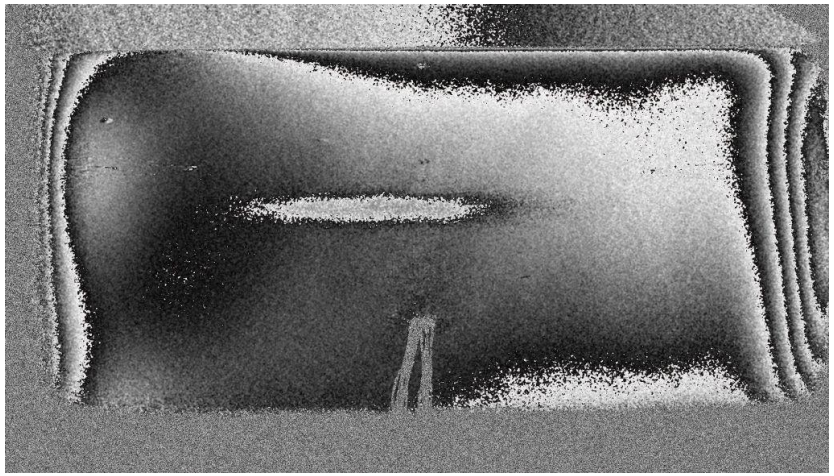
Shearography – Experimental Layout

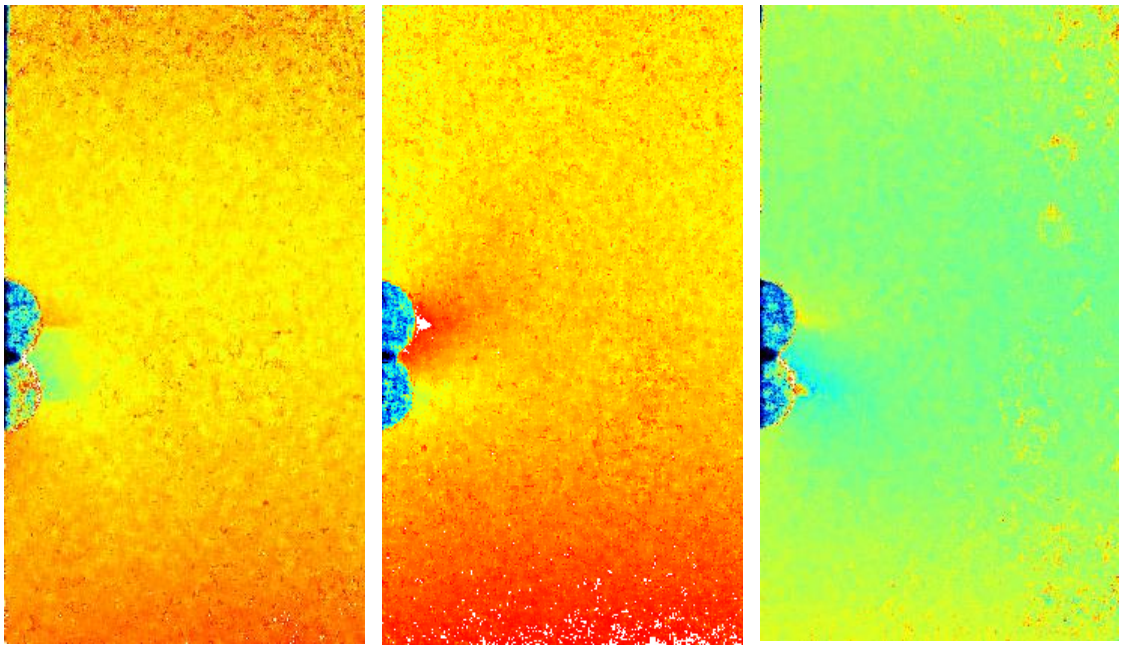




Example phase map from measurements on a cylinder

1a. 3D Fatigue Crack Investigation

- Measurement of titanium 10-2-4 Helicopter rotor head
- Agusta-Westland
- In-plane strain
- Data transfered to a FE-Model

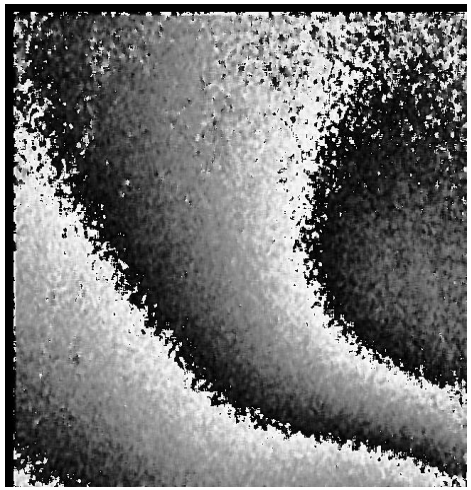


Surface strain maps measured using shearography

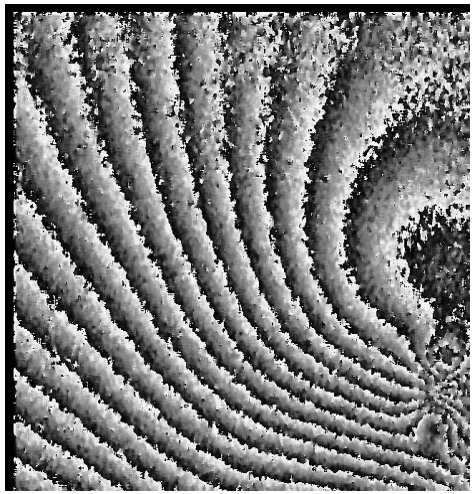
du/dy (l), dv/dy (m), dw/dy (r)

1a. Shearography - Non-Destructive Testing

- **AIM:** Location of non-visible impact damage defect in an aerospace composite panel
  - Loading by infra-red lamp



10 seconds

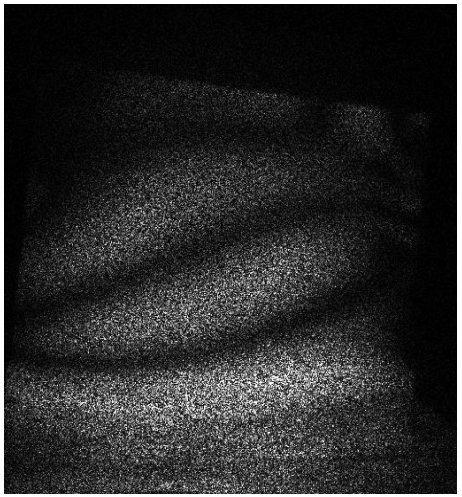


24 seconds

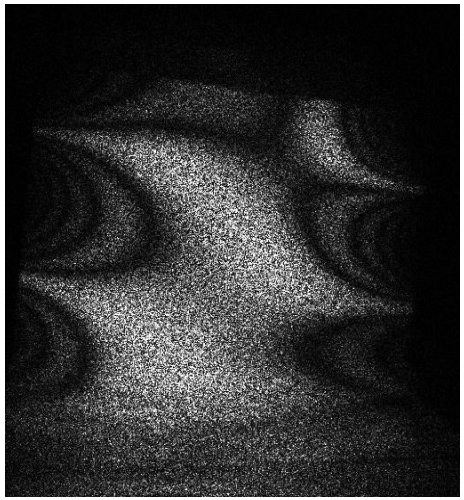
44 seconds

1a. Shearography - Vibration Characterisation

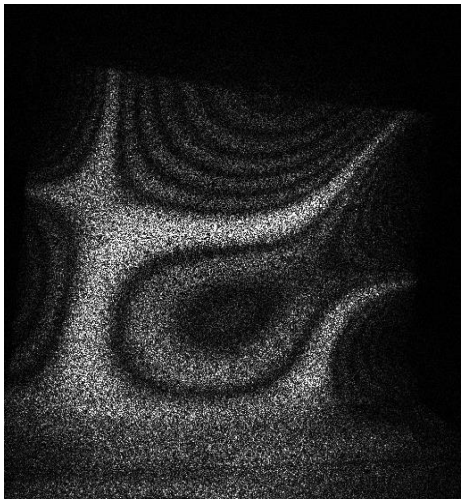
- **AIM:** Determination of resonant frequencies for a compressor turbine blade (time-average analysis)



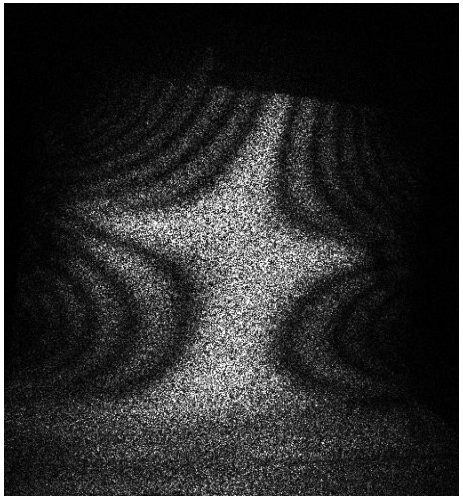
2.74 kHz (Blade flap)



4.45 kHz (Corner/side flap)



5.06 kHz (Whole blade resonance)



11.94 kHz (large amplitude corner/side flap)

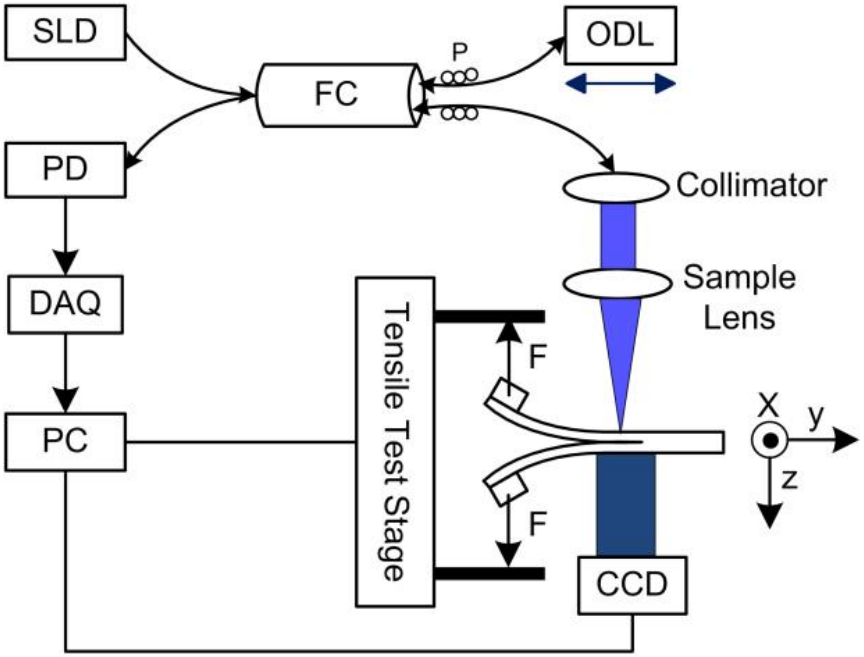
Fibre Optic Sensors Research Topics

Ping Liu, MSc (Ping.Liu@tudelft.nl)

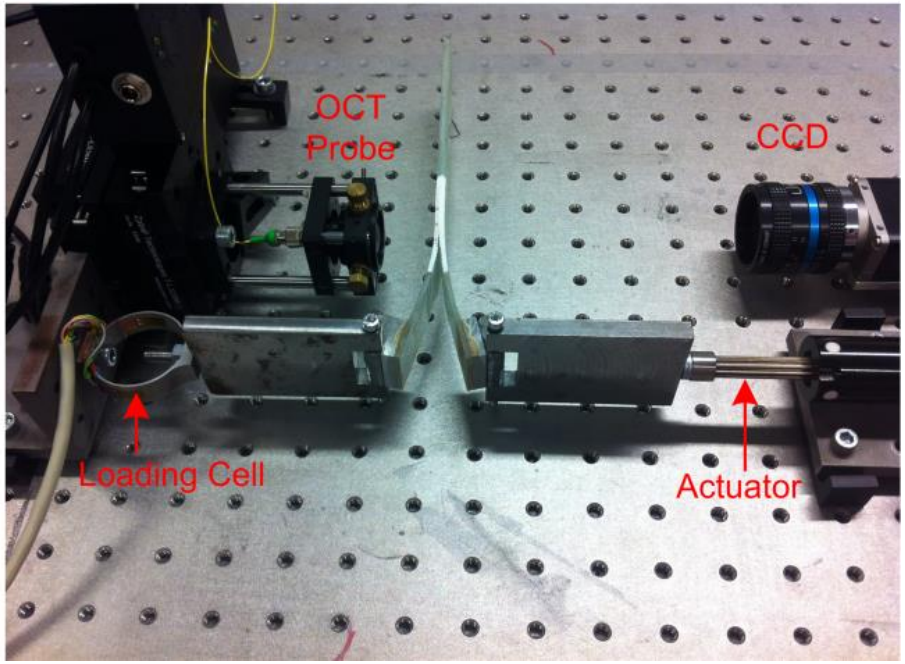
a. Optical Coherence Tomography (OCT)
   i. Coating thickness measurement
   ii. 3D materials charaterisation
b. Fibre Bragg Gratings (FBGs)
   i. Shape measurement (canera-based)
c. Structural Health Monitoring (SHM)
   i. Wireless sensor network
   ii. Energy harvesting

2a. Optical Coherence Tomography

(a)

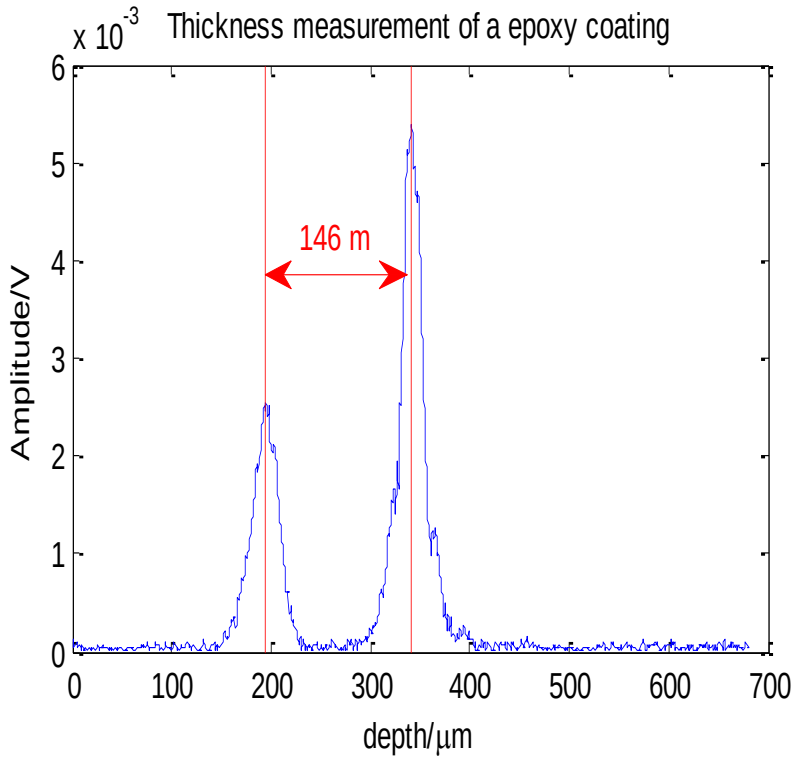


(b)



2a. OCT - Materials Testing

- **AIM:** Thickness measurements



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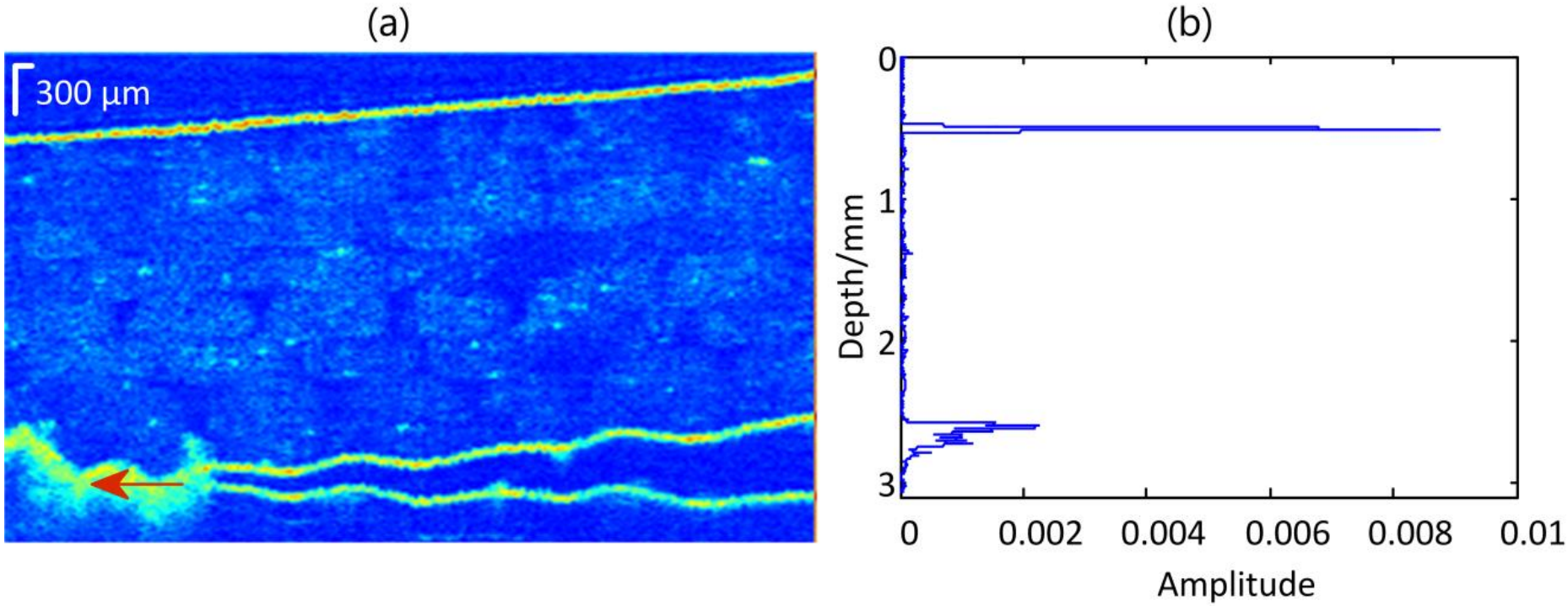
2a. Optical Coherence Tomography



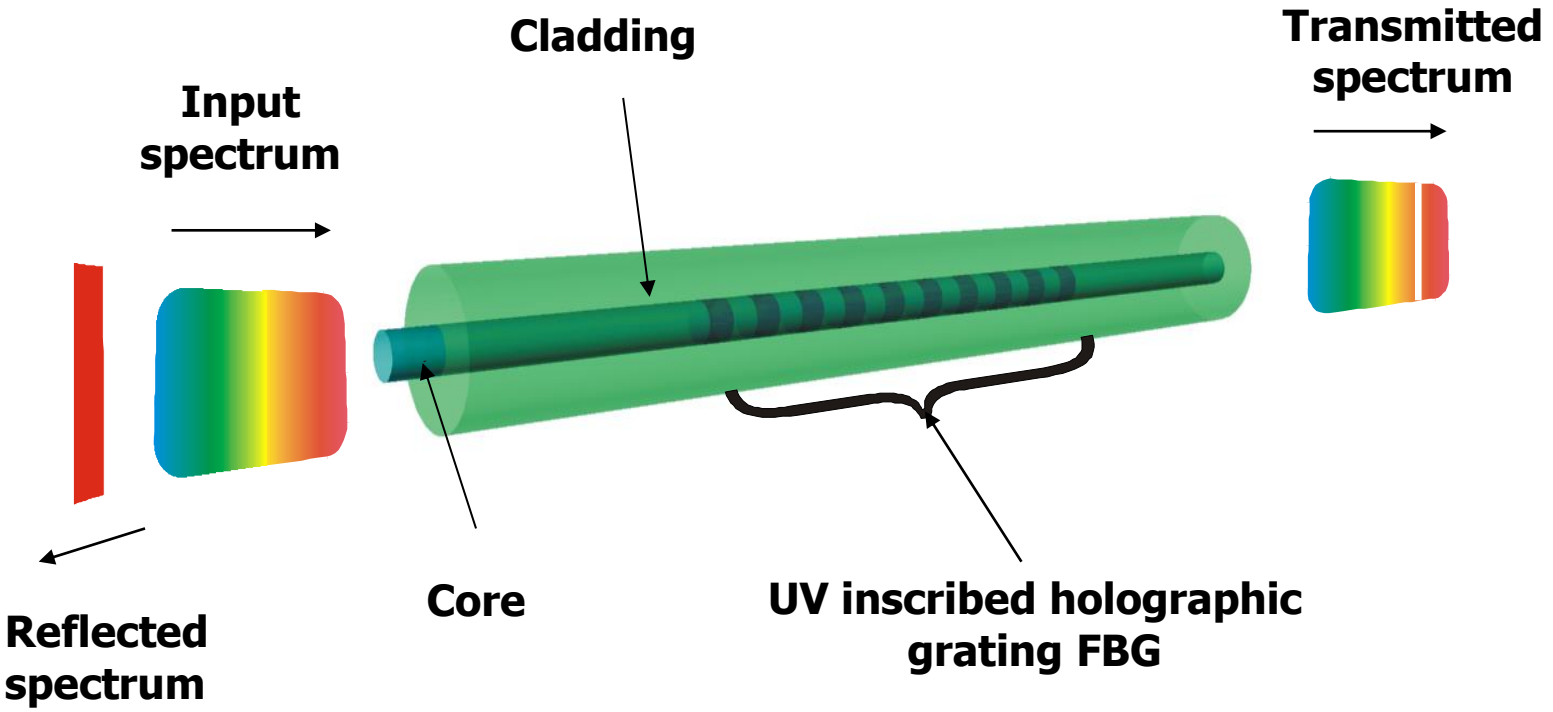
Monitoring

Long-term Monitoring

- Strain
- Temperature
- Relitive Humidity. Moisture content
- Displacement
- Light intensity
- Etc…

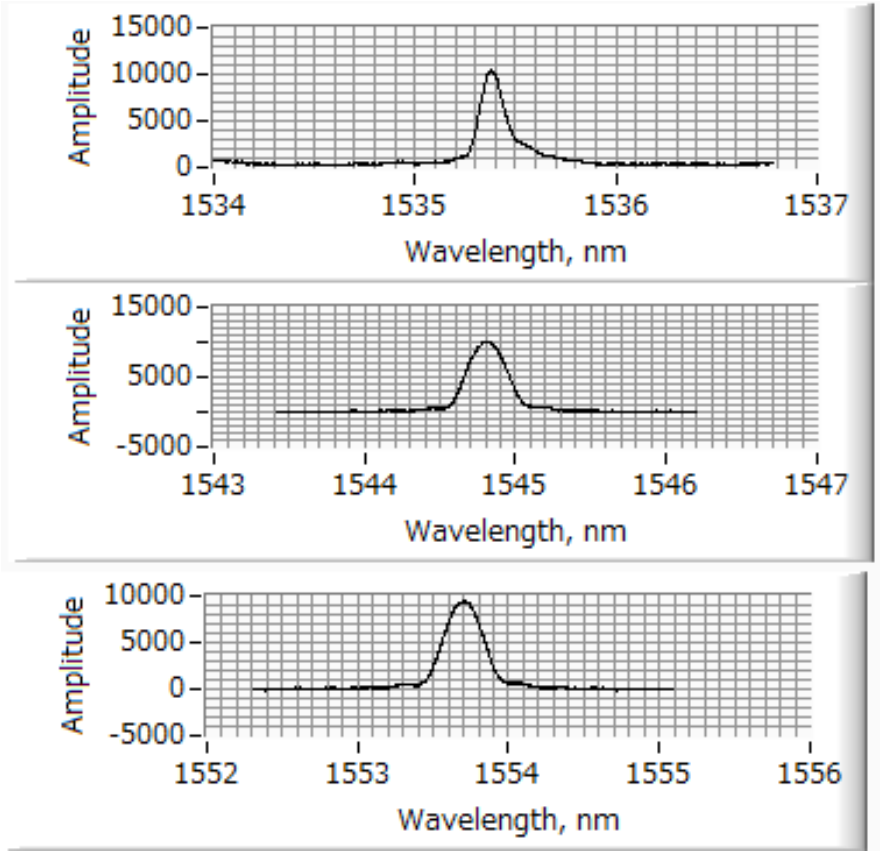
Monitoring: Fibre Bragg Grating

- Each FBG sensor reflects narrow wavelength spectrum
- Wavelength shifts due to strain change



2b. FBG - Multi-Parameter Strain and Vibration Measurement

- **AIM:** Multi-parameter measurement for composites NDT
- Simultaneous measurement of:
  - Bending
  - Tension *or* Compresion
  - Vibration



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Wireless Sensor Network

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Spectral Imaging Research Topic

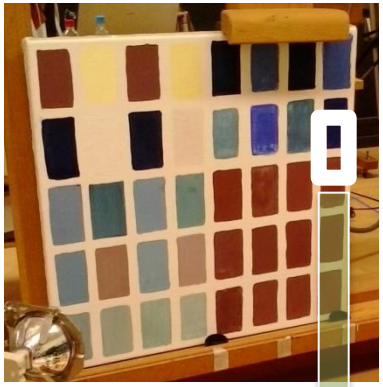
Dr Vassilis Papadakis (c/o R.M.Groves@TUDelft.nl)

a. Hyperspectral Imaging
   i. Visible & infra-red
b. Fibre Optic Reflectance Spectroscopy (FORS)
   i. Scanning point spectrometer
c. Spectal Processing
   i. Principal Component Analysis (PCA)
d. Terahertz Imaging
   i. LWIR/microwave tomography

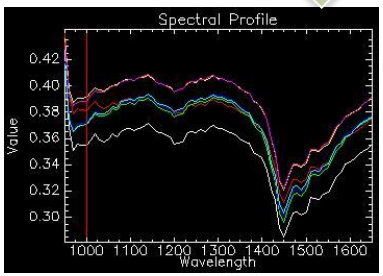
3a. Hyperspectral Imaging

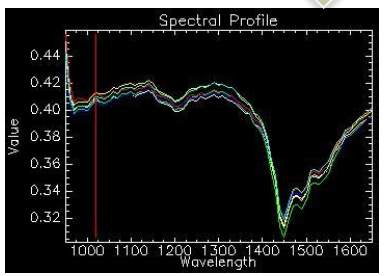
REF sample

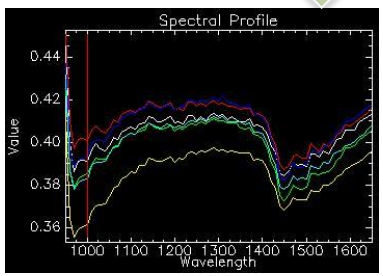
THD sample



UVD sample







Ultraviolet aging (UVD), but not thermal aging (THD) changes can be identified in 950-1650 nm spectral range

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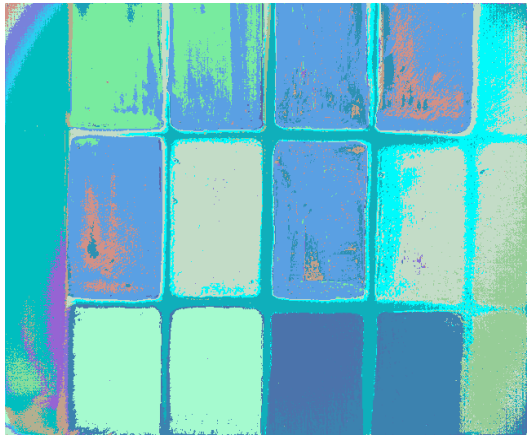
3c. Signature Classification with Principal Component Analysis

Classes (k-means)	Dimensions (PCA)	Classification method								
		#1	#2	#3	#4	#5	#6	#7_0	#7_1	#7_2
10	10	97.5	97.5	96.7	85.8	98.3	88.3	95.8	96.7	95.8
	30	97.5	92.5	96.7	60.8	98.3	86.7	96.7	96.7	96.7
20	10	95.0	93.3	89.2	80.0	94.2	87.5	95.8	97.5	95.8
	30	95.0	85.8	89.2	60.8	94.2	82.5	97.5	95.0	97.5
30	10	90.8	87.5	82.5	65.8	89.2	76.7	85.0	95.0	85.0
	30	92.5	79.2	82.5	51.7	89.2	77.5	87.5	91.7	87.5
40	10	90.0	87.5	82.5	75.0	90.0	84.2	86.7	92.5	87.5
	30	90.8	77.5	81.7	51.7	90.0	80.8	88.3	93.3	88.3



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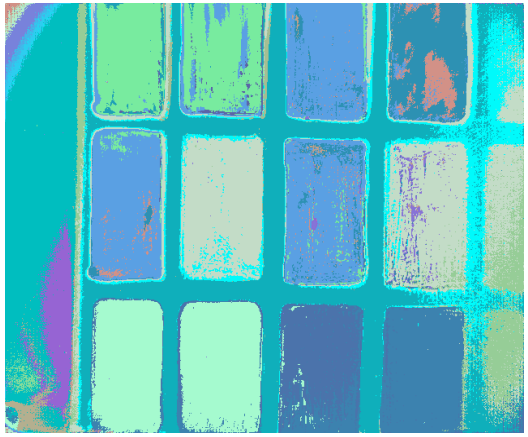
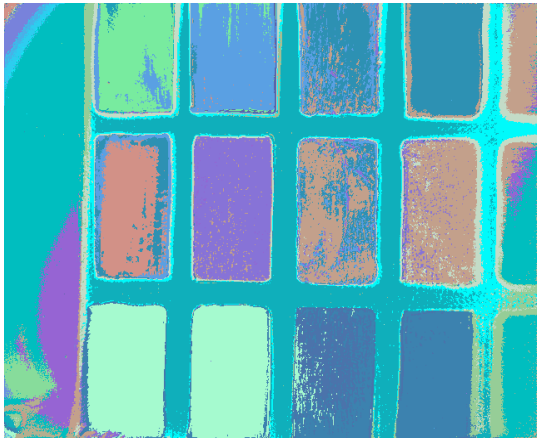


THD sample



UVD sample

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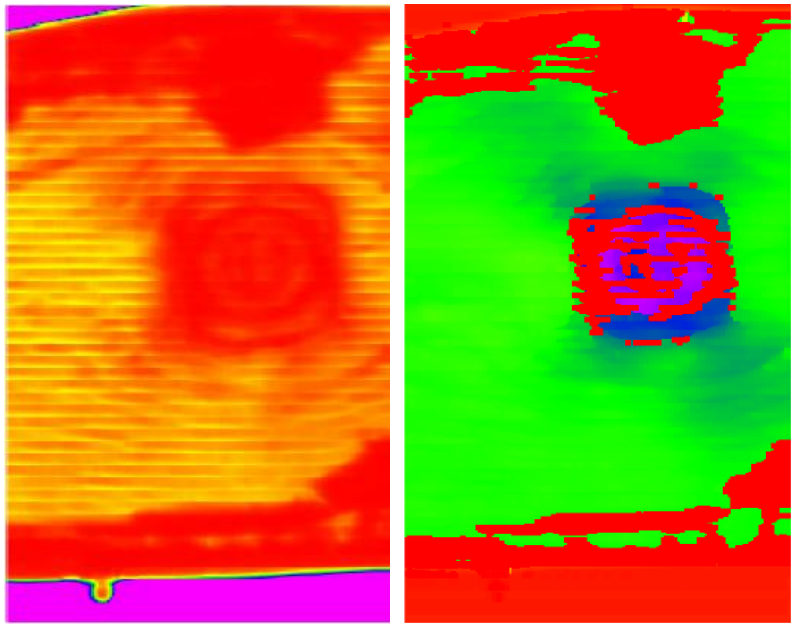
3d. Terahertz Imaging

Application: Detect in-thickness material defects in wooden panel paintings

Size 200x105x13 mm^3



Time delay Amplitude

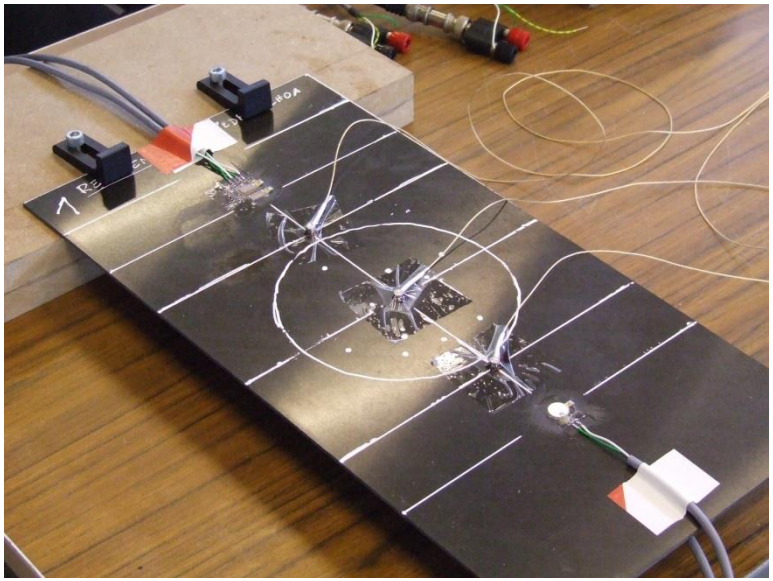
Ultrasonics Research Topics

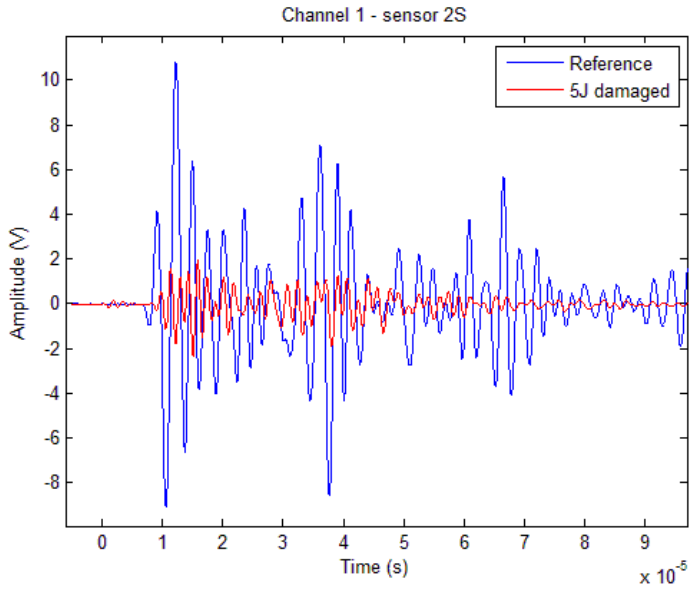
Dr Roger Groves (R.M.Groves@TUDelft.nl)

a. Guided Lamb wave ultrasonics
   i. NDT/SHM of composite plates
   ii. Time-reversal Lamb wave
   iii. Air-coupled ultrasonics
b. C-scan ultrasonics
   i. Data Fusion (ultrasonic C-scan and shape)
c. Phase-Array Ultrasonics
   i. Damage detection in composites

4a. Lamb Waves – NDT/SHM of Laminated Composites

- Damage detection of multiple-location barely visible impact damage (BVID)





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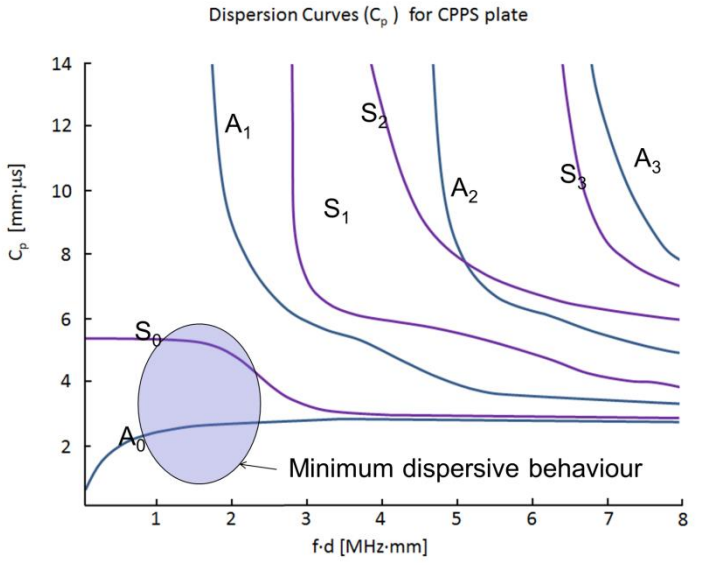
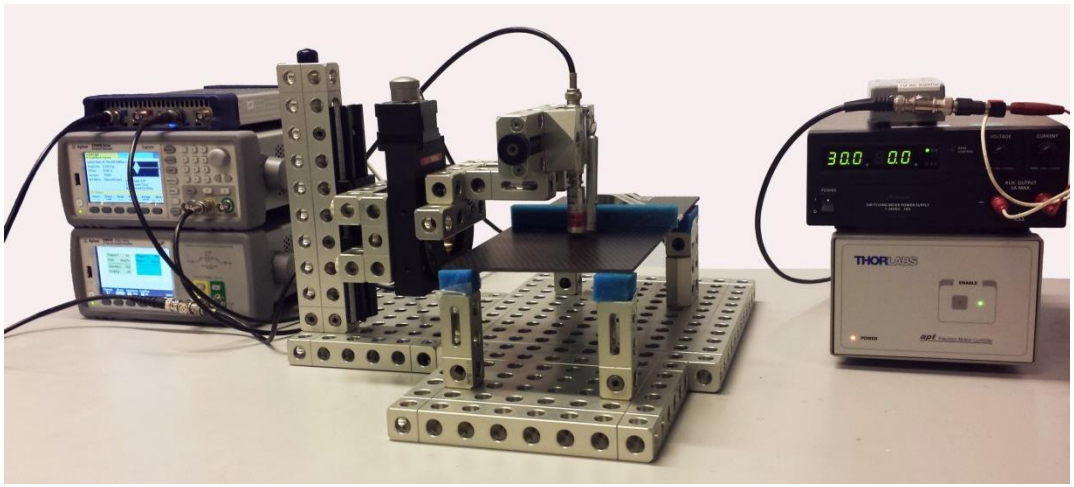
4a. Guided Lamb Wave Ultrasonics

Non-Contact NDT using Air-Coupled Sensors

- New Development of a Structural Health Monitoring technique for NDT
- Air-coupled transducers, with automated, e.g. robot, positioning allow non-contact high-speed damage detection in production environments
- Damage detection algorithms applied to received ultrasonic signals





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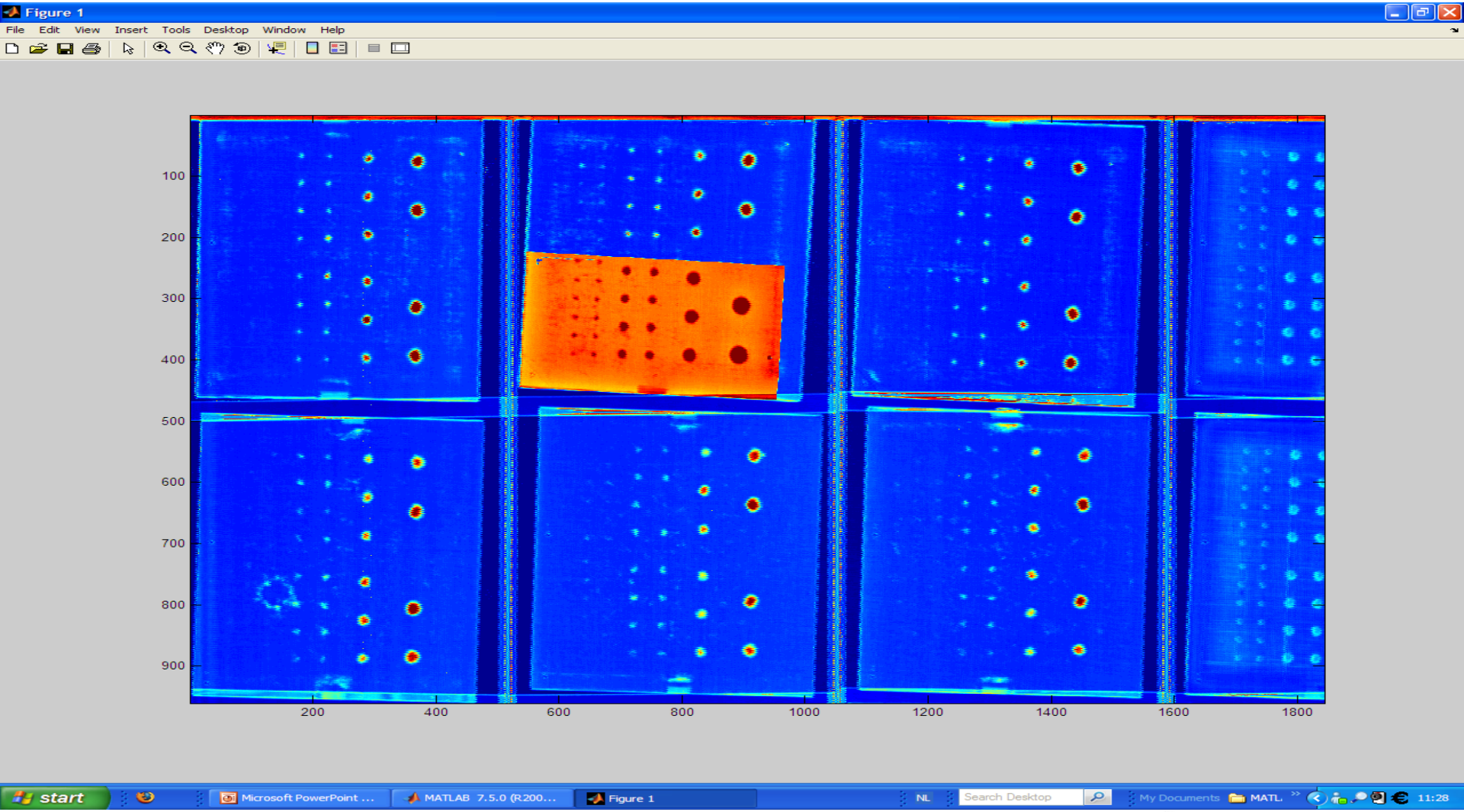
4b. Data Fusion (C-scan and shape)



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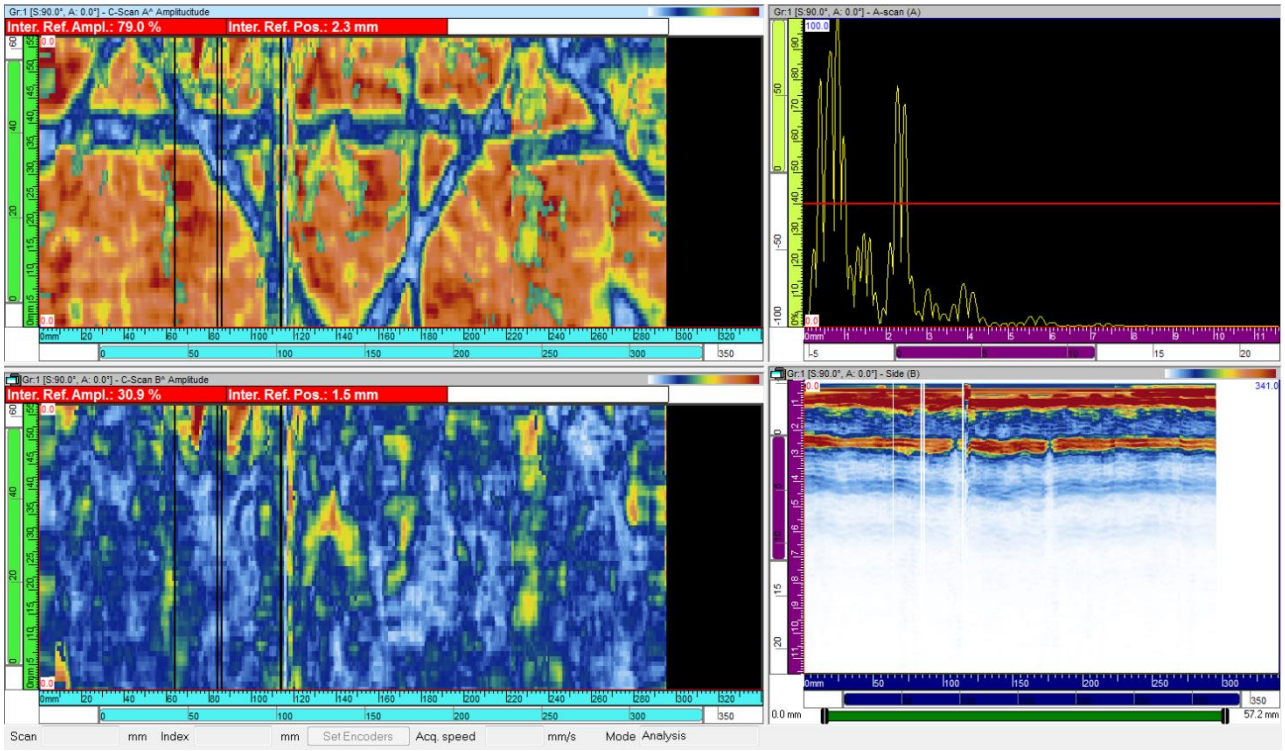
4c. Phase-Array Ultrasonics



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'Toolbox' of Measurement Techniques

- What do you want to measure?
  - *Don't know exactly is a common answer*
- Follow up question: What is the problem you are trying to solve?
  - Partnership of experts to specify the problem
- We then propose measurement technique(s)
  1. Available in my lab
  2. We put you in contact with a external partner
  3. We have to design something: *funded or student project*

Aerospace NDT Laboratory Team

- 20 researchers and project students developing instrumentation, algorithms and applications

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