UNIVERSITÉ LAVAL

"Synthetic Data in Infrared Thermography for NonDestructive Evaluation"

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in collaboration with
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CAP CONGRESS
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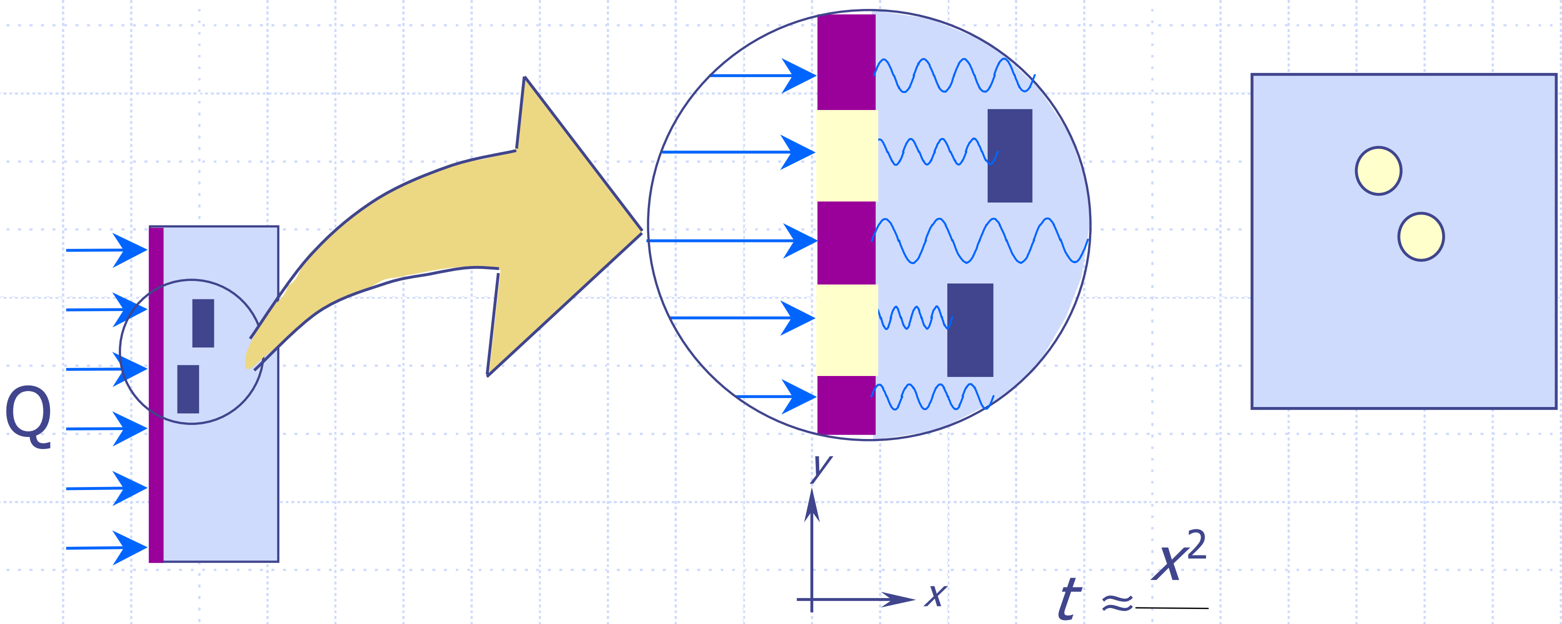
Computer Vision and Systems Laboratory

Outline

- Introduction: IRT for NDE
- Synthetic Data
- Experimental Procedures
- Conclusions & Perspectives

Introduction

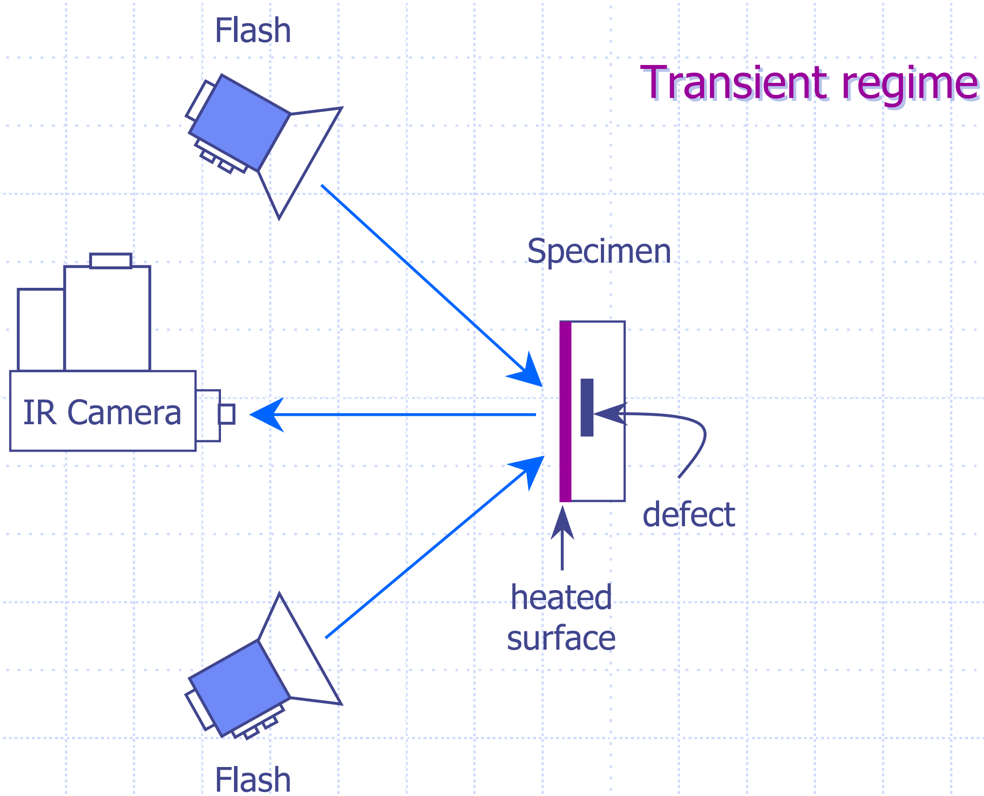
- Active Thermography for NDE



$$t \approx \frac{x^2}{\alpha}$$

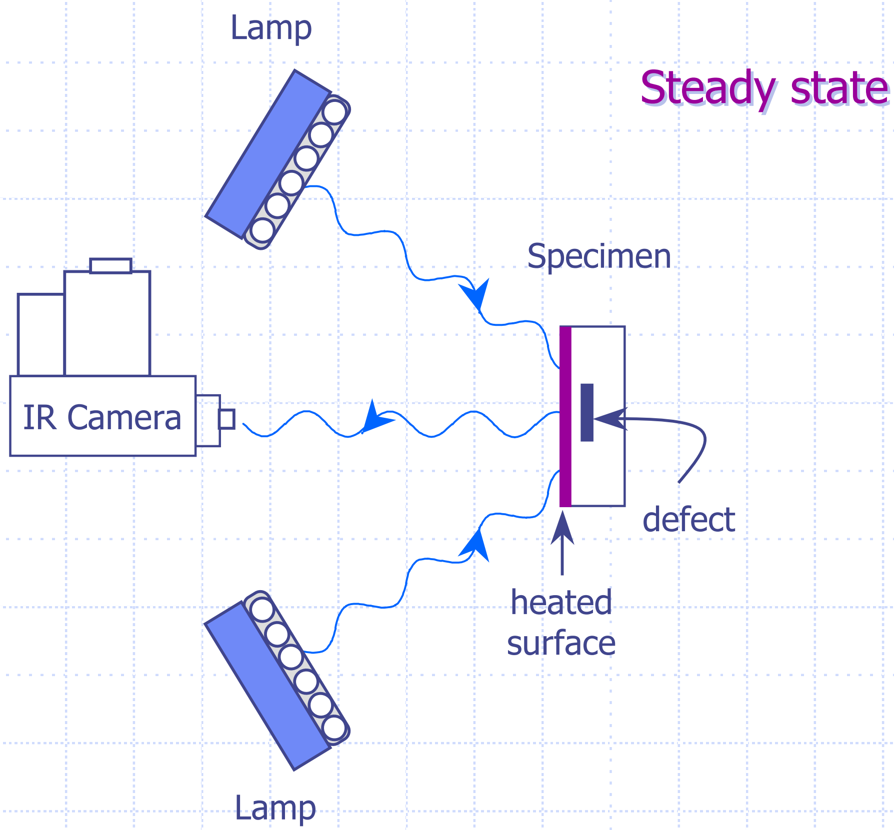
Introduction

- Pulse Thermography, PT



Introduction

- Lock-in Thermography, LT



Introduction

- Pulsed Phase Thermography, PPT
  - Experimental setup as in PT;
  - Fourier Transform ⇨ frequency domain
  - PPT several *f* (only one *f* at a time for LT);

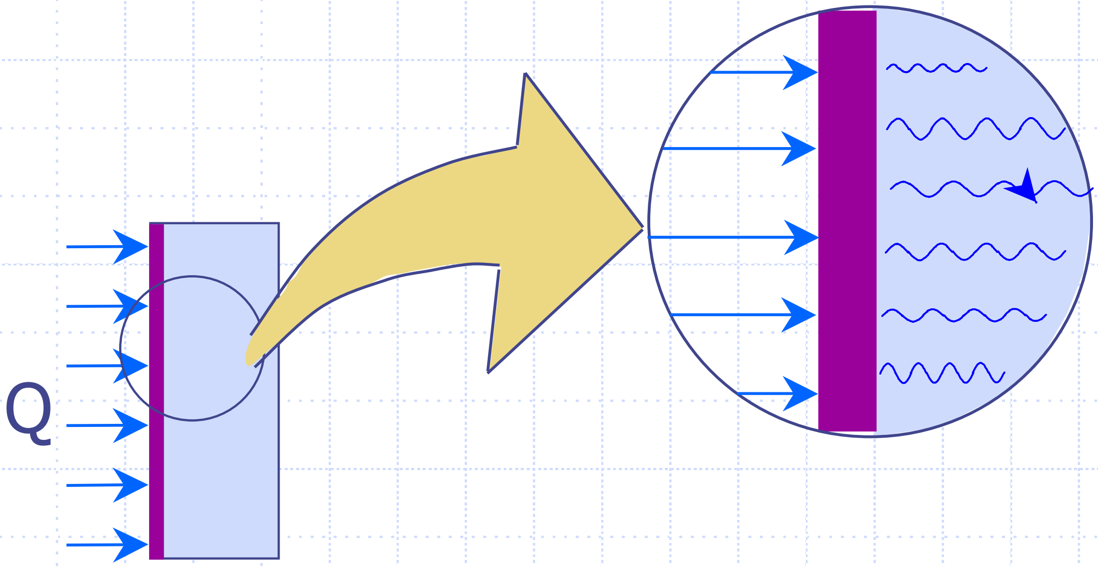
$$F_n = \sum T(k) e^{2\pi i k n/N} = \mathrm{Re}_n + \mathrm{Im}_n$$

$$A = \sqrt{\mathrm{Re}_n^2 + \mathrm{Im}_n^2}$$

$$\phi = \tan^{-1}\left(\frac{\mathrm{Im}_n}{\mathrm{Re}_n}\right)$$

Synthetic Data

- Semi-infinite plate without defect



3D diffusion equation

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

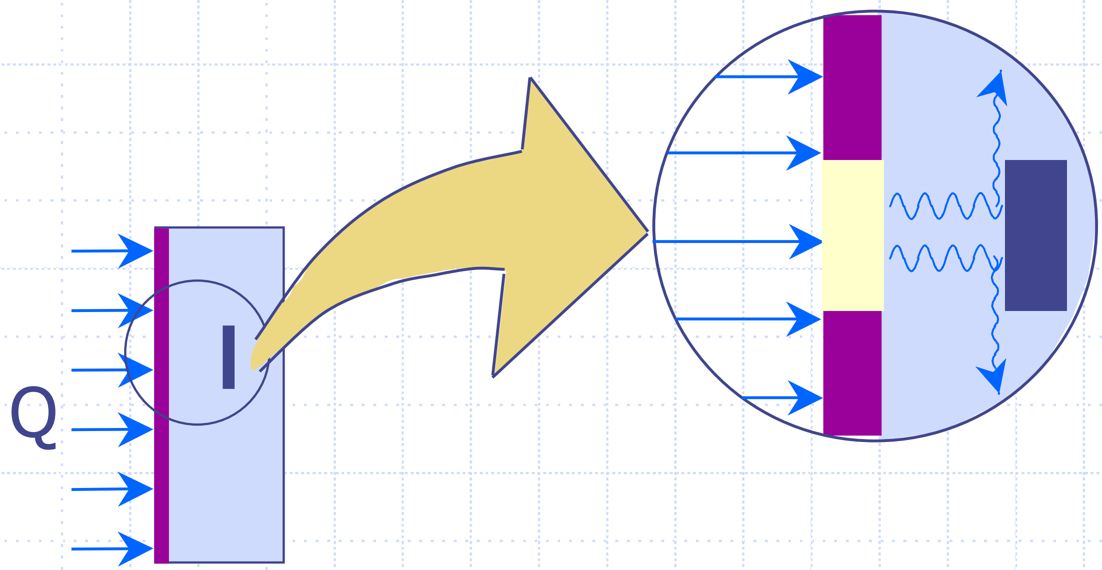
1D solution

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

$$T = \frac{Q}{e\sqrt{\pi t}}$$

Synthetic Data

- Semi-infinite plate with defect



3D diffusion equation

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

2D solution

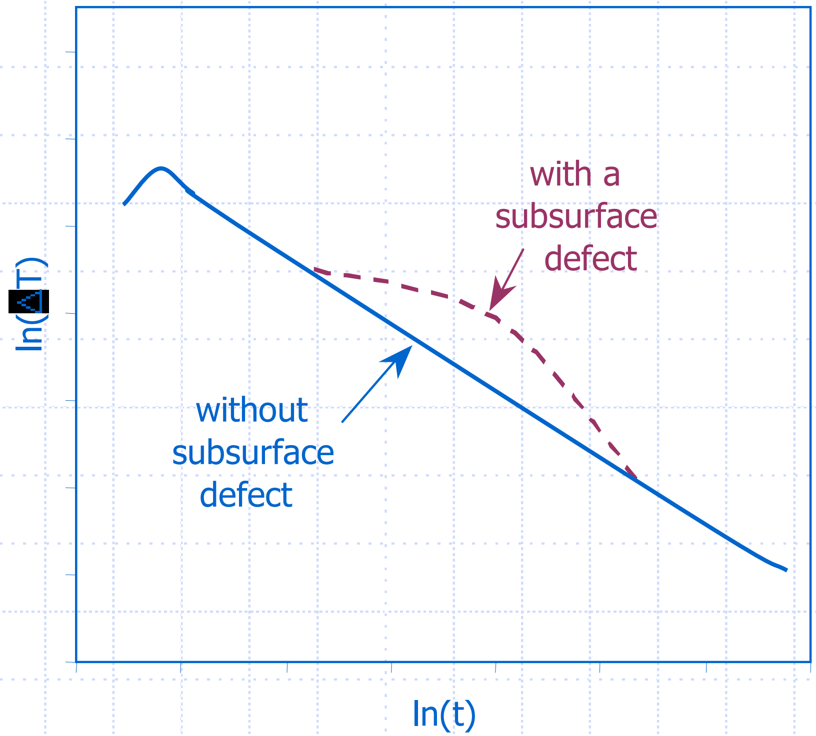
$$\nabla^2_{x,y} T - \frac{1}{\alpha}\frac{\partial T}{\partial t} = 0$$

Synthetic Data

- Log-Log fitting

$$T = \frac{Q}{e\sqrt{\pi t}}$$

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



Synthetic Data

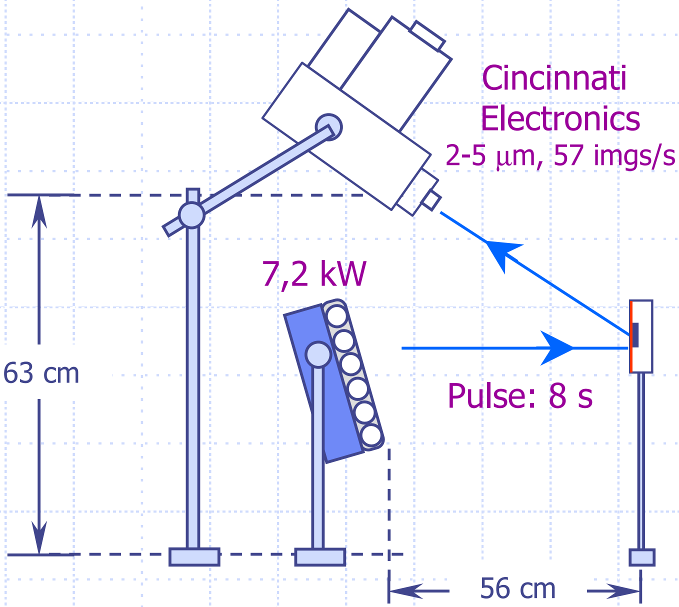
- Synthetic coefficients

$$\ln T = a_0 + a_1 \ln(t) + a_2 \ln^2(t) + \ldots + a_n \ln^n(t)$$

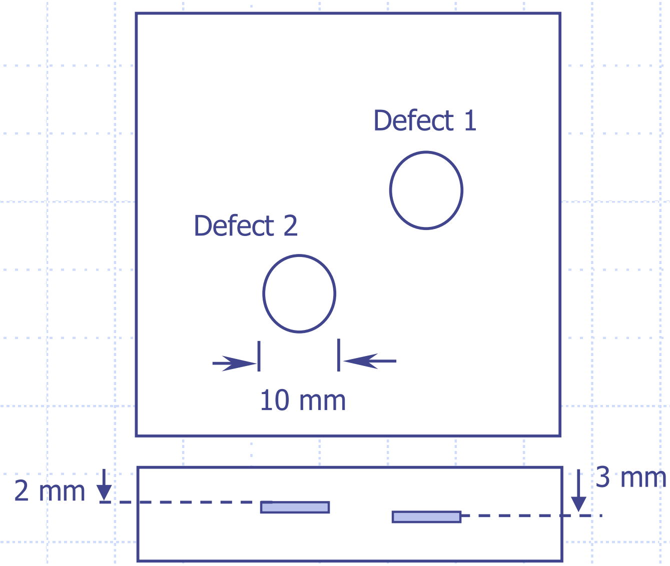
$$T(t) = \exp\left[a_0 + a_1 \ln(t) + a_2 \ln^2(t) + \ldots + a_n \ln^n(t)\right]$$

Experimental Results

- Case 1: Graphite-epoxy



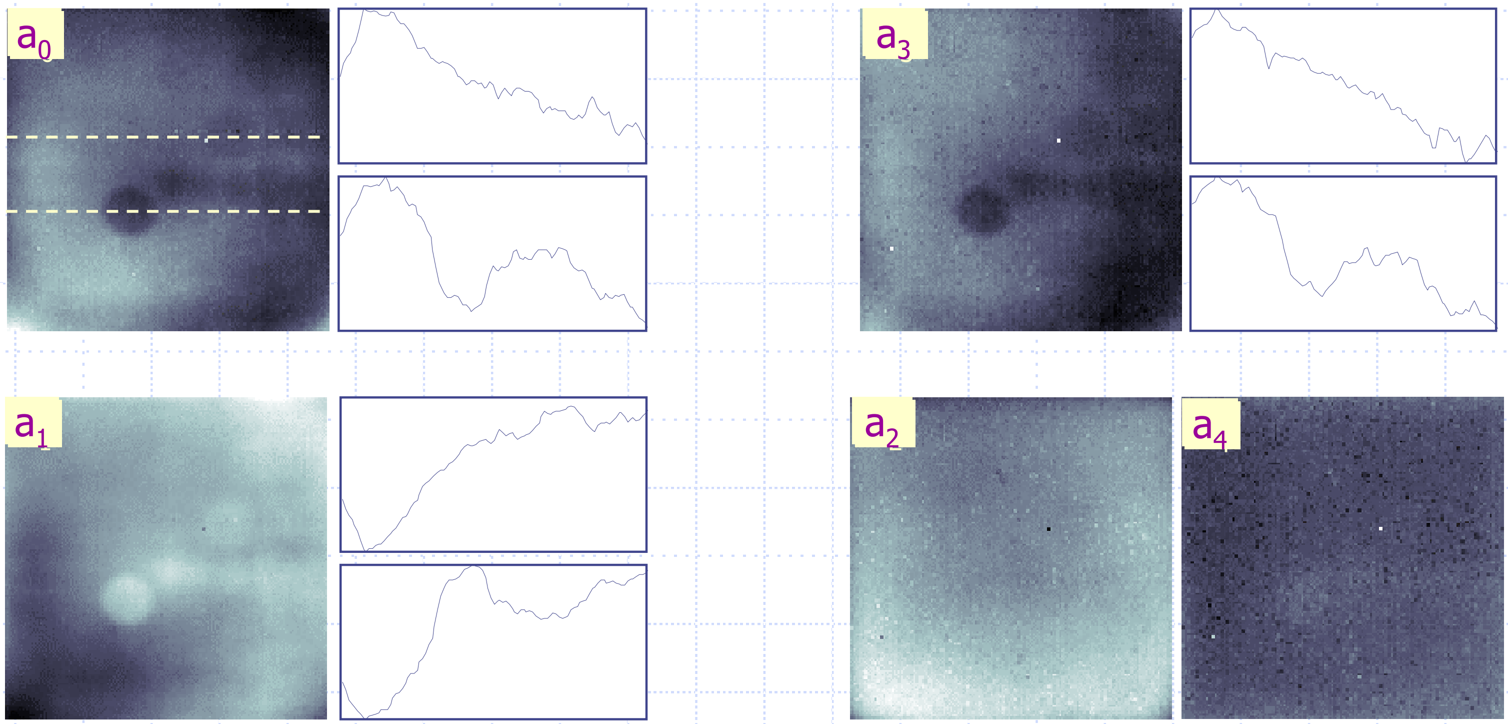
Graphite-epoxy
with 2 Teflon TM inclusions



Experimental Results

- Raw coefficients

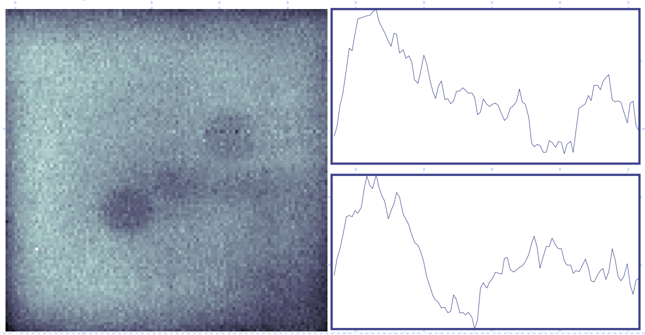
$$T(t) = \exp\left[a_0 + a_1 \ln(t) + a_2 \ln^2(t) + a_3 \ln^3(t) + a_4 \ln^4(t) \right]$$



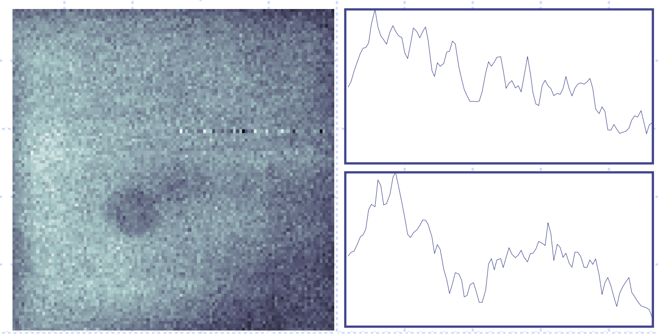
Experimental Results

- Direct PPT vs Synthetic PPT

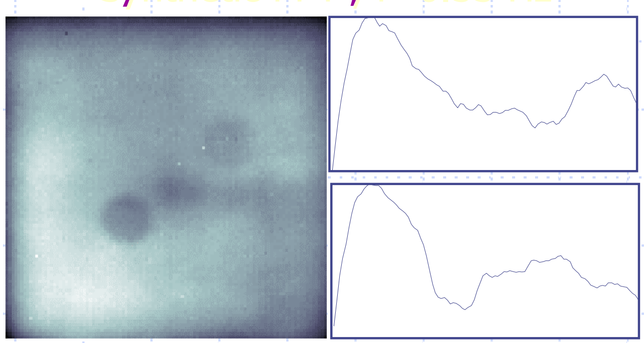
Direct PPT, f=0.33 Hz



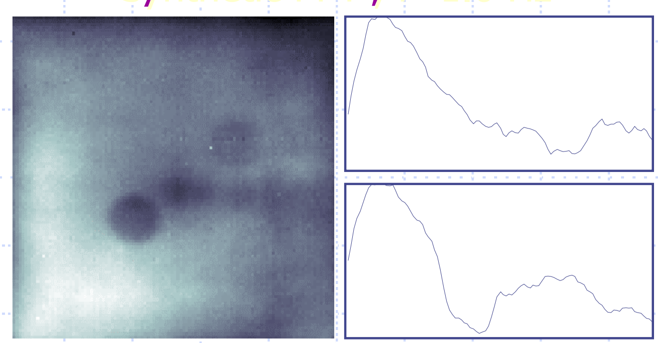
Direct PPT, f=1.0 Hz



Synthetic PPT , f=0.33 Hz

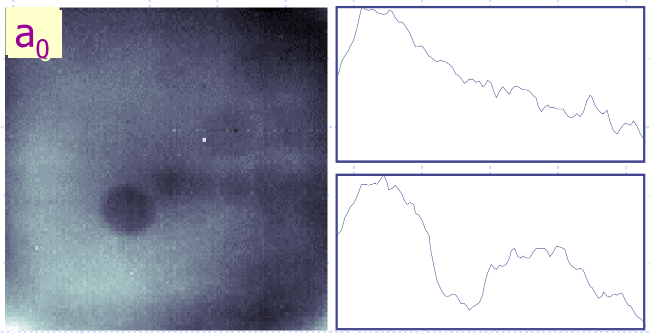


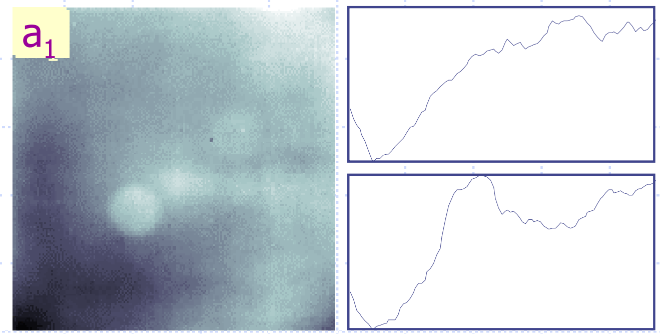
Synthetic PPT , f=1.0 Hz



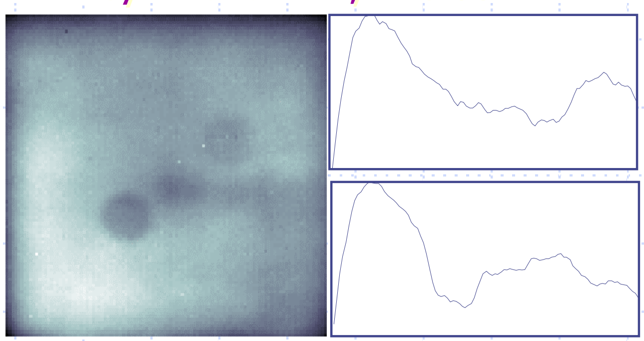
Experimental Results

- Direct PPT vs Synthetic PPT

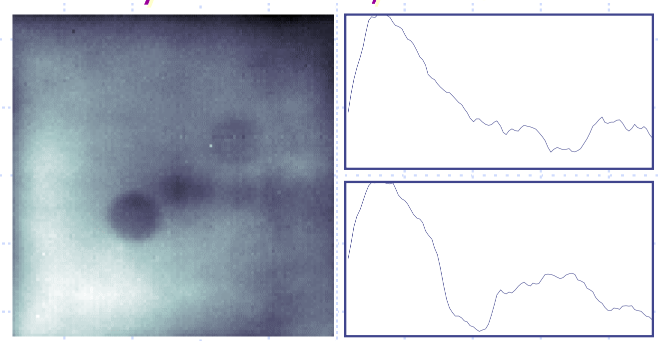




Synthetic PPT , f=0.33 Hz

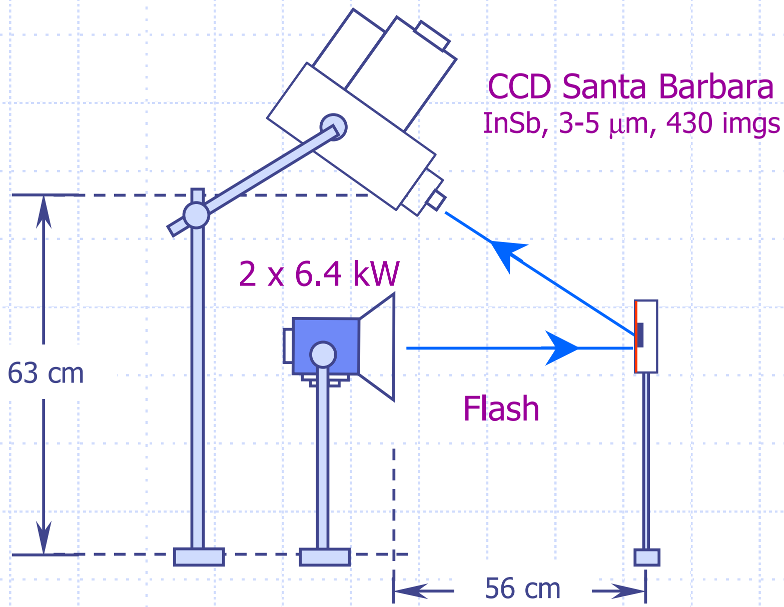


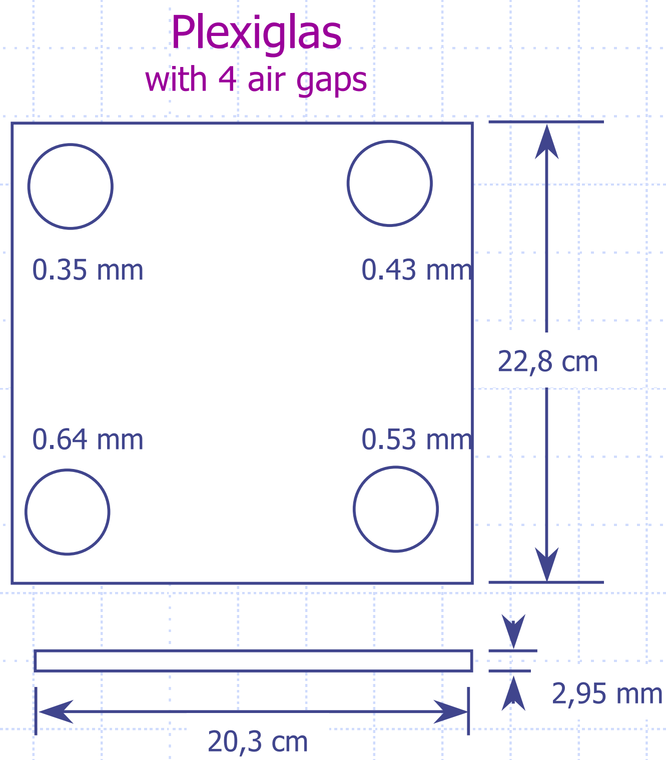
Synthetic PPT , f=1.0 Hz



Experimental Results

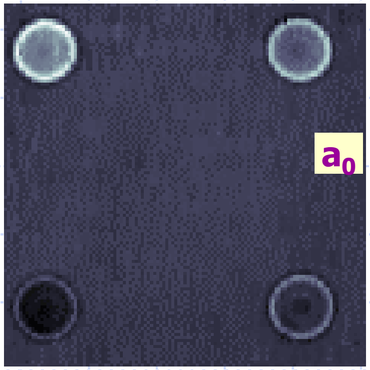
- Case 2: Plexiglas

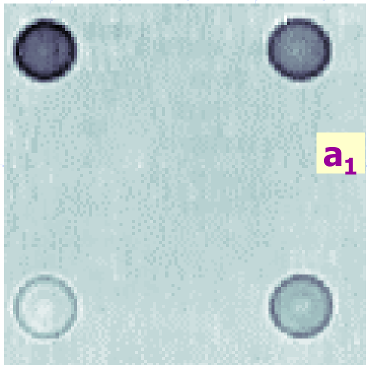


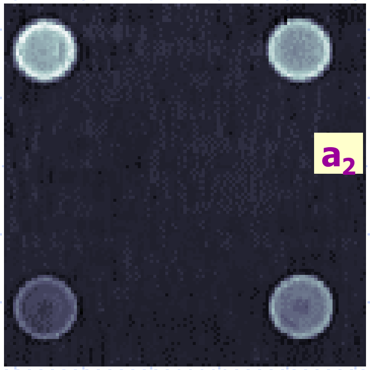


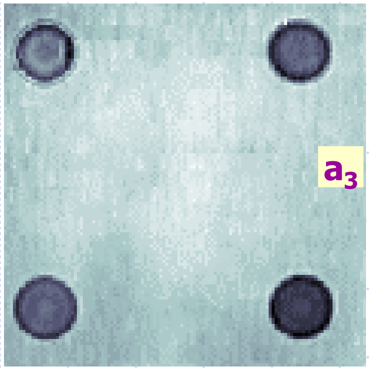
Experimental Results

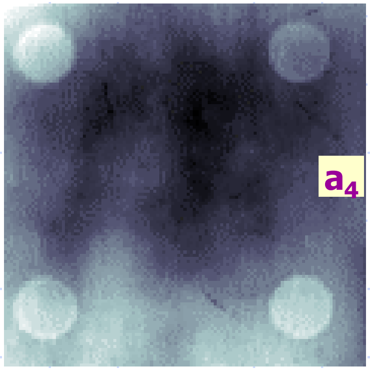
- Raw coefficients









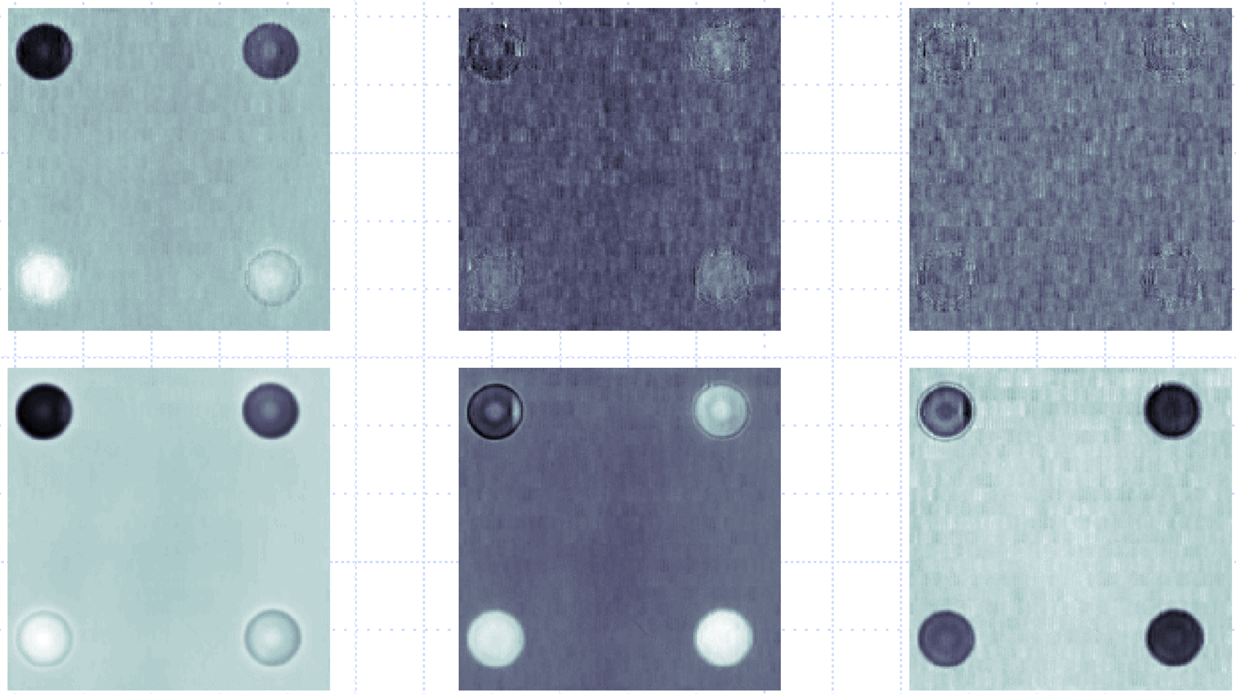


Experimental Results

- PPT vs synthetic

Direct PPT

Synthetic PPT



f=0.2 Hz f=0.76 Hz f=4.76 Hz

Conclusions & Perspectives

- ✓ Substantial data reduction;
- ✓ Possibility to work with analytical solutions;
- ✓ De-noising;
- ✓ Synthetic PPT images are OK for $f\uparrow$;
- Further processing of raw coefficients;
- Optimal polynomial degree;
- Depth measurement & defect characterization.

Thank you for your attention !

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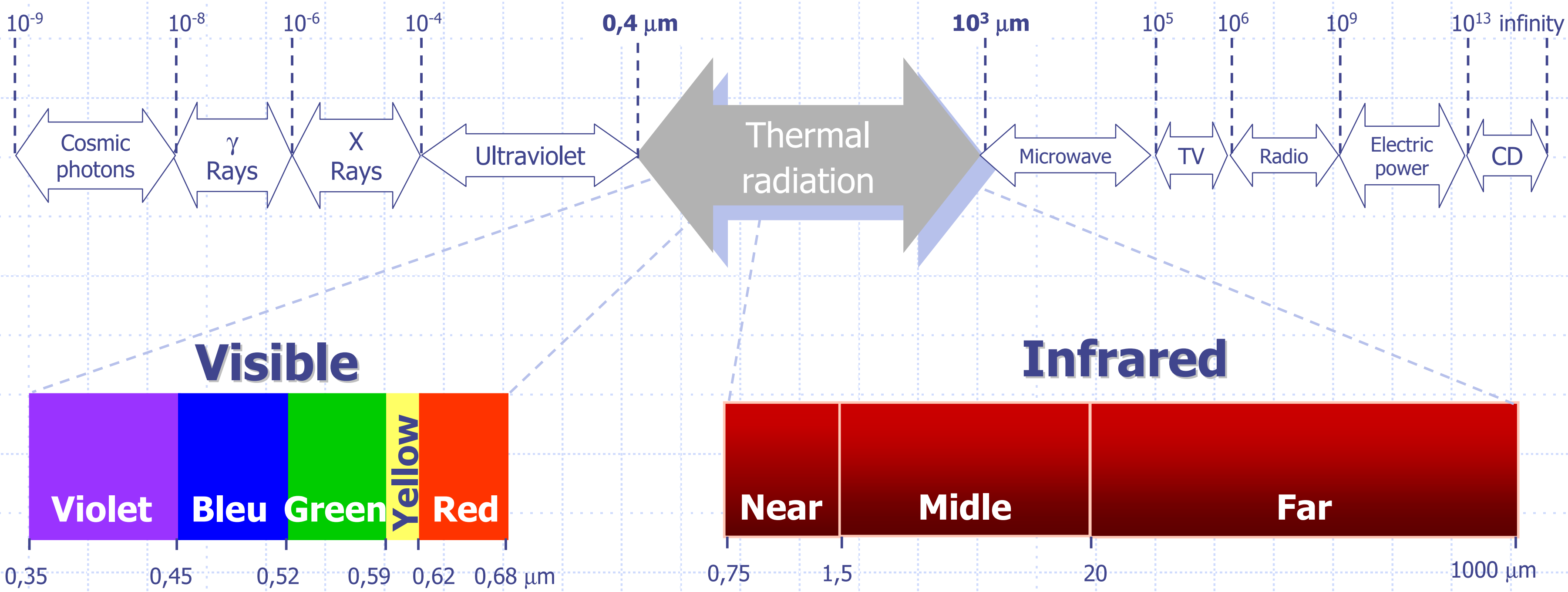
Computer Vision and Systems Laboratory

Annexes

- Electromagnetic spectrum



Annexes

Advantages & Limitations

- ✓ Fast surface inspection;
- ✓ Safety (no harmful radiations);
- ✓ Wide range of applications;
- ✓ Ease of deployment;
- ✓ No contact.

- × Non-uniform heating;
- × Specimen shape;
- × Thermal losses;
- × Cost of the equipment;
- × Limited thickness;
- × Emissivity problems.

Annexes

- Frequency response