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Machine Learning-Assisted Metasurface Design Using Deep Convolutional Generative Adversarial Networks

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Metasurfaces (MTSs) have attracted considerable interest in the research community due to their promise to achieve arbitrary transformation of electromagnetic (EM) wave fronts in a reduced form factor. Through careful design of sub-wavelength scattering elements, commonly referred to as meta-atoms, it is possible to achieve steerable high-gain apertures using MTSs as a low-cost alternative to traditional phased arrays [1]. Recent developments in MTSs create new opportunities in antenna design including beamforming, filtering, polarization conversion, and scattering reduction in a reduced form factor. This results in simpler and lighter radar and communications payloads and reduces the cost and amount of hardware requited in systems.

To realize more complex EM responses over frequency and polarization, there is a trend towards increasingly complex meta-atom structures. In particular, multi-layered meta-atom designs are often required to achieve a desired bianisotropic response. On the macroscopic level, more meta-atom variations are needed per MTS design to realize complex spatially varying surface impedance distributions. As result, meta-atom designs are becoming more time-consuming, difficult to realize, and often require many iterations of hand-tuning or full-wave optimization by an experienced practitioner. To help alleviate these MTS design challenges, there is a need for semi-automated meta-atom structure design techniques.

In this work, we present a deep learning (DL) solution to map MTS spatial features to their EM responses and perform inverse meta-atom design. Past works have been limited by fixed input geometry parameters. Advantages of DL-based MTS design include the ability to discover new designs not seen in literature, realize complex spectral responses on-demand, implicitly learn EM surface parameters, and the model can continue to improve with additional training data. In particular, we present a deep convolutional generative adversarial network (DC-GAN) with a simulator network to generate anisotropic meta-atom designs for MTS arrays. Our solution is applicable to single and multi-layer MTS designs and is able to generate able existing and new metamaterial structures from learned data. GAN-based techniques are a promising technology for designing low-cost MTSs with complex frequency polarization dependent scattering responses.

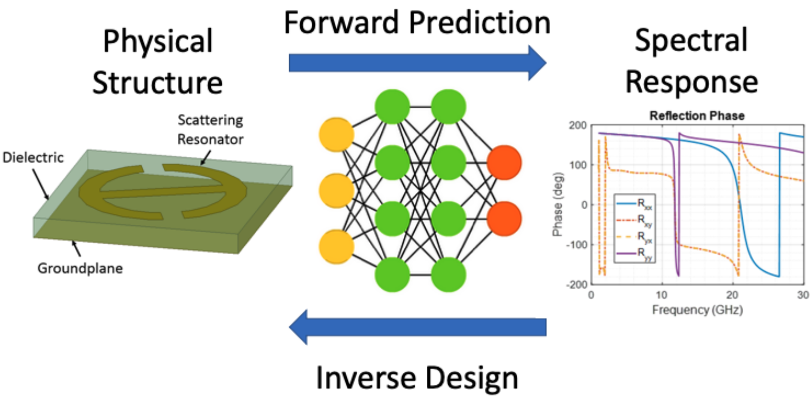

Figure 1. Conceptual illustration of how machine learning algorithms are able to learn generalize complex EM relationships from training data to perform forward performance prediction and solve practical inverse EM design problems.

References

[1] J. A. Hodge, K. V. Mishra, and A. I. Zaghloul, "Reconfigurable metasurfaces for index modulation in 5G wireless communications," in IEEE International Applied Computational Electromagnetics Society Symposium, 2019, pp. 1–2.