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13. ABSTRACT (Maximum 200 words)

The goal of this research project has been to develop simple models for the evaluation of the physics of different soil-mine-sensor systems. Our radar model requires as input: soil texture, water content, bulk density, particle density, and the depth of mine. Radar landmine sensors work well with nonmetallic mines in wet sand and silt soils and in dry clay soils whereas metallic mines are best detected in dry soils. Unfortunately, soil conditions can change over short distances. Therefore, a countermine specialist faces the considerable challenge of determining whether soil conditions are suitable for radar mine detection or are not suitable. In this project we also have simulated three-dimensional soil temperature distribution around landmines. At two times during each 24 hour period the thermal signature is at its maximum strength. Unfortunately, the time of appearance of the strongest thermal signature depends on soil texture, soil water content, and depth of the mine which makes it impossible to exactly predict at what time of the day it will occur. Therefore, a thermal infrared sensor will only give reliable mine detection information when used at the same location for at least six to twelve hours.

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Sincerely, Jan Hendrickx

Final Progress Report

Modeling Thermal, Moisture, Dielectric, and Electromagnetic Signatures for Landmine Detection

Research Agreement No. DAAG55-98-1-0415

Statement of the Problem Studied

The detection and disposal of anti-personnel and anti-tank landmines is one of the most difficult and uncontrollable problems faced in ground conflict. Since mines remain lethal long after military actions have terminated, they also have become a humanitarian disaster. Today at least 100 million landmines are scattered across more than 60 countries.

A wide range of landmine sensors has been developed for the detection of buried nonmetallic and low-metallic landmines. Two types of landmine sensors can be distinguished: substance analyzing sensors and imaging sensors. Substance analyzing sensors are magnetometers, bio-sensors, chemical sensors, and sensors based on principles of thermal neutron activation, X-ray backscatter, and nuclear quadruple resonance. Imaging sensors are based on passive and active infrared, passive and active mm-wave radar, and ground penetrating radar. Although several of these sensors perform quite well under certain conditions, there is a general agreement that none of the present technologies can reach good enough detection while maintaining a low false alarm rate. One reason is the variety of landmines: there are some 2,500 mine and “fuse” combinations. The other important reason is that the environment in which mines are placed is extremely variable due to variable climate, vegetation, soil type, depth of ground water table, and topography. For example, the three countries that have the largest average number of mines deployed per square mile are Bosnia-Herzegovina in a temperate zone, Cambodia in the humid tropics, and Egypt in an arid desert. Variations in the environmental conditions influence sensor performance because in general, landmine sensors exploit soil and environmental conditions to discern between mines and other objects.

Research efforts on mine detection are generally geared toward sensor development and sensor fusion. Little effort has been made on evaluating the environmental conditions that affect sensor performance. Changes in soil texture, soil bulk density, soil volumetric water content, and soil salinity affect microwave radar signals. Soil volumetric water content is known to affect thermal and electromagnetic soil properties. The performance of sensors based on radar and infrared imaging is expected to vary with soil and environmental conditions.

Much is known about the physics of the sensors used for mine detection as well as about the soil physical processes affecting mine detection. The overall goal of this research project has been to bring these two fields of physics together by developing simple models for the evaluation of the physics of different soil-mine-sensor systems. These models would allow to assess landmine sensor performance anywhere in the world where some basic weather and soil information is available. The four specific goals for the project were:

1. Develop a one-dimensional operational model for the prediction of the soil physical parameters that affect mine sensor performance.

2. Develop a three-dimensional operational model for the prediction of the strength of thermal, water content, dielectric, and electromagnetic signatures in soils worldwide.

3. Validate the one- and three-dimensional models with literature data and field measurements.

4. Use data from the mine lanes at Fort Belvoir and New Mexico Tech and from mine fields in Kuwait and Bosnia for the development of an operational mine detection procedure.

Summary of the Most Important Results

Modeling Water Content Distributions around Landmines

A critical first step in the project has been the simulation of the water content distribution around landmines. The water content distribution around a mine is important since it determines directly the distribution of dielectric, electromagnetic, and thermal soil properties around the mine. Using the model HYDRUS-2D we modeled three-dimensional water distributions around anti-tank mines buried in six soil textures varying from sandy loam to clay loam under the climatic conditions of Bosnia and Kuwait (Das et al., 2001; Hendrickx et al., 1999). The modeling results demonstrate that soil water content regimes around landmines are strongly affected by the interaction between climate, soil type, and landmine geometry. Soil water content distributions around landmines depend on local weather conditions and are very variable in time. Some of our model results have been successfully validated with experiments conducted by the TNO Physics and Electronics Laboratory in The Netherlands (Lensen et al., 2001; Rhebergen et al., 2002). Our work has shown how soil water content distributions near landmines and away from them can be predicted anywhere in the world where soil maps and meteorological data are available. Since soil water content is an important environmental variable that affects many sensors, the simulation of soil water content distributions are useful for the determination of windows of opportunity for mine detection.

An Operational Simple Model for Prediction of Landmine Radar Signature

Much of our research has focused on the effect of soil parameters on radar signatures since literature reports mention that soil conditions can have a large impact on the performance of ground penetrating radar (GPR) for landmine detection. We have used existing models from the literature to develop a simple MATLAB model to predict whether or not field conditions are appropriate for use of GPR sensors for mine detection (Borchers et al., 2000). The input variables for this model are: soil texture, water content, bulk density, particle density, and the depth of mine. We also have validated this model with field experiments around Socorro, New Mexico, and at the mine testing lanes of Yuma Proving Grounds in Arizona (Hong et al., 2001; Miller et al., 2002a,b; Rhebergen et al., 2002).

Our simple model captures well the main physics of landmine-radar-soil systems and demonstrates both the great potential and the pitfalls of landmine sensors based on GPR. Radar works well with nonmetallic mines in wet sand and silt soils and in dry clay soils whereas metallic mines are best detected in dry soils. Unfortunately, soil texture can change over relatively short distances and soil water content distributions around landmines exhibit a large temporal variability (Das et al., 2001). Therefore, a countermine specialist faces the considerable challenge of determining whether soil conditions are suitable for radar mine detection or are not suitable.

Thermal Landmine Signatures
Using the soil water content distributions simulated for the environmental conditions in Bosnia and Kuwait (Das et al., 2001; Hendrickx et al., 1999) we have simulated the three-dimensional soil temperature distribution around landmines (Simunek et al., 2001). Our simulations reconfirmed the well known fact that the strength of thermal signatures increases and decreases during the day and night. At two times during each 24 hour period the thermal signature disappears completely. We have confirmed this cyclic behavior of the thermal signature with soil surface temperature measurements in the field (Hong et al., 2001; 2002). Unfortunately, the time of appearance of the strongest thermal signature depends on soil texture, soil water content, and depth of the mine. This makes it impossible to exactly predict at what time of the day the strongest signature will occur. Therefore, a thermal infrared sensor will only give reliable mine detection information when used at the same location for at least six to twelve hours. A thermal sensor on a moving vehicle is bound to lead to accidents.

Our field measurements in New Mexico showed a peak in the strength of the thermal signature just before sun rise. They also revealed a sometimes rather large variability of surface temperatures which may have been partly caused by soil surface roughness and/or wind effects. More work needs to be done to evaluate the effects of soil texture, water content, and bulk density on thermal mine signatures.

Publications

a. Papers published in peer-reviewed journals

Das, B.S., J.M.H. Hendrickx, and B. Borchers. 2001. Modeling transient water distributions around landmines in bare soils. Soil Science 166(3):163-173.

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Hendrickx, J.M.H., S.-H. Hong, T. Miller, B. Borchers, and J.B. Rhebergen. 2003. Soil effects on ground penetrating radar (GPR) detection of buried non-metallic mines. *In*: C.S. Bristow & H.M. Jol (Eds), Ground Penetrating Radar: Applications in Sedimentology. Geological Society, London, U.K. Special Publications 211:187-194.

b. Papers published in conference proceedings

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c. Papers presented at meetings, but not published in conference proceedings

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Hong, S., B.S. Das, J. Simunek, B. Borchers, and J.M.H. Hendrickx. 2000. Water distributions around land mines. AGU Fall Meeting 2000, San Francisco.

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d. Manuscripts submitted, but not yet published

Miller, T.W., J.M.H. Hendrickx, and B. Borchers. 2002. Radar detection of buried landmines in field soils. Submitted to the *Soil Science Society of America Journal* on September 11, 2002.

e. Technical reports submitted to ARO

None

List of Scientific Personnel

Dr. Jan M.H. Hendrickx, Professor of Hydrology, PI
Dr. Brian Borchers, Associate Professor of Mathematics, Co-PI
Tim Miller, graduate student, MS in 2002
Sung-ho Hong, graduate student, MS in 2002
Dr. Jirka Simunek, Soil Physicist, U.S. Salinity Laboratory