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Title: **Detection of Underground Structures and Tunnels**

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Detection of Underground Structures and Tunnels

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Abstract

This is the final report for a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). There is a continuing need in United States defense and drug interdiction for effective overt, covert, and standoff means of detecting underground tunnels, structures, and "objects." This project sought to begin an assessment of electromagnetic and gravitational gradient detection approaches to the detection of underground structures and tunnels.

1. Background and Research Objectives

There is an increasing need in US defense, intelligence, and drug interdiction programs for effective overt and covert means of detecting underground tunnels, structures, and voids. Examples are the tunnels discovered in the Korean demilitarized zone, tunnels across the US-Mexican border east of San Diego, underground facilities for clandestine weapons operations in countries such as Iraq and North Korea, and underground voids left by concealed testing of weapons. A significant improvement in underground surveillance capability would benefit the Department of Defense/Defense Nuclear Agency, Department of Energy, Defense Intelligence Agency, Central Intelligence Agency, International Atomic Energy Agency, and US Customs Service, and it would bring a direct benefit to the mining, energy, construction, and waste cleanup industries [1]. This project focused on electromagnetic and gravitational gradient detection approaches.

Electromagnetic Scattering (EMS): In 1993 a series of tests, sponsored by the US Army Belvoir Research Development and Evaluation Center, was made on a clandestine

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tunnel discovered at Otay Mesa, California crossing the US-Mexican border. Six types of tunnel detection techniques were compared, namely: active and passive seismic; pulsed and multi-frequency continuous-wave (CW) electromagnetic, passive magnetic, and active electrical resistivity. Of these techniques, the Army Summary Report concluded that the active electromagnetic scheme called RIMtech, proved to be the best all-purpose method. It was developed by Raton Technology Research, Inc. (RTR) and used scattered CW EMS radiated from induced currents in tunnel conductors. This project was carried out in collaboration with RTR.

Gravity Gradient: Gravitational gradiometric inspection and monitoring of underground structures and voids is a complementary technique [2], notably unique in that measurements are completely passive. Gravitational anomalies caused by underground tunnels, structures or other voids can be directly and passively observed by mapping the magnitude of the gravitational field (gravimetry) or by measuring the gradient of the gravitational field (gradiometry). Gradiometry is superior to gravimetry for this project because the measurement and interpretation of results are generally simpler and gradiometry is less susceptible to masking by other effects.

The success of the RIMtech technology in the Otay Mesa and other tests demonstrate that the RIM approach to electromagnetic scattering provides an encouraging capability for underground structures and tunnel detection. A superconducting gravity gradiometer is well suited for gravitational gradiometric inspection and monitoring, where significant access to suspect areas is allowed. Despite promising results obtained with these techniques, substantial technological advances are required and possible before underground surveillance methodologies can approach the performance needed.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in analysis and assessment as well as complex experimentation and measurement. The project enhances Los Alamos capabilities in gravitational and electromagnetic modeling, superconducting quantum interference device (SQUID) sensor technology, pulsed power, supercomputing, systems studies, and advanced geophysics. Work performed on this project also enhances US national ability for on-site/remote verification of underground structures and tunnels through application of improved geophysical methods, which is one of the highest Department of Defense priorities. The EMS method studied here also has a dual benefit in the detection and analysis of nuclear and chemical explosions.

3. Scientific Approach and Results to Date

Assessment of the central technical issues and refinement of the technological requirements were initially emphasized. Buried-structures detection is greatly exacerbated by the fact that no known radiation or particle can selectively penetrate the earth and provide unique signatures for the expected plethora of targets. The pragmatic approach is to rely on a variety of technologies, each contributing to a portion of the detection phase space. Electromagnetic scattering and gravitational gradiometry were emphasized because their complimentary features enable a potentially wider coverage of surveillance circumstances. An advanced knowledge of geophysics is required to distinguish the signatures of man-made structures from the "noise" inherent in naturally occurring geologic formations, "geologic clutter." Expertise in SQUID technology may central to this project because detection of extremely weak magnetic fields is an enabling technology to optimize both electromagnetic and gravitational detection. Finally, the very large physical parameter space inherent to these detection techniques requires advanced modeling and systems studies capabilities.

Conceptually, for the EMS technology the transmitter and receiver would be initially surface-based and later placed on low flying UAVs. High-flying platforms would be desirable for many missions, but it was concluded that proof-of-principle in the near-earth regime is essential before extrapolating to the much more difficult domain of remote sensing. RTR has extensive experience and documented success [3] in detection of tunnels and geological features using properly configured electric and magnetic dipoles. Analyses done as a part of this project indicate that appropriate signals can be propagated through earth using low-frequency (5-100 Khz) magnetic-dipole antennas. It was determined that the utility and portability of the transmitter might be significantly enhanced with the use of super-cooled transmitter coils. Although monostatic systems (combined transmitter and receiver) are not ruled out, the experience of RTR indicates that best results are obtained with separate source and receiver units, where phase and amplitude data are taken at varying positions and frequencies. Currently, the RTR system uses a fiber optic link between the source and receiver to determine the relative phase of the two signals. More portable links, including the use of global positioning satellite (GPS) timing and microwave communications are being considered for this project.

Weak scattered signals embedded in significant background of extraneous clutter and interference from the reflected primary wave result in severe detection problems. Primary-wave cancellation electronics and the sensitivity and dynamic range inherent to SQUID technology should be investigated. Los Alamos expertise in magnetic encephalography and high-T_C superconductivity have been employed to provide relevant SQUID technology for both the electromagnetic and gravitational gradiometric aspects of this project.

The present EMS system is not limited to low power transmission (a few watts). Using technology developed for the induction heating industry and for communications, the transmitted power can be increased by a factor of a thousand, and amplifiers exist to increase the transmitted power by a factor of a million. Transmitter systems up to two megawatts are feasible with off-the-shelf components.

This program development project emphasizes a strong theory and modeling effort as outlined in Figure 1. "Quasi-analytic" techniques have been used to solve a wide range of physics problems without the detail and expense of numerical solution. Judiciously chosen representations of system components are being integrated into a large, global model of the system. Aspects of the underground detection problem that are beyond the grasp of quasi-analytic techniques are addressed through numerical solutions. These include the solution of scattering by complex geometrical shapes and the inversion problem. Inversion is the process by which data collected in the field are computationally processed to produce an image of an underground structure, for example a three-dimensional map of conductivity. In preliminary investigations of the inversion problem, three numerical imaging techniques have been cataloged: (1) multiple dipole placement in the target region (well developed for magnetic encephalography), (2) two-dimensional conductivity profile reconstruction, and (3) three-dimensional finite-difference conductivity reconstruction. As the physics models of surveillance concepts become well developed, they will be subjected to detailed systems studies, where the physics and engineering features of the concepts are combined to forecast performance.

References

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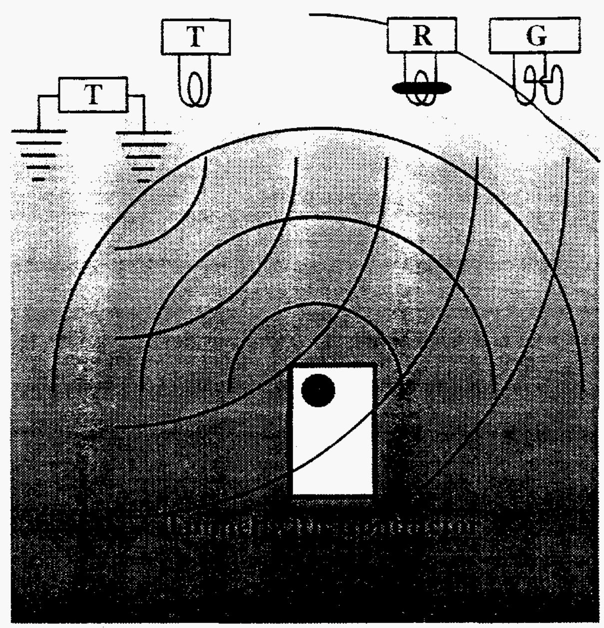
2. Jekeli, C., "A Review of Gravity Gradiometer Survey System Data Analyses," *Geophys.*, **58**, 508-514 (1993).

3. Mahrer, K. D. and D. F. List, "Radio-Frequency Electromagnetic Tunnel Detection at the Otay Mesa Site," *Geophys.*, **60**, 413-422 (1995).

Quasi-Analytic Modeling

- Dipole transmission or current injection
- Simple scatterers: long wires and spheres
- Stratified earthen conditions
- Quantitative scaling



Numerical Modeling

- 3-D targets
- Quantitative solution of multiple scattering problems
- Scattering in random geological media
- Essential component of inversion problem

Systems Studies

- Simulation of deployable system: transmitter → earth → target → receiver
- System optimization through integration of quasi-analytic models, numerical forward solvers, and inversion techniques

Figure 1. Our collaborative theory and modeling effort provides an ability to assess and optimize several detection technologies.