A. Statement of the Problem Studied

Significant progress has been made on electromagnetic modeling for FOPEN and GPEN SAR. We have developed a fast multipole method (FMM) simulator for electrically large targets embedded in a half-space region (i.e., for targets in the vicinity of soil). The model is applicable to very general targets, including buried or surface unexploded ordnance (UXO), vehicles and weapons. The model is also applicable for simulating the scattered fields from fiducial targets (trihedrals) placed above soil, these models playing a critical role in the calibration of foliage penetrating (FOPEN) radar systems, such as the ARL BoomSAR. In the future we will apply the FMM model for calibration of the BoomSAR, with this playing a critical role in the development of automatic target recognition algorithms for FOPEN systems.

B. Summary of Most Important Results

For the first time, the fast multipole method (FMM) has been extended to the case of targets in the presence of a half space. This is a notable escalation in complexity vis-à-vis previous work in this field, which has heretofore been restricted to the case of free-space scattering. Significant work has been undertaken to properly handle the dyadic half-space Green's function.

C. Refereed Publications

A. Sullivan and L. Carin, "Scattering from complex bodies using a combined direct and iterative technique," *IEEE Trans. Antennas Prop.,* vol. 47, pp. 33-39, Jan. 1999

N. Geng, C.E. Baum, and L. Carin, "On the low-frequency natural response of conducting and permeable targets, *IEEE Trans. Geoscience and Remote Sensing*, vol. 37, pp. 347-359, Jan. 1999.

L. Carin, R. Kapoor, C.E. Baum, "Polarimetric SAR imaging of buried landmines," *IEEE Trans. Geoscience and Remote Sensing*, vol. 36, pp. 1985-1988, Nov. 1998.

D. Wong and L. Carin, "Analysis and processing of ultra-wideband SAR imagery for buried landmine detection, *IEEE Trans. Antennas Propagat.,* vol. 46, pp. 1747-1748, Nov. 1998.

T. Dogaru, L. Collins, and L. Carin, "Optimal detection of a deterministic target buried under a randomly rough interface, submitted to *IEEE Trans. Antennas Propagat.*

L. Carin, N. Geng, M. McClure, J. Sichina, and L. Nguyen, "Ultra-wideband synthetic aperture radar for mine field detection, *IEEE Antennas and Propagation Magazine* (invited), vol. 41, pp. 18-33, Feb. 1999.

N. Geng and L. Carin, "Ultrawideband, short-pulse scattering from a dielectric body of revolution buried in a lossy, dispersive layered medium," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 610-619, April 1999.

N. Geng, D. Jackson, and L. Carin, "On the resonances of dielectric bodies of revolution buried in a lossy, dispersive layered medium," *IEEE Trans. Antennas Propagat.*, vol. 47, pp. 1305-1313, Aug. 1999.

P.K. Bharadwaj, P.R. Runkle, and L. Carin, "Target identification with wave-based matching pursuits and hidden Markov models," *IEEE Trans. Antennas Propagation*, vol. 47, pp. 1543-1554, Oct. 1999

N. Geng and L. Carin, "Short-pulse electromagnetic scattering from arbitrarily oriented subsurface ordnance," *IEEE Trans. Geoscience and Remote Sensing*, vol. 47, pp. 1543-1554 Oct. 1999.

N. Geng, M. Ressler, and L. Carin, "Wideband VHF scattering from a trihedral reflector situated above a lossy dispersive halfspace," *IEEE Trans. Geoscience and Remote Sensing*, vol. 37, pp. 2609-2617, Part 2, Sep. 1999.

N. Geng, A. Sullivan and L. Carin, "Fast multipole method for scattering from a arbitrary PEC target above or below a lossy half space," *Microwave and Optical Tech. Letts.*, June 20, 1999.

N. Geng, A. Sullivan and L. Carin, "Fast multipole method analysis of scattering from a three-dimensional target in a half-space environment," submitted to the *IEEE Trans. Antennas Propagation*

N. Dasgupta, N. Geng, T. Dogaru and L. Carin, "On the extended-Born technique for scattering from buried dielectric targets," accepted for publication in the *IEEE Trans. Antennas Propagation*

T. Dogaru and L. Carin, "Application of multiresolution time-domain schemes to two-dimensional electromagnetic scattering problems," submitted to the *IEEE Trans. Antennas Propagat.*

J. He, T. Yu, N. Geng and L. Carin, "Method-of-moments analysis of electromagnetic scattering from a general three-dimensional dielectric target embedded in a multi-layered medium," accepted for publication in *Radio Science*

T. Yu and L. Carin, "Extended-Born method for the modeling of buried voids," accepted for publication in *IEEE Trans. Geoscience and Remote Sensing*

N. Geng, A. Sullivan and L. Carin, "Multi-level fast-multipole algorithm for scattering from conducting targets above or embedded in a lossy half space," submitted to *IEEE Trans. Geoscience Remote Sensing*

A. Sullivan, R. Damarla, N. Geng, Y. Dong and L. Carin, "Ultra-Wideband Synthetic Aperture Radar for Detection of Unexploded Ordnance: Modeling and Measurements," submitted to *IEEE Trans. Antennas Propagation*

P. Gao, L.M. Collins, P. Garber, N. Geng and L. Carin, "Classification of landmine-like metal targets using wideband electromagnetic induction", accepted for publication in *IEEE Trans. Geoscience and Remote Sensing*

T. Dogaru and L. Carin, "Multiresolution time-domain analysis of scattering from a rough dielectric surface," submitted to *Radio Science*

D. Participating personnel

Dr. Norbert Geng (post doc)
Dr. Anders Sullivan (post doc)
Traian Dogaru (PhD earned June 1999)

E. Report of Inventions

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Lawrence Carin

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Duke University
Department of Electrical and Computer Engineering
Durham, NC 27708-0291

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13. ABSTRACT (Maximum 200 words)

This project has involved both numerical simulation of electromagnetic scattering for ultra-widenband synthetic aperture radar (SAR) for foliage and ground penetrating radar (FOPEN and GPEN, respectively). We have developed a fast multipole method (FMM) model for electromagnetic scattering from electrically large conducting targets in the presence of a half space, with application to scattering from surface/subsurface unexploded ordnance (UXO), as well as for scattering from surface vehicles, such as tanks. The FMM simulator is significantly faster than conventional method-of-moments (MoM) solvers, allowing solution of problems that were heretofore intractable. The code has been delivered to the Army Research Laboratory (ARL), and successfully compared with data measured by ARL. In addition to this modeling, we have developed hidden Markov model (HMM) automatic target recognition algorithms, applicable to the SAR detection and discrimination of concealed targets. Within the context of the HMM, we have employed a physics based matching pursuits feature parser. This signal processing paradigm has been successfully applied to ARL-measured FOPEN and GPEN data.

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