Unsupervised specification-driven design of antenna structures using artificial intelligence and machine learning

Antennas are the critical components of wireless communication systems, including 5G, internet of things, RFID, wearable/implantable devices, or virtual reality. Design of modern antennas is a challenging endeavor. It is laborious and heavily reliant on engineering insight. Due to its interactive nature, antenna development requires many weeks and significant involvement of human experts. The same reasons allow the designers to try out a limited number of options in terms of antenna geometry arrangements. Automated topology development is therefore of high interest from both academia and industry perspective, where time-to-market and human-related expenses are of paramount importance. The research on unsupervised antenna design has been sparse. Available approaches include spatially-discretized structures with metal patches set to on/off status, or pixel-type of antennas with specific inter-patch connections subject to the optimization process, often limited to a particular antenna section (e.g., the radiator). Other methods include topology optimization combined with custom solvers to expedite the optimization process. The obtained antenna structures are still limited in terms of flexibility but also present fabrication difficulties. Black-box design methodologies that offer sufficient flexibility while easy manufacturing of the realized antenna geometries, and offering control over physical size and/or other crucial properties, are lacking.

This project aims at the development of techniques for unsupervised design of antennas for emerging applications. The major tasks include the development of geometry parameterization (flexible yet featuring a limited number of dimensions to be manageable by modeling and optimization procedures), machine-learning-enabled algorithms for automated generation of antenna topology and geometric dimensions, and artificial-intelligence tools (including deep learning classifiers and regression models) to expedite the design process. These techniques will allow antenna development solely based on performance specifications, without engaging human experts. They will go beyond the capabilities of the state-of-the-art approaches in terms of rendering high-performance structures for demanding applications under reasonable computational budgets. Methodological advancements will be complemented by design of antennas for specific devices, e.g., smart glasses. The accomplishment of the goals will push forward the state of the art in EM-driven antenna development and design automation.

The project contains several highly innovative components, among others:

- Development of antenna parameterization offering flexibility in terms of possible range of achievable antenna geometries, while maintaining simplicity and reasonably low dimensionality. It will allow both combinatorial-based evolution of antenna topology and continuous optimization-based dimension sizing.
- Development of computational models implementing antenna parameterization and interfaces that allow embedding commercial EM simulation packaged into the unsupervised design frameworks.
- Development of novel procedures for artificial-intelligence-based specification-driven antenna design integrated with the mentioned parameterization.
- Development of deep-learning- and machine-learning-based procedures for expediting the design process, especially to accelerate repetitive design cycles by utilizing massive EM data acquired in the process.
- Development of customized CAD software integrating models, algorithms, and EM solver interfaces.
- Demonstrating design utility of the developed framework by generating antennas for specific applications (augmented reality devices, wearable devices, body area networks, IoT, 5G).

The principal outcome of the project will be novel, reliable, and computationally efficiency methodologies for unsupervised specification-driven design of antennas. The results will go beyond currently available paradigms and techniques of black-box development of antenna structures; consequently, they will have a direct and significant impact on the state of the art of antenna design. The second outcome of the project will be software implementation of the developed design methods, offering frameworks for reliable and automated design of high-frequency antenna structures for modern applications, as well as integration with commercial CAD software, e.g., CST Microwave Studio. Finally, the results of the project are expected to be of interest to engineers from academic and research institutions, as well as industrial and business enterprises, facing the necessity of developing unconventional antenna structures, reducing time-to-market, and improving the efficacy of antenna development workflows.

Furthermore, the results of the project will be published in the leading technical journals in the field of RF electronics and disseminated in the form of international conference papers. The developed techniques will be also presented to the leading EM simulation software manufacturers (Dassault Systemes, Sonnet ***em***) to stimulate future collaboration.