LAND MINE DETECTION IN BARE SOILS USING THERMAL INFRARED SENSORS

Sung-ho Hong, Timothy W. Miller, Brian Borchers, and Jan M.H. Hendrickx
New Mexico Tech, Socorro NM 87801
hendrick@nmt.edu

Henk A. Lensen, Piet B.W. Schwering and Sebastiaan P. van den Broek
TNO Physics and Electronics Laboratory, The Hague, The Netherlands.
lensen@fel.tno.nl

ABSTRACT

Soil surface temperatures not only exhibit daily and annual cycles but also are very variable in space and time. Without knowledge of the spatial and temporal variability of soil surface temperatures, it will be difficult to determine what times of day are most suitable for mine detection using Thermal Infra Red (TIR) technology. In this study we monitor the spatial and temporal variability of soil surface temperatures under a range of soil texture and soil moisture conditions on undisturbed plots and plots with a buried anti-tank mine in arid New Mexico. We also analyzed soil surface temperature measurements taken at the test facility for land mine detection systems at the TNO Physics and Electronics Laboratory under the temperate climatic conditions of The Netherlands. The measurements in both areas show a cyclic behavior of the thermal signatures of the mines during the day and night that can be predicted by physics of the mine-soil-sensor system. However, unexpected behavior of the thermal signatures in a silt loam demonstrated that prediction of thermal signatures of buried mines is not straightforward.

Keywords: landmines, detection, thermal infrared, thermal signature, test facility.

1. INTRODUCTION

Many sensors for landmine detection are affected by the water content, temperature, electrical conductivity and dielectric constant of the surrounding soil. The most important of these is soil water content since it directly influences the three other properties.

Simunek et al. (2001) have conducted a modeling study to evaluate how soil texture and water affect the thermal signatures of land mines. They concluded that the maximum temperature difference between the soil surface above the mine and away from it, i.e. the strong thermal signature, depends in a complex manner on the thermal properties of the soil which depend on soil water and soil texture as well as the soil heat flux which changes with geographical location and time of the year. The strong thermal signature seems to appear in two six-hour intervals centered around 12:00 am and 12:00 pm but its exact time is very difficult to predict. To make matters worse, the weak thermal signatures frequently can also be found in these time intervals. Therefore, their modeling study indicates that the use of a single thermal sensor for instantaneous mine detection carries a high risk. On the other hand if a given area can be monitored constantly with a thermal sensor for twelve hours or longer a thermal signature may be detected if the signal to noise ratio of the mine-soil-sensor system allows so. Moreover, a thermal sensor can be useful in addition to other types of sensors like metal detector or ground penetrating radar in a multi-sensor fused mine detection system.

DePersia et al. (1995) reported on thermal signatures in areas with land mines. Temperature differences between the soil surface above and away from the mine are attributed to differences in heat capacity between mine and soil as well as surface disturbance during mine burial. The major principle of thermal infrared (IR) sensors for mine detection is based on detecting localized temperature differences, apparent thermal contrast, introduced by the mines. The apparent thermal contrast also depends on background levels, and should be compared to the clutter contrast in order to derive the probability of detection of objects.

The objective of this study is to use field experiments to better understand the dynamic behavior of thermal signatures in field soils.

Detection and Remediation Technologies for Mines and Minelike Targets VII, J. Thomas Broach, Russell S. Harmon, Gerald J. Dobeck, Editors, Proceedings of SPIE Vol. 4742 (2002) © 2002 SPIE · 0277-786X/02/$15.00

2. METHODS AND MATERIALS

We report on thermal infrared recordings measured under different conditions and in different soils. In section 2.1 the infrared recordings in New Mexico are described and in section 2.2 we describe infrared recordings at the TNO test lanes in The Netherlands.

2.1 NMT infrared measurements in dry arid conditions

The study site is located in the Sevilleta National Wildlife Refuge16 miles North from Socorro, New Mexico. Two different soil types were selected for this study: a sand and a silt loam soil. An antitank mine was buried at each site. The sand soil was located near the Rio Salado sand dunes and had a composition of 95 % sand and 5 % clay. The silt soil was located closer to the Rio Salado and had a composition of 10 % sand, 15 % clay, and 75 % silt.
We used the ThermaCAM^{TM} SC3000 infrared 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. This IR (infrared) 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 were analyzed using the ThermaCAM^{TM} Researcher 2000 software provided by FLIR Systems.

In February 2001, we selected a one by two meter area at each site and enclosed it with a wooden frame. A surrogate antitank land mine (Figure 1, left mine) was buried within this frame at a depth of 11 cm. The surrogate mine used in this study has the same thermal properties as real antitank land mine type NR26. About one year later we recorded thermal images from a height of 2.4 m above the soil surface at 15 minutes intervals during a 24 hours period (Figure 2). Observations of the ambient temperature have been taken on February 11 and 6, 2002, at the sand site (Figure 3) and on February 16 and 21, 2002, at the silt loam site (Figure 4). Weather conditions on all four days were quite similar with the maximum and minimum air temperature was about -10 °C and 20 °C. Volumetric soil moisture contents were approximately 3 % in the sand and 5 % in the silt loam.

Figure 1: Surrogate antitank mines (30 cm diameter). The left mine surrogate was used in this study.

Figure 2: Infrared camera setup for thermal signature

Figure 3: Sand site (mine is buried 50 cm from each end).

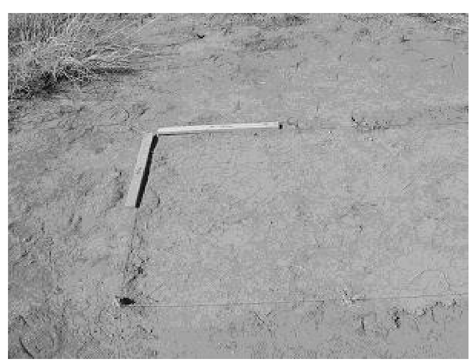

Figure 4: Silt loam site.

2.2 TNO infrared measurements in dry and wet temperate conditions

In this section we describe the experimental setup and some results obtained from infrared (IR) recordings in conditions with dry and wet soil. The IR recordings were performed with a Raytheon Amber Radiance-1T with 50 mm optics in the InSb 3-5 micron waveband at the Test facility for land mine detection systems at TNO-FEL in The Netherlands (De Jong et al.,1999).

The images presented in figure 5 were recorded on 6 August 1998 (sunny and dry conditions), making use of data recorded in all of the six test lanes. Grey scaling is performed identically in figure 5, hence the darker lanes, peat and forest, have a lower average apparent temperature than the other lanes. Note the clear locations of some of the mines, both placed at the surface as well as sub-surface, and the large amount of infrared clutter on this sunny and dry day, mainly due to surface heterogeneity.

The thermal infrared sensor has a field-of-view of 11.2° x 11.2° degrees, with a resolution of 0.76 x 0.76 mrad, and a thermal sensitivity of 0.02-0.03°C. Recording started at 10:37 AM (CEST) in the sand lane, and ended at 01:06 PM in the semi-hard rocky lane. At the measurement height of 1.80 m each image covers 35 x 35 cm with a resolution of 1.4 x 1.4 mm. Measurements were executed following a data recording protocol, with additional meteorological, soil and sensor positioning information. Each lane was covered by 11 tracks in parallel starting in the North-West of the lane (bottom-right of the image). The images in figure 5 are mosaics of 11 x 65 single thermal images showing warmer (whiter spots) and colder areas (darker spots). Dark lines around the surface-laid mines are due to thermal shadows. These recordings are part of the HOM 2000 Phase-A database of infrared imagery, which were recorded in the July-August 1998 period.

Figure 5: Infrared recordings under sunny and dry conditions on 6 August 1998 in the Test facility for land mine detection systems at TNO-FEL. The mosaic images show the six 10 m (South-North) by 3 m (East-West) test lanes with South at the top of the images.

In figure 6 we present the meteorological conditions, recorded at 30 cm height, for the period of two weeks preceding the measurements. From the standard meteorological recordings we have left out the wind direction. The cumulative precipitation is 0 mm/hr during the entire second week, and rain occurred on 29 and 30 July. For the recordings on 6 August the general meteorological conditions are as follows. The air temperature was approximately 25 degrees centigrade, relative humidity 52 %, solar energy of 650 Watt/m^2, a wind speed of 4 m/s and no precipitation. The average soil moisture is approximately 5 % (volume) in sand, 14 % in ferruginous and forest, and 30-50 % in clay and peat (for recordings between 29 July and 6 August). These moisture data were measured in the top 16 cm with a Trime-FM using a P2G probe.

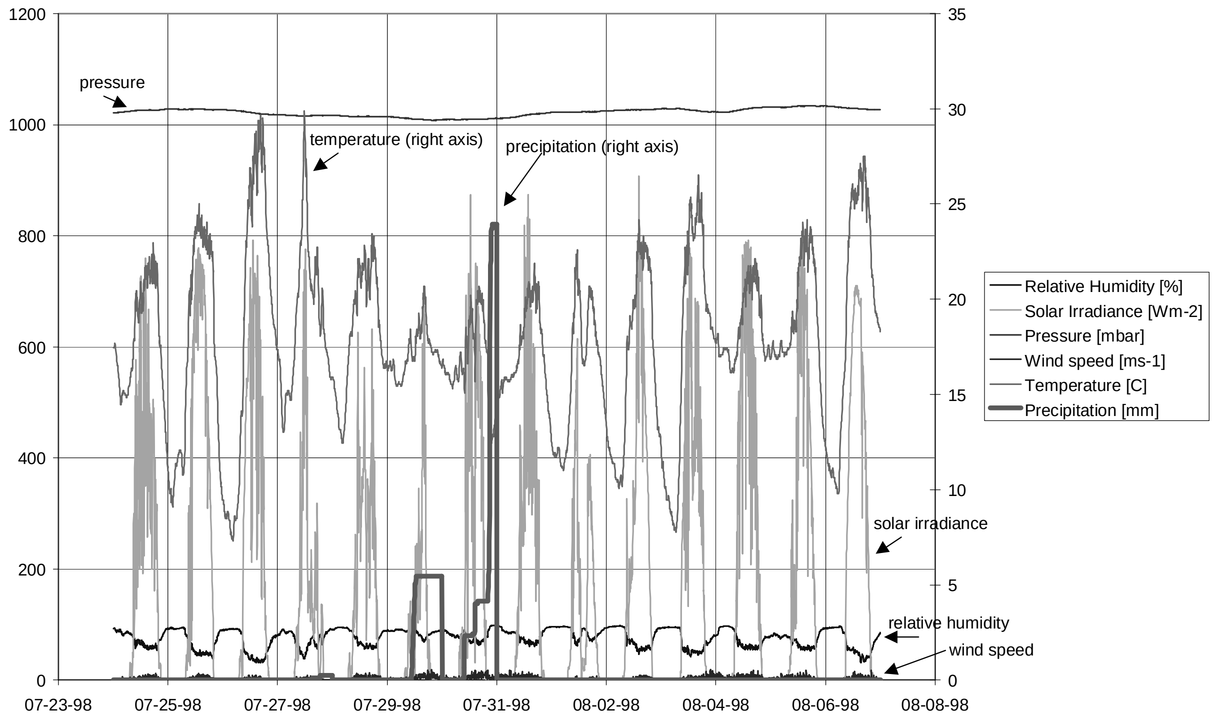

Figure 6: Meteorological parameters in a two-week period preceding the 6 August 1998 measurements.

Based on these meteorological conditions we have also selected measurements that were recorded with the same infrared camera under wet conditions the week before (on 29 July).

3. RESULTS AND DISCUSSION

The thermal contrast of mines with the soil background at the New Mexico sites has been quantified by determining the mean apparent temperature of the soil surface above the land mine (within a circle with radius 10 cm from center of mine) and the mean soil temperature of an area outside and around the mine (enclosed by two concentric circles with respective radii of 20 and 35 cm from center of mine). The differences between the mean temperatures above and away from the mine have been plotted in Figure 7.

The first feature in Figure 7 is the cyclic behavior of the temperature difference or thermal signature with time. For example, at the sand site on February 11, 2002, the temperature difference is about 0.5°C at 21:43, then increases to a maximum of about 1.6°C at 7:13, decreases to minimum of 0°C at 9:13 and reaches a maximum negative contrast of °C at 16:28. The maximum temperature differences coincide with the largest thermal contrast. Similar trends have been observed in the other observations in the sand and silt loam sites (Figure 7).
In Figure 8, the mine can be clearly seen at 7:13 am on February 12, 2002, when the temperature difference is at a maximum of 1.6°C. Only two hours later the mine cannot be detected since the temperature difference has completely disappeared. A similar behavior of the thermal signature was recorded on February 6, 2002.

The cyclic behavior of the thermal signature during a 24 hour period has been predicted by Simunek et al. (2001) and other investigators on the basis of the thermal physics of the soil-mine-sensor system. Our measurements are evidence that the thermal signature indeed strongly varies during a 24 hour period. Therefore it is complex to understand the thermal contrast at each instant in time, and hence it should be modeled accurately in parallel to the measurements to make full use of the thermal imager. This requires extensive model validation beforehand. For this purpose measurements of thermal diurnal cycles over a long period of time are inevitable.

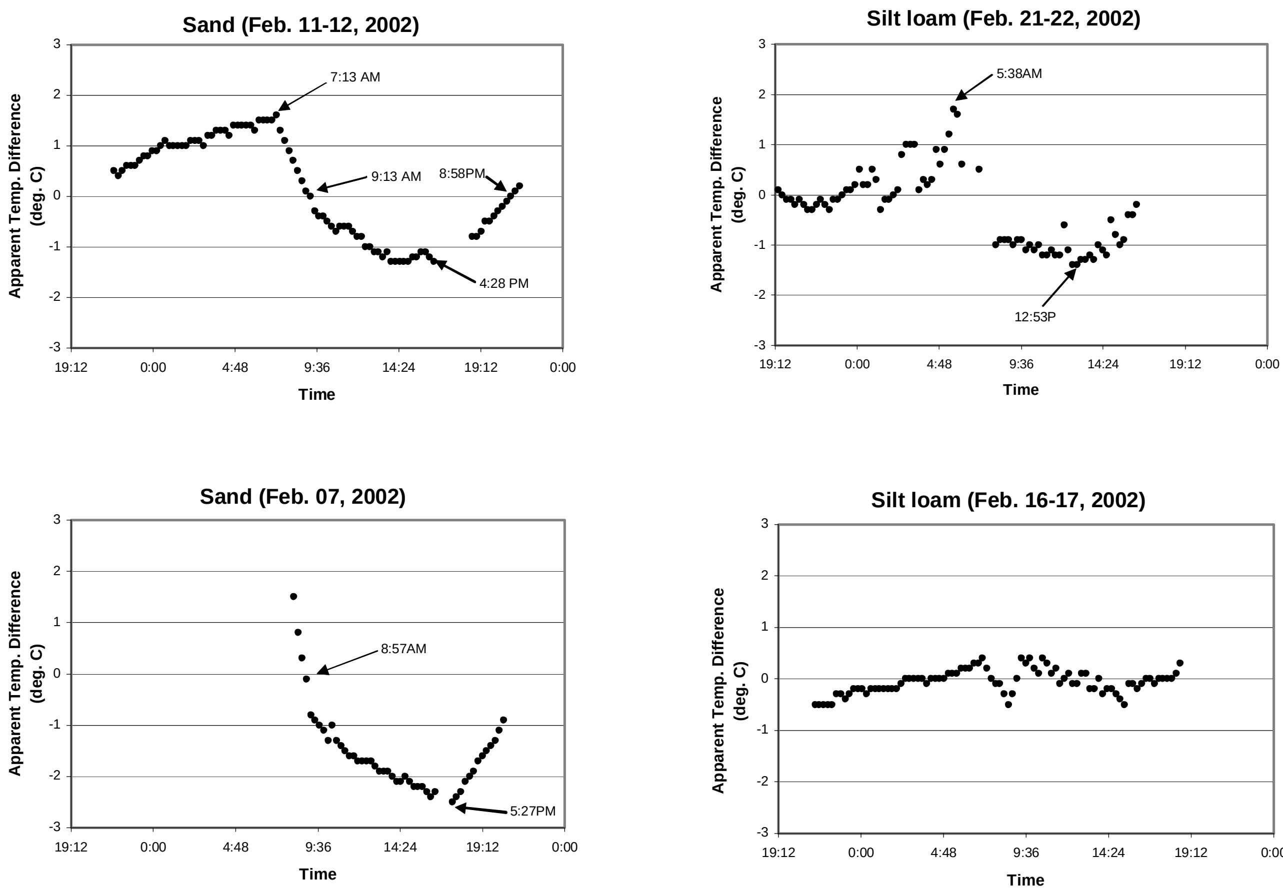

Figure 7: Temperature difference between mine and away from the mine area

Figure 7 also demonstrates a cyclic behavior for the silt loam but the observations show considerably more variability. Although the maximum observed temperature difference in the silt loam on February 21, 2002, is the same as in the sand soil, no thermal contrast could be detected with the IR camera (see Figure 8). The reasons for this unexpected result are not yet understood. The environmental conditions such as air temperature and cloudiness were approximately the same during the measurements at the sand and silt loam sites. The thermal properties for dry sand and dry silt loam are not very different. However, the soil surface of the silt loam is different from the sand. The former consists of a dense soil crust cut by cracks while the sand has a grainy surface without crust. It could be that weathering processes after mine burial in the previous year minimizes the contact between crust and underlying silt loam. This would lead to a thin layer of low thermal conductivity that would disconnect the thermal signature of the mine from the surface soil. A similar situation is found in the clay and ferruginous soil in the TNO lanes after a dry period, as was the case with the data presented in figure 5. Indeed in these cases a lower contrast is observed. However, under these conditions one would expect a much smaller temperature difference between soil above and away from the mine. Such a small difference was indeed observed on February 16, 2002, which would support our hypothesis. If this is true, than we could explain the large variability in temperature differences observed on February 21, 2002, by fluctuations of wind speed or clouds. In order to test these hypotheses we are preparing another test site for long time measurements of soil surface temperatures and micrometeorological conditions (including short and longwave irradiation).

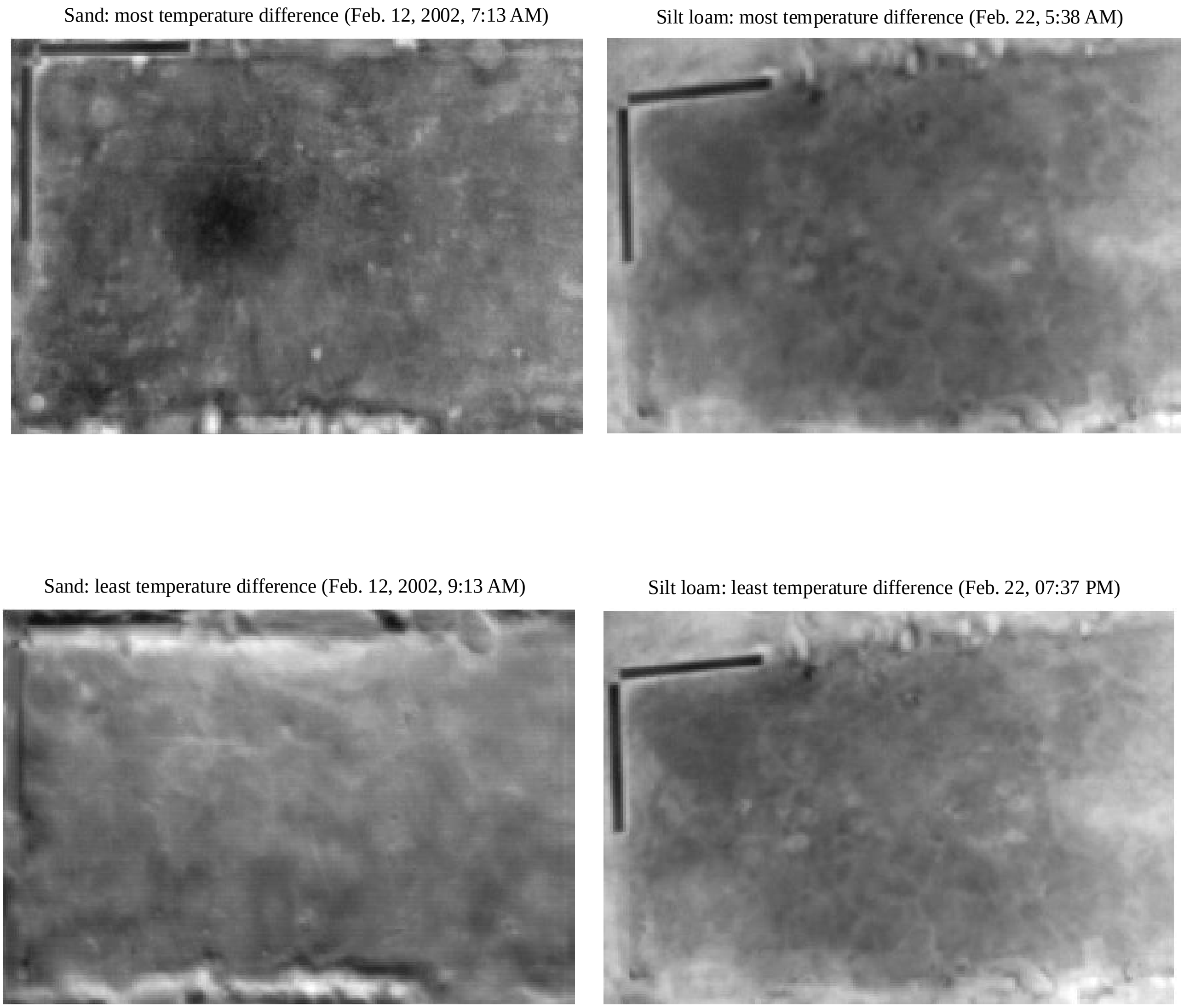

Figure 8: Thermal signatures from IR camera (left: sand, right: silt loam site).

Some comparison images, both for dry and wet conditions, are presented in figure 9, for the sand and the ferruginous lanes. As expected, the wet surface due to rain washes away the infrared contrasts of target and of clutter structure at the surface. The gray scale of the imagery with originally similar infrared dynamic range in both sets of data was increased for the wet period by a factor of six, and furthermore the offset had to be adapted. Note the enormous damping effect of the wet surface on the contrast. Examples of an AT (type NR26, the same type as used in New Mexico) surrogate mine are presented in figure 9 as well. A surface laid, a flush-buried, and a buried mine at 30 cm depth (for the top of the mine) are shown in the same two lanes in the two conditions. Clearly both contrasts of the target as well as clutter have diminished. Actually clear negative contrasts are found for some surface laid mines and for surface structure clutter, which means that a cross-over period takes place.

For detection purposes the ratio of target contrast degradation compared to clutter degradation is of primary importance. However, contrast for buried mines is too low to be determined from these measurements. Small shadow changes in the figure are due to differences in measurements times. In some images, camera artifacts (speckles) are visible. The measurements under wet conditions were recorded in 13 tracks per lane.

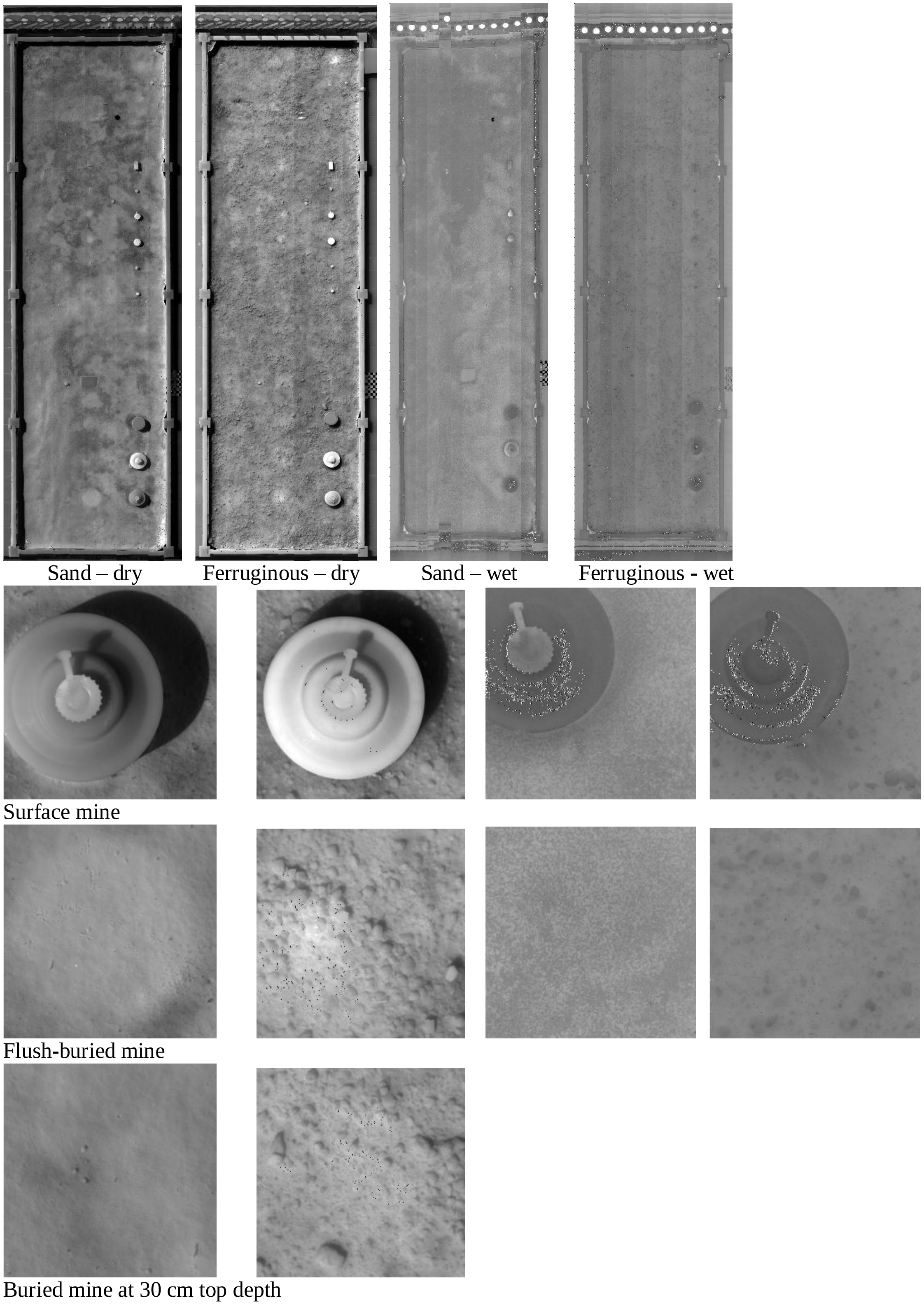

Figure 9: Test lane mosaics (first row) and single mines on surface (second row), flush-buried (third row) and 30 cm deep mines (fourth row), under dry (left two columns) and wet (right two columns) conditions in the sand land (first and third column) and the ferruginous lane (second and fourth column).

4. CONCLUSIONS

Our measurements confirm the cyclic behavior of thermal signatures during the day and night that are predicted by the thermal physics of the mine-soil-sensor system. From the TNO data it is concluded that the wet soil results in lower, and possibly reversed contrasts, but also in even lower clutter contrast levels. However, the contrasts for buried mines in this case were too small to be accurately determined. The unexpected behavior of the thermal signatures in the silt loam clearly demonstrates that the prediction of thermal signatures is not straightforward.

ACKNOWLEDGEMENT

This work of New Mexico Tech was funded by a grant from the Army Research Office (Project 38830-EL-LMD). The authors would like to thank Dr. Russell S. Harmon, Senior Program Manager at the Army Research Office, for his valuable advice and support. The work of TNO was partly funded by the Dutch Ministry of Defense and the Minister of Development and Cooperation.

REFERENCES

[1] Simunek, J., J.M.H. Hendrickx, and B. Borchers. Modeling transient temperature distributions around landmines in homogeneous bare soils. *Proc. of SPIE Vol. 4394:387-388.* 2001.

[2] DePersia, A.T., A. Bowman, P. Lucey, and E.M. Winter. Phenomenology considerations for hyperspectral mine detection. *Proc. of SPIE Vol. 2496:159-167.* 1995.

[3] De Jong, W., H.A. Lensen, Y.H.L. Janssen. Sophisticated test facility to detect land mines. *Proc. of SPIE Vol. 3710:1409-1418.* 1999.