Caractérisation des gaz basée sur un spectro-imageur interférométrique instantané (ImSPOC)

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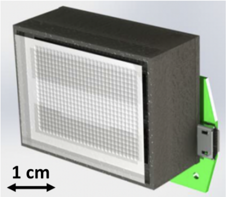
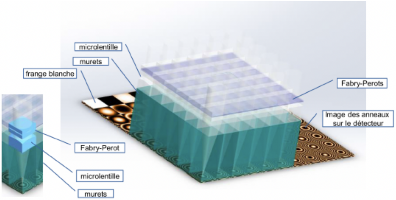
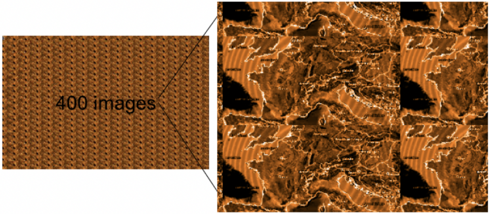
ImSPOC

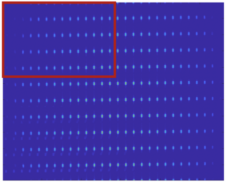

1 cm

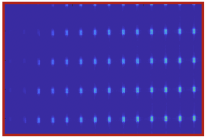

microlentille
murets
frange blanche
Fabry-Perots
Image des anneaux sur le détecteur
Fabry-Perot
microlentille
murets


400 images

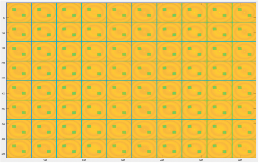
2 prototypes

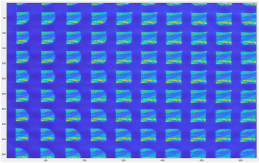
- ImSPOC-UV
  - Spectral range : UV et VIS
  - Applications :
    - O_4, O_3, O_2, NO_2





- Nanocarb
  - Spectral range : near IR
  - Applications :
    - CO_2

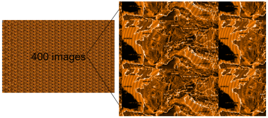


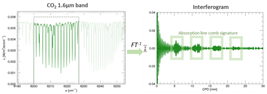


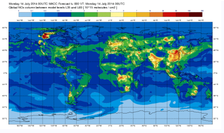
Outline

- 3 steps

Calibration → Spectrum reconstruction → Concentration estimation

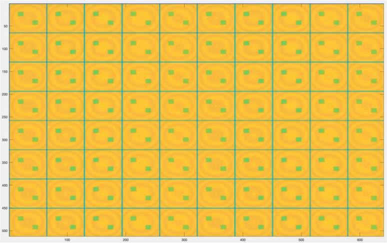


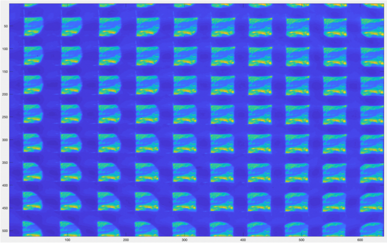




- Objectives
  - Calibration : optimal matching between the thumbnails
  - Spectrum reconstruction : interferogram inversion
  - Concentration estimation :
    - Gaz detection
    - Concentration quantification

Objective: optimal matching of the thumbnails





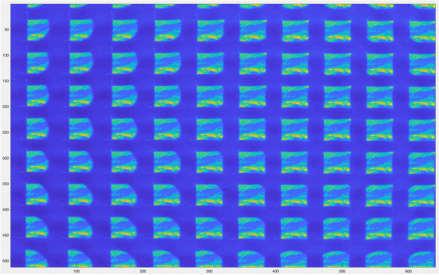
Spatially

- Thumbnail cutting
- Subpixel shifts
- Distorsion

Spectrally

- Non linearity

Considered solutions



Thumbnail cutting

- Edge detection

Subpixel shifts

- Discrete Fourier transforms [Guizar-Sicairos et al., OPTICS LETTERS, 2008]

Distorsion

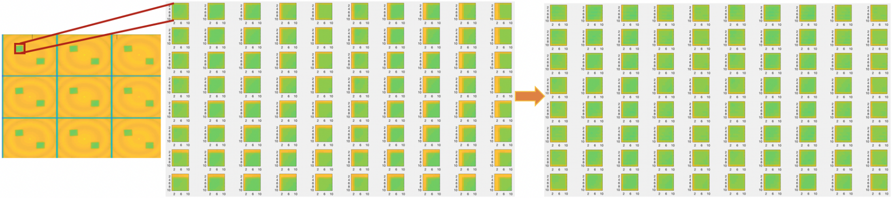
- To study

Interferogram non linearity

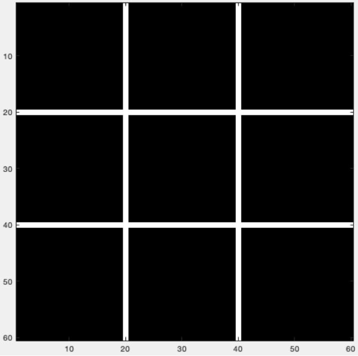
- Measured OPD to take into account

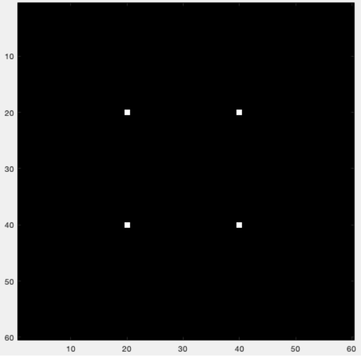
Subpixel shifts

- Discrete Fourier transforms [Guizar-Sicairos et al., OPTICS LETTERS, 2008]
  - Based on crosscorrelation
  - 2*2 images registration



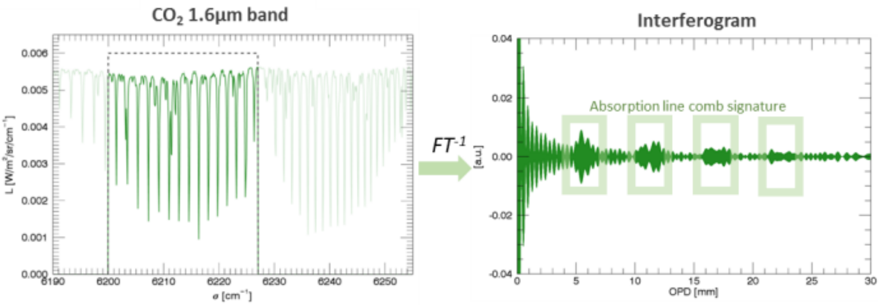
Dataset for validation





- Simulation
- ONERA and/or IPAG acquisition

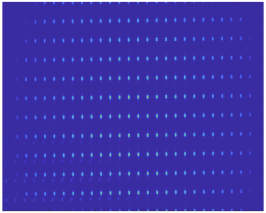
Objective: reconstruct the spectrum of each pixel from its interferogram



- Theory: Fourier transform
- Non linearity
- Small OPD missing

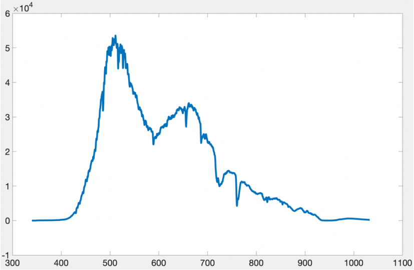
Model construction for inversion

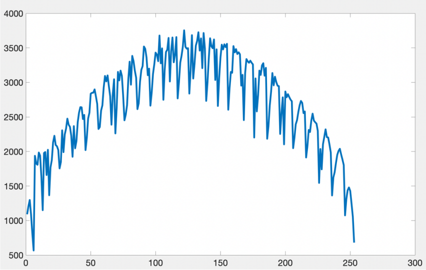
- Sensor fabrication induces some not known phenomena



Interferogram understanding

- Combined acquisitions
  - ImSPOC-UV and dispersive spectrometer
  - Following the sun during a day





Objectives

- Detection of specific gaz
- Quantification of specific gaz (abundance)

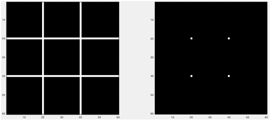
Open question: do the reconstructed spectra allows the use of classical unmixing algorithms ?

Considered tests

- Differential Optical Absorption Spectroscopy [Platt et al., PESE, 2008]
- Vertex Component Analysis [Nascimento et al., IEEE TGRS, 2004], Group Lasso with Unit sum and Positivity constraints [Ammanouil et al., IEEE TIP, 2014], N-FINDR [Winter et al., Proc. SPIE, 1999], etc.
- Fully Constrained Least-Square [Heinz et al., IEEE TGRS, 2001]

Conclusion and perspectives

- Many challenges
- Simulations and acquisitions with ground truth
  - Grid, points, ...



- Combined acquisitions with another system for comparison
  - Dispersive spectrometer

Two principal points to solve:

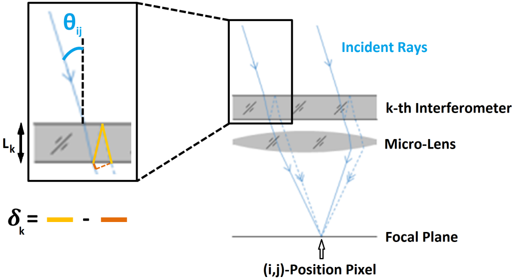
- Spatial calibration (subpixel shifts and distorsion)
- From interferogram to spectrum

The end!

Thank you !

Acquisition model

- An incident ray $I_{in}(\theta_{ij}, \sigma)$ is characterized in the two domains:
  - Spectral: As a function of the wavenumber σ (inverse of the wavelength); a leading optical system limits its range in the interval $[\sigma_{min}, \sigma_{max}]$
  - Spatial: As a function of its incidence angle θ_{ij}; strictly, that is defined as the solid angle range of the rays that, after collimation, excites the photo-detector on the focal plane in the position (i, j). Each sub-image, excluding disalignments, has the same behaviour for ray collimation.



Mathematical formulation: Transmittance function

- By ignoring all effects, apart the transmittance T_k of the interferometer itself, the detected light intensity I_k for the k-th sub-image can be expressed as:

$$I_k(i,j) = \int_{\sigma_{min}}^{\sigma_{max}} I_{in}(\theta_{ij},\sigma)T_k(i,j,\sigma)d\sigma$$

- The trasmittance may be expressed with different models:
  - Two-rays model: $T_k(i,j,\sigma) = 1 + R^2(1-R)^2 \exp\left(2\pi\sigma\delta_k\right)$
  - All-rays model: $T_k(i,j,\sigma) = \frac{1}{1+\frac{4R}{1+R}\sin^2(2\pi\sigma\delta_k)}$

where:

  - $R(\sigma)$ is the internal surface reflectivity
  - $\delta_k(i,j) = 2nL_k\cos(\theta_{ij})$ is the OPD between the directly transmitted ray and the one transmitted after a double reflection
  - L_k is the width of the k-th interferometer
  - n is the refraction index inside the interferometer

Inversion

- The inverse model target is to find an estimation of $I_in(\theta_{ij}, \sigma)$ from the collected acquisitions $I_k(i, j)$
- Two-rays model:
  - The transfer function is in the form: $I_k(i, j) = \int_{\sigma_{min}}^{\sigma_{max}} I_{in}(\theta_{ij}, \sigma)(1 + \alpha \exp(2\pi\sigma\delta_k))d\sigma$, which, if associable to a cosine Fourier transform from the domain of the wavenumbers σ to the ones of the OPDs δ
  - Ideally, the spectrum could be simply reconstructed by an inverse Fourier transform
- Problem linearization: The direct transfer function is modeled as a linear transformation.
  - Variational framework: Its target is to minimize a specific cost function, composed by a data fidelity term and a regularizer.
  - T-SVD: The matrix of linear transformation is decomposed through SVD and low-amplitude eigenvalues contributions are ignored before its inversion..