Final Report

Army Advanced Concept Workshop on Disturbed Soil Characterization and Exploitation

Dr. Michael Cathcart, Dr. Alan Thomas, Mr. Tim Harrell, Ms. Sarah Lane
Electro-Optical Systems Laboratory
Georgia Tech Research Institute (GTRI)
Atlanta, GA 30332-0834
Phone: 404-407-6028
michael.cathcart@gtri.gatech.edu

30 September 2008

Acknowledgements

Personnel within the Electro-Optical Systems Laboratory (EOSL) of the Georgia Tech Research Institute assisted with the organization and operation of this workshop. In particular, Ms. Sarah Lane, Ms. Tracy West, and Mr. Tim Harrell provided this assistance. The Georgia Tech Research Institute is a unit of the Georgia Institute of Technology.

Table of Contents

List of Tables

1 Introduction

Under the sponsorship of the Army Research Office (ARO), the Night Vision and Electronic Sensors Directorate (NVESD), and the U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC), Georgia Tech hosted a workshop to address Remote Sensing Methods for Disturbed Soil Characterization. The workshop was held January 15-17, 2008 in Atlanta on the Georgia Tech campus. The primary objective of this workshop was to take a new look at the disturbed soil problem as well as its relation to buried explosive detection and other manmade disturbances. More specifically, the participants sought to define the basic science questions that need to be addressed across the full spectrum of military applications to fully exploit this phenomenon. With these questions at hand, government agencies and personnel will have the requisite information to develop the necessary research and development programs that will enable full exploitation of this phenomenology and to develop the necessary remote sensing technologies to support the war fighter.

2 Executive Summary

Attendees at the *Army Advanced Concept Workshop on Disturbed Soil Characterization and Exploitation* addressed topics in disturbed soil research for the purpose of identifying the research and development priorities in this area. Over 45 individuals representing academia, industry and government met at this workshop to address this topic. These individuals were drawn from basic research, technology development, and operational groups to provide a complete picture of the issues involved with adequately exploiting this phenomena. The US Army Research Office (ARO), the Night Vision and Electronic Sensors Directorate (NVESD), and the U.S. Army Corps of Engineers (USACE) Engineering Research and Development Center (ERDC) sponsored this workshop and provided both guidance and resources to support the workshop.

A discussion-based format, supplemented with a few key technical presentations, was employed to provide the attendees with the opportunity to provide insight into this problem, to identify current phenomenology-based and technology-based shortcomings, and to discuss various means to alleviate these shortcomings. Three primary technical areas were set up to address the different aspects of the problem: near surface soil physics, sensor technology, and algorithm development. This technical-based division allowed experts in each area the opportunity to contribute to their particular specialty group and to supply information to the other technology areas.

Despite the fact that there has been a substantial amount of research and development work related to disturbed soil exploitation there remains much work to be done. Much of this prior work, especially over the last 15 years, has focused on exploiting the reststrahlen feature in the LWIR (8 – 12 microns). Basic research efforts are needed that will examine the fundamental aspects of soil disturbance, identify the impact of these disturbances on other soil properties, and, perhaps most importantly, identify soil observables across a spectrum of sensing modalities. Sensor technology developments need to focus on improving existing sensor characteristics to increase the data fidelity and accuracy. In addition, sensors need to collect additional data on the operational scenario so that contextual information can be used in algorithms. New sensor development was considered as an option though of a slightly lower priority due to the expense of developing a new sensor. If this option is to be pursued then the development should center on multimodal sensor packages and/or sensors that exploit observables across the spectrum. Algorithm development needs to address the technology associated with other sensing modalities beyond the LWIR, examine the use of multiple modalities for characterizing soil disturbance, and investigate methods to use operational contextual information to optimize detection performance. Continuing research with current sensor data fusion approaches as well as the development of new fusion approaches needs to be pursued to aid the detection approaches.

Future research across all of these areas should be linked together. A thorough and systematic research and development program is needed to provide a comprehensive and deployable solution for the successful exploitation of disturbed soil observables.

3 Background

3.1 Previous Efforts

The Hyperspectral Mine Detection Phenomenology (HMDP) Program's report (March 1999), "Spectral Mine Detection Study," reviews an extensive field spectral signature data collection on buried mines under different conditions. The reflectance and emissivity of buried mines and backgrounds were measured from 0.35 to 14 µm. The objectives of the study in addition to measuring the signatures were to determine the signature discriminants between mined and unmined soil, identify the phenomenology behind the spectra, and recommend sensor and algorithm development. This program was funded by NVESD.

Four US and two foreign sites were chosen for the measurements: Ft. A. P. Hill, VA, Milan Army Ammunition Plant, TN, Ft. Carson, CO, Ft. Bliss, NM, Sarajevo, Bosnia-Herzegovina, and Jordan River Valley, Jordan. At each U.S. site mines were buried in a mature soil area, a low vegetation area, and an engineered area (e.g. gravel road). The mines were buried at one day, two weeks, and four weeks prior to spectral measurement, giving rain and wind a chance to weather the surface. The foreign sites provided the opportunity to measure spectral characteristics of live minefields and long-term minefields (the minefield in Jordan dated from 1968).

The spectrum was divided into five sections for analysis: VNIR (0.35-1.0µ), SWIR (1.0-2.5µ), MWIR (3-5µ), LWIR (8-14µ), and LWIR3 (8-10.5µ). A difference between the disturbed and undisturbed soils was seen at all test locations and in all five spectral regions. Reststrahlen features for quartz, plagioclase feldspar, and calcite were observed in certain soils. In addition, spectral features due to chlorophyll, water, carbonates, ferric oxides, gypsum, hydroxyl, and cellulose were identified. Changes in soil particle size, surface roughness, and stressed vegetation over the buried mine could be observed as changes in the reflectance and emissivity of these features. The change in the quartz reststrahlen feature was shown to be the key spectral feature to distinguish disturbed from undisturbed soil. Overall, it was determined that the VNIR, SWIR, and LWIR regions showed the most potential for discrimination identification.

The phenomenology findings led to specifications for algorithm and sensor development. It was a goal of this report to initially identify methods to find minefields with a further goal of finding individual mines. Four types of algorithms were identified that show the greatest potential for minefield detection: a spectral matched filter, a fully-adaptive constant false alarm rate detector, a spectral background clustering based detector, and a spectral unmixing algorithm. The sensor performance was considered based on the platform requirements, spatial requirements, and spectral requirements for both the VNIR/SWIR and MWIR/LWIR regions.

Based on findings of this study, the report recommended further data collections at additional test sites. These collections would allow further analysis of spectral data, and allow incorporation of imaging of the VNIR and LWIR regions.

An extensive history of programs related to mine detection exists with funding and research extending back over 50 years. Programs by the US Army, US Navy, and DARPA over the past 30 years have examined various sensing modalities to detect landmines in a variety of operational environments. Similar studies to the one above, i.e., related to disturbed soil detection, have been funded by DARPA: *Hyperspectral Mine Detection* and NVESD: *Hyperspectral Measurements for Mine Detection* over the past 15 years. The focus of these programs has been the exploitation of the reststrahlen effect. Exploitation and development of other sensing modalities has also continued during this time (e.g., ASTAMIDS).

4 Workshop Review

The workshop employed both technical presentations and discussion groups to meet the primary objective of re-examining disturbed soil phenomena and related research. Three secondary objectives were identified and used to guide the discussions during the workshop. These objectives included benchmarking the current state of disturbed soil research, identifying new research approaches, and identifying obstacles to pursuing these new research directions. Technical presentations provided background information to the attendees; the presentations were given during the mornings of the first two days of the workshop.

Three breakout discussion groups were setup and attendees divided between these groups. Groups were setup for the following topical areas: *Near Surface Soil Phenomenology*, *Sensor Technology*, and *Algorithm Development*. Discussions in these groups were stimulated by addressing the questions listed in Table 5. Attendees were encouraged to move between these groups to provide “cross fertilization” of ideas and approaches as well as to bring different perspectives to each breakout topic (e.g., “phenomenologists” in *Sensors* discussion group, “algorithm developers” in *Phenomenology* discussion group, etc). A discussion lead was selected for each breakout discussion group to conduct and direct the technical discussions and to provide a summary of the findings from each group. Those leads were: *Near Surface Soil Phenomenology*: Mr. Gary Koh, ERDC; *Sensor Technology*: Mr. Thomas Berry, ERDC; *Algorithm Development*: Ms. Miranda Schatten, NVESD.

4.1 Presentations

The presentations listed below were given at the workshop. Presentations covered phenomenological aspects of disturbed soils, algorithm development, and applications. They provided the attendees background material for the discussions during the breakout sessions.

Diego Balcazar, *'Using the Disturbed Soil Finder (DSF) to Search for Buried Hazards'*

Jeremy Bolton, *'Context-Based Approach for Discrimination and Recognition of Disturbed Soil and Subsurface Targets'*

Ronen Boroda, *'Sedimentological, Pedological and Spectral Characteristics of Talus Chronosequences and Loess Deposites – Negev Desert, Israel'*

John Eylander, *'The Land Information System: A New Common Infrastructure for Surface Characterization'*

Stacy Howington, *'Computational Support for Detection of Landmines and IEDs'*

Gary Koh, *'Investigating Disturbed Soil Properties and Processes'*

Zhiqu Lu, *'Acoustic Study of the Disturbance of Soil Properties due to Weather Effects'*

Eric MacDonald, *'Integrated Terrain Forecasting for Military Operations'*

Jason McKenna, *'Disturbed Soil Meteorological Phenomenology'*

Dennis Menning, *'Multi-Optical Mine Detection System (MOMS)'*

Carlos Santamarina, *'Near-Surface Soils – Signatures'*

Miranda Schatten, *'Wide Area Airborne Minefield Detection (WAAMD) Program and Disturbed Soil Work'*

James Staszewski, *'Characterization of Landmine Signatures for Visual Detection: Status Report'*

Alan Thomas, *'When Bad Results Happen to Good Methods'*

Edwin Winter, *'A Revised Model for the Spectral Signature of Disturbed Soil and its Potential Exploitation for Mine Detection'*

Alina Zare, *'False Alarm Reduction Using Vegetation Mapping for Disturbed Soil Detection in Long-Wave Hyperspectral Imagery'*

4.2 Phenomenology

4.2.1 Summary

The phenomenology of disturbed soil detection requires understanding the contrast in soil properties and processes between the disturbed and undisturbed soil. These properties include mineralogy and grain size, bulk density, water content, etc. These physical properties of soil drive the electromagnetic, heat and mass transfer, and mechanical properties of the soil that impact the signatures detected by remote sensors.

Soils have been studied by geologists, geophysicists, and civil and construction engineers. These studies have largely been carried out for several purposes: to understand physical /mechanical; properties relating to long term changes in the earth's crust; to locate minerals and oil deposits, or to determine where and how to build stable structures. Surface signatures have been studied largely to gain a better understanding of agriculture, environmental impacts, and mineral distributions and to gather intelligence on human activity. Formal investigations into disturbed soil signatures for military purposes have been few until several years ago (e.g., DARPA & NVESD investigations during the 1990's).

The workshop participants discussed in detail only a few phenomena, listed below, that have been linked to signatures that would relate to finding disturbed soils or soils which may contain articles of interest. Disturbed soil phenomena include:

Signature Phenomena: *Reststrahlen, LWIR signature changes in soil*
Associated Soil Physics: *Change in the size distribution of particles in disturbed soil*

Signature Phenomena: *Thermal IR imaging indicates temperature distribution signatures*
Associated Soil Physics: *Changes in effective thermal conduction and heat capacity leading to dynamic changes in temperature with diurnal cycle*

Signature Phenomena: *Differential reflectance with respect to surrounding soils as observed by imaging radar*
Associated Soil Physics: *Surface roughness changes due to soil disturbance; possible mineral content changes in the surface soil*

Signature Phenomena: *Acoustic / Seismic signal changes*
Associated Soil Physics: *Changes in speed of sound in disturbed soil, foreign objects reflectance, and acoustical resonances associated with articles of interest*

Signature Phenomena: *Long term temporal changes in EO-IR and RF soil signatures (e.g., changes in particle size distribution)*
Associated Soil Physics: *Precipitation, bio-changes, temperature cycling, radiation*

Signature Phenomena: *Frost patterns over buried articles*
Associated Soil Physics (hypothesized reasons): *Thermal property changes; water pooling over buried article; moisture content difference of*

disturbed soil; particle size changes allowing for nucleation of water crystals

Additional Signature Phenomena (speculations): *Changes in blue band signatures; possible chemical signatures; moisture content changes (NIR measurement?)*
Associated Soil Physics: *differential soil moisture movement, TBD*

In addition to these direct disturbed soil phenomena, soil disturbances of interest are expected to fall within certain size envelopes (e.g., landmines, tire tracks). Disturbances spread over large fields may show patterns that are indicative of manmade versus natural activity. Other surface scarring may indicate human activity in the area. These disturbances taken together with other surface patterns may indicate an area of military interest. Consideration of these observations could be exploited and aid the development of algorithms (e.g., changes in certain levels of entropy in an image).

In considering the study of phenomena related to this problem, it is worth noting that some discussions emphasized that "Disturbed Surfaces" may be an alternate classification of the issue; this more general classification would allow inclusion of "disturbed vegetation" and "disturbed rocky surface" also.

4.2.2 Research Barriers

Diverse points of view were presented during the discussions on the phenomenology of disturbed soil. For example, the definition of "disturbed soil" differed depending on the background of he individual responding to the question. This diversity led to a general discussion beyond the questions initially proposed. Specifically, this discussion sought to outline more fundamental issues and approaches relevant to this problem; the particular issues included:

(1) Defining exactly what is meant by "disturbed soil"
    Is it a mechanical effect only?
    What properties of the soil are disturbed?

(2) Identifying the processes that create disturbed soil
    Is it sufficient to consider only "burying" as the creator of disturbed soil?
    What other processes create "disturbed soil"?

(3) Determining which soil properties that must be measured

(4) Determining anticipated signature changes for disturbed soil

(5) Field verification of laboratory measurements and model results

These questions represent the barriers to research efforts in this area. These questions and surrounding discussion indicated the need for research in two areas: (1) fundamental studies into the general nature of disturbed soils, and (2) applied investigations that address military operational needs. The first area is needed to address the issues raised during the general discussion. These issues speak to the need to understand the details of soil properties and interactions and the impact of external forces on those properties. An understanding of these effects will provide a means to classify soil disturbances and potentially provide a means to separate natural and manmade disturbances from each other. The second area addresses the more immediate need to understand the impact of manmade disturbances on soil properties. In this case, studies of soil disturbances created when landmines, IED's, etc are emplaced would be of immediate interest to military operations. A variety of processes would be of interest in this case including digging, vehicle tracks, and footsteps.

Additional topics of importance discussed during these sessions included methods to ascertain which soil properties (mechanical, thermal, acoustic, seismic, etc) were changed by the disturbance processes and methods to measure/monitor the impact of environmental processes (moisture, rain, freezing/thawing cycles, wet/dry cycles, etc) on soil properties. The former topic addresses the tie between the disturbed soil and the particular sensor modality that would observe a change in the soil. Specifically, a soil may appear disturbed in one modality and not in another. For example, compressing soil may change the seismic properties while having little or no impact on optical properties. The latter topic addresses the issue of natural processes and aging of disturbed soil. The persistence of the disturbed soil signature is an important question that has yet to be adequately addressed. The effect of rainfall, wind, and other environmental driving forces are not well-understood. The wide range of soil conditions make the persistence problem even more difficult to understand.

Changes in disturbed soil signatures occur over time. Determination of when these changes occur in the disturbed soil signatures can lead to establishing the "age" of a disturbed soil area. This information, in turn, would be valuable in determining when the disturbance occurred and serve as another potential discriminant for dangerous versus benign soil areas. Understanding the specific processes and their levels of contributions would enable a potential link between macroscopic events (e.g., rainfall, wind) and the level of change anticipated in the disturbed soil area. The time scale of these changes has only been examined at discrete intervals (i.e., measurements made every few weeks). Details on the how these temporal changes occur and what exactly is changing over these periods is therefore lacking.

Classification of a soil depends on its constituents not on its sensor observables. Thus, it can be expected that a sensor viewing such a supposedly homogeneous area, i.e., an area classified as a single soil type, will not see it as a homogeneous area. Instead the sensor will record signature variations appropriate to its modality due to the variation in the corresponding soil physical properties across that area. These variations in physical properties arise from several sources: differences in underground properties, random variations in soil constituents, differential impact of macroscopic processes (wind, rain, animals, etc) across an area, etc. These signature variations are difficult to predict in a deterministic manner. Thus, statistical approaches are needed to aid both the understanding of the disturbance process and the development of robust detection algorithms. Some information on surface variations has been collected but it is insufficient to comprehensively address the issue.

The consensus view point of the individuals involved in these discussions was a need to get "back to the basics" and to employ new methods/approaches to address this problem (i.e., "think outside the box").

4.3 Sensors

4.3.1 Summary

Discussions during this breakout session focused on reviewing a variety of sensing modalities that have been employed in various forms to exploit disturbed soil. Table 1 lists the various sensing modalities considered during these discussions. These sensors are at various stages of development and maturity; they span the gamut from existing operational sensors to developmental sensors. None of the operational sensors were developed specifically for disturbed soil detection.

Table 1 Current Sensor Technology

Ground Penetrating Radar	3rd Gen Image Intensifier
Synthetic Aperture Radar	Acoustic
V/NIR Imagers	Seismic
SWIR Imagers	Chemical
MWIR Imagers	Animal (odor detection)
LWIR Imagers	Human vision
LIDAR	Computer Vision
Hyperspectral Imagers	Multi-spectral Imagers

Hyperspectral sensing of disturbed soil has received much attention over the past 15 years due in large part to DARPA, NVESD, and ARO research programs. Much work in this area has focused on reststrahlen detection of disturbed soil as this phenomenon has exhibited both robustness and persistence. In particular, the specific reststrahlen feature of interest is present across large geographic areas due to the presence of silica in most all surface soils. Other spectral techniques are not as mature; i.e., backscatter enhancement, spectral reflectance in the near blue wavelength region. These optical techniques rely on the presence of certain soil properties. For example, current reststrahlen detection techniques require quartz bearing soils under relatively dust free conditions.

Multispectral approaches to the detection of the reststrahlen effect have received increased attention over the past several years. Hyperspectral sensing requires the collection and processing of a large volume of data; much of which may not be needed for disturbed soil detection. Multispectral sensing (particularly in the LWIR) is seen as a solution to this problem; a small number of spectral samples are required with a corresponding reduction in the data processing needs. The NVESD WAAMD program has focused significant resources in this area over the past several years to determine which spectral bands would be most useful for this purpose.

Numerous visual cues are associated with disturbed soil; these cues include color differences, texture changes, and size. As a consequence, visual detection of disturbed soil has also been pursued. Various imaging sensing modalities utilizing operational sensors (e.g., cameras, image intensifier devices) have been employed in this work. Algorithms for disturbed soil detection based on visible contrast have been developed and were presented at the workshop. Human detection of these disturbed soil areas has shown particular promise. However, taking advantage of these visual cues is still a challenge for automated target detection.

A significant limitation of optical techniques is the soil volume of the disturbances sampled by these sensors. Specifically, optical sensing samples the disturbance impact only on the surface, i.e., the penetration depth is minimal. Therefore the optical effects can be masked by carefully grooming the soil surface or by creating false alarms through simply raking the soil.

Lidar data have been collected on disturbed soil samples. To date, they have been shown to be of limited utility in detecting or characterizing soil disturbances.

Thermal measurements have shown some promise; these measurements can under certain conditions see differences in surface temperatures between disturbed and undisturbed soils. In fact, recent field tests conducted at multiple locations have shown that infrared imagers can be used to detected disturbed soil. Infrared imaging techniques appear to be superior to reststrahlen detection approaches; this is particularly true on roads where false alarms due to vegetation, rocks, etc are not an issue. In addition, disturbed soil areas due to IED emplacement can be large so false alarms are reduced (this is in contrast to mine detection). Also the infrared signature of disturbed soil can persists for months. Thus thermal detection of disturbed soil is now being explored as a feasible detection approach and is being explored in theater.

One of the limitations of thermal infrared techniques is the diurnal cross-over periods. However, the occurrence of these cross-over times can be adequately predicted using models. On the other hand it is not clear when and under what conditions the temperature difference between disturbed and undisturbed soils is the largest. During a single day this difference can be negative, positive, or negligible; it depends on many factors including soil moisture, time of day, amount of energy received, degree of soil disturbance, soil hydraulic properties, soil thermal properties, etc. Many of these properties exhibit some level of dependence and operate simultaneously. The capability to understand these complex interactions is missing.

Experimental data, though limited, suggest the potential for radar detection of disturbed soil. A review of previous ground penetrating radar (GPR) data suggests that surface reflections from soil above buried land mines are different from the surroundings. In addition, field test have also shown that high-frequency radar can detect the surface roughness contrast between disturbed and undisturbed soil. Further field work is needed with these sensors to determine the effectiveness of radar-based sensing for disturbed soil detection.

Acoustic and seismic detection of disturbed soil may also be possible. Again, results to date have been limited to testing done under controlled field conditions. Additional field work is needed to determine the potential for these sensing modalities in this application. In particular, studies are needed to determine the detection range possible with acoustic or seismic techniques.

4.3.2 Research Barriers

Discussions during this breakout session also focused on the perceived shortcomings of current sensor technology and what barriers existed that inhibited either sensor performance or advancement. These barriers covered three areas: technology, operational, and programmatic. Table 2 lists the technology-related barriers that were deemed to limit the effectiveness of sensors in detecting and characterizing disturbed soil regions.

Table 2 Sensor Technology Research Barriers

Barrier	Sensor Type	Comments
Pixels on target	Imaging	More pixels on target yields improved detection/identification
Bandwidth	RF	Deeper penetration with lower frequencies
Spectral Resolution	Spectral	Better separation of spectral features
Acquisition Range	All	Disturbed soil signals may be faint
Data logging	All	Recording of relevant ancillary data to improve sensor performance
Data transmission	All	Current communication bandwidths limit transmitted data volume
Post-processing	All	Computational resources and algorithm complexity limit speed of calculations.

Operational barriers in this context constitute the environmental factors that limit the operational performance of sensors. These factors focus primarily on propagation effects (attenuation, path radiance, turbulence, etc) which limit the detection/acquisition range of the sensor. Active sensors such as radar sensors can overcome some of these issues through an increase in radiated power but at a cost of an increase in system size, etc. Current optical and thermal sensors are passive sensors and thus must operate within the existing meteorological conditions.

Illumination conditions represent another environmental effect and prove relevant to optical sensors as they determine relative contrast differences and spectral signal content needed for target detection and identification. In addition, the acquisition conditions can lead to shadowing conditions that can inhibit discrimination functions. The impact of these conditions can be mitigated through appropriate selection of data collection times. Active illumination provides an additional means to overcome natural lighting limitations. No research activity was described that addressed the use of active EO-IR illumination for this purpose.

Diurnal heating cycles impact the operation of thermal sensors. While well known, this effect is still relevant to the discrimination capability of this sensing modality especially given the emphasis placed on the reststrahlen and thermal detection of disturbed soil. Thermal crossover times present contrast problems that constrain the operational times for thermal sensors.

Programmatic issues relate primarily to cost to develop new sensors and operate existing sensors. High development costs for new sensors require existing sensors be employed for disturbed soil data collection when they may not be optimally designed for this “target”. In addition, the demand for these sensors limits their availability for data measurements efforts. This either delays data collections or eliminates the sensor from the effort. Finally the development and operational deployment timeline for a new sensor tailored to a specific problem is on the order of years. This lengthy development period and corresponding expense forces sensor designers to develop sensors that meet general rather than specific target requirements.

4.4 Algorithms

4.4.1 Summary

Over the past 15 years, algorithm work related to disturbed soil has focused primarily on the exploitation of optical and spectral long wave infrared data. In addition, algorithms based on visible contrast have been explored and developed (several of these were presented at this workshop). Two major research efforts during this period were funded by DARPA and NVESD. These programs on landmine detection explored several algorithmic approaches to landmine and disturbed soil detection; these approaches focused primarily on the EO-IR spectral region and investigated discrimination techniques based on thermal, spatial, and spectral discriminants. Algorithms based on the first two discriminants typically showed relatively poor performance when each discriminant was employed alone.

Thermal differences between the disturbed soil above a landmine and the surrounding area exist but the corresponding thermal discriminant-based algorithm generated a large number of false alarms. These false alarms arose due to the location-to-location variation in the landmine thermal contrast, temporal variations in the thermal contrast and background clutter thermal contrast which typically generates similar thermal contrast variations.

Buried landmines possess size, shape, and texture features that provide potential discrimination features for detection algorithms. Current thermal imaging cameras generate thermal imagery that possesses the necessary characteristics to examine these features for discrimination purposes. Under the DARPA and NVESD programs, spatial processing was found to improve landmine detection over thermal contrast discrimination. This improvement occurred through both size/shape detection of landmine areas and reductions in false alarms through the imposition of size constraints in the detection process. Nonetheless, issues arose due to the variability of the spatial signatures across the target set (i.e., landmine size variation), the local site, and the geographic locations. These considerations create issues with the predictability and consistency of the spatial signatures (e.g., weak thermal contrast, variable shapes, etc) leading to missed detections and increased false alarms.

Spectral discriminants focused on the exploitation of the spectral variation in emissivity created by the soil disturbance process. These two research programs were specifically devised to investigate this effect in more detail. As a consequence, significant effort was placed on both the data collection across various soil types and regions and on the spectral processing. Various reports and papers have been produced that describe the results so they will not be reproduced here. It suffices to say that spectral processing provides the most promising approach to disturbed soil detection as it relates to landmine detection. The major issue for these methods is the marginal separation of the disturbed soil and background spectral features. Separation of these two spectral classes requires employment of nonlinear classification and detection techniques.

More recently, NVESD, through the WAAMD program, has investigated the detection performance of algorithms based on optical, infrared, and radar sensors – both as single sensors and through data fusion. Data from several field tests have been used to test and grade the performance of these algorithms. Most of the optically-based approaches have been based on exploiting airborne-collected, spectral long wave infrared data. Though these investigations have focused on landmine detection (and later IED's) disturbed soil detection has been a factor in these investigations. Table 3 lists various types of landmine detection algorithms under two general categories – trained and untrained.

Table 3 Landmine Detection Algorithms

Untrained Algorithms	Trained Algorithms
RX anomaly detectors	Support Vector Machine
HMD spatial algorithm	Relevance Vector Machine
Reststrahlen Ratio Test	Kernel Based Methods
Stochastic Target Detection	Invariant subspace
Fully Constrained Least Squares	

WAAMD established different performance levels and used these levels to grade the overall performance of these algorithms. For optically-based algorithms, this comparison indicated that, in general, signature-based methods work best over anomaly-based approaches. The main drawback to signature-based methods is that they require training data taken in the local area of interest. Anomaly-based methods, on the other hand, have the advantage of working directly on any data set without prior training data. Their main drawback is the number of false alarms. These false alarms can be significant for disturbed soil detection due to the spatial variability inherent in soils. For anomaly detectors, the STD outperforms RX-based approaches.

In addition to the research efforts outlined above other investigations related to landmine detection have also been conducted. In particular, additional algorithms for disturbed soil detection have been explored under various NVESD mine detection programs.

It should be noted that these results came from the landmine community and focus on that specific problem. In this case the geometry of the landmine aids the performance. Algorithms focused solely on disturbed soil as a target may have slightly different results due mainly the different militarily-significant actions that can generate disturbed soil, i.e., digging, vehicles, walking, etc.

Despite the results obtained in these earlier studies, thermal detection of disturbed soil is now being explored as a feasible detection concept in theater. Observations from thermal sensors in the field have led to a re-examination of this particular discriminant feature. Theater-specific measurements are being conducted to better understand in detail these observations. Results from these efforts are pending.

4.4.2 Research Barriers

Development of robust algorithms requires a substantial amount of well-documented field data covering the range of operational environments where the algorithms will be expected to operate. These data provide information on target signature variations within and across the various environments as well as clutter statistics and false target/alarm sources. Frequently these data are obtained in locations that do not replicate operational scenarios or conditions. As a consequence algorithms become "optimized" for the wrong environments. For algorithms that require training, this limitation has more impact since they depend on the availability of a priori target signatures and training data in relevant contexts.

Well-documented data sets are needed from the locations where military operations will be conducted. Well-documented in this case varies with the sensor and algorithm(s) but in general it can be inferred that it means, at a minimum, ground truth data on targets, detailed meteorological data, geo-registration of data, and comprehensive sensor information.

Many detection methods are limited by the requirement of high spatial resolution. In this context, this requirement characterizes the number of pixels on target versus the ground sampling distance. In part, this issue arises due to the fact that the variation in the background clutter can overlap the disturbed soil signature. More pixels on "target" allows the disturbed soil signature to be spatially separated from the background clutter (given enough signal is present). In addition, high spatial resolution allows better operation of shape-based algorithms.

Algorithms are often limited by the signal to noise ratios of the sensors. This limitation becomes particularly acute for the detection of objects in soil or for characterizing disturbed soil because the physical property distributions between the two classes (disturbed vs. undisturbed) tend to substantially overlap. Thus the differences in the resulting signatures, using any sensor, are typically small. Noise levels in the sensors infringe into these small signals and add to the difficulty of separating the object of interest from the background.

From a historical viewpoint, most of the algorithm development in detection has focused on hyperspectral LWIR data. This single sensor focus has imposed a restriction on the ability of algorithm developers to examine, in detail, other sensing modalities for detecting objects in soil or for characterizing the disturbed soil phenomena through other modalities.

Sensor data fusion has long been held up as a solution to the landmine detection problem, particularly across the wide range of expected operational environments and conditions. Unfortunately, research in multi-sensor data fusion is limited by the availability of multimodal sensor data. This limited availability means that the resulting sensor fusion approaches are developed from a restricted set of data and are typically "tuned" to that data set. The ultimate consequence of these limited data sets is that the algorithm performs well in a very limited operational context. Collection of multi-modal sensor data presents unique challenges as one must provide ground truth across the entire sensor set.

5 Research Directions

5.1 Phenomenology-related Research

A first step in moving forward should be to categorize soil types or surface types and prioritize the study of these types according to value of understanding to the government. Methods for sample collection, storage and transport should be developed that will maintain moisture content and other characteristics. “High priority soil” samples should be provided by the government to labs for studies. Meteorological data for high priority operational locations should be provided as well. Characterization of these high priority soils should be conducted and the outputs, along with physical characteristics of devices should then pass to computational modeling efforts.

At a more fundamental level, research is needed that examines the basic process of disturbing a soil. In particular, investigations are needed that consider the various processes that impact/change soil properties and characteristics, and determine the effect these changes have on soil observables. Both manmade (e.g., digging, etc) and natural (e.g., precipitation, etc) processes should be considered since it will ultimately be important to determine if manmade processes produce different observable changes than natural processes, thus providing a means to separate the two. Relative magnitudes of these processes will also be important as this will determine the contribution level each process has, if any, to the disturbed soil signature. This information can also aid the study of the temporal evolution of soil signatures, both disturbed and undisturbed.

The temporal evolution of disturbed soil properties was identified as a key research area that requires future investment. These studies require both laboratory and field experiments. Laboratory experiments would allow us to systematically investigate this area by careful control of the different environmental conditions and particular soil characteristics as well as to artificially speed up the soil aging processes. Field experiments should include diverse soil types and environmental conditions to increase the breadth of the laboratory results. Field tests will require in-situ soil measurement techniques that minimize soil disturbance. In-situ techniques are needed to characterize both the disturbed and undisturbed soil in their natural state. Long term studies are needed that employ multiple sensor modalities to capture these temporal changes across all the sensors of interest.

Simulation efforts on weathering conducted in laboratories, as well as field studies should help to define what happens with aging of the soils in terms of particle and mineral redistribution with time. Such studies should include simulated explosive and other devices to see if the presence of these devices alters these changes. Simulants might also shed light on the nature of water penetration and migration with and without devices present.

In addition, the various physical properties of soil typically feature high spatial variability which can affect performance of all sensors. Techniques are needed to characterize these lateral properties of soil; these techniques should possess high lateral resolution, be performed quickly, and require simple interpretation. A research team with expertise in both soil and near surface geophysical methods will be needed to adequately address this issue.

Complex numerical models of soils that include the various physical processes (e.g., thermal, hydraulic, mechanical, etc) and disturbances are needed. These models would enable comprehensive analyses to be conducted to understand the impact of various physical parameters on soil signatures and to determine the optimal viewing conditions for different sensing modalities. Validation of these models will be critical to insure the accuracy of the results and acceptance by the operational community.

Several additional areas for phenomenological-based research include the impact of soil disturbance on vegetation stress, understanding the biological component in soil and the effect of the disturbance process on this component, the effect of organic components on soil aging, and the influence of different surface topologies on disturbed soils. For soil measurements, it will be important to understand and compensate for the impact of probes for one soil characteristic on other soil measurements/properties.

5.2 Sensor-related Research

For the sensor area, the most promising sensors should be studied in combination to see what incremental improvements to the detection and false alarm performance (i.e., the ROC curve) can be obtained under different acquisition conditions. Use of orthogonal data sets should allow one to optimize the benefit / cost ratio. This analysis will require data sets from the same field site at the same time. The study should also examine the use of data sets that are separated in time and under different conditions to study performance degradation. The field site should allow for registration of spatial information. One critical aspect of this effort would be to define what constitutes orthogonal data sets.

Hyper-spectral information in the LWIR has proved valuable and should be expanded to include other EO bands including the UV, Visible, NIR, SWIR and MWIR. Again, these studies should be conducted in combination with other sensing modalities to determine the incremental or combined value of adding different data sets together to improve the area under the ROC curve vs. cost.

Sensors from different communities should be examined as a part of this process. Communities such as Homeland Security, mining, and tunneling may provide different sensors or modalities that may benefit the detection and characterization of disturbed soil.

Additional sensor development should also be explored during this process. Existing sensors may not provide enough information or the correct data to optimize the detection of objects in disturbed soil. New sensing modes and modalities may be required. Potential sensing modalities presented at this workshop that may aid this detection problem include high range resolution ground penetrating radar (HRR GPR), active acoustic sensors, and polarization sensing. Passive acoustic sensors that exploit environmental noise have been proposed but untested. Though existing LIDAR data has been of limited benefit, advanced LIDAR sensors may possess the necessary capabilities to improve detection performance.

Each of these sensors must meet certain requirements in order to contribute new information/data to the detection problem in an operational scenario. For example, the spatial resolution requirement on a HRR GPR sensor was deemed to be 1-cm at a standoff range of 1000 meters. As a second example, a polarization sensor must provide the full Stokes Matrix in an imaging format. Each requirement and sensor needs to be fully explored under the appropriate field conditions to determine exactly what data is needed and its characteristics. Table 4 lists some general requirements (in no particular order) discussed during the Workshop that should be considered during the conceptual design and development of new sensors. Packaging requirements covered the gamut from man-portable systems to vehicle-mounted systems. An important and significant "requirement" from the operational community was the need to engage the operational user early in the design process to determine his actual requirements.

Table 4 General Sensor Requirements

Packaging
Communication Bandwidth
Geospatial Registration Capability
Temporal Registration Capability
Cost
User Friendly
On-board Processing
Data Archiving (off sensor)

Operational studies should also be conducted. Frequent surveillance of sites should be conducted to determine the value vs. cost of monitoring changes from day to day with various sensors. Static images may yield a given ROC, while comparing an image to what the same site looked like yesterday may dramatically increase detectivity, i.e., change detection approaches.

If possible a common test bed should be used to evaluate the potential for multiple approaches for disturbed soil detection. A test bed of this type would provide a common benchmark against which all sensor modalities could be fairly compared. Ground truth and environmental data would need to be measured and recorded to enable accurate studies of sensor performance as a function of acquisition conditions.

5.3 Algorithm-related Research

Discussion of algorithm research directions covered all aspects of the detection problem. These aspects included requirements for phenomenology measurements, changes in sensor performance, development of new sensor packages, improvements in operational data collections, and new approaches to algorithm development. In addition, the contribution of computational models to the algorithm development process was discussed and considered relevant to that process.

On the phenomenology aspect, collection of sensor data from various regions around the world was considered a critical need. These data were required for several uses: algorithm development algorithm testing and training data. Hyperspectral LWIR approaches would benefit from spectral data collections for the current theater of operations, i.e., the various regions of Iraq and Afghanistan. These data need to incorporate vegetation, rocks, roads, etc (i.e., clutter objects). Algorithm improvements would result from data collected during soil weathering experiments.

Sensor improvements focused primarily on enhancements in sensor performance. These recommended enhancements included the collection of higher spectral resolution data, higher spatial resolution sampling, and better signal to noise ratios (i.e., improved sensor sensitivity). All of these enhancements require new component technology developments or the incorporation of more costly components. In either case, the need is for an investment in sensor technology. Sensor fusion efforts require the development of a multimodal sensor package; data from this sensor package will prove important for both the creation of large multimodal data sets and, more significantly, the advancement of fusion research. Finally, the collection of ancillary or metadata will support the development of algorithms that will exploit scene context information to optimize algorithm selection during theater operations. This ancillary data will include time, location, and weather data; other sensors could also serve as potential data sources.

Operational considerations to aid algorithm performance would include development of appropriate CONOPS (concept of operations) for specific algorithms to restrict use of those algorithms to those operational conditions and environments where they operate best. Specific recommendations would need to be developed for each algorithm to define those conditions and to define what “best” means in this context. Research will be needed to implement this concept. Another aspect from the operational side would be to have the operational conditions conveyed to algorithm developers so they could be used during the development of algorithms.

Computational models were considered as an additional element in the research process that could aid the development of effective and robust detection algorithms. Weathering models that predict changes in the soil signature over time would provide a method to characterize signatures obtained in the field more completely, perhaps enabling the identification of suspicious areas and elimination of benign areas. Predictive models of the reststrahlen effect, when used in conjunction with ancillary soil information, would enable algorithms to predict disturbed soil signatures across a variety of terrains. Finally, the development of a general disturbed/undisturbed soil signature model that encompasses multiple sensor modalities would provide linkage for multimodal sensing approaches.

Algorithm research needs to focus in several areas to provide the improved detection performance in operational scenarios. First, more emphasis needs to be placed on developing approaches that use both spatial and spectral information together. This was seen in the earlier DARPA and NVESD programs of the 1990’s but more work is needed here. Texture information needs to be exploited as well as higher order statistics especially with high spatial resolution sensors. More advantage needs to be taken of contextual information in order to select either the appropriate parameters for an algorithm(s) or the appropriate algorithm(s). Creation of a “master” algorithm would be of interest as it could codify the selection methodology for the sensor(s). This methodology would utilize contextual information, target type, acquisition conditions, and other data to make the appropriate selection. Finally, work needs to continue in the sensor data fusion area. While progress had been made here under WAAMD and other programs, more development work is needed. One area of particular emphasis would be the determination of what data, in a multimodal sensor environment, is needed to improve the detection performance, i.e., what is the missing data link.

6 Summary

This workshop was held with the intent of taking a new look at the disturbed soil problem. The sponsors (Army Research Office, Night Vision and Electronic Sensors Directorate, and U.S. Army Corps of Engineers Engineering Research and Development Center) agreed that, after several years of intensive research by various DoD organizations it was time to see what this research had yielded and where future research programs should focus. These objectives were particularly relevant given the current operational state of affairs in Iraq and Afghanistan (i.e., roadside bombs, IED's, UXO, etc) and the belief that future conflicts will need to deal with similar asymmetric warfare issues.

More than 45 researchers from government, industry, and academia met at the Georgia Tech Research Institute in Atlanta, GA for this 2-1/2 day workshop to discuss this topic. The format consisted of technical presentations during the morning of the first two days followed by a breakout into discussion groups in the afternoon of those days and the morning of the third day. Breakout sessions were organized around three topic areas: near surface soil physics & phenomenology, sensor technology, and algorithm development. The technical presentations served to disseminate information on research and development activities as well as current technology applications related to disturbed soil detection. Discussions in the breakout sessions were focused on addressing three main areas: a review of the current state of the art, identification of barriers to current research efforts, and recommendations on future research directions. A set of questions was devised for each of these areas to help stimulate and guide these discussions.

Conference attendees used this discussion forum to air various ideas, approaches, etc on the three topics. It was evident, from these discussions, that there were several different viewpoints on the primary issues and the research way forward. The major differences arose along the traditional lines of basic research versus engineering development versus operational deployment. Though no solution to these differences was provided, insight was gained from these discussions into the major problems and how to proceed ahead in this area.

All participants agreed that the disturbed soil problem as it relates to the detection of hidden explosives, devices, etc requires additional, intensive research. On the phenomenology aspect, work is required that examines the basic physics of the disturbance process, identifies the impact of disturbance on all soil properties, and **identifies the observables in all sensor bands**. This last point is particularly relevant as a majority of the research and development efforts in recent years has focused on exploiting the reststrahlen feature changes in the LWIR. On the sensor technology aspect, consideration should be given to exploiting different sensor bands, improving sensor characteristics (i.e., sensitivity, ground sampling distance), and acquiring additional information from the scene under observation. Since new sensor development is costly, the approach summarized here focused on utilizing existing sensor architectures (with some improvements) as much as possible and using contextual information to improve the detection process, i.e., increase the detection of targets, lower the false alarms. On the algorithm aspect, research emphasis should be given to algorithm development that utilizes multimodal sensing and scene contextual information. Multimodal sensing exploits the potential for different aspects of the soil disturbance being observable across multiple sensor bands/modalities. It will necessarily build from new phenomenology research. Algorithms exploiting contextual information (e.g. soil type, time of day, surface conditions, atmospheric data, etc) would be valuable not only in improving detection performance but also in selecting the appropriate algorithm for the operational scenario. Enhancements to current sensor data fusion approaches and development of new fusion approaches lay at the center of this research area.

Future research across all of these areas should be linked together. A thorough and systematic research and development program is needed to provide a comprehensive and deployable solution for the successful exploitation of disturbed soil observables.

Discussion Group Questions

The table below lists the questions used in each group to stimulate and guide the discussion.

Table 5 Discussion Questions

Discussion Group	Questions
Near Surface Soil Phenomenology	*What signatures are typically associated with disturbed soil?* *What is the phenomenology (physical processes) associated with these signatures?* *Over what time scale(s) do these signatures change?* *What spatial scales are associated with these signatures?* *What physical and environmental processes impact these signatures?* *Is the impact of soil type and composition known? If so, what is it?* *What additional phenomenology associated with disturbed soil might be expected to generate a signature?* *What sensing modalities could be used to collect this signature?* *What "secondary" signatures might be expected (e.g., vegetation stress, water flow, …)?*
Sensor Technology	*What sensors & modalities are currently employed to detect "disturbed soil"?* *What are the data products from these sensors?* *Are these COTS sensors? If not, what were these sensors developed to do?* *What platforms are used by these sensors?* *What phenomenology is being exploited by these sensors?* *What factors (technology, environmental, etc) limit the performance of these sensors?* *Are sensors in development for disturbed soil detection?* *What is required to improve the sensor performance in the disturbed soil applications, e.g., better resolution, higher sensitivity, on-board processing, etc?* *What types of sensors or modalities will be needed for additional exploitation of disturbed soil?* *What are the requirements on these sensors or modalities?* *What sensors need to be a part of a multi-sensor package?* *What ancillary data is required to support disturbed soil detection?* *Can existing sensors provide this data? If not, what*

	sensors are needed?
Algorithm Development	*What algorithms are currently used to exploit disturbed soil?* *What are the data requirements on these algorithms?* *What is the performance of these algorithms?* *What fusion methods have been used? How effective are they?* *What are the factors limiting the performance of these algorithms?* *What additional data is needed to test the algorithms or to improve the performance? Can time series data help?* *Can models aid either the algorithm development and/or performance?* *What types of models would be needed? Model requirements?* *What sensing modalities could potentially improve detection performance?* *What new fusion approaches could potentially improve detection?* *What new data are needed to support future algorithm development and testing?*

Participants

Last Name	First Name	Affiliation	
Affleck	Rosa	US Army ERDC	Hanover, NH
Balcazar	Diego	Marine Corps Intelligence Activity	Suitland, MD
Berry, Jr.	Thomas	US Army ERDC	Vicksburg, MS
Bolton	Jeremy	University of Florida	Gainesville, FL
Boroda	Ronen	Ben-Gurion University	Israel
Broach	Tom	US Army NVESD	Ft. Belvoir, VA
Broadfoot	Seth	US Army ERDC	Vicksburg, MS
Caldwell	Todd	Desert Research Institute	Reno, NV
Cathcart	Michael	Georgia Institute of Technology	Atlanta, GA
Crabtree	David		
Daniels	Jeff	The Ohio State University	Columbus, OH
Eylander	John	HQ Air Force Weather Agency	Offut AFB, NE
Folks	Ray	University of Central Florida	Orlando, FL
Frankenstein	Susan	US Army ERDC	Hanover, NH
Harmon	Russell	US Army Research Office	Durham, NC
Harrell	Tim	Georgia Institute of Technology	Atlanta, GA
Hickey	Craig	University of Mississippi	Oxford, MS
Higgins	Todd	Lincoln University	Jefferson City, MO
Hintz	Kenneth	George Mason University	Fairfax, VA
Howington	Stacy	US Army ERDC	Vicksburg, MS
Kelley	Julie	US Army ERDC	Vicksburg, MS
Koenig	George	US Army ERDC	Hanover, NH
Koh	Gary	US Army ERDC	Hanover, NH
Kwon	Heesung		
Lane	Sarah	Georgia Institute of Technology	Atlanta, GA
Leonard	Carrie	BAE Systems	Honolulu, HI
Lu	Zhiqu	University of Mississippi	Oxford, MS
McDonald	Eric	Desert Research Institute	Reno, NV
McGill	Thomas	US Army ERDC	Vicksburg, MS
McKenna	Jason	US Army ERDC	Vicksburg, MS
Menning	Dennis	Swedish Defence Research Agency	Tumba, Sweden
Pappas	George	JIEDDO	Arlington, VA
Peixoto	Nathalia	George Mason University	Fairfax, VA
Peters	John	US Army ERDC	Vicksburg, MS
Robinson	Tito	National Geospatial-Intelligence Agency	
Sabol, Jr.	Donald	Desert Research Institute	Reno, NV
Santamarina	Carlos	Georgia Institute of Technology	Atlanta, GA
Schatten	Miranda	US Army NVESD	Ft. Belvoir, VA
Scott	Waymond	Georgia Institute of Technology	Atlanta, GA
Simunek	Jirka	University of California-Riverside	Riverside, CA
Staszewski	Jim	Carnegie Mellon University	Pittsburgh, PA
Stough	Ross	Applied Analysis Inc.	Billerica, MA
Thomas	Alan	Georgia Institute of Technology	Atlanta, GA
Wakeley	Lillian	US Army ERDC	Vicksburg, MS

Wert	Robert	Naval Research Laboratory	Washington DC
West	Tracy	Georgia Institute of Technology	Atlanta, GA
Wilson	Patrick	AEC - Counter IED	Arlington, VA
Winter	Ed	Technical Research Associates	Honolulu, HI
Zare	Alina	University of Florida	Gainesville, FL

Agenda

Army Advanced Concept Workshop on Disturbed Soil Characterization and Exploitation

Georgia Tech Research Institute Conference Center
January 15-17, 2008

AGENDA

Tuesday, January 15

0815	*Registration/Breakfast*	119B
0845	**Introductions & Workshop Overview**	Auditorium
0900	**WAAMD Program and Disturbed Soil Work** Miranda Schatten, CERDEC RDECOM NVESD	Auditorium
0925	**EO-IR Work in Iraq** Jason McKenna, US Army ERDC	Auditorium
0950	**Disturbed Soil Finder Software** Diego Balcazar, SSgt, US Marine Corp Intelligence Activity	Auditorium
1015	*Break*	119B
1045	**The Land Information System** John Eylander, US Air Force, HQ AFWA	Auditorium
1110	**Status of Ft. Leonard-Wood Measurements** James Staszewski, Carnegie Mellon University	Auditorium
1135	**Investigating Disturbed Soil Properties and Processes** Gary Koh, US Army ERDC	Auditorium
1200	*Lunch*	119B
1300	**Context-based Approach for the Recognition/ Discrimination of Disturbed Soil & Subsurface Targets** Jeremy Bolton, University of Florida	Auditorium
1325	**Breakout Session #1: Overview & Approach** ○ State-of-the-Art Assessment	Auditorium
1340	**Breakout Session #1**	119A/C/Auditorium
1500	*Break*	119B
1515	**Continue Breakout Session #1**	119A/C/Auditorium
1630	**Reassemble for Breakout Session #1 Reports** **Group Discussion**	Auditorium
1700	*Adjourn*	

Army Advanced Concept Workshop on Disturbed Soil Characterization and Exploitation

Wednesday, January 16

0815	*Breakfast*	119B
0845	**Welcome and Announcements**	Auditorium
0850	**MOMS – Multi Optical Mine Detection System** Dennis Menning, FOI – Swedish Defence Research Agency	Auditorium
0915	**When Bad Results Happen to Good Methods** Alan Thomas, Michael Cathcart, Georgia Tech	Auditorium
0940	**False Alarm Reduction Using Vegetation Mapping for Disturbed Soil Detection in Long Wave Hyperspectral Imagery** Alina Zare, University of Florida	Auditorium
1005	*Break*	119B
1020	**Algorithm Work Related to Disturbed Soil & Mine Detection** Ed Winter, Technical Research Associates, Inc.	Auditorium
1045	**Computational Support for Detection of Landmines & IEDS** Stacy Howington, John Peters, US Army ERDC	Auditorium
1110	**Acoustic Study of the Disturbance of Soil Properties Due to Weather Effects** Zhiqu Lu, James Sabatier, The University of Mississippi	Auditorium
1135	**Desert Terrain Characterization** Eric McDonald, Desert Research Institute	Auditorium
1200	*Lunch*	119B
1300	**Sedimentological and Pedological Characteristics of Talus Chronosequences in Hyper-arid Deserts, Negev Desert, Israel** Ronen Boroda, Ben Gurion University, Israel	Auditorium
1325	**Bio-Chem-Thermo-Mechanical Properties of Near Surface Soils – A Particle-level Analysis** Carlos Santamarina, Georgia Tech	Auditorium
1350	**Breakout Session #2: Overview & Approach**	Auditorium
1400	**Breakout Session #2**	119A/C/Auditorium
1500	*Break*	119B
1515	**Continue Breakout Session #2**	119A/C/Auditorium
1630	**Reassemble for Breakout Session #2 Reports** **Group Discussion**	Auditorium
1700	*Adjourn*	
1800	**Evening Social Event**	

Army Advanced Concept Workshop on Disturbed Soil Characterization and Exploitation

Thursday, January 17

0815	*Breakfast*	119B
0845	**Welcome and Announcements** **Breakout Session #3: Overview & Approach** ○ Identify Future Research Directions; Generate reports	Auditorium
0900	**Breakout Session #3**	119A/C/Auditorium
1000	*Break*	119B
1030	**Continue Breakout Session #3**	119A/C/Auditorium
1130	**Reassemble for Breakout Session #3 Reports** **Group Discussion** **Finalize & deliver group reports**	Auditorium
1200	**Workshop Summary**	Auditorium
1215	**Final Report Organization** (Organizing committee & Session Leaders)	Auditorium
1230	*Adjourn*	

Breakout Session Topic Areas

1. Operational environments and requirements
2. Near surface soil physics and signatures
3. Sensor technology
4. Algorithm development

Selected References

Balick, Lee, William Clodius, Christopher Jeffery, James Theiler, Matthew McCabe, Alan Gillespie, Amit Mushkin, and Iryna Danilina, “Model and measurements of linear mixing in thermal IR ground leaving radiance spectra,” *Proc. SPIE,* 6749, 674914 (2007).

Balick, Lee K., Alan R. Gillespie, Matthew F. McCabe, and Amit Mushkin, “Forward modeling of linear mixing in thermal IR ground leaving radiance spectra,” *Proc. SPIE*, 6396, 63960H (2006).

Bartholomew, Mary Jane, Anne B. Kahle, and Gordon Hoover, “Infrared spectroscopy (2-3-20 μm) for the geological interpretation of remotely-sensed multispectral thermal infrared data,” *International Journal of Remote Sensing*, Vol. 10, Issue 3: 529 – 544 (1989).

Beaven Scott G., Alan D. Stocker, and Edwin M. Winter, “Joint multisensor exploitation for mine detection,” *Proc. SPIE*, 5415, 1094 (2004).

Bowman, A. P., E. M. Winter, A. D. Stocker, P. G. Lucey, “Hyperspectral infrared techniques for buried landmine detection,” *Second International Conference on the Detection of Abandoned Land Mines*, (Conf. Publ. No. 458), 129-133 (1998).

Buck, Paul E., Donald E. Sabol, and Alan R. Gillespie, “Sub-pixel artifact detection using remote sensing,” *Journal of Archaeological Science*, Vol. 30, Issue 8: 973-989 (2003).

Carlisle, Orion, Paul G. Lucey, and Sarah B. Sherman, “Long-wave infrared hyperspectral imagery of weathering trajectories on Hawaiian basaltic rock,” *Proc SPIE*, 5655, 427 (2005).

Christensen, Philip R., Joshua L. Bandfield, Victoria E. Hamilton, Douglas A. Howard, Melissa D. Lane, Jennifer L. Piatek, Steven W. Ruff, and William L. Stefanov, “A thermal emission spectral library of rock-forming minerals,” *Journal of Geophysical Research*, Vol. 105, No. E4: 735–9739 (2000).

Cooper, B.L., J. W. Salisbury, R. M. Killen, and A. E. Potter, “Midinfrared spectral features of rocks and their powders,” *Journal of Geophysical Research*, Vol. 107, Issue E4: 5017, (2002).

DePersia, A. Trent, Anu P. Bowman, Paul G. Lucey, and Edwin M. Winter, “Phenomenology considerations for hyperspectral mine detection,” *Proc SPIE*, 2496, 159 (1995).

Gillespie, Alan R., Tsuneo Matsunaga, Shuichi Rokugawa, and Simon J. Hook, “Temperature and emissivity separation from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images,” *Proc SPIE*, 2817, 82 (1996).

Gillespie, A., S. Rokugawa, T. Matsunaga, J.S. Cothern, S. Hook, A.B. Kahle, “A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images,” *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 36, Issue 4 (1998).

Gu, D. and A. R. Gillespie, “A new approach for temperature and emissivity separation,” *International Journal of Remote Sensing*, Vol. 21, Issue 10: 2127 - 2132 (2000).

Horton, Keith A., Jeffrey R. Johnson, and Paul G. Lucey, “Infrared Measurements of Pristine and Disturbed Soils 2. Environmental Effects and Field Data Reduction,” *Remote Sensing of Environment*, Vol. 64, Issue 1: 47-52 (1998).

Hunt, G. R. and J. W. Salisbury, “Mid-infrared spectral behavior of metamorphic rocks,” Environmental Research Papers Air Force Cambridge Research Labs., Hanscom AFB, MA. (1976).

Jiménez-Muñoz, Juan C., José A. Sobrino, Alan Gillespie, Donald Sabol, and William T. Gustafson, “Improved land surface emissivities over agricultural areas using ASTER NDVI,” *Remote Sensing of Environment*, Vol. 103, Issue 4: 474-487 (2006).

Johnson, Jeffrey R., Paul G. Lucey, Keith A. Horton, and Edwin M. Winter, “Infrared Measurements of Pristine and Disturbed Soils 1. Spectral Contrast Differences between Field and Laboratory Data,” *Remote Sensing of Environment*, Vol. 64, Issue 1: 34-46 (1998).

Kahle, A.B., “Simple thermal model of the Earth’s surface for geologic mapping by remote sensing,” *Journal of Geophysical Research*, Vol. 82, Issue 11: 1673-1680 (1977).

Kahle, Anne B., “Surface emittance, temperature, and thermal inertia derived from Thermal Infrared Multispectral Scanner (TIMS) data for Death Valley, California,” *Geophysics*, Vol. 52, No. 7: 858-874 (1987).

Kahle, Anne B.; Alan R. Gillespie, and Alexander F. H. Goetz, “Thermal inertia imaging: A new geologic mapping tool,” *Geophysical Research Letters*, Vol. 3, Issue 1: 26-28 (1976).

Kahle, Anne B. and Alexander F. H. Goetz, “Mineralogic Information from a New Airborne Thermal Infrared Multispectral Scanner,” *Science*, New Series, Vol. 222, No. 4619: 24-27 (1983).

Kahle, Anne B., Michael S. Shumate, and David B. Nash, “Active airborne infrared laser system for identification of surface rock and minerals,” *Geophysical Research Letters*, Vol 11, Issue 11: 1149-1152 (1984).

Kenton, Arthur C., Duane M. Geci, Kristofer J. Ray, Clayton M. Thomas, John W. Salisbury, John C. Mars, James K. Crowley, Ned H. Witherspoon, and John H. Holloway, Jr., “Littoral assessment of mine burial signatures (LAMBS): buried landmine/background spectral-signature analyses,” *Proc SPIE*, 5415, 608 (2004).

Kenton, Arthur C., Craig R. Schwartz, Robert Horvath, Jack N. Cederquist, Linnea S. Nooden, David R. Twede, James A. Nunez, James A. Wright, John W. Salisbury, and Kurt Montavon, "Detection of land mines with hyperspectral data," *Proc SPIE*, 3710, 917 (1999).

Kirkland, Laurel, Kenneth Herr, Eric Keim, Paul Adams, John Salisbury, John Hackwell, and Allan Treiman, "First use of an airborne thermal infrared hyperspectral scanner for compositional mapping," *Remote Sensing of Environment*, Vol. 80, Issue 3: 447-459 (2002).

Koh, Gary, Edwin M. Winter, and Miranda A. Schatten, "Rainfall degradation of LWIR disturbed soil signature," *Proc SPIE*, 6217, 62170G (2006).

Korb, Andrew R., John. W. Salisbury, and Dana M. D'Aria, "Thermal-infrared remote sensing and Kirchhoff's law 2. Field measurements," *Journal of Geophysical Research*, Vol. 104, Issue B7: 15339-15350 (1999).

Logan, L. M., G. R. Hunt, J. W. Salisbury, S. R. Balsamo, "Compositional implications of Christiansen frequency maximums for infrared remote sensing applications," *Journal of Geophysical Research*, Vol. 78: 4983-5003 (1973).

Lucey, Paul G., Michael E. Winter, Edwin M. Winter, and Donovan Steutel, "Automated material map generation using hyperspectral data: a case study using AVIRIS imagery," *Proc SPIE*, 4725, 140 (2002).

Lucey, Paul G., Michael E. Winter, Edwin M. Winter, and Donovan Steutel, "Efficient materials mapping for hyperspectral data," *Proc SPIE*, 4381, 164 (2001).

Mushkin, Amit, Lee K. Balick, and Alan R. Gillespie, "Temperature/emissivity separation of MTI data using the Terra/ASTER TES algorithm," *Proc SPIE*, 4725, 328 (2002).

Mushkin, Amit, Iryna Danilina, Alan R. Gillespie, Lee K. Balick, and Matthew F. McCabe, "Roughness effects on thermal-infrared emissivities estimated from remotely sensed images," *Proc SPIE*, 6749, 67492V (2007).

Salisbury, John W. and Dana M. D'Aria, "Emissivity of Terrestrial Materials in the 3-5µm Atmospheric Window," *Remote Sensing of Environment*, 47:345-361 (1994).

Salisbury, John W. and Dana M. D'Aria, "Infrared (8-14 gm) Remote Sensing of Soil Particle Size," *Remote Sensing of the Environment*, 42:157-165 (1992).

Salisbury, John W. and John W. Eastes, "The Effect of Particle Size and Porosity on Spectral Contrast in the Mid-Infrared," *ICARUS*, 64, 586-588 (1985).

Salisbury, John W. and Andrew Wald, "The Role of Volume Scattering in Reducing Spectral Contrast of Reststrahlen Bands in Spectra of Powdered Minerals," *ICARUS*, 96, 121-128 (1992).

Salisbury, John W., Andrew Wald, and Dana M. D'Aria, "Thermal-infrared remote sensing and Kirchhoff's law 1. Laboratory measurements," *Journal of Geophysical Research*, Vol. 99, Issue B6: 1,897–11,911 (1994).

Schmugge, Thomas J., Michael J. Abrams, Anne B. Kahle, Yasushi Yamaguchi, and Hiroyuki Fujisada, "Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)," *Proc SPIE*, 4879, 1 (2003).

Smith, Milton O., Susan L. Ustin, John B. Adams, and Alan R. Gillespie, "Vegetation in Deserts: I. A Regional Measure of Abundance from Multispectral Images," *Remote Sensing of Environment*, 31:1-26 (1990).

Stein, D.W.J., S. G. Beaven, L. E. Hoff, E. M. Winter, A. P. Schaum, A. D. Stocker, "Anomaly detection from hyperspectral imagery," *IEEE Signal Processing Magazine*, Vol. 19, Issue 1: 58-69 (2002).

Steutel, Donovan, Michael E. Winter, and Paul G. Lucey, "Improved error mitigation in endmember unmixing of hyperspectral images via image partitioning of targetlike spectral anomalies," *Proc SPIE*, 5093, 390 (2003).

Thomson, Janice L. and John W. Salisbury, "The Mid-Infrared Reflectance of Mineral Mixtures (7-14μm)," *Remote Sensing of the Environment*, 45:1-13 (1993).

Tsu, Hiroji, Yasushi Yamaguchi, and Anne B. Kahle, "ASTER science mission overview," *Proc SPIE*, 2817, 52 (1996).

Wald, Andrew E. and John W. Salisbury, "Thermal infrared directional emissivity of powdered quartz," *Journal of Geophysical Research*, 100 B12: 24,665–24,675 (1995).

Walter, Louis S. and John W. Salisbury, "Spectral characterization of igneous rocks in the 8- to 12-micron region," *Journal of Geophysical Research*, 94: 9203-9213 (1989).

Weeks, Robin J., Milton Smith, Kyung Pak, Wen-Hao Li, Alan Gillespie, Bill Gustafson, "Surface roughness, radar backscatter, and visible and near-infrared reflectance in Death Valley, California," *Journal of Geophysical Research*, Vol. 101, Issue E10: 23077-23090 (1996).

Winter, Edwin M., "Detection of mines using hyperspectral remote sensors and detection algorithms," *Proc SPIE*, 5089, 625 (2003).