CHAPTER 6. CONCLUDING REMARKS AND FUTURE WORK

The work presented in this thesis was motivated by the need to provide a better means of understanding electromagnetic radiation mechanisms. In the past, empirical techniques were used to analyze antenna structures; however, these techniques were quite limited since the probes used to measure the near-field quantities altered the operation of the antenna. A number of publications have demonstrated that computational algorithms can be used to accurately simulate the near-field behavior of an antenna. In this thesis, visualization capabilities and image-processing techniques have been developed to aid in the interpretation of the large data sets generated by computational codes. The effectiveness of these methods has been demonstrated using two canonical cases: a microstrip patch antenna and an open-ended rectangular waveguide.

In Chapter 2, we defined the essential components of a visualization capability. A post-processing routine was developed that interfaced the computational algorithm with the visualization software. That essentially involved a restructuring of the raw data file along with a change of data types. Additionally, phasor-domain data was transformed to the steady-state time-domain. By performing that conversion, we were able to view the magnitude and phase information simultaneously as an animation, which made the analysis of the data somewhat easier. Also in Chapter 2, we provided an overview of the visualization software. The various shading techniques used by the visualization package were analyzed in order to determine what effect they had on the data. Finally, we discussed methods of visualizing vector information.

An example of the visualization technique was provided in Chapter 3. We used a FDTD computational code to simulate the near-field operation of a rectangular microstrip patch antenna. The patch antenna was selected because its operation was well explained analytically and well documented in the literature. The data was visualized by employing the techniques that were defined in Chapter 2. The resulting images provided a unique, global perspective of the data. This viewpoint is well suited for analytical investigations and can also be used as a powerful debugging tool during modeling and simulation. We identified the radiation mechanisms of the antenna using the visualization techniques and compared the results to the established theory. Using this example we were able to show that radiation mechanisms can be identified visually.

In Chapter 4, we extended the visualization capabilities by incorporating image-processing concepts. We used a FFT to convert the data to the spectral domain, where we applied a variant of the Gabor filter to isolate the various electromagnetic waves that propagated with different characteristics. Finally, we returned the data to the spatial domain using an inverse FFT. That allowed us to perform an independent analysis on each of the modes supported by a radiating structure. Several simple examples were given to develop strategies for determining the properties of electromagnetic waves. The technique that was developed is not limited to problems involving electromagnetic waves. For instance, we saw that a similar procedure is used to measure image velocities. Additionally, these techniques might have applications in vibration analyses of mechanical systems or other problems where modal solutions exist.

An example of the image-processing analysis tools was provided in Chapter 5. An open-ended rectangular waveguide was used as the canonical case because it supports multiple modes and its theory of operation is well established. We modeled and simulated the waveguide in a FDTD computational code for both dominant and mixed-mode excitations. When we analyzed the data, we found a limitation of the image-processing techniques. To adequately describe a signal, the windowed data needs to extend over at least one full-wavelength. Since the data window was only a half-wavelength in extent, we were required to artificially extend the data set using properties of the waveguide structure. When we applied the image-processing tools to the extended data, we obtained excellent results. We were able to analyze each mode independently despite the fact that one mode was much lower in amplitude relative to the other.

Through the analysis of canonical problems, we were able to demonstrate the effectiveness of visualization techniques and image-processing tools. We are now prepared to analyze unknown radiating structures. The tools that we developed in this thesis are well suited to printed circuit antennas and other radiating structures that involve an effective aperture. Using the visualization capability, we can identify the radiating mechanisms of an antenna. Additionally, we can use the image-processing tools to identify regions on a structure where standing and traveling waves are present. Armed with this information we will be able to explain how design parameters affect the performance of an antenna. Additionally, these techniques may also aid in understanding the non-radiating properties of antennas. By analyzing the surface waves on an antenna,

we might be able to develop a better explanation of blind-spot phenomenon and devise methods to reduce its effects.

In some cases, we may wish to analyze a structure whose effective aperture is less than a full-wavelength. In order to accomplish this we need to remove or reduce the existing limitation on the spatial extent of the data window. One solution involves using the discrete cosine and discrete sine transforms to convert to the spectral domain. By doing so, we can improve the spatial resolution by a factor of two. This means that we can reduce the window size to a half-wavelength. Alternatively, we could analyze the structure using wavelet-based transforms. Wavelet transforms are unique in that they allow a multi-resolution analysis. This property may be particularly useful when analyzing wideband or frequency independent antennas. Both of these techniques improve the image-processing tools and allow a wider variety of antennas to be analyzed.