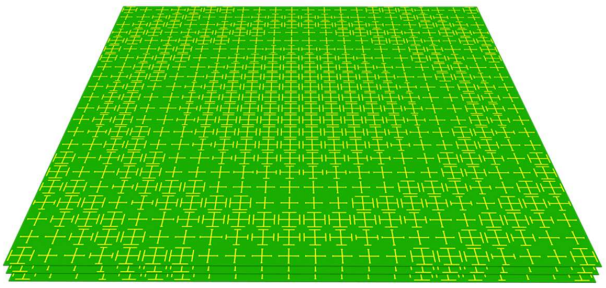
Machine Learning-Enabled Optimization and Synthesis of Metasurface Antennas

Abstract:

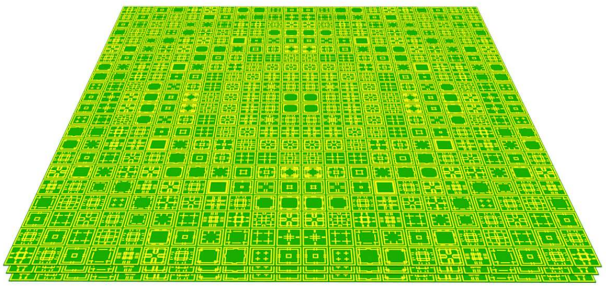
Recently, the rapidly growing wave of artificial intelligence (AI) is pushing against the performance ceiling of antenna design and optimization. Machine learning (ML)-based approaches, which usually employs artificial neural networks or deep learning algorithms have provided new and innovative ways to optimize and synthesize the complex antenna problems. It is a powerful tool and a promising research direction in both engineering and scientific domains.

The objective of this short course is to showcase recent advancements and new frontiers in theory and applications of ML-based metasurface antennas. We hope to bring more attention and research efforts to this emerging multi-disciplinary field.

Graphical abstract:



Metalens Antenna Using Conventional Jerusalem-Cross Metacells



Metalens Antenna Using PK-DL Synthesized Metacells

Recommended prerequisites for attendees:

The course requires a basic knowledge on electromagnetics and antennas.

Learning objectives:

After the course the participant will be able to know the following contents:

- Fundamentals of and state-of-the-art progress in metamaterial-based antennas (metantennas)
- Fundamental knowledge of ML algorithms, such as artificial neural networks (ANNs), convolutional neural networks (CNNs), and generative adversarial networks (GANs)
- Development of ML-based synthesis and optimization of metantennas
- State-of-the-art ML-based metasurface antenna design with case study

Course outline:

The Short Course will consist of the following contents with presentation deck. This course focuses on the physical mechanism and operating principle of both metasurfaces and ML algorithms. There is no pre-requisite for programming in this course.

- Introduction
  - Metamaterials and metamaterial-based antennas (metantennas)
    - Metamaterials, metasurfaces, and metalines
    - Metamaterial/metasurface/metaline-based antennas
  - Basis of machine learning
    - Development of machine learning (ML)
    - Fundamental ML algorithms
    - ML in antenna design and optimization
- Optimization and Synthesis of metasurface antennas using artificial neural networks (ANN)
  - Wideband metasurface antennas
  - Large-phase-shift metacell
- Synthesis of metalens antennas using generative adversarial networks (GANs)
  - Prior-knowledge-guided deep-learning-enabled (PK-DL) synthesis method
  - Pixelated metacell synthesis
  - Enhanced performance of metalens design
- Challenges and opportunity of applications of AI-enabled synthesis and optimization

Zhi Ning Chen is a Provost Chair Professor at the Department of Electrical and Computer Engineering, and Director of Advanced Research and Technology Innovation centre, National University of Singapore. His current research interest includes electromagnetic metamaterials and antenna engineering. He has published 720+ papers and five books. He is the recipient of IEEE John Kraus Antenna Award 2021. So far, he has delivered more than 180 keynotes and invited talks at international events.

Professor Zhi Ning Chen received his BEng, MEng, and PhD degrees all in Electrical Engineering from the Institute of Communications Engineering, China and his second PhD degree from University of Tsukuba, Japan, respectively. He evaluated to Fellow of IEEE in 2007 and Fellow of Academy of Engineering, Singapore in 2019. He is the Fellow and Vice President of Asia-Pacific Artificial Intelligence Association.

During 1988-2016, Professor Chen conducted his research and teaching at Institute of Communications Engineering, Southeast University, City University of Hong Kong, Tsukuba University, IBM T. J. Watson Research Center, and Institute for Infocomm Research. Concurrently, he has served industrial companies and institutions as Chief Scientist, Chief Antenna Expert, Visiting Professors, and Consultant.

Professor Chen has organized two short courses about UWB antennas and one short course about ML-Enabled Optimization and Synthesis of Metasurface Antennas at EuCAP.

Peiqin Liu received his BEng degree from the University of Electronic Science and Technology of China, in 2014, and the Ph.D. degree in Electronic Engineering from Tsinghua University, Beijing, China, in 2019. Since 2019, he has been with National University of Singapore as a Research Fellow. His current research interests include metamaterials and antenna theory, particularly in the applications of machine-learning enabled methods for novel metasurfaces and antennas.

Dr. Liu has authored and co-authored more than 20 technical papers published in international prestigious journals and conferences. He holds 5 granted Chinese patents. He is the recipient of the third prize of the Best Student Paper Award of 2017 Asia-Pacific Conference on Antennas and Propagation (APCAP); the Best Student Paper Award of 2017 National Conference on Antennas (NCANT); the Outstanding Student Paper Award of 2018 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC).

Dr. Liu has one short course about ML-Enabled Optimization and Synthesis of Metasurface Antennas at EuCAP.

Key bibliography

- P. Liu and Z. N. Chen, “Full-Range Amplitude–Phase Metacells for Sidelobe Suppression of Metalens Antenna Using Prior-Knowledge-Guided Deep- Learning -Enabled Synthesis,” IEEE Trans. Antennas Propag., vol. 71. no. 6, pp. 5036-5045, Jun. 2023.
- P. Liu, L. Chen, and Z. N. Chen, “Prior-knowledge-guided deep-learning-enabled synthesis for broadband and large phase shift range metacells in metalens antenna,” IEEE Trans. Antennas Propag., vol. 70. no. 7, pp. 5024-5034, Jul. 2022.
- P. Liu, Z. Shan, and Z. N. Chen, “Machine-Learning-Based Optimization Method for Wideband Metasurface Antenna,” 17 th European Conference on Antennas and Propagation, Florence, Italy, 2023.
- P. Liu and Z. N. Chen, “Beam-scanning metalens antenna using prior-knowledge-guided machine-learning-based synthesis,” IEEE Antennas Propagation Society Int. Symposium, Denver, CO, USA, 2022.
- P. Liu, S. Xu, X. Peng, Z. N. Chen, “Machine-learning-based optimization method for large-phase-shift metacells (Invited),” IEEE 10th Asia-Pacific Conference on Antennas and Propagation, Xiamen, China, 2022.
- P. Liu, Z. Zhu, and Z. N. Chen, “Machine-learning-based optimization method in metasurface Mosaic antennas,” IEEE Antennas Propagation Society Int. Symposium, Singapore, 2021.