2022-2023 MSc research internship proposal

Title:
Fusion methods of multispectral data with multiple resolutions and missing entries. Application to Sentinel-2 and Sentinel-3 images

Subject description:
The satellite observation of our planet has known important instrumental advances for several decades, with significant developments in terms of spatial resolution (e.g., in water color remote sensing, with a high spatial resolution of 10-60 m) and in terms of spectral resolution (hyper-spectral imagery). A Multi-Spectral (MSI) or Hyper-Spectral Image (HSI) consists of a data cube whose two axes describe the spatial variations and one axis describes the spectral variations. The main difference between HSI and MSI lies in the very small number of spectral bands observed in the latter.

However, due to physical constraints, increasing the number of spectral bands in HSI implies a decrease of the spatial resolution. Therefore, today, our planet is observed by MSI sensors—with a good spatial resolution but a low spectral one—HSI sensors—with a good spectral resolution but a low spatial one—and imagers with intermediate properties.

In the framework of this internship, we are interested in coastal marine observation via data from the Sentinel-2 and Sentinel-3 satellites. The images obtained by these two satellites allows to study the color of the ocean, *i.e.*, the spatial and temporal distribution of the concentration of phytoplankton, suspended matter, and organic matter. Sentinel-2 data consists of cubes with 13 spectral bands for a spatial resolution varying from 10 to 60 m (depending on the bands), acquired approximately every 5 days. Sentinel-3 data are cubes with 21 spectral bands for a spatial resolution of 300 m, which are daily acquired. In marine observation, to understand the complex phenomena occurring in coastal environments, the data available must combine:

- a good spectral resolution to better analyze the biogeochemical medium (chlorophyll, particles in suspension, etc.);

- a good spatial resolution to better understand the distribution phenomena of this environment which are much more complex in a coastal environment than in the open sea;

- a short period of acquisition of these images to identify phenomena that are very concentrated in time (phytoplankton blooms for example).

No satellite data currently allows these three constraints to be met.

Our recent work on multi-sharpening [1, 2], in spatio-temporal fusion [3], and in spatial-(spectral-)temporal fusion [4] allowed us to initiate some work on different problems.

- In [1] we studied the performance obtained with state-of-the-art multi-sharpening methods on Sentinel-2 and Sentinel-3 data.

- We then proposed a deep learning methods for that problem in [2].

- We also worked on Sentinel-2 time series completion from observed Sentinel-3 data [3].

- Lastly, we proposed a spatial-(spectral-)temporal fusion method based on generative adversarial networks [4].

In the framework of this internship, we propose to jointly process Sentinel-2 and Sentinel-3 data approximately acquired at the same time (spatial-spectral fusion aka multi-sharpening), in order to generate new MSI data with the number of spectral bands of Sentinel-3 and the spatial resolution of Sentinel-2. However, this internship significantly differs from our previous work as follows:

1. We aim to process data on which atmospheric correction we performed [5], so that a comparison with *in situ* measurements is possible. However, this processing provides new issues such as missing entries (corresponding to land areas, clouds, and ships) or negative values without any physical meaning.

2. We aim to jointly process the three Sentinel-2 spatial resolutions with the unique Sentinel-3 one, thus hoping improving the fusion quality.

3. We aim to perform comparisons with *in situ* measurements.

The considered methods will use a regularized matrix / tensor factorization formalism and/or a deep-learning formalism.

Keywords:
Multispectral and Hyperspectral Imaging, Multi-sharpening, Deep Neural Networks, Matrix/Tensor Factorization, Time Series

Supervisors:
The internship will take place in the new Longuenesse branch of LISIC laboratory which is currently dedicated to hyperspectral imaging. Today, this recently created branch has 6 faculty members, 1 post-doctoral researcher, and 4 Ph.D. students. The intern will be supervised by Claire GUILLOTEAU, Matthieu PUIGT, and Gilles ROUSSEL who will bring their respective expertise in MSI / HSI processing and machine learning (deep learning, matrix factorization, optimization) for satellite imagery.

Many exchanges will take place with the LOG laboratory, located in Wimereux (and more particularly with Cédric JAMET and Vincent VANTREPOTTE). The LOG will bring its skills on ocean color, in particular on the analysis of merged images and their validation. The LOG will provide *in-situ* validation measurements and images in coastal areas of interest (Eastern Channel, Guyana, Cambodia, Vietnam).

Both laboratories are located in the heart of the Regional Natural Park of "Caps et Marais d'Opale", close to Lille, England, Belgium, and Northern Europe (Amsterdam is only 4 h drive from Longuenesse).

Applications:
Pursuing scientific studies in the field of data sciences (signal and image processing, computer science with a focus in artificial intelligence / machine learning, applied mathematics), you are curious and very comfortable in programming (Matlab, Python). You read and speak fluent English with ease. Although not compulsory, a first experience in data factorization—e.g., matrix or tensor decomposition, blind source separation, dictionary learning—or in deep learning will be appreciated.

To apply, please send an e-mail to {`claire.guilloteau, matthieu.puigt, gilles.roussel`} [at] `univ-littoral.fr` while attaching the documents that can support your application:

- your resume;

- a cover letter;

- your transcripts for the last year of B.Sc, the first year of M.Sc, and the last year of M.Sc (if the latter is available);

- two reference letters or the names and means of contact of two academic advisers.

References

[1] A. Alboody, M. Puigt, G. Roussel, V. Vantrepotte, C. Jamet, and T. K. Tran. Experimental comparison of multi-sharpening methods applied to Sentinel-2 MSI and Sentinel-3 OLCI images. In *Proc. IEEE WHIS-PERS'21*, 2021.

[2] A. Alboody, M. Puigt, G. Roussel, V. Vantrepotte, C. Jamet, and T. K. Tran. DeepSen3: Deep multi-scale learning model for spatial-spectral fusion of Sentinel-2 and Sentinel-3 remote sensing images. In *Proc. IEEE WHISPERS'22*, 2022.

[3] C. T. Cissé, A. Alboody, M. Puigt, G. Roussel, V. Vantrepotte, C. Jamet, and T. K. Tran. A new deep learning method for multispectral image time series completion using hyperspectral data. In *Proc. IEEE ICASSP'22*, 2022.

[4] A. Hadir, A. Alboody, M. Puigt, G. Roussel, V. Vantrepotte, C. Jamet, and T. K. Tran. S2S3-STFGAN: a GAN-based spatio-temporal fusion method for sentinel-2 and sentinel-3 data. soumis.

[5] F. Steinmetz and D. Ramon. Sentinel-2 MSI and sentinel-3 OLCI consistent ocean colour products using POLYMER. In *Proc. SPIE "Remote Sensing of the Open and Coastal Ocean and Inland Waters"*, volume 10778, 2018.