M2 research internship proposal

Robust joint detection-estimation methodologies for massive radio telescopes

Internship supervisors:

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Guest institution:

- *Laboratoire des signaux et systèmes* (L2S), Bât. IBM, Rue Alfred Kastler, 91400 Orsay.

Important dates:

- *Reception of applications:*: until mid-January[1]
- *Duration of the internship*: between 4 and 6 months
- *Period of the internship*: from February to September 2024.

Scientific context

One of the key features characterizing the new generation of radio telescopes is the large number of their antenna elements. Built in 2010, the Low-Frequency Array (LOFAR) is currently the largest radio telescope in operation with 100 000 antenna dipoles distributed across several European countries [1]. Furthermore, the upcoming Square-Kilometer Array (SKA) will be made up of more than 130 000 antennas [2]. Such a large number of antennas will make it possible to acquire increasingly accurate and detailed images of the celestial vault. Such images will form the basis for promising developments in astrophysics and cosmology in the coming years.

However, as in any other "remote sensing system", the signal collected by a radio telescope is affected by different sources of disturbance that will degrade the quality of the collected image. Consequently, to take full advantage of the potential of the new radio telescopes, one must first take the disturbance into account. In general, this disturbance is characterized as a zero-mean Gaussian random process with possibly unknown correlation structure. Unfortunately, the Gaussian assumption is often violated by some impulsive noise sources whose presence may produce a breakdown of the performance of Gaussian-based procedures. In order to take into

[1] Do not hesitate to enquire with us about other opportunities!

consideration the impulsive behavior of the disturbance, different classes of heavy-tailed distributions (including the Gaussian one as a special case) have been proposed in array processing literature [3]. However, any choice of a specific heavy-tailed distribution is arbitrary to some extent, since none of them, taken individually, can fully describe the physical behavior of the disturbance.

Then, the crucial question is: *is it possible to derive robust imaging algorithms, without any assumption on the specific form of the noise distribution, and that still remain accurate? If yes, which is the price to pay?* In a generic array processing context, a positive answer has been recently provided in [4], where a robust test for the detection of sources of interest in heavy-tailed noise has been proposed. It suggests that it is possible to achieve a desired detection/estimation performance level regardless the (generally unknown) disturbance model, provided that the number of antennas is sufficiently large. These results could be leveraged to derive original imaging algorithms for modern radio telescopes, which naturally fulfill the requirement of a large amount of sensors.

Description of the expected work

This internship is funded by *GDR ISIS*[2] and is part of the "SIDEREAL"[3] project. The objectives of the internship are the following:

1. Building upon the existing works such as [5–7], we will adapt the array signal model used in [4] to the context of radio telescopes. Particular attention will be devoted to the disturbance model to be used in astronomical data analysis and on its statistical description. The main goal here will be to clarify the similarities and the differences between classical array processing [4] and radio telescope [5–7] applications (e.g., detection of a target vs imaging and source reconstruction).

2. After these preliminary investigations, the project will focus on the development of original image reconstruction algorithms for radio astronomy, based on the detection/estimation method presented in [4], and exploiting the massive number of antenna elements available in modern radio telescopes. Their performance and statistical properties will be assessed by means of simulated data.

Required profile:

Master 2 or equivalent in machine learning / statistical signal processing or any related field, programming skills in Matlab or Python.

References

[1] van Haarlem, M. P. and al., "Lofar: The low-frequency array," *A&A*, vol. 556, p. A2, 2013.

[2] P. E. Dewdney, P. J. Hall, R. T. Schilizzi, and T. J. L. W. Lazio, "The square kilometre array," *Proceedings of the IEEE*, vol. 97, no. 8, pp. 1482–1496, 2009.

[3] E. Ollila, D. E. Tyler, V. Koivunen, and H. V. Poor, "Complex elliptically symmetric distributions: Survey, new results and applications," *IEEE Transactions on Signal Processing*, vol. 60, no. 11, pp. 5597–5625, 2012.

[2] *Groupement de Recherche Information, Signal, Image, viSion*: `https://www.gdr-isis.fr/`.

[3] "robuSt joInt Detection-estimation mEthodologies foR massivE rAdio teLescopes"

[4] S. Fortunati, L. Sanguinetti, F. Gini, M. S. Greco, and B. Himed, “Massive MIMO radar for target detection,” *IEEE Transactions on Signal Processing*, vol. 68, pp. 859–871, 2020.

[5] S. J. Wijnholds and A.-J. van der Veen, “Multisource self-calibration for sensor arrays,” *IEEE Transactions on Signal Processing*, vol. 57, no. 9, pp. 3512–3522, 2009.

[6] S. J. Wijnholds and A.-J. van der Veen, “Fundamental imaging limits of radio telescope arrays,” *IEEE Journal of Selected Topics in Signal Processing*, vol. 2, no. 5, pp. 613–623, 2008.

[7] A. Leshem and A.-J. van der Veen, “Radio-astronomical imaging in the presence of strong radio interference,” *IEEE Transactions on Information Theory*, vol. 46, no. 5, pp. 1730–1747, 2000.