University of Duisburg-Essen
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UNIVERSITÄT DUISBURG ESSEN

Offen im Denken

Bachelor's / Master's Thesis Open Position

Development of an Intelligent Optimization Platform for Planar Antennas in Photonic Terahertz Systems

Short Description: The optimization of broadband planar antennas for integrated photonic THz systems has become increasingly challenging due to the growing number of independent geometric design parameters. As the design space expands, exhaustive electromagnetic parameter sweeps rapidly become computationally infeasible, motivating the need for more efficient optimization strategies. Recent advances in artificial intelligence (AI) and machine learning (ML) provide new opportunities to accelerate this process by learning the relationship between antenna geometry and electromagnetic performance from simulation data. The objective of this thesis is to investigate suitable AI-assisted optimization approaches for high-dimensional antenna design and to develop a software framework capable of generating promising antenna design candidates from existing electromagnetic simulation data.

Keywords:
Artificial Intelligence · Machine Learning · Neuronal Networks · Python · Electromagnetic Simulation · Terahertz · Photonics

Motivation and Background

Planar broadband antennas play a key role in integrated photonic THz systems based on modified Uni-Traveling-Carrier photodiodes (MUTC-PDs). Their electromagnetic performance strongly depends on numerous geometric design parameters, which determine the impedance matching, bandwidth, gain, and radiation characteristics.

Conventional log-periodic antennas are typically described by only a few global design parameters. The corresponding design space is spanned by the parameter vector

$$\mathbf{p} = \begin{bmatrix}\tau & \sigma & \alpha & \beta\end{bmatrix}^{\mathrm{T}}. \tag{1}$$

Here, τ and σ define the relative tooth spacing and width, whereas α and β describe the overall opening angle of the antenna and the tooth length.

Recent investigations have shown that allowing each radiating element to possess its own individual geometric parameters can significantly improve the reflection performance. Consequently, the antenna is described by

$$\tilde{\mathbf{p}} = \begin{bmatrix} \alpha & \boldsymbol{\beta}^{\mathrm{T}} & \boldsymbol{\tau}^{\mathrm{T}} & \boldsymbol{\sigma}^{\mathrm{T}} \end{bmatrix}^{\mathrm{T}} \in \mathbb{R}^{1+3N}, \tag{2}$$

with

$$\boldsymbol{\beta},\, \boldsymbol{\tau},\, \boldsymbol{\sigma} \in \mathbb{R}^{N}. \tag{3}$$

As a result, the antenna design problem becomes a high-dimensional optimization task involving several dozen independent design variables, making exhaustive parameter sweeps computationally infeasible.

For an antenna with 28 independent design parameters, each discretized into only three possible values, an exhaustive parameter sweep would already require

$$3^{28} \approx 2.3 \times 10^{13} \tag{4}$$

electromagnetic simulations. Assuming a simulation time of only ten minutes per design, the total computation time would exceed **435 million years**, clearly illustrating the need for more efficient optimization strategies.

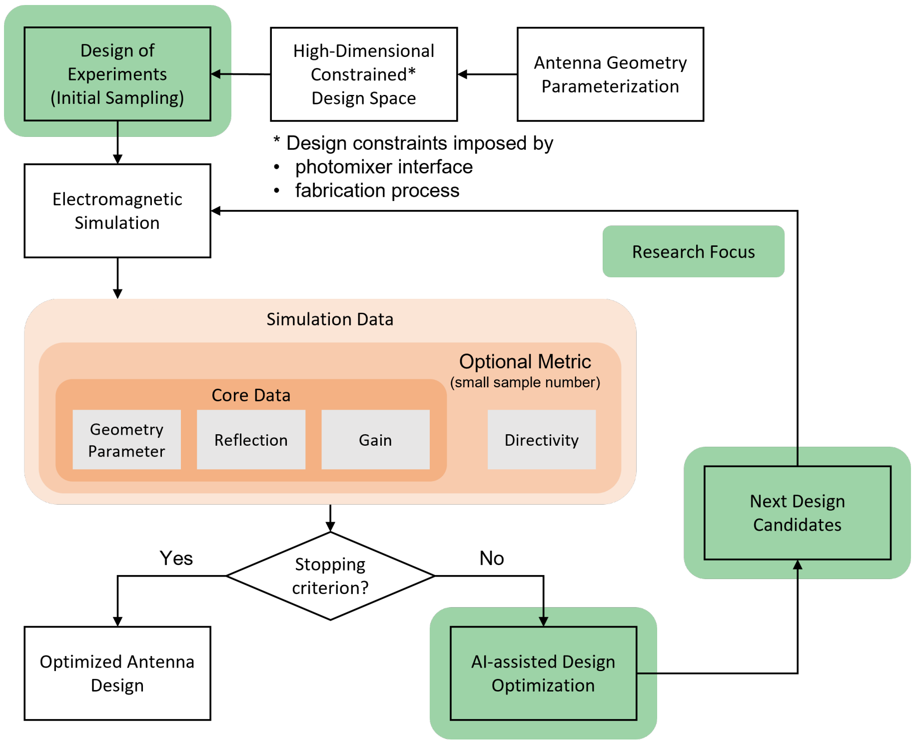

Figure 1: Conceptual workflow of an AI-assisted optimization framework for high-dimensional planar antenna design. Starting from an initial Design of Experiments (DoE), electromagnetic simulations generate a database linking antenna geometry parameters with electromagnetic performance metrics. Based on these simulation data, AI-assisted optimization methods iteratively propose new design candidates, which are subsequently validated by additional simulations until a predefined stopping criterion is satisfied. The highlighted elements indicate the research focus of this thesis.

Instead of relying on exhaustive parameter sweeps, modern data-driven optimization approaches combine electromagnetic simulations with machine learning and artificial intelligence. Simulation results are used to establish relationships between antenna geometry and electromagnetic performance. Based on these data, intelligent algorithms can propose promising new antenna designs, which are subsequently validated through additional electromagnetic simulations in an iterative optimization loop (see Fig. 1).

The objective of this thesis is to investigate suitable AI-assisted optimization approaches for high-dimensional antenna design problems and to develop a software framework that generates new antenna design candidates from existing simulation data. The developed concepts will be evaluated using simulated antenna data and provide the foundation for future AI-assisted electromagnetic design optimization.

Tasks and Objectives

The following tasks are to be completed as part of this thesis:

- **Literature Review**

  Review of current research in

  - AI-assisted engineering design
  - Machine Learning for optimization
  - Bayesian Optimization
  - Surrogate-assisted Optimization
  - Evolutionary Algorithms
  - Broadband THz antenna design

- **Analysis of Electromagnetic Simulation Data**

  Investigation of existing simulation data to identify suitable input parameters and objective metrics for AI-assisted optimization.

- **Software Framework Development**

  Development of a modular Python framework for AI-assisted antenna optimization including

  - data import and preprocessing
  - parameter management
  - optimization workflow
  - visualization and evaluation tools

- **Investigation and Implementation of AI-assisted Optimization Methods**

  Evaluation and implementation of suitable optimization approaches such as

  - Machine Learning
  - Bayesian Optimization

- Surrogate Models
- Evolutionary Algorithms
- Active Learning

Generation of New Antenna Design Candidates

Development of an optimization workflow capable of proposing promising antenna geometries based on existing electromagnetic simulation data.

Performance Evaluation

Comparison of different optimization strategies with respect to

- prediction quality
- convergence behavior
- computational efficiency
- reduction of required electromagnetic simulations

Requirements

- Background in Computer Engineering, Computer Science, Electrical Engineering, or a related field
- Interest in Artificial Intelligence, Machine Learning, or Data-Driven Optimization
- Programming experience in Python
- Interest in software development, scientific computing, and algorithm design
- Basic understanding of numerical methods or optimization algorithms is advantageous
- Independent, structured, and scientific working style

Note: The methodology of this thesis is intentionally open. The selection of suitable AI/ML techniques, optimization strategies, and the resulting software architecture will be derived from a comprehensive literature review and evaluated using existing electromagnetic simulation data.

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