• Infrared holographic interferometry for metrology of space payloads
• NDI by optical-laser techniques for aeronautical composites

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Optics for Space

Simulated space environment testing
Large chambers with optical benches

Development of optical Space instrumentation

Development of Advanced Technologies
- Vacuum-Cryogeny
- Quality insurance
- Thermal Design
- Signal Processing
- Spaceborne Electronics
- Smart sensors
- Surface processing
- Optical Design
  - Optical Metrology
  - Non Destructive Testing

CNR, Naples, Feb 25, 2015
The Laser & NDT Lab

Research in laser and optical metrology and NDT for aerospace

**Dimensional measurement**
- Fringe projection
- Digital Image Correlation

**Thermography**
- Pulsed + Lock-in
- Vibrothermography (ULg)

**Full-Field Deformation measurement**
- Holography
- Speckle interferometry
- Shearography

**Laser Ultrasonics**

CNR, Naples, Feb 25, 2015
Laser & NDT Techniques

Infrared holographic interferometry for metrology of space payloads
Holographic camera

- Analog hologram recording
- Photorefractive crystals (Bi$_{12}$SiO$_{20}$)
- In-situ recording + Fully erasable + Reusable

- Green Laser (532 nm)
- Displacement range: 15 nm - 25 µm
- Very high resolution
Holographic camera

- Applications

Defect Detection in composites (CFRP)

Vibration Mode Shapes

Metrology – FEM comparison
Metrology on composite structures

- Thermo-mechanical assessment of composite space materials/structures

Space instrument structure in test bench

Samples

Interferograms

Deformation field

Caméra thermographique

Caméra holographique

Bras à 2 illuminations

Chambre à vide

Fenêtre ZnSe

Fenêtre verre

DSIRIS module
dual-illumination camera

Thermographic camera

Metamorphic camera

X - Test

X - Sim

X - Diff.
Test of large optics

HERSCHEL

PLANCK

Aspheric reflectors
Test of large optics

- ESA and other space agencies need:
  - Full-field *deformations* of reflectors in vacuum-thermal testing
  - Large reflectors: up to 4 m diameter
  - Range of deformations: 1 µm – 250 µm
  - **Reflectors cannot be equipped with cooperative targets nor sprayed with scattering powder!**
Test of large optics

Development of holographic setup in lab

Setup in CSL vacuum chamber

This experiment motivated the use of longer wavelengths applied to holography

Good results of Deformation (mechanical load)

Poor results (thermal load)

Instability of Setup (vibrations, …)
Infrared Holography

Zoom of local interference pattern (hologram-specklegram)

Pattern must be stable during recording (depends on frame rate)

Set-up stability criterion: $\frac{\lambda}{10}$

Visible lasers: stability better than 50 nm

Phase map / displacement field

Measurement range $\leftrightarrow$ Number of fringes

Visible lasers: range = 50 nm – 10 µm

CO$_2$ laser $\lambda=10$ µm (LWIR range)

stability can be only 1 µm

range = 1 µm – 200 µm
HOLODIR project

• HOLODIR instrument implemented in laboratory to measure its performances
• Observation of a parabolic reflector
  – Diameter : 1.1 m
  – F# : 1.4

Diffuser

Uncooled µ-bolometer
640x480 pixels
Pixel Pitch : 25 µm
Frame rate 60 Hz
16 bits
**HOLODIR project**

- **Acquisitions (x4)**
  - Amplitude
  - Phase #1
  - Phase #2

- **Mask**
  - Phase diff.

- **Filtered and masked phase diff.**
  - Unwrapping

- **Displacement map**

**Slide 14**

- **Amplitude**
- **Mask**
- **Filtered and masked phase diff.**
- **Displacement map**

**Slide 15**

- **Amplitude**
- **Mask**
- **Filtered and masked phase diff.**
- **Displacement map**
Nondestructive inspection by optical-laser techniques for aeronautical composites
Various projects with Belgian industries

- Purposes
  - Study non-contact NDI techniques
  - Complex shaped composites structures

- Techniques considered
  - Shearography
  - Thermography
  - Laser Ultrasound
Samples

Monolithic samples
Calibrated defects (teflon inserts, flashbreaker, ...)

1. Monolithic sample
2. Calibrated defect
3. Another monolithic sample
4. Two men with a large sample and a poster
Techniques used

- Shearography with heating
Techniques used

- Thermography: Optical Pulse Thermography (OPT)

Surface observation of thermal wave and its effect on internal defect

\[ t \approx \frac{z^2}{\alpha} \]

The observation time \( t \) is related to the defect depth

\( \alpha : \text{thermal diffusion coefficient} \)
Techniques used

- Thermography: OPT
  - Pulse Phase Thermography (PPT)
Techniques used

• Laser Ultrasounds

Generation of ultrasound by laser
Thermoelastic effect

Detection of ultrasound by laser
Interferometric probe (with laser) and Two-Wave Mixing

✓ No couplant – No water
✓ Signal independent of geometry
✓ Economically interesting for curved parts (see. EADS-Lockheed Martin publications)
Techniques used

• Examples of existing systems

LUIS (Tecnocampus Nantes)

LUIS (Sacramento, 1996)

Lockheed Martin (2000)

LUCIE (Tecnocampus Nantes, 2011)
Techniques used

- Equipements used

CTA Montreal
- Generation: pulsed CO$_2$ laser (10.6 µm)
- Detection: pulsed YAG laser (1064 nm)
- Probe TWM
- Repetition rate: 100 Hz
- Laser Spot: 2 mm
- Scanning step: 0.5 mm
- Manufacturer TECNAR
Results

• Sample 1: Comparison
Results

• Sample 2 : Comparison
Results

- Sample 4: Laser Ultrasound
### Comparison

<table>
<thead>
<tr>
<th></th>
<th>Thermography</th>
<th>Shearography</th>
<th>Laser UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>1,5 mm</td>
<td>&gt; 1,5 mm</td>
<td>&gt;&gt;&gt;&gt; 1,5 mm</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3-4 mm</td>
<td>3-4 mm</td>
<td>2 mm</td>
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<tr>
<td>Interpretation</td>
<td>+</td>
<td>-</td>
<td>++</td>
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<tr>
<td>Measurement</td>
<td>Qualitative</td>
<td>Qualitative</td>
<td>Quantitative</td>
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<tr>
<td>Depth assessment</td>
<td>-</td>
<td>- -</td>
<td>++</td>
</tr>
<tr>
<td>Set-up</td>
<td>+</td>
<td>+</td>
<td>- (scanning)</td>
</tr>
<tr>
<td>Cost</td>
<td>$$</td>
<td>$</td>
<td>$$$$$</td>
</tr>
</tbody>
</table>

**NDT techniques must be envisaged in complementarity**
Combined holography-thermography

Infrared holography

\[ I(x, y) = I_{\text{thermal}}(x, y) + I_{\text{average}}(x, y) + C(x, y) \cos[\psi(x, y)] \]

Laser OFF

Laser ON

Thermal background

Hologram/Specklegram
FANTOM project

- Laboratory set-up
- Laboratory compact prototype
- Transportable field prototype

**Components:**
- BS: Beamsplitter R90-T10
- Sh1, Sh2: Shutter
- L1: Illuminating lens
- P: Polariser
- L2: Injection lens
- MPZT: Mirror + Piezo-element
- M: Mirror
- BC: Beam combiner

**Prototypes:**
- Laboratory compact prototype
- Transportable field prototype

**Equipment:**
- Water pipes
- Water cooler
- Rack with all supplies
- Computer for control and post-processing
- Electronics cabinet
FANTOM project

• Decoupling temperature and deformation
FANTOM project

(a) FANTOM interferogram
(b) FANTOM deformation
(c) OLT phase thermogram
(d) FANTOM thermogram
(e) SHEARO deformation
FANTOM project

• Industrial tests: Airbus (D41, Toulouse)
FANTOM project

- Industrial tests: delamination on composite

\[ \Delta T \]
\[ \Delta \phi \]

Lamp start

After 2 seconds  After 30 seconds  After 6 minutes

\text{time}
Current developments

- Robotized full fibered laser ultrasound system
  - Generation (532 nm)
  - Detection (1064 nm)
  - 30 Hz rep. rate
Current developments
Current developments

• Data fusion between
  – Thermography
  – Shearography
  – Laser ultrasound
  – Shape measurement or CAD

• Modelling for helping interpretation of NDI
  – Finite Element Analysis
  – Reverse Engineering on defect

• New post-processings for shearography
Current developments

- Shearography: automated detection
Current developments

- Shearography: Principal Components Analysis

Temporal sequence shows various defects at different instants
Heat wave travelling through the sample

PCA provides
- A few eigenvectors showing different variability of signal in space and time
- Low order eigenfunctions show all defects
Thanks for your attention!

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Chapter VI. Infrared digital holography