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# An adaptive finite element solver for three-dimensional electromagnetic inductions

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## Summary

Forward modelling of three-dimensional (3-D) electromagnetic (EM) data over realistic Earth models remains important but also challenging due to complexities in mesh design and high computational costs. Typical examples of realistic Earth models in terms of electrical conductivity distribution include high conductivity contrast (e.g., highly conductive ore bodies in mineral deposit explorations, seawater effects in marine magnetotelluric and controlled-source EM surveys), realistic topography and bathymetry (e.g., seafloor) and extreme geometries (e.g., small steel-cased wells). In these scenarios, generating and manipulating 3-D meshes with sufficient quality required by corresponding numerical algorithms in modelling EM responses are difficult and time-consuming even with the state-of-the-art meshing tools.

To solve such challenge, an adaptive finite element solver designed for EM data over 3-D models is being developed. The Maxwell's equations for electric and magnetic fields are transformed into the second-order Helmholtz equation for the electric field which is then numerically solved using edge-based finite element method. The Earth model is discretized using unstructured tetrahedral meshes to provide maximum conformity in approximating realistic geometries with a minimum amount of cells in the mesh.

The adaptive EM solver takes advantage of the open-source finite-element package `MFEM` in terms of adaptively refining the tetrahedral mesh. The adaptive mesh refinement in the package supports local iterative refinements (i.e., goal-oriented refinement), and both conformal and non-conformal subdivisions of selected tetrahedra of the mesh. As to finite element method, the package supports various orders of basis functions using hierarchical finite element approach, leading to the potential capability of $p$-adaptivity of the EM solver.

To demonstrate the capability of the developed solver so far, a 3-D frequency-domain controlled-source EM survey that comprises a long electric wire source (of length 100 m) at the surface and a rectangular conductor (conductivity of 1 S/m, dimension of 1 km by 1 km by 100 m) buried in a uniform, resistive subsurface (conductivity of 0.01 S/m) is used. This survey mimics a typical EM survey for metallic mineral deposits. The modelling accuracy and performance of the newly developed solver are illustrated by comparing the modelled responses to those obtained using a previously developed, stand-alone high-order finite-element solver.

**Keywords:** three-dimensional modelling, finite element, numerical method, adaptive