IMAGING METHODS FOR DETECTION OF BURIED MINES IN THE SURF ZONE AND FOR DETECTION OF BURIED ORDNANCE

Steven A. Johnson, Ph.D., TechniScan, Inc.
Northgate Business Center, 850 North 300 West, Suite 102
Salt Lake City, Utah 84103
Telephone (801) 521-0444 FAX (801) 521-0666 ; e-mail: johnson@ee.utah.edu
Award Number(s): N00014-96-0273

LONG-TERM GOALS

Our long-term goal is to study low to high frequency (3 kHz to 30 MHz) electromagnetic (EM) methods for three-dimensional (3-D), quantitative and qualitative, characterizing and imaging of the un-perturbed and perturbed (e.g. by man or nature) ocean environment. These long-term goals include the immediate goal of this project, which as stated in the title is to develop "imaging methods for detection of buried mines in the surf zone and for detection of buried ordnance". The approach if successful could lead to spin-off methods for solving corresponding commercial and civilian problems such as: (1) finding buried cables, pipes and other buried objects; (2) characterizing soils for moisture content or liquid contaminants.; (3) and new method for geophysical applications where improved 3-D and quantitative imaging are desired.

OBJECTIVES

Our scientific objectives combine both theoretical and experimental aspects. The results of basic computer simulations will be verified by laboratory simulation experiments conducted in a 16 foot diameter, 6 foot deep, redwood tank containing sand, conducting salt water and buried objects. These steps may be summarized into the following list of scientific objectives:

1. to write computer code, that incorporates accurate theoretical models, to numerically simulate the operation of a hybrid imaging system comprising: (1) a single coil-pair and multiple coil-pair (array of coils) induction system; and (2) a multiple source and multiple receiver electrode array for current tomography.
2. move the inductive probe above simulated mines buried in a 16 foot diameter tank .
3. work with subcontractor to design / test inductive coils, electrodes and system.
4. where possible use other of our imaging tools e.g. a cone penetrometer tool (CPT).

APPROACH

<u>Background and Problem</u>**:** Finding buried or proud mines in the surf zone is a difficult problem using present methods. Acoustic methods suffer from air bubble interference and from ocean surface and bottom reverberation. High frequency electromagnetic (EM) methods are not possible because of high absorption [1]. Low frequency EM methods give better penetration, but spatial resolution is poor [1-4]. Making images (rather than looking for features in the data) has the following advantages [4]: (1) targets are localized thereby improving the contrast over the background clutter and noise; (2) the size and/or conductivity of the target can be better resolved or estimated; (3) the 3-D location can be found; and (4) non metallic mines can be seen more easily. Our approach uses algorithms that make quantitative images of conductivity and improve target classification.

<u>Methods</u>: For the proposed military applications, the method we are developing is based on using low to medium frequency (10 kHz to 300 kHz), inductively coupled electromagnetic (EM) transmitted fields, inductively coupled electromagnetic (EM) receivers and direct sampling of the induced electric field by electrodes, to produce a data set that is then imaged by three-dimensional (3-D) migration and inverse imaging codes to produce images of the conductivity of the ocean bottom, sub-bottom, adjacent water or land. The work plan we propose to accomplish the objectives of this research is describes by the following Tasks and Sub-tasks:

1. Develop software to make images

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Imaging Methods for Detection of Buries Mines in the Surf Zone and for Detection of Buried Ordnance**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **TechniScan, Inc,Northgate Business Center,850 North 300 West, Suite 102,Salt Lake City,UT,84103**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.1 Write direct scattering/diffusing & imaging codes: (1) integral equation methods; and (2) finite difference, time domain (FDTD, incorporating PML & 6^{th} order, staggered grids.
1.2 Test imaging codes with simulated data (using both analytic and numerical codes).

2. Prepare scanning gantry for imaging systems
   2.1 Prepare-y-x linear motion gantry for inductive and electrode arrays described above.
   2.2 Prepare x-y-x linear motion gantry for Cone Penetrometer Tool (CPT).
3. Conduct studies with hybrid induction-coil / current-electrode tomographic scanning array
   3.1 scan test objects in air; 3.2 scan test objects in water and in salt water (to simulate ocean conductivity); 3.3 scan objects in sand under water
4. Conduct studies with CPT tool
   4.1 scan objects in air; 4.2 scan objects in water; 4.3 scan objects in sand under water

RESULTS

The concept of using higher order multipole coil configurations to produce a directed field for 3-D imaging has been verified by computer simulation using analytic solutions for a dipole, basis-function expansion. An analytic solution for 3-D scattering from layered concentric sphere modes of conductivity has been written and tested. Three codes for predicting scattering and generating simulated test data from arbitrary, inhomogeneous conductivity in air and in the ground have been written and verified against this analytic code: (1) a 3-D, finite difference, time domain (FDTD), forward scattering code that incorporates conductivity and dielectric scattering and uses a perfectly matched boundary layers (PML) and efficient, sixth order, staggered grids [5, 6]; (2) an integral equation code [7]; and (3) a quasi-linear code (written by Prof. Zhdanov, Dept. Geology, University of Utah). Prof. Zhdanov has also written EM migration imaging codes that have been tested with simulated data and produce good results. Integral equation inversion codes have been written and have produces similar images but are about an order of magnitude slower than the migration codes (but can operate above 10 MHz where EM migration fails). Construction the x-y-z motion gantry is now completed and operates under computer control as planned. The hybrid induction / electrode imaging system has been constructed by EMI and has been delivered. It is undergoing testing and integration into the system.

SCIENTIFIC IMPACT

The imaging system is the most advanced in terms of its capability (combining induction coils current and potential electrodes, scanning capability, imaging algorithms and higher frequency of operation (up to 100 kHz for hybrid system, up to 1 MHz for the CPT system). The practical impact should be that objects can be detected to a depth of about the length of an array, the size of the object being about the spacing of the array close to the array and decreasing to about half the length of the array at a depth of the array. The induction coil array operating at 100 kHz or less can detect/image metallic objects but not insulating objects. The current electrode array can detect/image both insulating and conducting objects.

TRANSITIONS ACCOMPLISHED

Transitions accomplished are: (1) the addition of Prof. Michael Zhdanov to our team and the porting of his faster software to our computer to supplement our more flexible, but slower inversion and forward codes; (2) completion of the motion and imaging hardware; (3) completion of the essential imaging and control software components (software for controlling the induction/electrode system is still in progress); (3) testing of this software and hardware; and (4) the receipt of reports on scattering code and imaging code from Prof. Zhdanov and the receipt of reports data collection codes and operating instructions from EMI on hardware operation.

RELATED PROJECTS

Below we list ongoing work that is related, but different from this project.

1. Detection of Dense Non Aqueous Phase Liquids (DNAPLs) by the use of low frequency (10 kHz to 1 MHz) vertical induction coil transmitter and 3-Axis orthogonal receiver coils in a instrument package near the tip of a cone penetrometer technology (CPT) probe. The forward problem and the and imaging problems are similar, although the CPT probe does not have current electrode arrays as does the surf zone array. On the other hand, the CPT tool makes use of simultaneous imaging from multiple, vertical holes. This funding comes as a phase-2 SBIR from the US Air Force.

2. Detection and diagnosis of breast cancer with ultrasound reflection tomography imaging methods. We have constructed a water tank scanner using a transducer array with 32 vertical elements and 2 horizontal elements. The array rotates about a vertical axis and moves both horizontally and vertically. A tissue sample or organ is held stationary with its center near the vertical axis of rotation. Rotation produces a horizontal tomographic image plane normal to the vertical axis of rotation with vertical focusing. At 5 MHz, the resolution is 0.3 mm in-plane and 1.5 mm normal to the plane (image slice thickness). This work is funded by a phase-2 SBIR from NCI. Similar control of stepping motors and image processing is used.

3. Detection and diagnosis of breast cancer with ultrasound inverse scattering methods. This work combines transmission inverse scattering imaging methods with some of the reflection imaging methods from the above ultrasound reflection tomography imaging methods. The frequency will be 2 MHz for the transmission inverse scattering. We believe it may will be the first use of inversion methods in clinical ultrasound imaging. This is funded by a phase-1 SBIR from NCI.

REFERENCES

1. Zhdanov, M.S. and Keller, G.V., 1994, *The Geoelectric Methods in Geophysical Exploration*. Elsevier, Amsterdam

2. Zhdanov, M.S., Traynin, P. and Booker, J.R., 1994, "Principles of Electromagnetic Migration," CEMI Project Review (submitted in Geophysics).

3. Zhdanov, M.S., Traynin, P., and Portniagune, O., 1995, "Time domain electromagnetic migration in INEL RWMC cold test pit characterization," *Symposium on the application of geophysics to engineering and environmental problems*, *Proceedings*, April 23-26, 1995, Orlando, Florida, Environmental and Engineering Geophysical Society, compiled by R.S. Bell..

4 . Johnson, S.A., Borup, D.T., Wiskin, J.W., Berggren, M.J., Zhdanov, M.S., Bunch, K. and Eidens, R., "Application of Inverse Scattering and other Refraction Corrected Methods to Environmental Imaging with Acoustic or EM Energy." US Environmental Protection Agency workshop on Next Generation Environmental Models Computational Methods (NGEMCOM), National Environmental Supercomputing Center (NESC), Bay City, Michigan, August 7-9, 1995. reprinted as book by *S.I.A.M.* ,1997.

5. X. Yuan, D. Borup. J.W. Wiskin, M. Berggren, R. Eidens, and S.A. Johnson,"Formulation and Validation of Berenger's PML Absorbing Boundary for the FDTD Simulation of Acoustic Scattering," accepted for publ., *IEEE Trans. on Ultrason., Ferro., and Freq. Control*. 1997.

6. Yuan, X., D. Borup D. T., Wiskin, J. W., Berggren, M., Johnson, S. A. and R. Eidens, "Simulation of acoustic wave propagation in dispersive media with relaxation losses by using FDTD methods with PML absorbing boundary condition", in review, Trans. of Ultrasonics, Ferro., and Freq. Control, 1997.

7. J.W. Wiskin, D.T. Borup, and S.A. Johnson. "Inverse Scattering arbitrary two-dimensional objects in stratified environments via a Green's operator," *J. Acoust. Soc. Am.*, Sept., 102 (2)