Domain Adaptation of Unrolled Neural Networks

Keywords: Deep learning, domain adaptation, unrolled neural network, Through The Wall RADAR imaging, SAR imaging, InSAR
Gratification: In accordance with current legislation
Laboratory: Laboratoire LISTIC, Université Savoie Mont Blanc
Location: Annecy, France
Duration: 6 months starting from February/March 2025

Context

Recent advances in deep learning have revolutionized many signal and image processing tasks. In fact, deep neural networks excel at learning complex, non-linear patterns from large datasets, often outperforming classical methods. However, the application of deep learning to signal processing tasks presents specific challenges. These methods require vast amounts of labeled training data, which are often scarce on real signal processing scenarios, limiting the generalization power of complex neural architectures. Moreover, the black-box nature of these approaches limits their interpretability, which is problematic for operational systems.

Unrolled (or unfolded) neural networks represent a promising hybrid approach that addresses some of these limitations. These architectures are constructed by unrolling iterative optimization algorithms such as ISTA (Iterative Shrinkage-Thresholding Algorithm), ADMM (Alternating Direction Method of Multipliers), or proximal gradient methods over a finite number of iterations. Unrolled networks inherit the interpretability of their underlying optimization algorithms and naturally incorporate domain-specific knowledge, such as the statistical properties of the noise measurements. Moreover, the structured architecture acts as a strong inductive bias, reducing the number of parameters and consequently the amount of training data required to achieve competitive performance [3].

Yet, Unrolled Neural Network are often trained on simulated or synthetic data and fail to generalize to real-world scenarios due to the simplifications of the simulation models. **Domain adaptation** frameworks address this challenge by adapting models trained on a **source domain** (where labeled data are available) to a **target domain** (where only unlabeled data are available), with the objective of minimizing the generalization error on the target domain. However, existing domain adaptation techniques have been primarily developed for standard deep learning architectures and have not been specifically tailored to the constraints imposed by unrolled networks.

Project summary

The research will investigate strategies for adapting unrolled architectures trained on a source domain to perform effectively on a target domain. The student will develop and evaluate domain adaptation techniques tailored to the structure of unrolled networks.

A first approach will be to adapt classical domain adaptation approaches to the structure of unrolled networks. To that extent, we propose to leverage the statistical alignment of feature distributions between source and target domains using divergence metrics such as Maximum Mean Discrepancy (MMD) or Wasserstein distances [2]. After a study on the features produced by known unrolled architectures, the student will try various feature alignment strategies for domain adaptation. By the end of the internship, he/she will propose the best strategy to integrate domain adaptation framework in unrolling architecture.

To test our approach, we will first focus on Through The Wall (TTW) RADAR applications, as we have already developed an unrolled architecture for this subject [1] and real data will soon be available thanks to a collaboration with CentraleSupelec. TTW consists of imaging a room using a mobile RADAR where the wave is transmitted and received through a wall. TTW RADAR imaging is a detection task. In this case, the unrolled architecture is learned on simulated data that assumes a few types of walls. In fact, to avoid excessive complexity costs, not all types of walls can be considered. Yet, as soon as the wall differs from the training data, performance declines very rapidly. The domain adaptation strategy developed during the internship will therefore be very interesting to improve the robustness of the learned architecture.

Other applications in the field of SAR remote sensing will be studied in the context of image denoising or the fusion of SAR images from different modalities (C and X bands).

The position can be started anytime from February 2026 for a duration of up to 6 months.

Candidate Profile: M2 or engineer diploma in one or more of the following fields: applied mathematics, signal and image processing, computer science. The candidate should have good programming skills (Python, PyTorch or TensorFlow).

Contacts and Application Procedure:
Students should send a detailed CV and short cover letter to:

- Guillaume Ginolhac (`guillaume.ginolhac@univ-smb.fr`)
- Christophe Lin-Kwong-Chon (`christophe.lin-kwong-chon@univ-smb.fr`)
- Yassine Mhiri (`yassine.mhiri@univ-smb.fr`)

References

[1] Hugo Brehier et al. "Deep Unrolling of Robust PCA and Convolutional Sparse Coding for Stationary Target Localization in Through Wall Radar Imaging". In: *2024 32nd European Signal Processing Conference (EUSIPCO)*. 2024, pp. 1881–1885. DOI: 10.23919/EUSIPCO63174.2024.10715348.

[2] Mingsheng Long et al. "Learning transferable features with deep adaptation networks". In: *International conference on machine learning*. PMLR. 2015, pp. 97–105.

[3] Vishal Monga, Yuelong Li, and Yonina C Eldar. "Algorithm unrolling: Interpretable, efficient deep learning for signal and image processing". In: *IEEE Signal Processing Magazine* 38.2 (2021), pp. 18–44.