



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

itee_{PhD}
information technology
electrical engineering



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Matteo Ciotola

**Deep Learning-based
Pansharpening and Super-Resolution
of Remote Sensing Images**

Tutor: Prof. G. Poggi
Cycle: XXXVI

co-Tutor: Prof. G. Scarpa
Year: Third

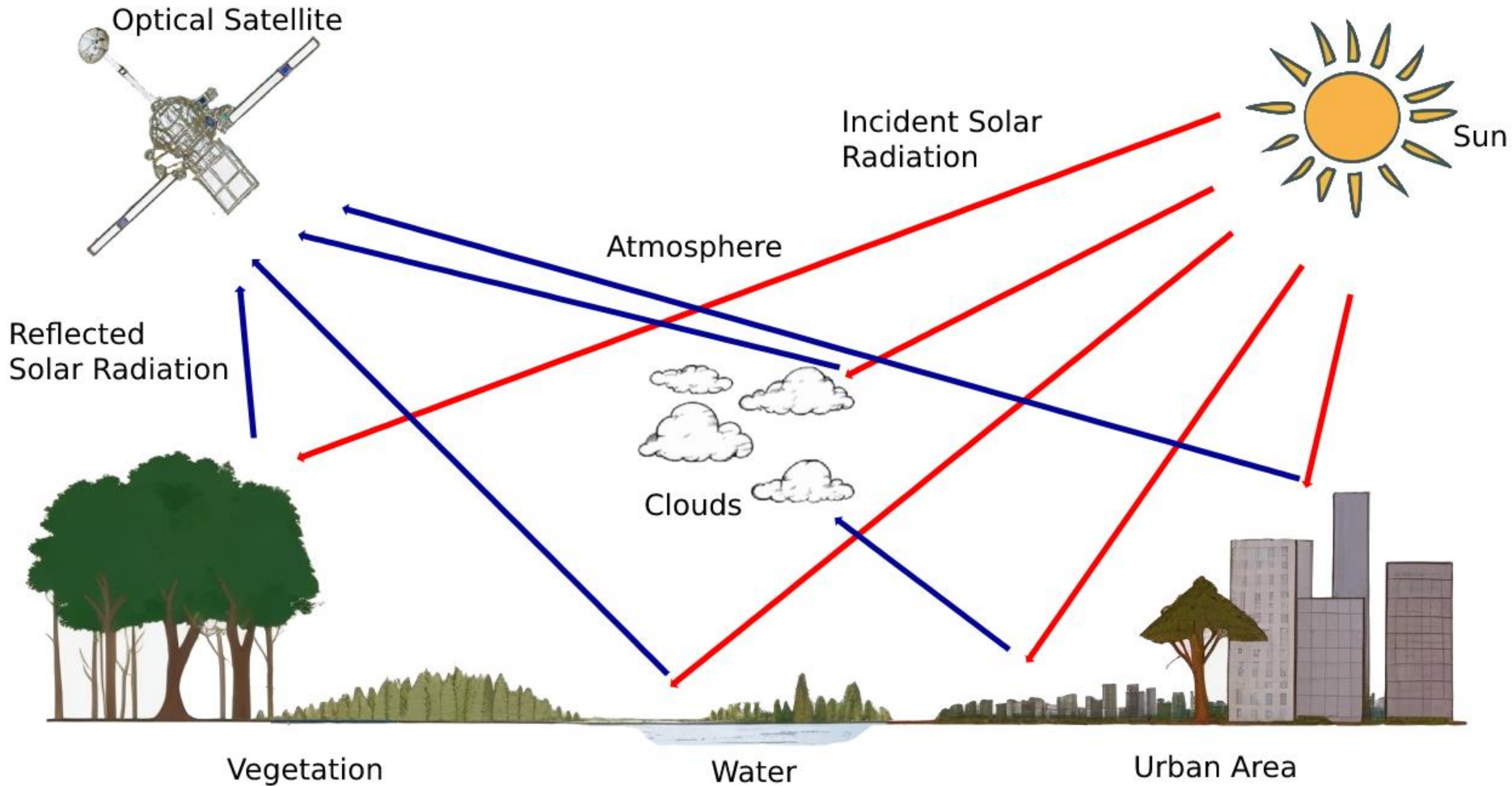
Background information

- **MSc degree:** Automation Engineering – University Federico II
- **Research group/laboratory:** GRIP Research Team
- **PhD start date – end date:** 1/11/2020 - 31/10/2023
- **Scholarship type:** University Federico II
- **Periods abroad:** From 1/11/2022 to 31/1/2023 to Université Bretagne Sud – Vannes, France

Summary of study activities

- Ad hoc PhD courses:
 - **Scientific Programming and Visualization with Python**
 - **Introduction to Deep Learning**
 - Model Complex System
- Courses attended borrowed from MSc curricula:
 - **Elaborazione Numerica dei Segnali**
 - **Elaborazione di Segnali Multimediali**
 - Visione per Sistemi Robotici
- Attended PhD Schools:
 - IEEE - EURASIP 8 th **Summer School on Signal Processing 2021 (S3P)** – Rome, Italy
 - **DeepLearn 2022 Summer**, Las Palmas de Gran Canaria, Spain
- Conferences attended:
 - IEEE International Geoscience and Remote Sensing Symposium (**IGARSS**) 2021 – Brussel, Belgium
 - IEEE International Geoscience and Remote Sensing Symposium (**IGARSS**) 2022 – Kuala Lumpur, Malaysia
 - IEEE International Geoscience and Remote Sensing Symposium (**IGARSS**) 2023 – Pasadena, USA

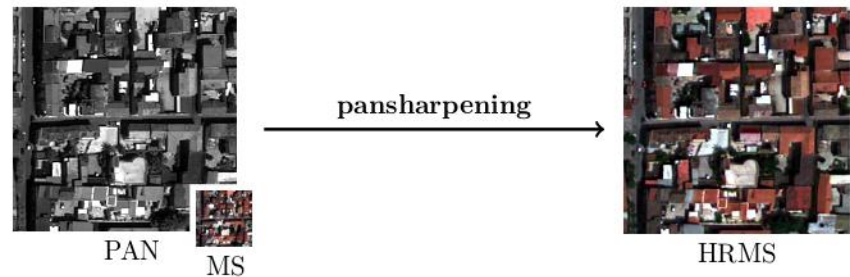
Research area(s)



Research area(s)

Image Enhancement through Data Fusion techniques:

- Spatial Resolution Enhancement:
 1. Pansharpening
 2. Hyperspectral Pansharpening
 3. Single Image Super Resolution, exploiting multi-resolution fusion
 4. Multiple Image Super Resolution
- Fusion of Multitemporal SAR-Optical images for recovering missing or corrupted multispectral indices.

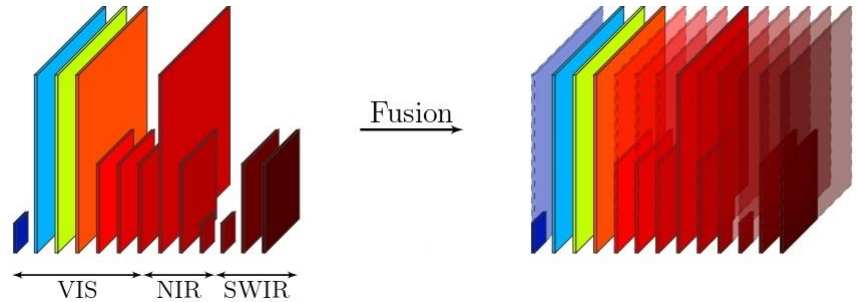


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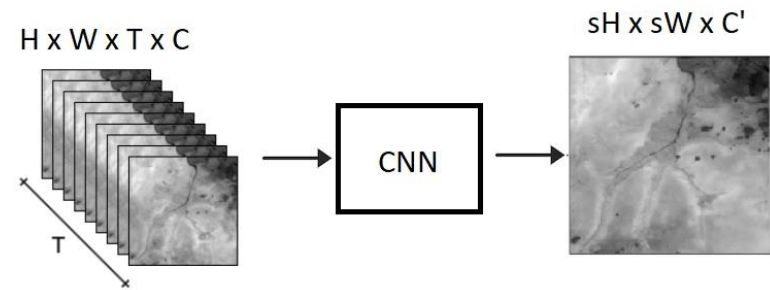


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Credits: ESA

Research results

In the context of Multispectral/HyperSpectral Pansharpening:

- Definition of a full-resolution training framework for Convolutional Neural Networks
- Development of a new algorithm, which include a new CNN, new more effective spectral loss function with a coregistration-at-loss paradigm
- Definition of a new no reference-based assessment protocol, with the proposal of a new structural index

In the context of Multi-resolution Fusion:

- Definition of a full-resolution training framework for Deep Learning-based algorithms

Research products

Journal Papers

[J1]	<p><u>M. Ciotola</u>, S. Vitale, A. Mazza, G. Poggi and G. Scarpa, <i>Pansharpening by Convolutional Neural Networks in the Full Resolution Framework</i> IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-17, 2022, Art no. 5408717, doi: 10.1109/TGRS.2022.3163887.</p>
[J2]	<p>G. Scarpa and <u>M. Ciotola</u>, <i>Full-Resolution Quality Assessment for Pansharpening</i> Remote Sensing, vol. 14, no. 8, p. 1808, Apr. 2022, doi: 10.3390/rs14081808.</p>
[J3]	<p><u>M. Ciotola</u> and G. Scarpa, <i>Fast Full-Resolution Target-Adaptive CNN-Based Pansharpening Framework</i> Remote Sensing, vol. 15, no. 2, p. 319, Jan. 2023, doi: 10.3390/rs15020319</p>
[J4]	<p><u>M. Ciotola</u>, G. Poggi and G. Scarpa, <i>Unsupervised Deep Learning-Based Pansharpening With Jointly Enhanced Spectral and Spatial Fidelity</i> IEEE Transactions on Geoscience and Remote Sensing, vol. 61, pp. 1-17, 2023, Art no. 5405417, doi: 10.1109/TGRS.2023.3299356.</p>
[J5]	<p>G. Guarino, <u>M. Ciotola</u>, G. Vivone, G. Poggi, G. Scarpa, <i>PCA-CNN Hybrid Approach for Hyperspectral Pansharpening</i> IEEE Geoscience and Remote Sensing Letters, doi: 10.1109/LGRS.2023.3326204.</p>

Research products

Conference Papers

[C1]	<p><u>M. Ciotola</u>, M. Ragosta, G. Poggi and G. Scarpa, <i>A Full-Resolution Training Framework for Sentinel-2 Image Fusion</i> 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Brussels, Belgium, 2021, pp. 1260-1263, doi: 10.1109/IGARSS47720.2021.9553199.</p>
[C2]	<p><u>M. Ciotola</u>, A. Martinelli, A. Mazza and G. Scarpa, <i>An Adversarial Training Framework for Sentinel-2 Image Super-Resolution</i> 2022 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Kuala Lumpur, Malaysia, 2022, pp. 3782-3785, doi: 10.1109/IGARSS46834.2022.9883144</p>
[C3]	<p><u>M. Ciotola</u>, G. Guarino, A. Mazza, G. Poggi and G. Scarpa, <i>Pansharpening by efficient and fast unsupervised target-adaptive CNN</i> 2023 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Pasadena, USA, 2023, pp. 5579-5582, doi: 10.1109/IGARSS52108.2023.10281456.</p>
[C4]	<p>G. Guarino, <u>M. Ciotola</u>, G. Vivone, G. Poggi and G. Scarpa, <i>An unsupervised CNN-based hyperspectral pansharpening method</i> 2023 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Pasadena, USA, 2023, pp. 5982-5985, doi: 10.1109/IGARSS52108.2023.10282928.</p>
[C5]	<p>A. Mazza, <u>M. Ciotola</u>, G. Poggi and G. Scarpa, <i>Synergic use of SAR and optical data for feature extraction</i> 2023 IEEE International Geoscience and Remote Sensing Symposium IGARSS, Pasadena, USA, 2023, pp. 2061-2064, doi: 10.1109/IGARSS52108.2023.10281855.</p>

Research products

In Progress Journal Papers

[R1]	G. Guarino, <u>M. Ciotola</u> , G. Vivone and G. Scarpa, <i>Band-wise Hyperspectral Image Pansharpening using CNN Model Propagation</i> IEEE Transactions on Geoscience and Remote Sensing, <u>Major Review</u>
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Awards:

[A1]	2023 Prof. Francesco Carassa Award (Radar and Remote Sensing), At “ <i>Riunione Annuale GTTI 2023</i> ”, 11-13 September 2023, Rome - IT Gruppo Telecomunicazioni e Tecnologie dell'Informazione (GTTI) and Consorzio Nazionale Interuniversitario sulle Telecomunicazioni (CNIT)
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PhD thesis overview

- Problem statement

Need of higher resolution spectral images for analyzing and understanding the complexity of nature or planning and managing human activities.

- Objective

*Propose an **innovative training framework** for **deep learning**-based solutions for this problem, adapting it to the available information (PAN-MS, PAN-HS, MS-MS)*

- Methodology

*The employed methodology is **data-driven**. For a given sensor an ad-hoc training procedure is achieved, with specific CNNs, loss functions and hyper-parameters.*

PhD thesis

Satellites suffer from trade-offs among spatial and spectral resolutions.

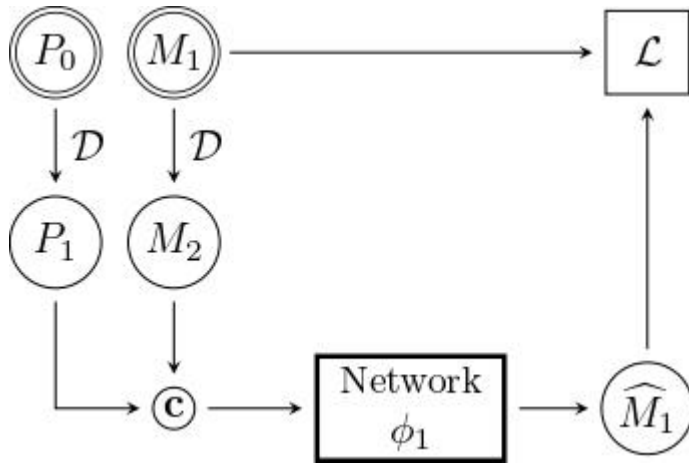


Multi-source data fusion

PhD thesis

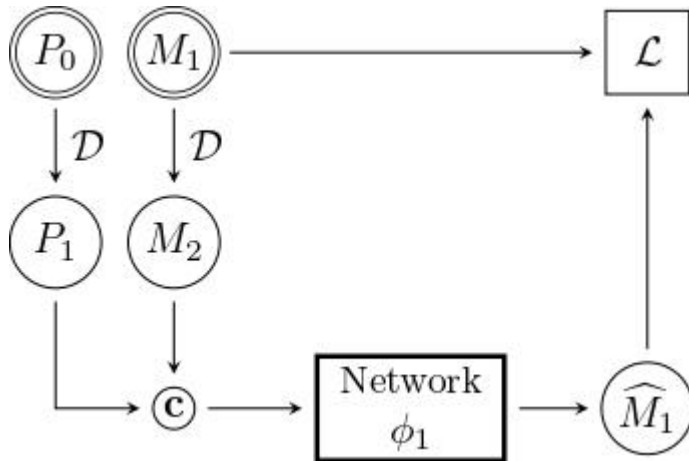
- Deep Learning overcome the limitations of model-based solutions, which rely on statistical and mathematical assumptions.
- **Problem:** absence of ground-truth with which perform a supervised training

PhD thesis

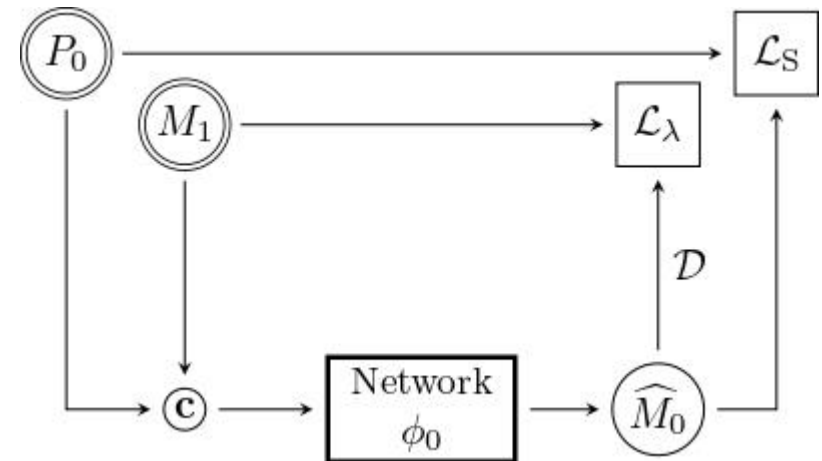


- P_0 : Original PAN
- M_1 : Original MS
- P_1 : Synthetic (Downgraded) PAN
- M_2 : Synthetic (Downgraded) MS

PhD thesis



- P_0 : Original PAN
- M_1 : Original MS
- P_1 : Synthetic (Downgraded) PAN
- M_2 : Synthetic (Downgraded) MS



Benefits:

- No scale-invariance assumption
- More data for training

Drawbacks:

- Computational and time cost
- Impact of global/local misalignment

PhD thesis

MS

PAN

Pretrained

Fine-Tuning RR

Fine-Tuning FR



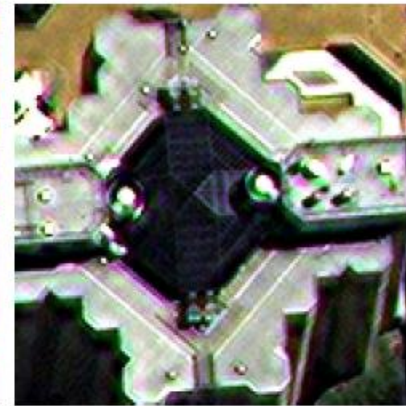
PhD thesis



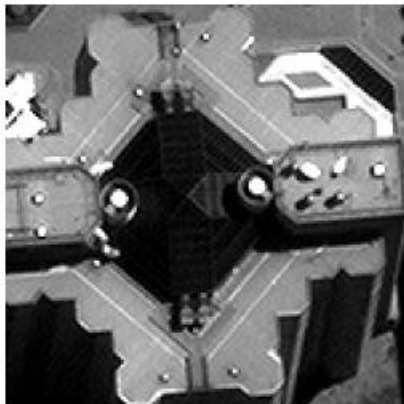
MS



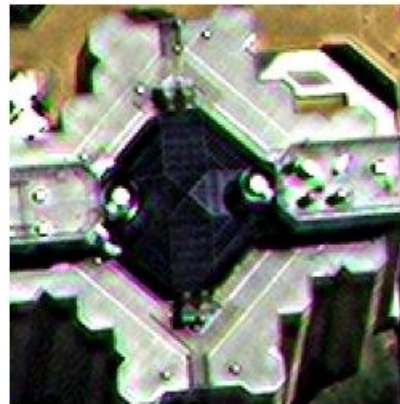
C-BDSD



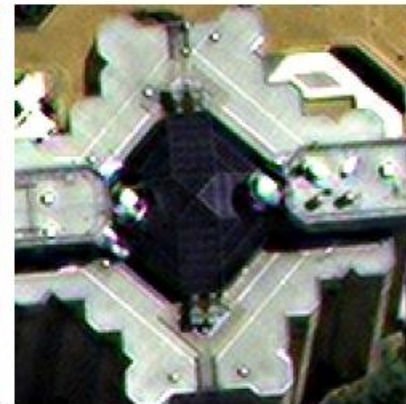
MTF-GLP-HPM-H



PAN

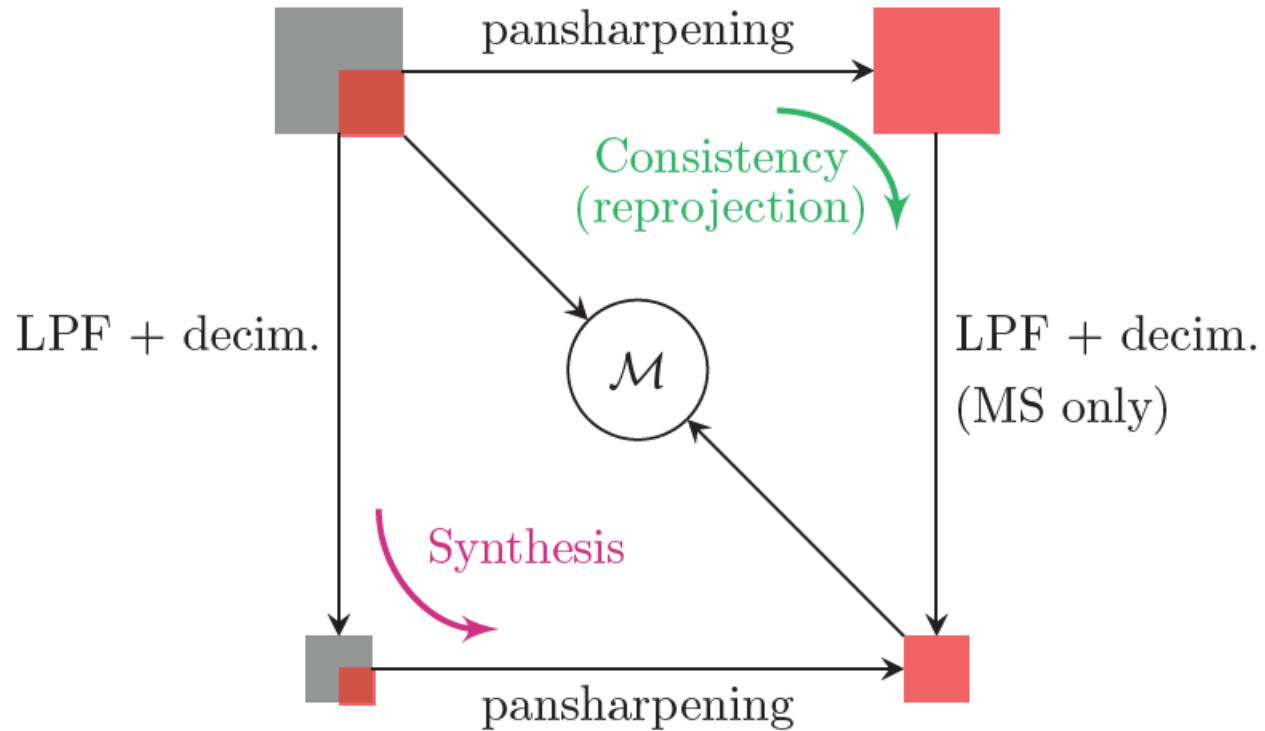


FE-HPM



Proposed

PhD thesis



PhD thesis

MS

PAN

EXP

Proposal



$$D_S^{(R)} = 0.133$$
$$D_S = 0.078$$

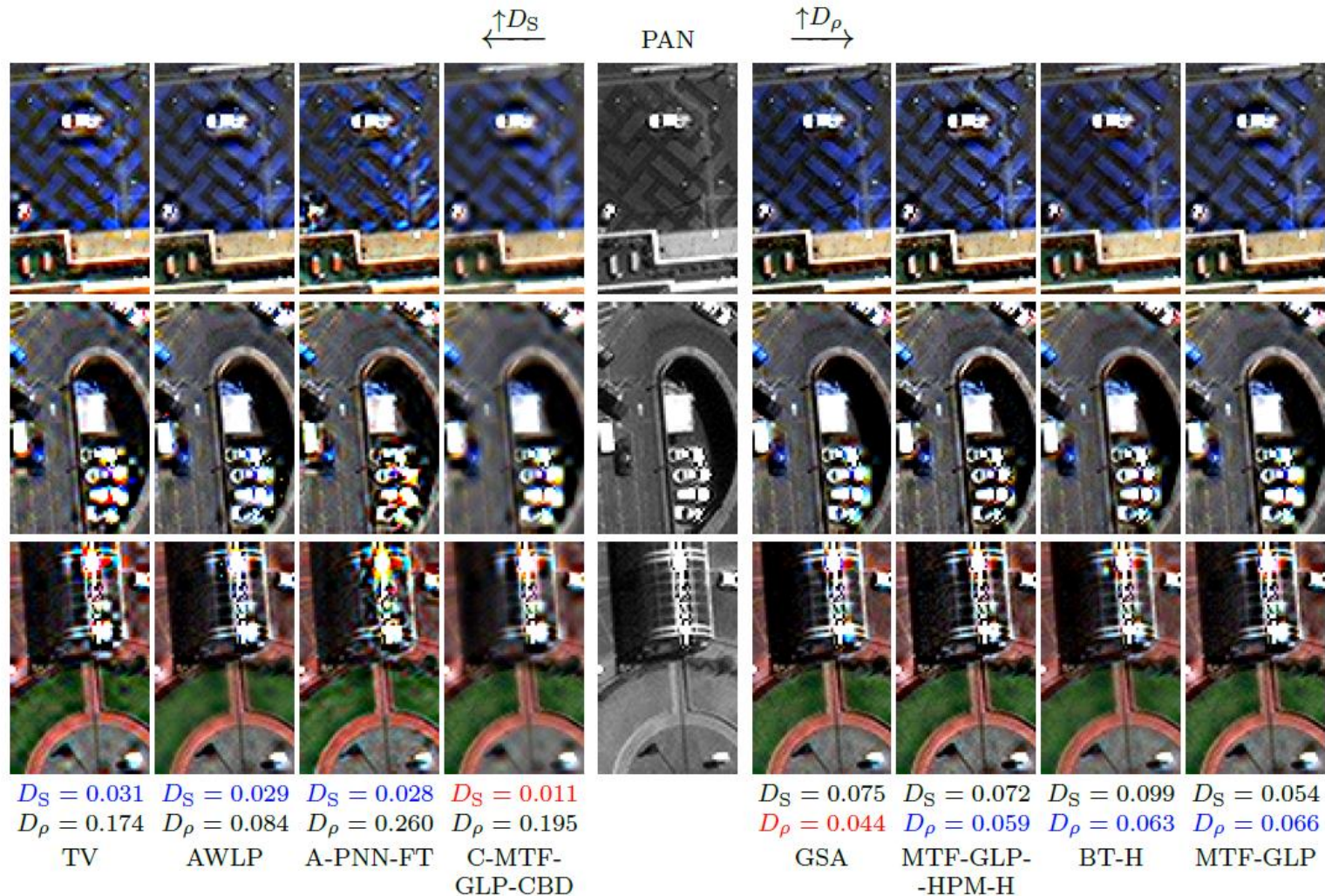
$$D_S^{(R)} = 0.178$$
$$D_S = 0.095$$

PhD thesis

$$\rho_{XY}^{\sigma}(i, j) = \frac{\text{Cov}(\mathbf{X}_{w(i,j)}, \mathbf{Y}_{w(i,j)})}{\sqrt{\text{Var}(\mathbf{X}_{w(i,j)}) \text{Var}(\mathbf{Y}_{w(i,j)})}},$$

$$D_{\rho} = \langle 1 - \rho_{X,Y}^{\sigma}(i, j) \rangle$$

PhD thesis



PhD thesis

In conclusion, we think that full-resolution training and evaluation frameworks hold significant promise for achieving spatially accurate outcomes while preserving spectral fidelity.

Nonetheless, despite the promising results of our proposed algorithms, several challenges and avenues for improvement remain:

- Developing solutions for joint local and global co-registration and pansharpening of images containing moving objects.
- Extending pansharpening techniques to multi- or hyper-spectral bands with weak correlation to PAN, necessitating the definition of a suitable spatial loss term.
- Enhancing the selection of tuning crops to further improve the robustness and generality of the proposed framework.
- Refining the spatial loss component to prevent “oversharpening” in specific scenarios.

Thank you for your kind attention