Deep-learning based inversion algorithms for beamforming interferometric data

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Centre Borelli is the Mathematics Teaching and Research department (DER) of ENS Paris-Saclay. It's a mixed CNRS and multi-disciplinary unit (URM 9010) which combines researchers working in diverse fields, including Mathematics, Computer Science, and Neurosciences. It's located at several places, including ENS Paris-Saclay, Université Paris Cité at the Instruction des Armées of HIA Bégin and HIA Percy hospitals.

CESBIO is a public research laboratory which aims to better understand the functioning of continental surfaces and their interactions with climate and humans. Remote sensing is heavily used by Cesbio scientists to monitor the evolution of the planet at various scales and develop models to tackle societal challenges on biodiversity, climate change, food security, water resources, etc. The laboratory also contributes to the development and promotion of Earth Observation by participating in the definition, implementation and scientific exploitation of space missions.

Environment. The *stagiaire* will be integrated in the image processing team at Centre Borelli. The responsibility of the supervision of this internship will be shared by Miguel Colom from Centre Borelli as well as by Éric Anterrieu and Nemesio Rodriguez-Fernandez from CESBIO, who will have weekly meetings with the intern to discuss the scientific aspects of the project and ensure that it advances normally. The internship will physically be at Centre Borelli, with visits to CESBIO in Toulouse.

Context. This internship will propose methods for aperture synthesis imaging based on deep-learning approaches. This approach was started in 2021 by an R&T CNES project for the reconstruction of images from interferometric data (multiplicative synthesis) coming from passive radiometers in the L-band of the spectrum. Specifically, this is the type of data that one can obtain from the MIRAS instrument of the SMOS satellite. The validation of this method was done with simulated dates, and the results were published in IEEE-JSTARS [Faucheron et al. 2024].

This work continued in order to adapt this method to actual SMOS data and improve the existing deep learning processor by proposing an architecture better suited to real data.

Several factors were considered during this work, such as radiometric noise, Faraday rotation, external sources (such as the Sun or RFI[1]), and the choice of the proper database for learning. A new architecture was also proposed to better manage the presence of radiometric noise and residuals from external sources, given that the correction of these sources is never perfect. In this new model, a priori information has been included in order to better identify each pixel and to link this information to the temperature/visibility pair (for example, the water fraction calculated from SMOS auxiliary files has been taken into account).

In 2025 CESBIO worked on validating these approaches and a comparison was made with the standard SMOS algebraic method. Over the ocean, the comparison was made with brightness temperature models. The deep learning approach significantly reduces noise, bias, and land/sea contamination. There is also better attenuation of solar residues and radio interference. Over land, the comparison is more difficult given the absence of a brightness temperature model but, however, a clear reduction in radiometric noise could be observed, as well as aberrant peaks with a more regular variation in brightness temperature depending on the angle of incidence. A paper on this work was also published in IEEE-JSTARS [Khazaal et al. 2025].

Objectives. In the context of the FRESCH mission, the next objective is to conduct the same comparative studies (traditional algebraic methods vs. deep learning) for the beamforming paradigm in additive aperture synthesis. Given that the imaging relationship between the observations and the data is much simpler with beamforming than with interferometry [Anterrieu et al. 2022], the first studies are planned to be conducted as part of a 4- to 6-month M2 internship at Centre Borelli of ENS Paris-Saclay, with the support of CESBIO.

The first objective will be to design a neural network architecture adapted to the relationship between the antenna array temperatures in each direction pointed and the distribution of brightness temperatures of the observed scene. The second objective will be to train this network, test it, and evaluate its performances.

To this purpose, we will use the same dataset as that used by Faucheron et al. (2024), substituting the complex visibilities of the interferometry setup with the antenna array temperatures of the beamforming paradigm. At the same time, the information encoded in the intermediate layers of the network will be studied in order to improve the interpretability of the results. By reserving the same scenes for network training, then validation, and finally testing, it will be possible to compare the two paradigms.

A PhD project could be envisaged after the internship.

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[1] Radio Frequency Interference.

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