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Combining Wave Physics and Deep Learning to Solve Inverse Scattering Problems

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The inverse scattering problem is generally ill-posed and its solution is computationally expensive. Deep learning shows potential in fast and accurate imaging. However, the high performance of purely data-driven approaches relies on constructing a training set that is statistically consistent with practical scenarios, which is often not possible in inverse scattering problems. Consequently, generalizability becomes a major concern. On the other hand, physical principles underlie EM phenomena and provide baselines for current imaging techniques. Combining wave physics and deep learning enables us to benefit from prior knowledge in big data and the theoretical constraint of physical laws. A hybrid of physics- and data-driven methods can analyze and predict data more effectively.

We present two types of the combination: physics-embedded data-driven approaches and learning-assisted physics-driven approaches. The first type mainly solves the inverse scattering problem in data-driven manners, where algorithms are designed according to physical laws, including deep unrolling forward and inverse problems. The second type seeks the optimal solution in physics-based frameworks, where learning approaches are applied to augment the performance, including improving the bandwidth of measured data, generating better prior models, and encoding prior knowledge. We also present the applications of these methods in biomedical microwave imaging, electrical impedance tomography, electromagnetic geophysical explorations, and multi-physics joint data inversion in biomedicine and geophysics.

Artificial intelligence has blossomed in recent years due to the advancement of modern hardware and software, which builds the foundations of these progresses. Physics theory provides baselines for electromagnetic sensing and imaging. Combining wave physics and deep learning can improve the interpretability and generalizability of algorithms and thus improve safety in real-world applications. Recent research on this topic has proven its feasibility.

References

[1] M. Li, R. Guo, K. Zhang, Z. Lin, F. Yang, S. Xu, X. Chen, A. Massa, and A. Abubakar, "Machine learning in electromagnetics with applications to biomedical imaging: A review," IEEE Antennas and Propagation Magazine, vol. 63, no. 3, pp. 39–51, 2021..

[2] V. Monga, Y. Li, and Y. C. Eldar, "Algorithm unrolling: Interpretable, efficient deep learning for signal and image processing," IEEE Signal Processing Magazine, vol. 38, no. 2, pp. 18–44, 2021.

[3] R. Guo, Z. Lin, T. Shan, X. Song, M. Li, F. Yang, S. Xu, and A. Abubakar, "Physics embedded deep neural network for solving full-wave inverse scattering problems," IEEE Transactions on Antennas and Propagation, vol. 70, no. 8, pp. 6148-6159, 2021.