M2 — Data fusion and prior learning

Keywords. Prior learning, heterogeneous data fusion, inverse problems, high dimensions, images.

Tools. Optimization, Bayesian approach, machine learning.

Applications. Hyperspectral, astronomy, medical imaging.

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Funding. The subject can lead to a funded PhD, by CNES for 50% and the LabCom LAB4S2 for 50%.

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1 Context

Hyperspectral and multispectral imaging are ubiquitous in many observation modalities like earth observation (like copernicus project), astronomy, medical imaging, material analysis. Both modality produces an important amount of data.

The objective of the subject is to develop new methods based on Bayesian and learning approach for fusion of heterogenous data like hyper and multispectral data. In particular, the subject take place in the international James Webb Space Telescope (JWST) project, the most ambitious space telescope ever launched, as a case study.

2 Methodology

2.1 Data model and fusion

The aim of the thesis is to develop efficient algorithms for joint processing:

- of multispectral data obtained with imager over a large field of view
- with hyperspectral data with high spectral resolution but for small fields of view.

This problem, which can be likened to a data fusion problem (like so-called pansharpening methods in Earth observation), in a context where the effects due to the instrument are negligible. The problem could be solved by minimization of a joint criterion

$$J(\boldsymbol{x}) = \|\boldsymbol{y}_{img} - \boldsymbol{H}_{img}\boldsymbol{x}\|^2_{\boldsymbol{\Sigma}_{img}} + \|\boldsymbol{y}_{hyp} - \boldsymbol{H}_{hyp}\boldsymbol{x}\|^2_{\boldsymbol{\Sigma}_{img}}$$

with explicit data models $\boldsymbol{H}_{img}$ and $\boldsymbol{H}_{hyp}$ for both instruments, with data $\boldsymbol{y}$ and unkown $\boldsymbol{x}$. This step constitutes an essential preliminary.

2.2 Learning for ill-posed problem

The above-mentioned method is a model driven. However, the model can be inefficient is some case, when $ker(\boldsymbol{H})$ is not null for instance, or when the degradation is important. A common approach is to add prior

$$\bar{J}(\boldsymbol{x}) = J(\boldsymbol{x}) + \lambda R(\boldsymbol{x}).$$

However these prior are often ad hoc. One objective is to use machine learning, with a database in a supervised way, or directly from measured data with semi-supervised approach, to construct more adapted prior than usual.

3 Planning

- In a first time, the student will use work from the PhD of A. Hadj-Youcef (defended in 2018, see [4]) and R. Abi-Rizk (defense planned for September 2021, see [1]).
- It will then be necessary to develop an inversion algorithm. The first approach will use a new composite criteria that must be minimized.
- Then, depending on the results, the students will study learning approach (dimension reduction, invertible networks [2], structured networks, semi-supervised . . .) to enrich the regularization.

4 Supervision

The subject will be supervised at the Laboratoire des Signaux et Systèmes (L2S) by François Orieux on the data processing and inversion aspects and the Institut d'Astrophysique Spatiale (IAS) by Alain Abergel on the instrument and astrophysical aspects.

The students will benefit from years of collaboration between the L2S and the IAS. The work will also use the expertise present at Paris-Saclay on the instruments and, if necessary, at the Space Telescope Science Institute in Baltimore.

References

[1] Ralph Abirizk, Francois Orieux, and Alain Abergel. "Non-Stationary Hyperspectral Forward Model and High-Resolution". In: *Proc. of 27th IEEE Int. Conf. on Image Processing.* 27th IEEE International Conference on Image Processing, ICIP 2020. Abu-Dhabi, United Arab Emirates, Oct. 2020, p. 5.

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[3] Claire Guilloteau et al. "Fusion of Hyperspectral and Multispectral Infrared Astronomical Images". In: *2020 IEEE 11th Sensor Array and Multichannel Signal Processing Workshop (SAM)*. 2020 IEEE 11th Sensor Array and Multichannel Signal Processing Workshop (SAM). June 2020, pp. 1–5. DOI: 10.1109/SAM48682.2020.9104393.

[4] Mohamed Amine Hadj-Youcef et al. "Fast Joint Multiband Reconstruction from Wideband Images Based on Low Rank Approximation". In: *IEEE Trans. Comput. Imaging* (May 28, 2020), pp. 922–933. ISSN: 2333-9403, 2334-0118, 2573-0436. DOI: 10.1109/TCI.2020.2998170.

[5] François Orieux et al. "Estimating Hyperparameters and Instrument Parameters in Regularized Inversion. Illustration for Herschel/Spire Map Making." In: *Astronomy & Astrophysics* 549.A83 (Jan. 2013). DOI: 10.1051/0004-s6361/201219950.

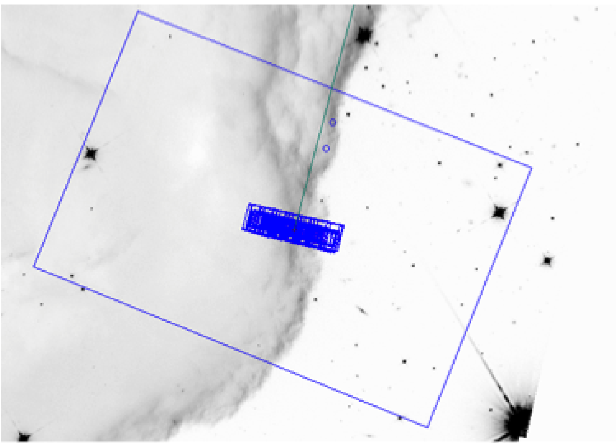

Figure 1: Horsehead observation with the JWST