Using Machine Learning Techniques to Analyze Characteristic Mode Data of Electrically Large Structures

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The theory of Characteristic Mode (CM) analysis is a recently re-popularized method that provides for any conductive structure a set of unique current modes with orthogonal far-field patterns. The method is centered around the generalized eigenvalue problem $\mathbf{XJ} = \lambda\mathbf{RJ}$ where $\mathbf{X}$ and $\mathbf{R}$ are the imaginary and real parts of the Method-of-Moments (MoM) impedance matrix, respectively. As such, the size of a CM solution is directly related to the electrical size of the structure being analyzed. For a structure with an $N \times N$ MoM impedance matrix, a complete solution of the generalized eigenvalue problem produces a solution set of N eigenvalues and an $N \times N$ matrix of eigencurrents. These primary output values (eigendata) are then often used to determine modal application-focused values, such as modal excitation coefficients, far-fields, Q-factors, and impedances.

CM analysis is often used on small devices since the driven current distribution of an electrically small antenna can often be represented by a sum of just the first few modes of a CM solution. As we look to study larger conductive structures, we must also have the means to analyze larger sets of CM data. For these larger structures, the scale of the CM output data and the number of application-focused outputs makes it difficult to inspect and determine modal trends of interest. To address this problem, we are making use of machine learning-based data analysis techniques. For structures with distinct regions (such as an antenna array with a ground plane) clustering methods can distinguish modes associated with certain areas of the design, entirely from the structure's CM eigenvalue data. We will demonstrate how these methods operate on a CM simulation of an array of dipoles over a rectangular ground plane, and the different types of modes produced. For more complex output, such as modal excitation coefficients as a function of design parameters, we are investigating how learning methods can draw non-linear hypotheses from the data in order to identify modal trends that would otherwise be very difficult to discern. Additionally, we will show how the information generated from these methods compares to attempts to analyze high-dimensional output data visually. For work dealing with larger structures or parametric applications, these methods could greatly reduce the amount of time needed to inspect and draw design insights from CM results.