URSI AP-RASC, Sydney, Australia, 17 – 22 August 2025

Robust R2D2 for scalable radio-interferometric imaging

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The R2D2 Deep Neural Network (DNN) series was recently introduced for monochromatic intensity imaging in radio interferometry [1]. This novel paradigm can be understood as a learned version of the matching pursuit algorithm, CLEAN, whereby its minor cycles are replaced by iteration-specific DNNs [2]. Maintaining a telescope-specific approach, we present our latest work [3] revisiting the R2D2 paradigm to improve its robustness in terms of generalisability to varying observational and imaging conditions, and epistemic uncertainty. Our contributions focus on three key improvements: training methodology, network architecture, and series convergence.

First, to enhance the learning process, we have considered varying integration times of the Fourier sampling, multi-scan multi-noise configurations, and diverse imaging settings, including pixel resolution and visibility-weighting scheme. Second, we substitute R2D2's original U-Net DNN with a novel architecture dubbed U-WDSR, combining U-Net and the WDSR residual block, which leverages wide activation, dense connections, weight normalisation, and low-rank convolution, optimising feature reuse and improving reconstruction precision. Third, we introduce a convergence criterion whereby the reconstruction process stops when the data residual is compatible with noise, rather than simply using all available DNNs. This not only increases the reconstruction efficiency by reducing its computational cost, but also refines training by pruning out the data/image pairs for which optimal data fidelity is reached before training the next DNN.

This new R2D2 incarnation has been trained using the antenna configuration of the Very Large Array (VLA) for the formation of 512×512 images. Simulations on a wide range of inverse problems reveal that it consistently outperforms its earlier version, in image reconstruction quality, data fidelity, and epistemic uncertainty. It also supersedes state-of-the-art algorithms in precision and computational efficiency. R2D2 has been further showcased on real high-sensitivity VLA observations of the quasar 3C 273, revealing filamentary structure within its jet.

Finally, we also present ongoing work to extend the applicability of the R2D2 paradigm to the formation of large-scale images by incorporating a faceting functionality, and to generalise the paradigm to wide-field imaging on celestial sphere [5].

References

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