Chaire de recherche du Canada

MIVIM

Multipolar Infrared Vision Infrarouge Multipolaire

Computer Vision and Systems Laboratory

gel-glr

Infrared vision applications for the nondestructive testing of materials

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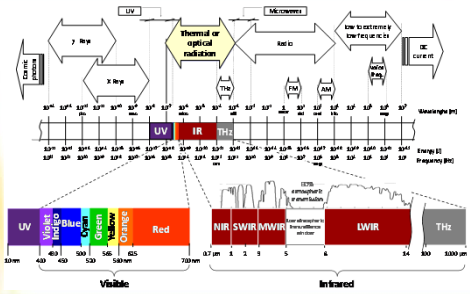
Outline

1. Active infrared thermography;
2. Infrared signal processing;
3. Active techniques
4. Applications;
5. Conclusions.

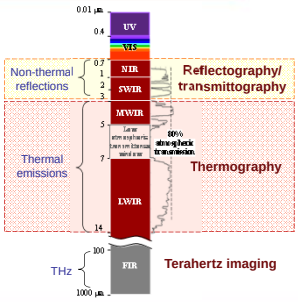
1. Active infrared thermography

Electromagnetic spectrum



Infrared vision

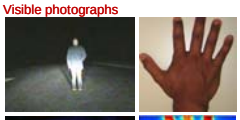
- Infrared vision is a subdivision of computer vision (*i.e.* the use of computers to emulate human vision), which employs (low-, mid- and high-level) computerized processes to "make sense" of images generated in the infrared part of the electromagnetic (EM) spectrum.



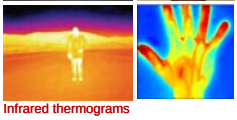
Infrared thermography

- Infrared thermography is a nondestructive, nonintrusive, noncontact technique that allows the mapping of thermal patterns, i.e. thermograms, on the surface of objects, bodies or systems through the use of an infrared imaging instrument, such as an infrared camera.

Visible photographs

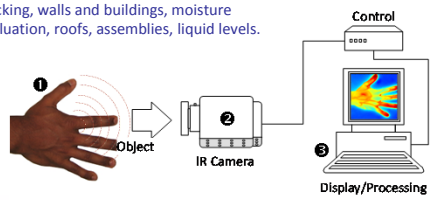


Infrared thermograms



Passive thermography

- The passive approach is used whenever the object of interest has enough thermal contrast to be detected with an infrared sensor. Typical applications include: surveillance, people tracking, walls and buildings, moisture evaluation, roofs, assemblies, liquid levels.



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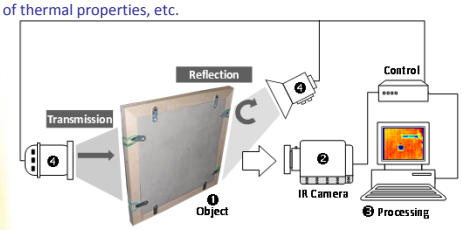
Active thermography

- In active thermography, an external stimulus is required in order to generate a thermal contrast between the defect and the sound material. Typical applications include: NDT of materials, estimation of thermal properties, etc.



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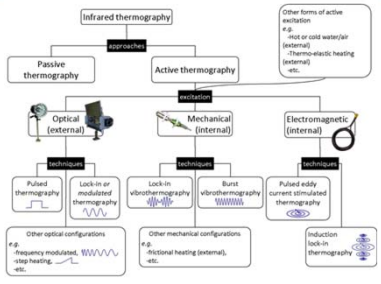
Infrared thermography: approaches, techniques



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Advantages and limitations

Advantages:

- Fast;
- Easy to deploy;
- One-side inspection;
- Safe;
- Thermal models are available;
- Varied applications;
- Sometimes, the only possible solution.

Limitations

- Emissivity variations;
- Thermal losses;
- Atmospherical attenuation;
- Non-uniform heating;
- Relatively shallow defects;
- Raw thermograms have often limited contrast.

* **MALDAGUE X. P. 2001.** Theory and Practice of Infrared Technology for Nondestructive Testing. John Wiley & Sons, N. Y.

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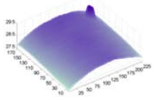
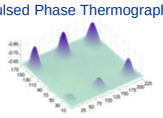
Problems

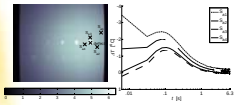
- Emissivity variations;
- Environmental reflexions;
- Non-uniform heating;
- Surface geometry;
- Reference area definition.

Thermogram



Phasegram
(Pulsed Phase Thermography)





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2. Infrared signal processing

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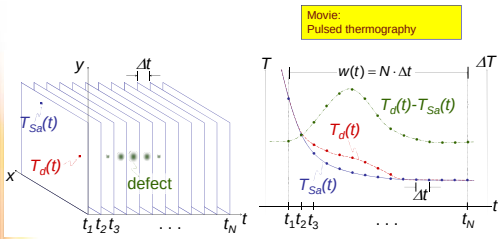
Thermogram sequences



Advanced signal processing techniques

- Thermal contrast-based techniques (max. contrast, FWHM, etc.)

$$\Delta T(t) = T_d(t) - T_{Sa}(t)$$

- Differential Absolute Contrast, DAC

$$\Delta T_{dac} = T_d(t) - \sqrt{\frac{t_r}{t}} \cdot T(t_r)$$

- Thermographic Signal Reconstruction, TSR

$$\ln(\Delta T) = \ln\left(\frac{Q}{e}\right) - \frac{1}{2}\ln(\pi t)$$

- Principal Component Thermography, PCT

$$A = USV^T$$

- Pulsed Phase Thermography, PPT

$$F_n = \Delta t \sum_{k=0}^{N-1} T(k\Delta t)\exp^{(-j2\pi nk/N)} = \mathrm{Re}_n + \mathrm{Im}_n$$

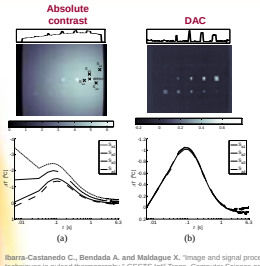
3D diffusion equation

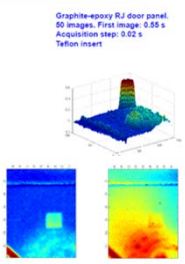
$$\nabla^2 T - \frac{1}{\alpha}\cdot\frac{\partial T}{\partial t} = 0$$

1D solution for a Dirac pulse

$$T(0,t) = T_o + \frac{Q}{e\sqrt{\pi t}}$$

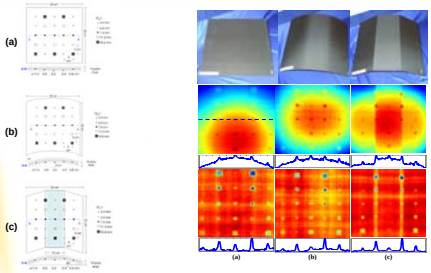
Example: DAC on CFRP





Ibarra-Castanedo C., Bendada A. and Maldague X. "Image and signal processing techniques in pulsed thermography." *GESTS Int'l Trans. Computer Science and Engr.*, **22**(1): 89-100, November 2005 available online: http://www.gests.org/down/2709.pdf.

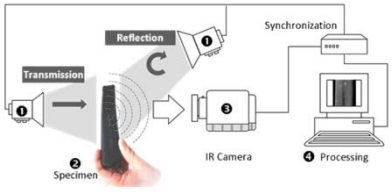
Example: PPT on CFRP



3. Active thermography techniques

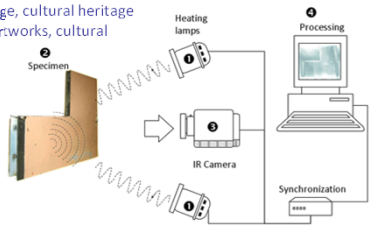
Pulsed thermography, PT

- Metal corrosion, crack detection, disbonding, impact damage in composites, turbine blades, delaminations, porosity, defect characterization: depth, size, thermal properties, artworks.



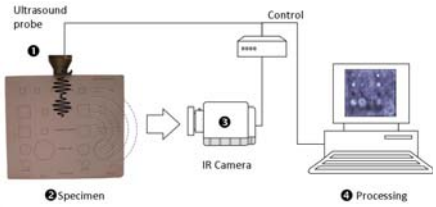
Lock-in thermography, LT

- Crack identification, disbonding, impact damage, cultural heritage inspection, artworks, cultural buildings.



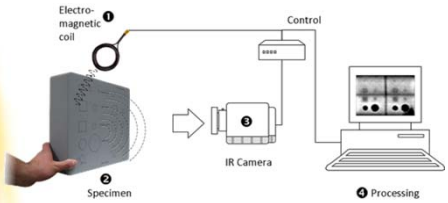
Vibrothermography, VT

- Coating wear, fatigue test, crack detection.



Eddy current (or Inductive) thermography, ECT

- Crack detection in electro-conductive materials, detection of impact damage in composites, inspection of soldering joints.

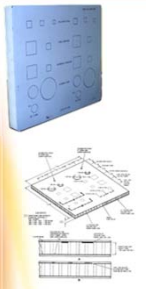


Inspection of honeycomb sandwich structures

Movie:
Eddy current thermography

4. Applications

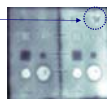
Comparative example 1



Optical PT

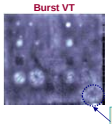
Paint detached from the surface

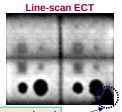
Optical LT



Burst VT

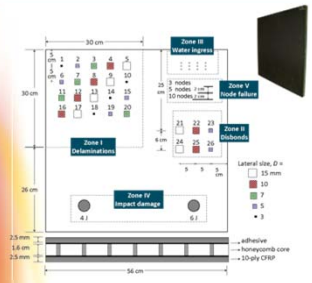
Line-scan ECT





Real crushed core produced during VT inspection

Comparative example 2

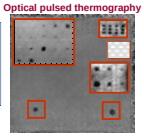


Defect distribution in Zone I and Zone II

	Defect number	Thickness, t [mm]	Lateral size, D [mm]	Between plies	Depth, z [mm]	Ratio D/z
Zone I	1	0.16	3	1 and 2	0.25	12
	2	0.16	5	2 and 3	0.5	10
	3	0.16	7	3 and 4	0.75	9.3
	4	0.16	10	4 and 5	1	10
	5	0.16	15	5 and 6	1.25	12
	6	0.16	5	6 and 7	1.5	3.3
	7	0.16	7	7 and 8	1.75	4
	8	0.16	10	8 and 9	2	5
	9	0.16	15	9 and 10	2.25	6.7
	10	0.16	3	9 and 10	2.25	1.3
	11	0.33	7	1 and 2	0.25	28
	12	0.33	10	2 and 3	0.5	20
	13	0.33	15	3 and 4	0.75	20
	14	0.33	3	4 and 5	1	3
	15	0.33	5	5 and 6	1.25	4
	16	0.33	10	6 and 7	1.5	6.7
	17	0.33	15	7 and 8	1.75	8.6
	18	0.33	3	8 and 9	2	1.5
	19	0.33	5	9 and 10	2.25	2.2
	20	0.33	7	9 and 10	2.25	3.1
Zone II	21	0.16	15	adhesive and core	2.5	6
	22	0.16	7	adhesive and core	2.5	2.8
	23	0.16	3	adhesive and core	2.5	1.2
	24	0.16	15	face sheet and adhesive	2.5	6
	25	0.16	7	face sheet and adhesive	2.5	2.8
	26	0.16	3	face sheet and adhesive	2.5	1.2

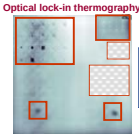
Comparative example 2 (cont.)

Optical pulsed thermography



Easiest to perform, best overall results. Only node failure defects were not detected.

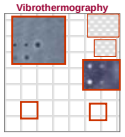
Optical lock-in thermography



Best defect contrast once the proper frequency is selected

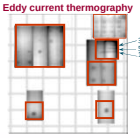
Not inspected
Not detected

Vibrothermography



Fast, to perform, most difficult to implement in practice

Eddy current thermography



Only technique able to detect node failure, detects all defect types with low resolution IR camera

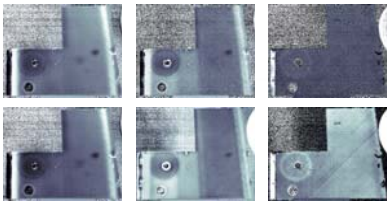
Inspection of CF-18 rudders (1/3)

Inspection of CF-18 rudders (2/3)

- Impact of de-noising with synthetic data

PPT from raw pulsed data

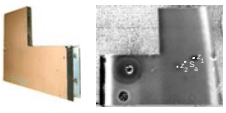
PPT from synthetic pulsed data

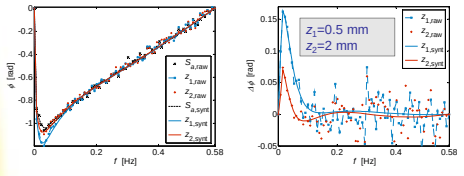


f=0.015 Hz *f*=0.04 Hz *f*=1.2 Hz

Inspection of CF-18 rudders (3/3)

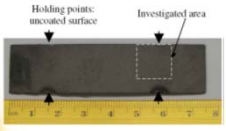
- Depth retrieval with phase profiles

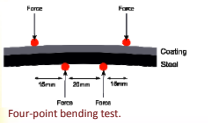




Micro-cracks detection

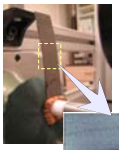
Almen strip subjectd to a high velocity oxy fuel (HVOF) process.





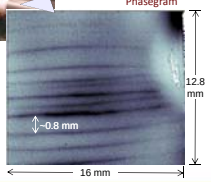
Four-point bending test.

Vibrothermography test



The coating (~100-200 mm) is formed by a mixture of tungsten-carbide and cobalt powder accelerated and heated in a plasma jet and sprayed onto a 1 mm thick steel substrate. Developed to replace chrome, which is harmful for the environment.

Phasegram



Reliability in NDT and the PoD

- Non-destructive Testing (NDT) reliability :

  'the probability of detecting a crack in a given size group under the inspection conditions and procedures specified'

- Repeat inspections of the same flaw size or the same flaw type will not result in consistent *hit* or *miss* indications.
- The PoD has become the accepted formal measure of quantifying NDT reliability, it is usually expressed as a function of **flaw size** although many other physical and operational parameters are involved:

  - material type
  - geometry
  - flaw type
  - NDT method
  - testing conditions and
  - NDT personnel (certification, experience).

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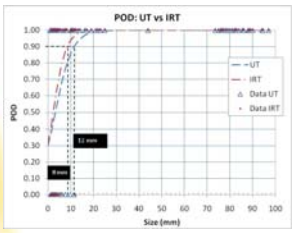
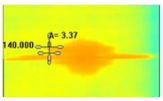
Probability of detection (PoD)





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5. Conclusions

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Conclusions

- Active thermography is widely used in aerospace among other industries.
- Data processing and analyzing techniques are required to enhance contrast, to improve the spatial resolution and to increase the signal-to-noise ratio of the infrared signal.
- The MIVIM Chair is constantly on the search of new and varied applications for active infrared thermography and studying and developing new signal processing techniques for infrared thermography applied to aerospace inspection.

THANK YOU FOR YOUR ATTENTION