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A Tutorial on Electromagnetic Inverse Scattering and Inverse Source Problems

Puyan Mojabi
Electrical and Computer Engineering Department, University of Manitoba, Winnipeg, Manitoba, Canada

1. Tutorial Abstract

The goal of electromagnetic inversion is to determine some (internal) properties of an investigation domain from external electromagnetic data. The external electromagnetic data can have different forms such as scattered electric/magnetic fields, radar cross-section data, or near-field antenna measurements. Electromagnetic inversion offers various (potential) applications in the forms of imaging, remote sensing, and detection; *e.g.*, in medical imaging (complex permittivity reconstruction), antenna diagnostics (equivalent current reconstruction), arctic remote sensing (snow and sea ice thickness retrieval), geophysics (oil exploration), security (concealed weapon detection), agriculture (grain bin imaging), environmental engineering (soil moisture retrieval), and industrial non-destructive evaluation (structural health monitoring). The electromagnetic inversion framework is applicable to a wide range of the electromagnetic frequency spectrum; however, the focus of this tutorial is on the microwave frequency range.

The investigation domain may include scatterers such as *in vivo* biological tissues or snow-covered sea ice, which are irradiated by some known electromagnetic fields. For such cases, the goal is to characterize these scatterers (*e.g.*, in terms of their complex permittivity profiles) by processing their measured electromagnetic response (*e.g.*, their resulting scattered fields) via an appropriate electromagnetic inversion algorithm. For these inversion scenarios, the associated electromagnetic inversion problem is then referred to as the electromagnetic inverse scattering problem. On the other hand, the investigation domain may include electromagnetic sources such as antennas or unintended radiators. In such cases, the purpose of electromagnetic inversion is often to characterize these sources in terms of their equivalent electric or magnetic currents from their measured near-field or far-field data. These problems are then referred to as electromagnetic inverse source problems.

In this tutorial, after a brief overview of different application areas, we focus on two specific applications: active microwave imaging for reconstructing the complex permittivity profile of an object of interest, and antenna characterization via equivalent current reconstruction. To this end, this tutorial starts with describing the relationship between electromagnetic inverse source and inverse scattering problems. We then discuss one of the challenges associated with solving electromagnetic inverse problems: proper stabilization of the inversion process by employing an appropriate regularization scheme. Advantages and disadvantages of some regularization techniques, namely, projection-based, additive, and multiplicative regularization methods, in conjunction with regularization parameter choice methods, are described. The use of nonlinear inversion algorithms to take into account multiple scattering effects in microwave imaging is explained, with a focus on the Born iterative method, Gauss-Newton inversion, and contrast source inversion algorithms. Finally, some experimental and practical aspects of these applications are discussed including phaseless measurements, data calibration, and system design.

The target audience for this tutorial are those who are to begin their research in this area and would like to learn some of its basic considerations and fundamentals.