Topology Optimization for Maxwell Solvers

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Over the past two decades, advances in scientific computing together with dramatic increase in computational horsepower has made computational methods more prominent in the design of novel devices. Many industries have incorporated computational modeling and testing into the design process, often replacing experimentation for simulations. Though many algorithms and software packages exists to model electromagnetic phenomena, much of the design decisions rely on the intuition of the designer, with the simulations only providing insight in to the next decision to be made. In order to make better use of the computational power available to designers, increased research is needed in combining robust solvers with optimization techniques.

Of the optimization techniques available, topology optimization is a promising method. In this method, a material is distributed in a specified region to satisfy some objective function. Additional constraints can be placed on the distribution, such as connectivity or the overall weight of the material. Additionally, it is possible to add manufacturing and cost requirements in addition to performance goals. These features make topology optimization a powerful tool in computer-aided design. Because of this flexibility, this method has been widely used in both electromagnetics and optics for a host of applications. In optics, metasurface lens have been designed (Z. Lin *et al.* Physical Review Applied 9, no. 4, 2018). In electromagnetics, topology optimization has been used to design metamaterials (A. R. Diaz and O. Sigmund Structural and Multidisciplinary Optimization 41, no. 2, 2010) and antennas (E. Hassan, E. Wadbro, and M. Berggren IEEE Trans. Antennas Propag 62, no. 5, 2014). In general, the design space has been largely restricted to two dimensions, limiting the scope of problems that can be analyzed.

In most of these works, the focus in more prominently on the designed system and less on the underlying numerical method. Topology optimization is a gradient based approach wherein novel designs can be achieved to meet specified requirements, and has been used extensively in structural engineering. Given a design goal and a set of constraints, topology optimization forms a framework in which one can find quasi-optimal solutions. Compared to optimization strategies like genetic algorithms, topology optimization methods guarantee at least a locally convergent solution and is capable of handling and adjusting many design variables. It forms a framework wherein changes to the topology are effected via changes in material properties.

As most topology optimization formulations are gradient-based methods, sensitivity analysis of the paired numerical method is required to completely define the total method. In this research, we seek to delve into application of these methods to electromagnetic systems, via the use of mixed finite elements. Our goal will be explore the use of topology optimization for meta-surfaces/photonic bandgap structures as well as develop different topology optimization methods inspired by phase-field models.