DOE Final Report for "Applied Mathematics Research: Simulation Based Optimization and Application to Electromagnetic Inverse Problems"

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March 17, 2014

1 General Research Progress

The focus of research was

- *Developing adaptive mesh for the solution of Maxwell's equations.*

  To achieve this goal we have developed a new code. The code, EH3DTD-AG, computes the 3D time dependent electric field $\vec{E}$ and the magnetic field $\vec{H}$ on locally adaptive grids. We have developed a new multigrid method for this type of mesh. In extensive testing we have shown a factor of speedup of this code compared to other codes which work in the same parameter regime.

- *Developing a parallel framework for time dependent inverse Maxwell's equations.*

  We have developed a new code for the parallelization of time dependent inverse Maxwell's. This code can also work with extended sources.

- *Developing multilevel methods for optimization problems with inequality constraints.*

  We have developed new multigrid and multilevel algorithms for optimization problems with inequality constraints. The algorithms and codes can deal with elliptic problems with simple bound constraints.

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- *A new inversion code for inverse Maxwell's equations in the* 0^{th} *frequency (DC resistivity).*

  We have wrote a code, RESINVM3D, for the inverse problem. This code is the first publicly free code for the inversion of 3D DC Geophysical data.

- *A new inversion code for inverse Maxwell's equations in low frequency regime.*

  We have wrote an inversion code, for the inverse Maxwell's equation. This code is has been tested on field data sets in collaboration with the University of British Columbia.

Although the research concentrated on electromagnetic forward and inverse problems the results of the research was applied to the problem of image registration. As a result, new concepts as well as codes have been written and over 5 highly cited publications have appeared.

2 Papers submitted and accepted

1. An octree multigrid method for quasi-static Maxwells equations with highly discontinuous coefficients E Haber, S Heldmann Journal of Computational Physics 223 (2), 783-796, (2007)

2. Image registration with guaranteed displacement regularity E Haber, J Modersitzki International Journal of Computer Vision 71 (3), 361-372, (2007)

3. M. Benzi, E. Haber, L. Hanson, Multilevel algorithms for large-scale interior point methods in bound constrained optimization, Submitted (2006).

4. Numerical methods for coupled super-resolution J Chung, E Haber, J Nagy Inverse Problems 22 (4), 1261, (2006)

5. RESINVM3D: A 3D resistivity inversion package A Pidlisecky, E Haber, R Knight Geophysics 72 (2), H1-H10, (2007)

6. Inversion of time domain three?dimensional electromagnetic data E Haber, DW Oldenburg, R Shekhtman Geophysical Journal International 171 (2), 550-564, (2007)

7. An octree method for parametric image registration E Haber, S Heldmann, J Modersitzki SIAM journal on scientific computing 29 (5), 2008-2023, (2007)

8. Adaptive finite volume method for distributed non-smooth parameter identification E Haber, S Heldmann, U Ascher Inverse Problems 23 (4), 1659, (2007)

9. E. Haber, A parallel method for large scale time domain electromagnetic inverse problems, To Appear in IMACS J. of Applied Numerical Mathematics (2006).

10. Cone-based electrical resistivity tomography A Pidlisecky, R Knight, E Haber Geophysics 71 (4), G157-G167, (2006)

11. A multilevel method for image registration E Haber, J Modersitzki SIAM Journal on Scientific Computing 27 (5), 1594-1607, (2006)

12. On effective methods for implicit piecewise smooth surface recovery UM Ascher, E Haber, H Huang SIAM Journal on Scientific Computing 28 (1), 339-358, (2006)

3 Outreach Activities

3.1 Talks given

1. Short course: Simulation based optimization, Copper Mountain, April 2006.

2. An OcTree-Multigrid method for 3D Maxwell's equations, Copper Mountain, April 2006.

3. Multilevel algorithms for large-scale interior point methods in bound constrained optimization, Copper Mountain, April 2006 (Talk given by Lauren Hanson).

4. Balancing iteration accuracy in control problems governed by PDEs, Copper Mountain, April 2006 (Talk given by Maria Karampataki).

3.2 Short course

Together with George Biros (U. Penn) I have delivered a short course on simulation based optimization in the Copper Mountain meeting (April 2006).

The short course had 27 attendance which included graduate students and researches in the fields of PDE's and optimization.

3.3 Public domain Software

Together with Adam Pidlisecky (Geophysics, Stanford) I have wrote a code for the inversion of 0^{th} frequency electromagnetic data. This is the first publicly 3D code that can invert such data. Preliminary results from this code are described in our paper (see paper 5 above). We are in the process of writing a paper that describes the software.

4 Ph.D Student and Post-Docs research projects

As of today I work with two Ph.D students and a Post-Doctoral fellow

- Maria Karampataki (Ph.D student) is working on preconditioning KKT systems that arise in inverse problems. She has presented her work in Copper Mountain conference.
- Lauren Hanson (Ph.D student) has worked on multigrid methods for optimization problems with inequality constraints. She has presented her work in Copper Mountain conference and we have submitted a paper that summarize our progress.
- Stefan Heldmann (Post-Doc) is working on adaptive grids for Maxwell's equations.