Efficient Direction-of-Arrival Estimation via Model-based Machine Learning

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Abstract

Precise direction-of-arrival (DoA) estimation is crucial for array signal processing, supporting key applications in radar, localization, and integrated sensing and communication (ISAC). Achieving high-accuracy, computationally efficient DoA estimation is essential for enabling real-time performance in spectrum-constrained and dynamic ISAC environments. Traditional atomic norm minimization (ANM) is effective in enforcing angular sparsity and resolving closely spaced targets, but its reliance on computationally intensive semi-definite programming (SDP) limits scalability for large-scale or real-time ISAC systems. To address this limitation, we approximate the atomic norm using the ℓ_1-norm and develop a deep unfolded-based gradient descent method to solve the resulting optimization problem. Each layer of the unfolding network corresponds to an iteration of gradient descent, with both the step size and regularization parameter optimized through data-driven training. Our approach merges the interpretability of model-driven optimization with the flexibility of learning-based methods, enabling efficient loss minimization while reducing computational complexity. The proposed method is expected to improve robustness under low signal-to-noise ratios and highly correlated targets. Overall, our approach offers a scalable, high-performance DoA estimation framework tailored for next-generation ISAC systems.

Keywords: direction of arrival (DOA), gradient descent, atomic norm minimization (ANM), and machine learning.

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