# Some Approaches to Infrared Spectroscopy for Detection of Buried Objects

by

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## ABSTRACT

Detection of buried objects presents a formidable challenge which requires many different approaches. Infrared imaging has proven its versatility in a number of applications. Recent advances in technology have opened the door for spectroscopic imaging systems which can produce images of reflectivity or emissivity as a function of two spatial dimensions and wavelength. These imagers have been largely unexploited for detection of buried and surface–laid landmines.

Several promising opportunities exist for this application in different parts of the infrared spectrum. Variations in soil moisture content, vegetation condition, and soil composition may well be related to the presence of shallow–buried objects. In addition, polarimetric signatures appear useful in detecting man–made objects on the surface and may even help in detecting buried objects.

This paper will explore both the feasibility of using infrared spectral imagery in the 1–to–2.5 and 8–to–12 micrometer infrared bands to detect surface–laid and buried objects.

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## 1. INTRODUCTION

The detection of landmines is widely recognized as an extremely difficult challange, requiring multiple sensing strategies with different operating scenarios, sensor modalities, and algorithms. In this work, we explore the use of hyperspectral imaging in two bands of the infrared spectrum. We consider the short–wavelength infrared band from 1 to 2.5 micrometers, in which water and soil contamination are detectable using scattered sunlight, and the long–wavelength IR band from 8 to 12 micrometers, in which material properties and surface characteristics can be determined from emissions from the surface. In the latter case, we also consider polarimetric measurements.

Recent advances in technology allow nearly simultaneous imaging and spectral characterization in what is called hyperspectral imaging. A dispersive element is placed in front of a camera and multiple images are collected. In one configuration, the dispersive element acts as a filter, allowing the camera to capture an image at only one wavelength. Successive pictures are collected at different wavelengths. In another, the optical system causes the camera to image a single line in space, for example, in the horizontal direction on the camera, while the dispersive element distributes the contributions from different wavelengths across the camera in the vertical direction. If the camera is scanned or mounted on a vehicle, successive pictures build a two–dimensional image in a "pushbroom" mode. In either case, a three–dimensional array of data is obtained, in which the coordinates correspond to two spatial dimensions and wavelength. Conventional spectroscopy can be performed on each spatial pixel, or more sophisticated processing can be performed on the full three–dimensional array. Furthermore, data can be collected in polarimetric channels to extract further information from the scene.

In preparation for using hyperspectral imaging in the detection of landmines and similar objects, we explore the spectra of relevant materials to determine what signatures may be expected in conditions related to demining. Here we report on some studies in two wavelength bands.

## 2. SHORT–WAVELENGTH–IR MEASUREMENTS

In the short–wavelength infrared band, self–emission is low, and the spectrum of an object is determined by reflected sunlight. The reflection spectrum can be used to determine composition of a material. Frequently soil composition varies strongly with depth. Disturbance of the soil in laying a buried mine will result in deeper soil being brought to the surface and the spectral difference between the disturbed region and the surroundings will remain for a long time. Given the many natural variations which can be expected in soil spectra, this technique is not sufficient to locate landmines by itself, but is likely to be useful in conjunction with others, particular to address the issue of false alarms.

A laboratory spectrometer was modified to hold soil samples in a reflective mode. Known soil samples were placed in the holder and measured from 1.1 to 2.5 micrometers. Figure 1 shows two soil spectra with different water content. Soil 1 is a loam with 10%

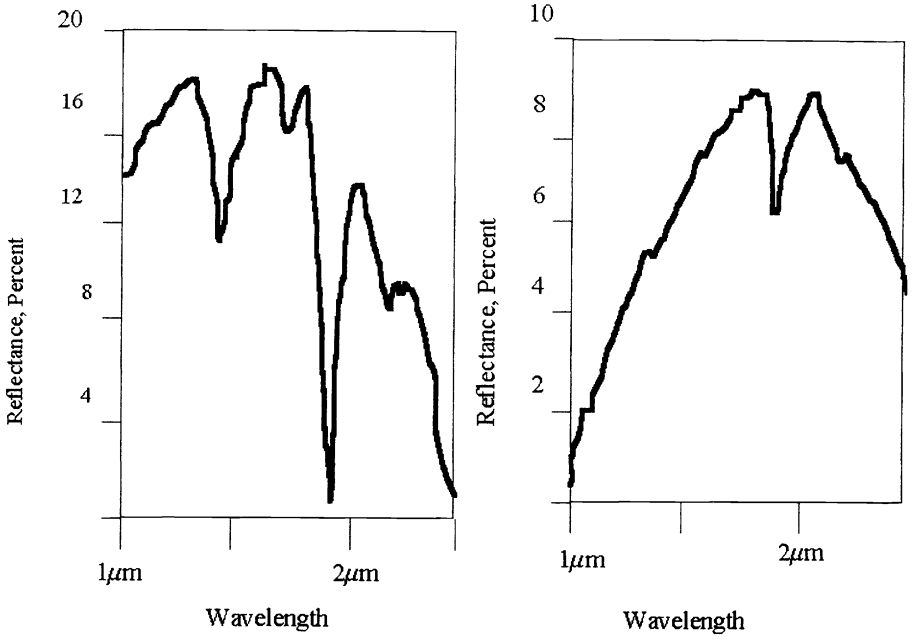

*Figure 1 — Soil Spectra with Varying Water Content.*

clay, 50% sand and 40% silt, while Soil 2 has 10% clay, 65% sand and 25% silt. There are significant differences in the content of several elements as well. The difference in absorption around 1.9 micrometers is a measure of the water content. In soil 1, several other water absorption lines become apparent. Soil 1 has an overall higher reflection. The overall reflectivity is probably not a useful parameter in detecting burial of objects, as wide ranges of variation are to be expected, and in operational scenarios, these results would be affected by lighting conditions. What may prove useful is the comparison of adjacent regions. Thus, hyperspectral imaging will permit simultaneous detection of the spatial variations in overall reflectivity and spectral features.

The emerging technology of acousto–optical tunable filters may permit the development of hand–held hyperspectral cameras to detect soil moisture, spatial changes in soil composition, and perhaps changes in the condition of vegitation, which can indicate the presence of objects below the surface. Used in conjunction with other, more established demining detectors, this technology could help to reduce the false–alarm rate and thus improve the speed of the overall demining process.

## 3. LONG-WAVELENGTH-IR MEASUREMENTS

In the long-wavelength infrared band, the contribution of scattered sunlight is low and the spectrum of an object is determined by its temperature and emissivity. Infrared thermography can detect changes in these parameters and, combined with polarimetry, can detect different surface characteristics. The emissivity of a surface depends on its composition, shape, and orientation. In the case of soil, transmission does not occur, so conservation of energy dictates that the sum of reflectivity and absorption equal unity.

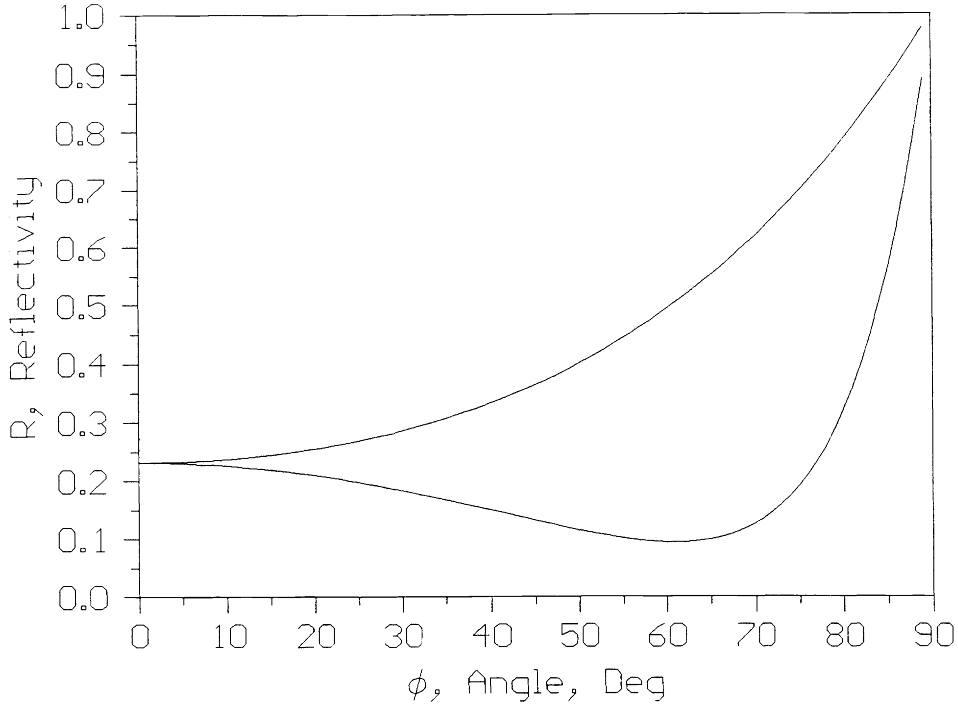

*Figure 2 — Fresnel Reflection from a Lossy Medium.*

Furthermore, the laws of thermodynamics require that the absorptivity equal the emissivity. Thus, emissivity is related to reflectivity by

$$\epsilon_x(\lambda, \theta) = A_x(\lambda, \theta) = 1 - R_x(\lambda, \theta),$$

where $\epsilon$ is the emissivity, $A$ is the absorptivity, $R$ is the reflectivity, and all are functions of the wavelength $\lambda$, the angle of observation $\theta$, and the state of polarization, $x$. As an example, Figure 2 shows the Fresnel reflectivity of a surface having an index of refraction equal to $1.5 + 1.25i$. At the grazing angles typical of forward–looking mine detection, a significant difference exists between the two polarizations. This plot is for a smooth surface typical of a man–made object. For rough surfaces, the results become more complicated, involving details of the surface texture.

Spectral measurements were made using a FTIR spectrometer with a wire–grid polarizer before the lens against realistic target scenes on the test range shown in Figure 3.

Polarmetric difference images showed greatest contrast at polarization angles of zero and 60 degrees. Figure 4 shows results for a plastic frisbee on a sand backgrouund. The left panel shows the two spectra and the right panel shows their difference. The difference is particularly significant in view of the fact that the plastic only subtends 7 percent of the field of view. Interestingly, the polarimetric signature depends strongly on wavelength, and a polarimetric sensor could see a positive, negative, or zero signal, depending on the wavelength band.

Table 1 summarizes the polarimetric data. When the polarimetric signatures are converted to degree of linear polarization (DOLP), and corrected for the fraction of the field of view that is filled by the target, it is evident that strong polarimetric signatures exist for several targets.

**Table 1**

*Key Polarimetric Results*

| | Sandy Asphalt | Tan CARC | Frisbee | Green CARC |
|---|---|---|---|---|
| DOLP (Tgt and Bkg) | 0.02 | 0.02 | 0.01 | 0.02 |
| Fractional FOV | ? | 0.24 | 0.07 | 0.15 |
| Angle Normal to LOS | 83 | 59 | 75 | 69 |
| DOLP (Tgt Only) | ? | 0.08 | 0.14 | 0.13 |

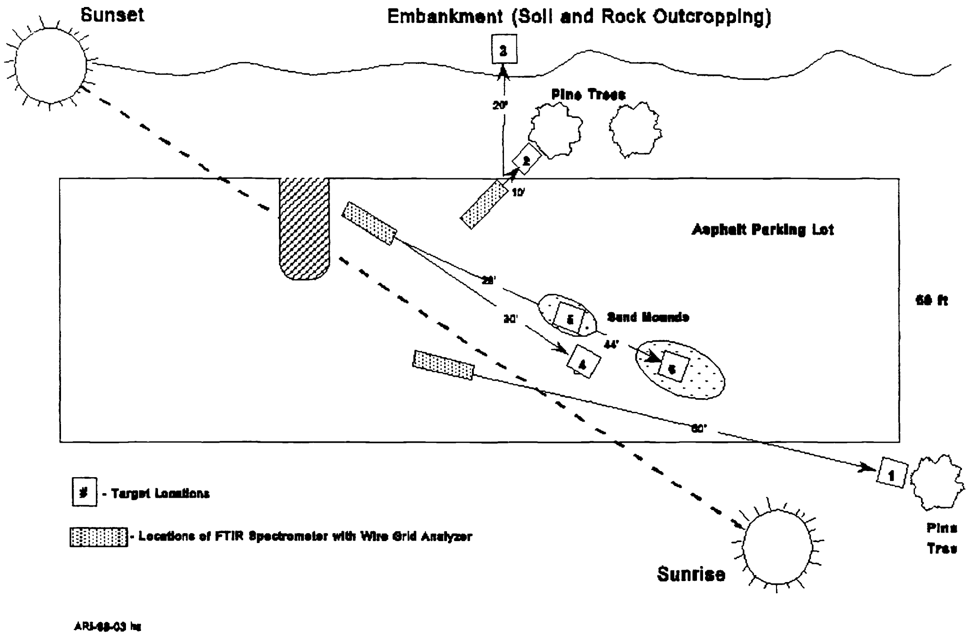

*Figure 3 — Outdoor Test Range.*

Polarimetric differences for a tan CARC (chemical–agent resistant coating) target are shown in Figure 5. In this case, the CARC target is placed against sandy asphalt, which has a net polarimetric signature, integrated over the spectrum, as indicated by the degree of linear polarization shown in Table 1, similar to that of the CARC. However, the spectral signatures are noticably different, as are the spectral polarimetric signatures, suggesting that both polarimetry and spectral data are important.

The possibility also exists for detecting soil disturbances associated with mine burial in this spectral band. Figure 6 shows spectra obtained in the laboratory for a "chunk" of soil removed from near the test range and for the same soil after being pulverized. The soil is placed on an IRTRAN window in the laboratory spectrometer, and is not to be considered representative of soil which will be encountered *in situ*. Nevertheless these results suggest that soil characteristics are dependent upon recent activity. These results

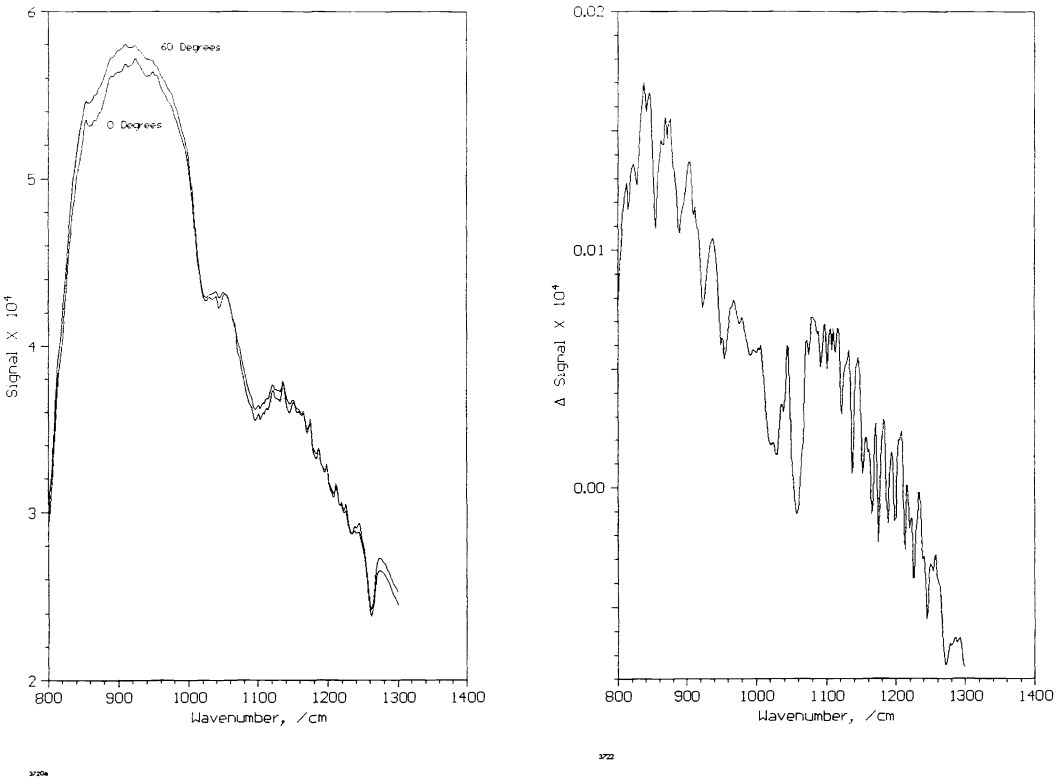

*Figure 4 — Polarimetric Spectra for Plastic Frisbee.*

are consistent with recent data in the literature *[Johnson et. al.]*, which suggest that the increased reflectivity in the 8 to 10 micrometer region of the spectrum is caused by an increase in the number of small particles which are created when the soil is disturbed, but are later removed through erosion by wind and water. Polarimetric signatures of these samples were not investigated, but such a study is proposed for the future.

In conclusion, polarimetric signatures in the band from 8 to 14 micrometers are useful in detecting surface objects. Hyperspectral images are also useful and appear to be complementary. Combined polarimetric, hyperspectral FIR imaging may yield additional information about landmines scattered on the surface. Preliminary measurements suggest that this technique can be used to detect subsurface landmines as well, indirectly by measuring soil disturbances.

Future plans include, in the short term, additional measurements and polarimetric images using an uncooled microbolometer camera and a wire-grid polarizer. In the long term, filters will be added to produce hyperspectral, polarimetric images. More careful studies of different types of surfaces and soils will continue, using the existing FTIR instrument.

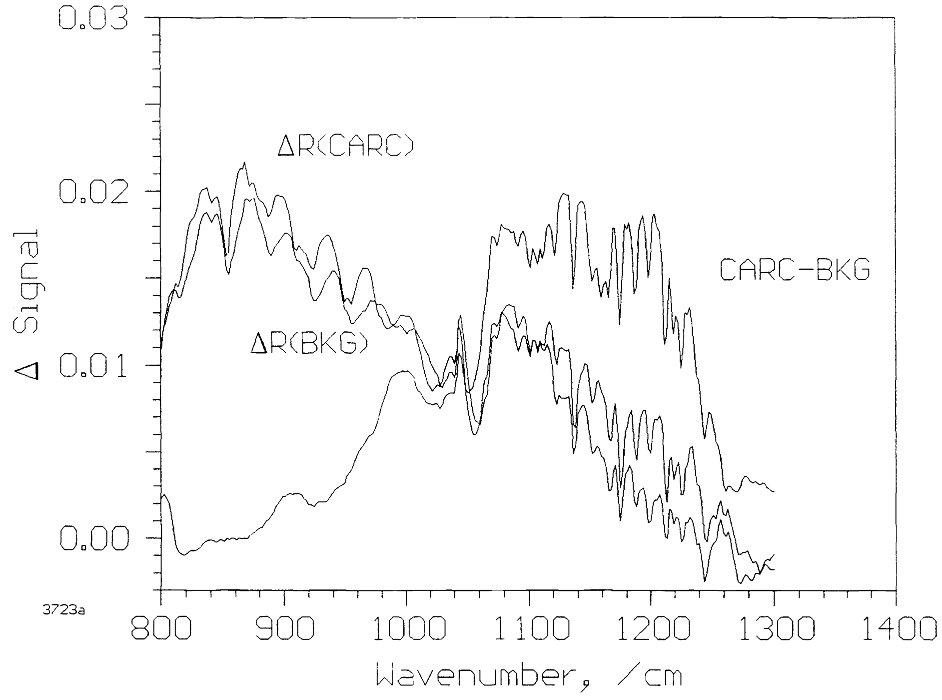

*Figure 5 — Polarimetric Spectra for Tan CARC.*

## 4. ACKNOWLEDGEMENT

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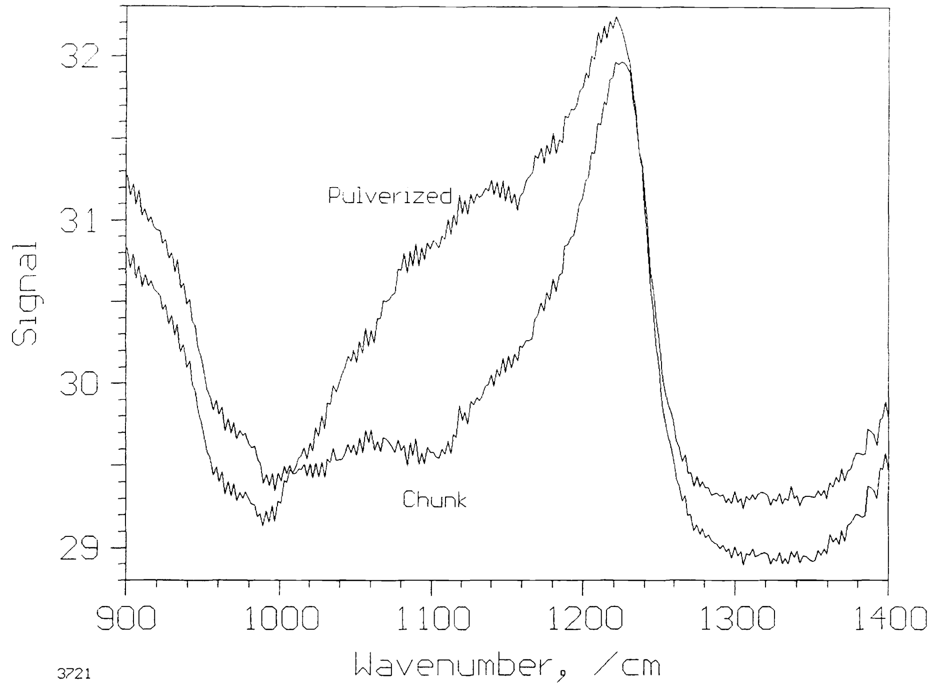

*Figure 6 — Reflectance Spectra for Soil, Before and After Pulverizing.*

## 5. REFERENCES

Johnson, et. al. "Infrared Measurements of Pristine and Disturbed Soils," *Remote Sensing of the Environment 64*, Pp. 34–46. 1998.