A controlled outdoor test site for evaluation of soil effects on land mine detection sensors

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ABSTRACT

Previous modeling studies and experimental work have demonstrated that soil physical properties have a significant effect on most sensors for the detection of buried land mines. While a modeling approach allows for testing of the effects of a wide range of soil variables, most experimental work is limited to (field) soils with poorly known or controlled properties. With this in mind, we constructed a new outdoor test site with full control of soil water content and continuous monitoring of important soil properties and environmental conditions. In three wooden frames of 2 × 2 × 1 meter, filled with different soil types (sand, loam, and clay), we buried low-metal anti-tank and anti-personnel land mine simulants. We installed time domain reflectometry (for measurement of soil water content) and temperature probes at different depths above and below the land mines as well as in homogeneous soil away from the land mines. In this paper we document the features of this new test site and present results from the monitoring equipment.

Keywords: land mine test lane, detection, spatial variability, temporal variability, climatic conditions

1. INTRODUCTION

Land mines are one of the cheapest weapons used in armed conflicts, and remain lethal for years after the ending of a war. Currently land mines pose a threat to civilians in many tens of countries around the world. In recent years, the efforts to reduce negative effects of land mines have grown. Many non-governmental and governmental organizations have developed programs to raise mine awareness, to support victims medically, and to identify and clear mine fields [1]. Nevertheless, the rate at which land mines get cleared is probably slower than the rate at which others get placed. One part of the problem is the price of land mines, just a few dollars, which makes it a popular tool in (guerilla) conflicts. The other side of the problem is that the detection and removal of buried land mines is a laborious and thus expensive process. Most programs use dogs and metal detectors for finding land mines, while prodding is used for exact localization and subsequent removal of the mines. Apart from logistical problems such as dense vegetation and topography, the limited speed of the current approach is a drawback [2].

Many programs are ongoing to develop new methodologies for efficient detection of buried land mines. These methodologies can be grouped in 3 main categories:

(1) Sensors that detect anomalies in the subsurface through scattering or transformation of transmitted energy. Sensors in this category include metal detectors and active microwave techniques, such as ground penetrating radar (GPR).
(2) Sensors that detect surface anomalies, caused by buried objects. Passive thermal infrared is the primary technique in this group.
(3) Sensors that detect the land mine explosives or chemicals that are associated with the explosives. In this group fall chemical sniffers (artificial dogs), biological detectors (animals and genetically altered plants), molecular radio frequency resonance absorption spectroscopy, and nuclear radiation methods.

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Most of these technologies, apart from the metal detector, are not in widespread use. Even though GPR seems to be making a careful entrance in the humanitarian demining user community [3], all sensors (including GPR and metal detectors) experience difficulties reducing their false alarm rates while maintaining a large probability of detection under all conditions. Spatial and temporal variability in soil conditions are among the primary causes for non-optimal performance of sensors, discrimination algorithms, and sensor fusion algorithms [4,5,6,7,8,9,10,11].

Soil moisture content is one of the most important soil parameters to consider because it controls or influences many other soil properties such as the dielectric constant, electrical conductivity, thermal conductivity, heat capacity, and vapor diffusion rates. The natural variability in water content around land mines can be extreme [12,13]. As a result, many sensors from GPR [14], to infrared [15], and chemical sniffers [16,17] are affected by changes in water content. Recent modeling studies and field experiments at New Mexico Tech have predicted and shown these effects for ground penetrating radar and thermal infrared [18,19,20,21,22]. The soil texture and environmental conditions (precipitation, evapotranspiration, radiation, and temperature) are other important factors in explaining the variability in soil conditions. To get a better understanding of these effects on land mine detections sensors it is necessary to be able to accurately monitor, or in some cases control, these conditions. For this reason we have decided to build an outdoor test site focusing on monitoring the soil and environmental variability.

2. RATIONALE

The land mine detection community already has a large number of and variety in available test facilities. For example the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) at Fort Belvoir, VA, have a recently renovated facility equipped with lanes of different soil types [23]. The Physics and Electronic Laboratory (FEL-TNO) in The Netherlands has a test facility equipped with 6 outdoor lanes and a weather station [24]. Many army bases in the United States, including Jefferson Proving Grounds, Yuma Proving Grounds, and Shofield Barracks have extensive testing lanes. Also, Defense Research and Development Canada has a set of test lanes with different soil types. In many countries contaminated with buried land mines, local organizations and NGO's have developed land mine sensor test facilities to address the specific problems occurring in these countries. Thus, the question may be asked why another test facility is needed. There are a few key points that may answer this:

(1) accessibility. Many test facilities have restricted accessibility because of the presence of explosives. We have decided to use only land mine simulants for out site, which is gated but has unrestricted accessibility.
(2) climate. As stated above, environmental and soil moisture conditions are of great importance for understanding the behavior of many sensors. The New Mexico climate is very steady with little precipitation and sunshine year round. This allows for naturally dry soils that can be modified using a sprinkler system.
(3) environmental monitoring. An indoor site has the advantage of perfect control of the conditions; however, these conditions are unnatural. To study the effects of natural variability an outdoor site is desirable. Equipment to monitor this variability, both in the atmosphere and in the subsurface is essential.
(4) material. We believe it is important to study the effects for a set of natural, but characteristic soil types. For this reason we chose grain sizes that represent extremes in the textural triangle, sand and clay and an intermediate soil type, loam [25].

Few, if any of the existing test facilities comply with all of our preferences for the ideal test site to study the effect of environmental conditions on land mine detection sensors.

a) b)

Fig. 1. a) The NMT outdoor land mine detection test facility at the foot of "M-mountain". b) The setup in detail with datalogger and sensor control in the white boxes in the foreground and the field office in the background.

3. DESIGN AND FACILITIES

3.1 The general setup and material

We have set up three test boxes of 2 × 2 × 1 meter dimensions (Fig. 1). The boxes have been filled with well-sorted sand, a typical loam soil with some (<5%) larger gravel, and a clay soil (~70% clay-size fraction). In each of the three wooden boxes 2 anti-tank (AT) mine simulants and 4 plastic anti-personnel (AP) mine simulants have been buried. The AT mine simulants were buried with their tops at 0.05 meters depth in the north-east and south-east quadrants of the boxes. The AP mine simulants were buried in the north-west quadrants of the boxes, at the surface, and at 0.02, 0.04, and 0.06 meters depth (Fig. 2). Each box is equipped with 8 sensors for soil moisture content and 8 soil temperature sensors, and were all placed in the southern half of the boxes (Fig. 2). Five sensors of each are placed above and below the buried AT mine simulant; at 0.02, 0.2, 0.3, 0.4, and 0.5 meters depth. In the undisturbed soil in the south-western quadrant 3 probes of each were installed at 0.02, 0.2, and 0.5 meters depth. The boxes are equipped with a PVC tube in which a metal rod can be placed (for GPR time-depth conversion). The tubes run north-south at 0.5 meter depth (Fig. 2).

Sprinkler system – In order to control the soil moisture content we use a 3 × 3× 1 meter sprinkler system, constructed using PVC plastic tubing. The steel center pipe has Rain Bird XS-360TS-1032 sprinkler nozzles attached to it. The system has been tested successfully to distribute moisture homogeneously over a 2 × 2 meter area [26].

Land mines – The AT land mine simulants used are completely inert and composed of Dow Corning 3110 RTV silicon rubber. They have been designed to simulate a Netherlands land mine of type NR26, which is a nonmetallic land mine and measures 0.3 meter in diameter and 0.12 meter in height (Figs. 3a&b). The TNO Physics and Electronics Laboratory in the Netherlands manufactured these land mines. The anti-personnel land mine simulants have been manufactured by New Mexico Tech using silicon rubber and a plastic casing. The mines have an air gap on top of the rubber (Figs. 3c&d).

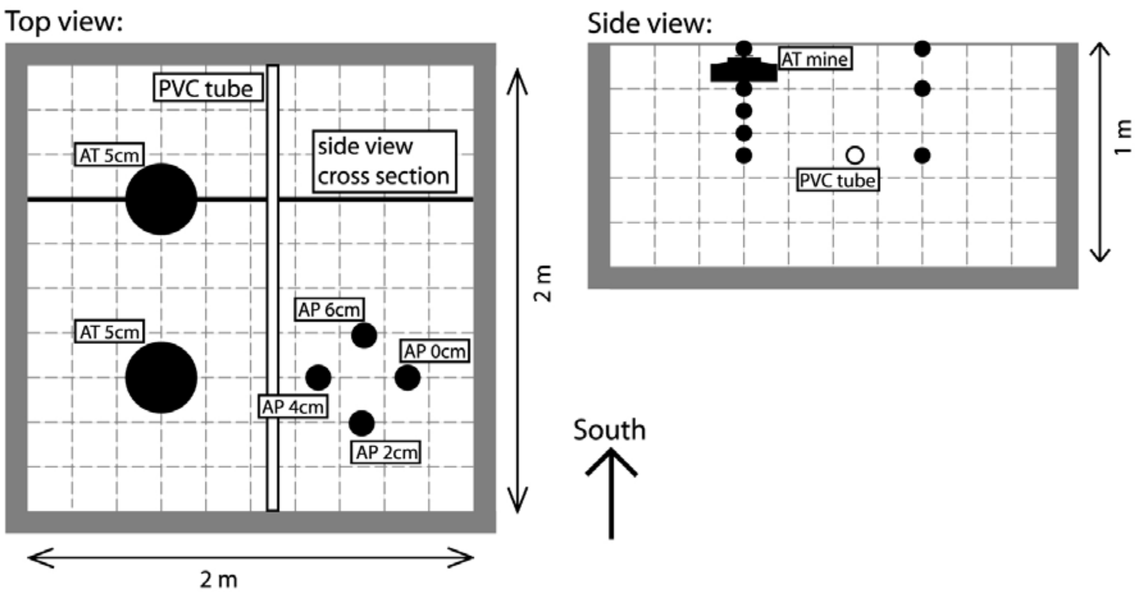


Fig. 2. Layout of the test plots at the NMT land mine detection test facility. In the side view, the open circle marks the location of the PVC tube. The black circles mark the locations of the temperature and soil moisture sensors.

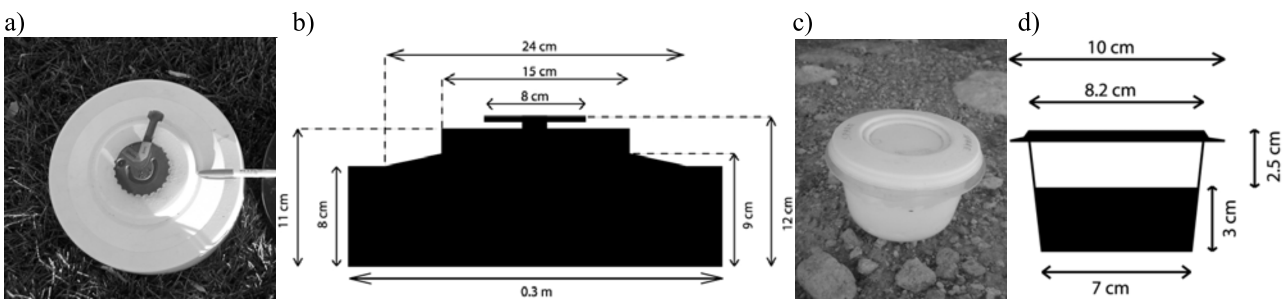


Fig. 3. Pictures and schematic diagrams with dimensions of buried land mines. Picture (a) and dimensions (b) of the NR26 simulant AT land mine. Picture (c) and dimensions (d) of NMT fabricated simulant AP land mine.

3.2 Sensors

3.2.1. Weather station

The site has a fully equipped weather station for continuous monitoring of all relevant atmospheric conditions (Fig. 4). The weather station is equipped with a net radiometer, a sonic anemometer, a rain gauge, a thermocouple, an hygrometer, and a scintillometer (see Table 1). The net radiometer measures the difference between incoming and outgoing short-wave and long-wave radiation. The incoming radiation consists of direct and diffuse solar radiation plus long-wave irradiance from the sky. The outgoing radiation consists of reflected solar radiation plus the long-wave radiance from the soil. The anemometer measures turbulent fluctuations of wind speed and speed of sound on three nonorthogonal axes. The wind speeds are transformed into the orthogonal wind components (i.e., horizontal wind speed and direction) while the speed of sound is used to determine the ambient air temperature. The thermocouple measures air temperature at a height of two meters above the ground. The sensitive hygrometer measures rapid fluctuations in atmospheric water vapor. The combination of data from the sonic anemometer, the hygrometer, the thermocouple, and the net radiation, plus an estimate of the soil heat flux is used to calculate the evapotranspiration (ET). The tipping bucket rain gauge measures precipitation at 0.01 inch increments. The large aperture scintillometer measures atmospheric turbulence, heat flux and crosswind over a large distance of several kilometers.

Table 1. Summary of equipment installed at NMT land mine detection test facility.

Description	Product name	Amount	Manufacturer
Net radiometer	Q7_1	1	Campbell scientific
3-D sonic anemometer	CSAT3	1	Campbell scientific
Tipping bucket rain gauge	TE525WS	1	Campbell scientific
Fine wire thermocouple	FW05	1	Campbell scientific
Krypton hygrometer	KH20	1	Campbell scientific
Large aperture scintillometer		1	Kipp & zonen
Thermocouple	107	24	Campbell scientific
Time domain reflectometry probes	-	24	New Mexico Tech
Datalogger	CR23X	2	Campbell scientific

3.2.2. Soil sensors

It is essential to be able to continuously measure soil moisture conditions and soil temperatures above and below the land mines and away from them in homogeneous soil. For this we installed time domain reflectometry (TDR) probes and temperature sensors at different depths and locations in the test boxes (Fig. 2), and connected them to a datalogger for continuous monitoring (Table 1).

3.2.3. Geophysical sensors

Infrared camera – We use a ThermaCAM SC3000 infrared (IR) camera manufactured by FLIR Systems Inc., Sweden, for measurement of the apparent temperature of the soil surface above and away from the buried land mines (Fig. 5). This IR camera has a spectral range from 8 to 9 µm with thermal sensitivity of 0.03 °C at +30 °C. It uses a quantum well infrared photon detector. The raw thermal IR images are analyzed using the software provided by FLIR, and using standard spreadsheet programs.

Ground penetrating radar – For ground penetrating radar (GPR) measurements we use a pulseEKKO1000 system manufactured by Sensors&Software, Canada (Fig. 6). The system is equipped with 450, 900 and 1200 MHz antennae. To accurately guide the GPR system over the land mine plots, we use a wooden positioning frame (Fig. 6). Mounted in this frame, the transmitting and receiving antennae are elevated about 4 cm above the surface.

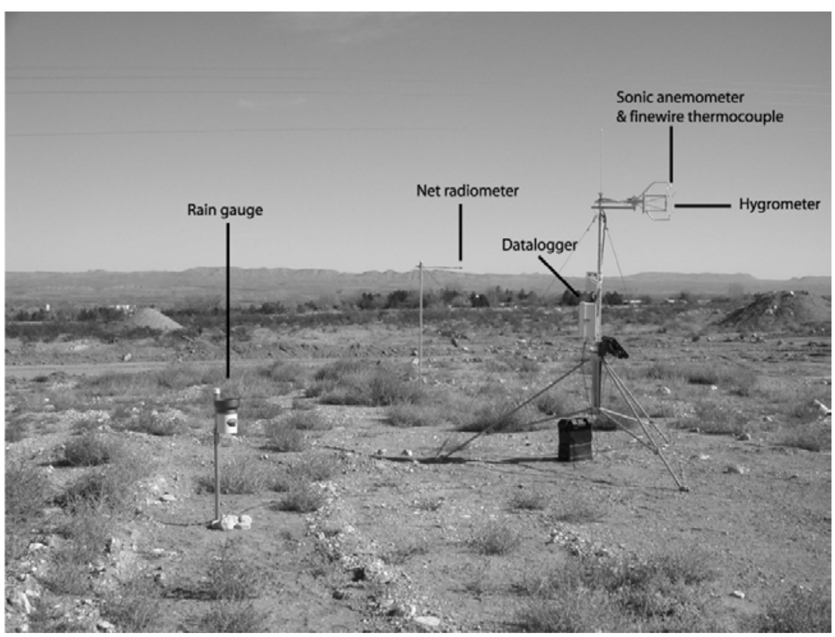


Fig. 4. Picture of the weather station.

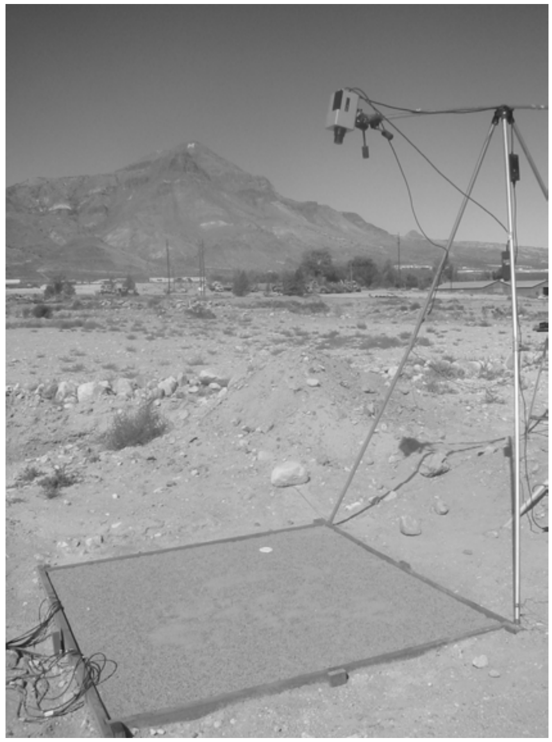


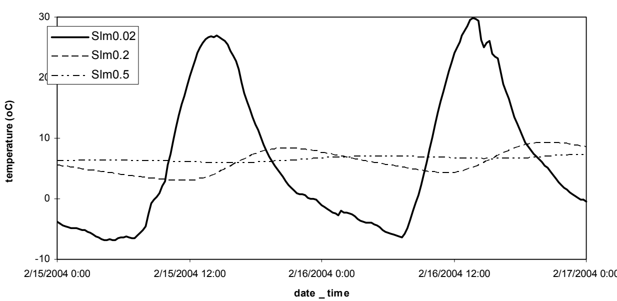
Fig. 5. Picture of FLIR thermal infrared camera.

Fig. 6. Picture of pulseEKKO 900 MHz ground penetrating radar antennae and mounting frame.

4. EXAMPLE DATA

In Fig. 7 data series of temperature at different depths in the three soil pits are presented. These data clearly show the strong decrease in the diurnal temperature amplitude with depth. Also, the phase shift of the temperature cycle going from 0.02 m depth to 0.2 m depth is obvious for all soil types. Figure 8 shows soil temperatures at 0.5 meters depth in three soil types for an eight-day period. The diurnal cycle is superimposed on a trend that shows a sharp decrease in temperatures around halfway in the measurement period and a subsequent increase. This trend is caused by larger time scale (on the order of days) variation in atmospheric conditions. Both the amplitudes of the diurnal cycle and the height of the mean temperatures are related to the soil type and are highest for the sand soil and lowest for the clay soil. Also the clay and the loam soil experience a phase shift relative to the sand soil. These characteristics are the result of the different thermal properties for each soil type [18]. Figure 9 is a late-afternoon sample image from the thermal camera over the loam plot. In the image several of the land mines are clearly visible. The buried AT mine simulant is visible as a warmer spot in the lower left of the plot. In the lower right of the image, several of the AP land mine simulants are visible as colder spots. The strengths of the thermal signatures of the AP mines clearly decrease with burial depth.

a)



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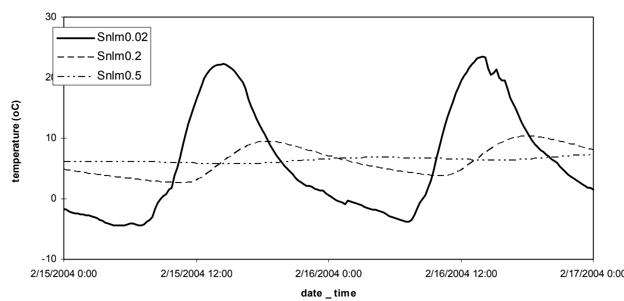

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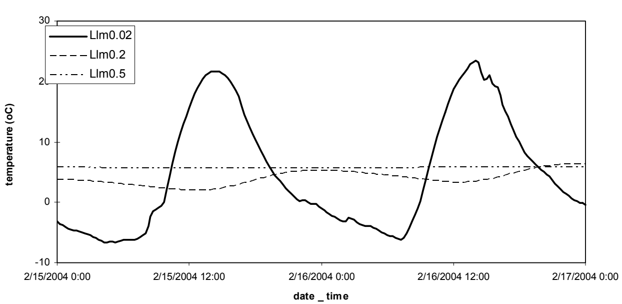

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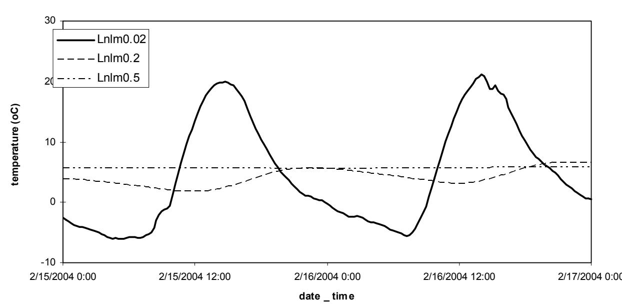

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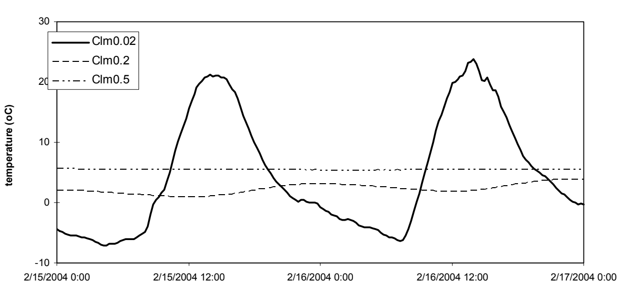

f)

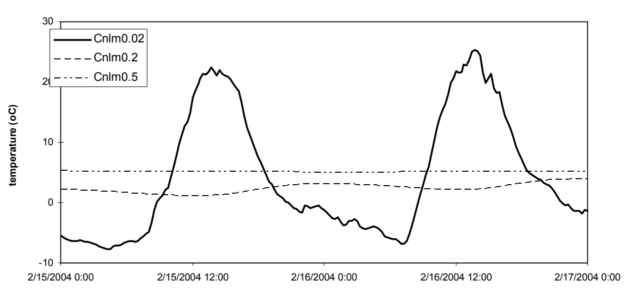

Fig. 7. Time series showing temperature distribution for different soils and at different depths. a) Sand soil, above and below land mines; b) homogeneous sand soil; c) Loam soil, above and below land mines; d) homogeneous loam soil; e) Clay soil, above and below land mines; f) homogeneous clay soil. The numbers in the legends refer to the depths of the temperature probes, 0.02, 0.2 and 0.5 meters.

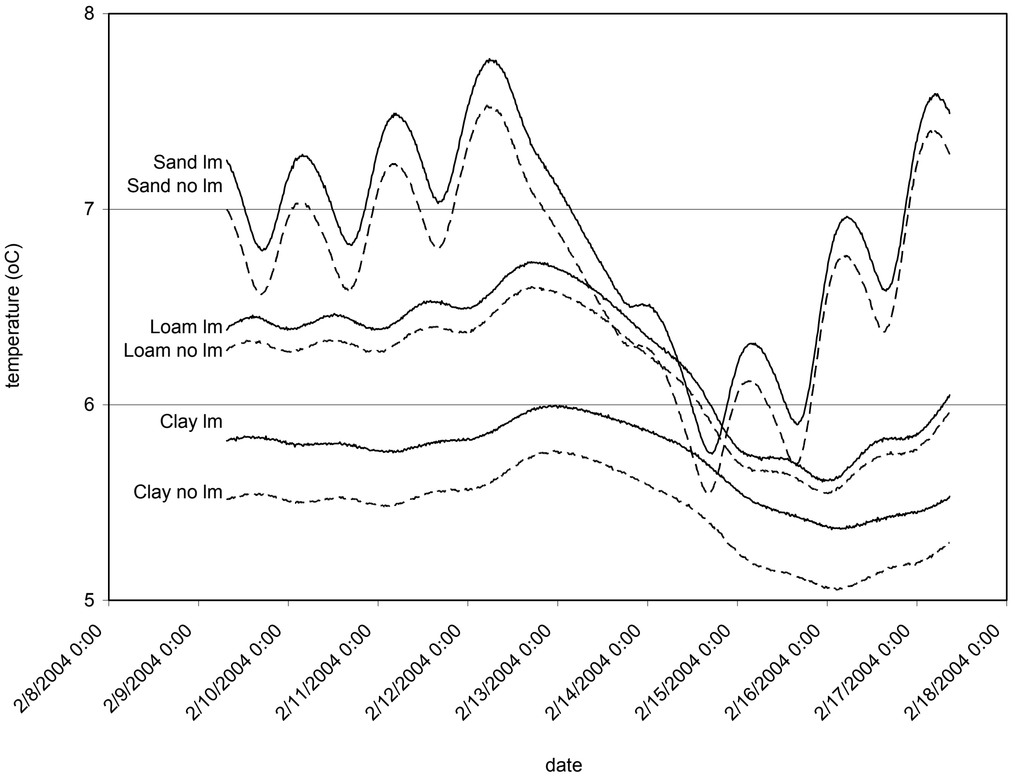

Fig. 8. Plot of soil temperatures for an eight-day period in February 2004 at 0.5 meters depth in three soil types. “lm” stands for a temperature measurement under an AT land mine simulant. “no lm” stands for a temperature measurement in homogeneous soil.

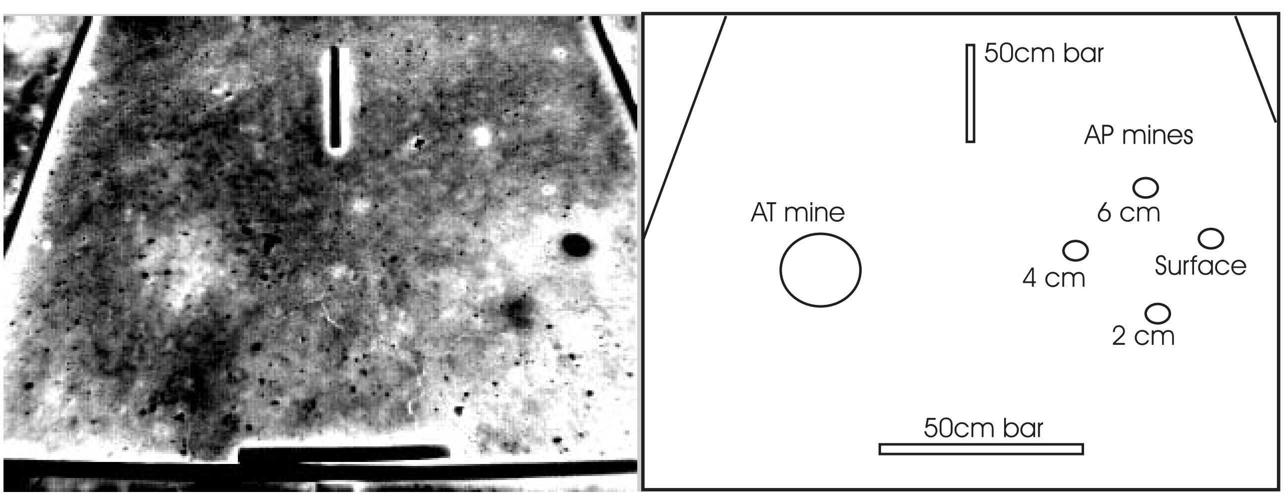

Fig. 9. Thermal infrared image of the loam test plot at 6:40 PM on January 28, 2004. The surface temperature differs 5.5 °C between the area above the AT mine simulant (warm) and the AP mine simulant at the surface (cold).

5. CONCLUSIONS

The New Mexico Tech land mine detection facility is especially designed to study the effects of spatial and temporal variability in environmental conditions and soil properties on land mine detection sensors. For this we have constructed an outdoor site at which land mine simulants have been buried in characteristic soil types: sand, loam, and clay. At the site climatic conditions are continuously monitored using a fully equipped weather station. Important soil properties such as moisture content and temperature are monitored using probes buried at different depths around and away from buried land mine simulants. The site is easily accessible and anyone interested is welcome to use it for testing their equipment.

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