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Measurement Techniques for Spectral Characterization for Remote Sensing

The general purpose methodology developed is illustrated with a case study involving remote detection of deer.

(Abstract on next page)

Introduction

A general spectroscopic approach to remote sensing deals with the transfer of optical radiation between a target and associated background to a sensor through the intervening medium. This approach is formally presented by Olson (1963) and Colwell (1963). The objective of the research reported in this paper is to present a set of experimental methods which fit into the above approach, and to discuss its utility in addressing a specific problem of remote detection of deer in winter ranges of the western United States.

Note that the detection of the target, in a passive system, depends upon the sensor's ability to extract and interpret signals emanating from the target and background. This can only be accomplished by fully utilizing the target and background characteristics or attributes. Most target attributes cannot be measured directly but must be inferred from the sensor response to the radiant flux incident upon it's aperture (Wyatt, 1978). The ability of a sensor to detect a target is fundamentally dependent upon the quantity and quality of information extant in the optical signals. This information may be present in the spatial, spectral, or temporal domains (Landgrebe, 1981).

Generally, spatial information consists of the size and shape of the target, which must be unique if it is to be discerned by pattern recognition techniques. The temporal domain can be utilized provided the target moves with respect to its environment. The spectral domain seems to be of great utility in a large number of studies, particularly where the spatial and spectral properties are not particularly unique in the setting. Therefore, acquisition of spectral signatures of target and associated background can be considered an appropriate starting point toward the development of a remote sensing scheme utilizing multispectral algorithms.

Investigation of the spectral signatures of the target and its background for information content takes precedence over other considerations such as method of deployment, utilization of the spatial, or temporal domain, pixel mixing, sensitivity, etc. The existence of unique spectral signatures for targets of interest is a necessary, but not a sufficient, condition for target detection. A system may ultimately utilize information in more than one domain to be fully successful.

Spectral signatures measurement techniques must take into account the transmittance properties of the atmospheric column that separates the scene from the operational sensor. As pointed out by Slater (1980), atmospheric windows occur between 0.4 to 2.8, 3.2 to 4.2, and 8 to 14 μm (interrupted

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ABSTRACT: *Success of a remote sensing scheme depends, to a great extent, on the amount and nature of the information contained in the optical signals detected by the sensors. In this paper techniques to acquire spectral characterization of objects of interest for remote sensing studies are described. The instrumentation required consists of circular variable filter spectrometers and a spectrophotometer with integrating sphere attachment. The general purpose methodology developed is illustrated with a case study involving remote detection of deer. Laboratory studies to measure the thermal emission spectra in both the 3.5- to 5.0-μm and 7.5- to 10.0-μm bands and the reflectance spectra in the 0.3- to 2.6-μm band are described. The emissivity measurements indicate that most biological samples exhibit emission spectra which do not have appreciable wavelength dependent features, whereas the reflectance measurements indicate presence of unique signatures for deer and some commonly occurring backgrounds like snow and evergreens. This study forms the basis for a design of a multispectral classification approach for the remote detection of deer. The results acquired in the spectral signature study would have relevance to remote sensing projects where similar objects are sensed.*

by ozone absorption band between 9 to 10 μm) within the 0.4 to 16 μm spectral range where most of the emitted and reflected radiation occur in the natural environment.

It is necessary to investigate both reflectance and emission spectra, within the appropriate atmospheric windows, in an attempt to determine the optimum band based upon the apparent information content of the optical signals.

This study reports laboratory measured spectral signatures of samples of deer, snow, and various types of trees, brush, and soils, in the visible and near infrared (NIR) reflectance bands of 0.3 to 0.75 and 0.75 to 2.6 μm, and in the short wavelength infrared (SWIR) 3.5 to 5.0 μm and long wavelength infrared (LWIR) of 7.5 to 10 μm emission bands, the intent being to determine the optimum band based primarily upon the appearance of unique spectral variations.

It should be noted that the laboratory scans of samples of individual species reveal the quantity of information present in the optical scans; however, the quality of the information can only be known by statistically analyzing samples of the spectral data obtained in natural settings.

The instrumentation utilized to obtain the reported spectra include cryogenically cooled circular variable filter (CVF) spectrometers, and a recording spectrophotometer fitted with an integrating sphere attachment.

METHODS

In this section detailed methodology for the acquisition of the spectral signatures of samples in a laboratory environment is presented. Methods for measuring both emissivity and reflectance of the samples are discussed.

METHODS FOR MEASURING EMISSIVITY OF SAMPLES

Thermal IR signatures result from variations in surface temperature and/or emissivity. Spectral emissivity can be measured utilizing cryogenically cooled CVF spectrometers as illustrated in Figures 1 and 2. The SWIR spectrometer is cooled with liquid nitrogen and covers the range of 2.07 to 5.47 μm (Figure 1). The LWIR spectrometer is liquid helium cooled and has a range of 6.75 to 23.2 μm (Figure 2). The resolution of these spectrometers ranges from 3 to 4 percent.

The sensors were fitted with an appropriate baffle and sample holder to facilitate emissivity measurements using the method described by Brown and Young (1975). The cross-section of the baffle and sample holder are illustrated in Figure 3. The entire optical section, including detector, CVF, lenses, and baffle, are cooled to cryogenic temperatures to eliminate self emission. The cold pin-hole is used to reduce the sensitivity of the sensor to a range appropriate for near-ambient temperature samples.

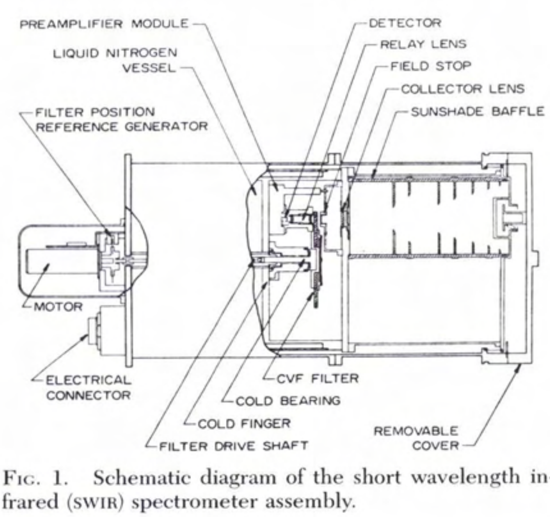

FIG. 1. Schematic diagram of the short wavelength infrared (SWIR) spectrometer assembly.

A beneficial side-effect of the pin hole is to improve the CVF resolution to approximately 1 percent.

A warm IR window is necessary to maintain the high-vacuum and cryogenic conditions and to prevent frost build-up which would otherwise occur on a cold window. The spectrometer responds to the sum of the radiation emitted by the sample and the warm IR window. It is, therefore, necessary to measure the window emissions.

The emissivity is defined as the ratio of the sample radiation to that of a blackbody at the same temperature. Several experimental problems arise in making emissivity measurements. First, the emissivity will appear to be unity if the sample and environment are at the same temperature. For an opaque sample, the emissivity, $\epsilon(\lambda)$, and the reflectivity, $R(\lambda)$, are related by

$$\epsilon(\lambda) = 1 - R(\lambda)$$

where λ is the wavelength of interest. The above equation indicates that the emissivity is low where the reflectivity is high; consequently, the sum of the reflected and emitted components is equal to that of a blackbody at the same temperature.

To eliminate this reflected radiation, the sample surface is shielded by the black cold baffle. The effect of ambient radiation, and subsequent reflection from the target, does not necessarily preclude the use of spectral emissivity in a practical remote sensing system because the ambient reflected radiation may not exhibit the same temperature as the target.

Exposing the target to a cold radiative environment creates the second problem. The sample cools by radiation coupling to the cold baffle. It is difficult under these conditions to determine or control the surface temperature. This is particularly difficult for biological samples such as deer hide that are good insulators. Again, the method suggested by Brown and Young (1975) was used. The sample surface temperature was maintained near the desired level by passing preheated dry nitrogen gas through the sample holder. The gas temperature was measured as it exited the sample holder by using a bead thermistor. It was assumed that the equilibrium temperature of the gas was representative of the sample surface. An error of 0.5° K in the determination of the sample temperature means an error of almost 1 percent in the measured value of the emissivity, and the error increases with decreasing wavelength.

The measurement of the emissivity is facilitated by the following considerations. The sensor response is linear over the region of the measurements, and utilizing a blackbody at the same temperature as the sample provides the emissivity as a simple ratio of sensor voltages.

The measurement procedure is as follows. The preheated nitrogen gas is passed through the sample holder until equilibrium is achieved and the sensor output $V_s(\lambda)$ recorded. The sample holder is replaced with a blackbody simulator at the same temperature and the sensor output $V_b(\lambda)$ is recorded. Finally, the window emissions are measured, so that they can be subtracted from the sample and blackbody measurements, by replacing the sample holder with a nitrogen cooled (77°K) blackbody source and recording the sensor output $V_w(\lambda)$.

The emissivity is given by

$$\epsilon(\lambda) = \frac{V_s(\lambda) - V_w(\lambda)}{V_b(\lambda) - V_w(\lambda)}.$$

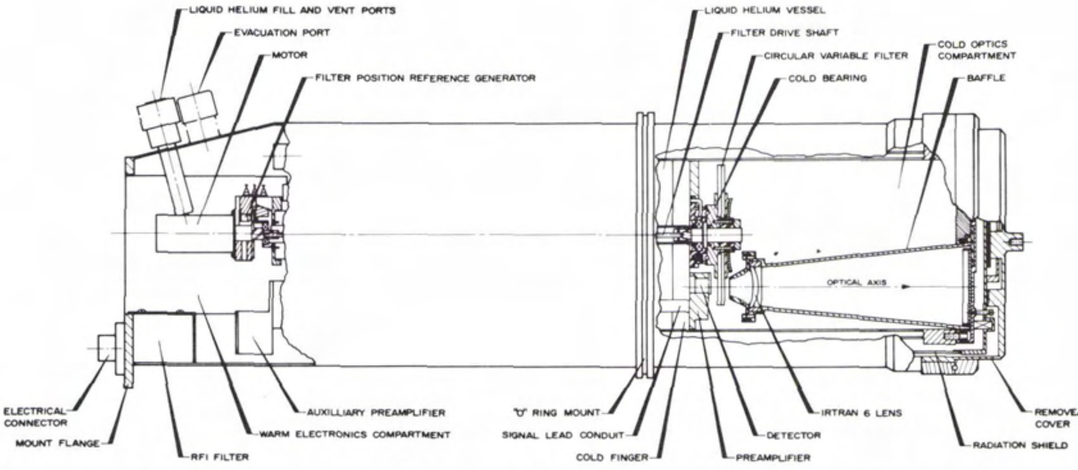

FIG. 2. Schematic diagram of the long wavelength infrared (LWIR) CVF spectrometer assembly.

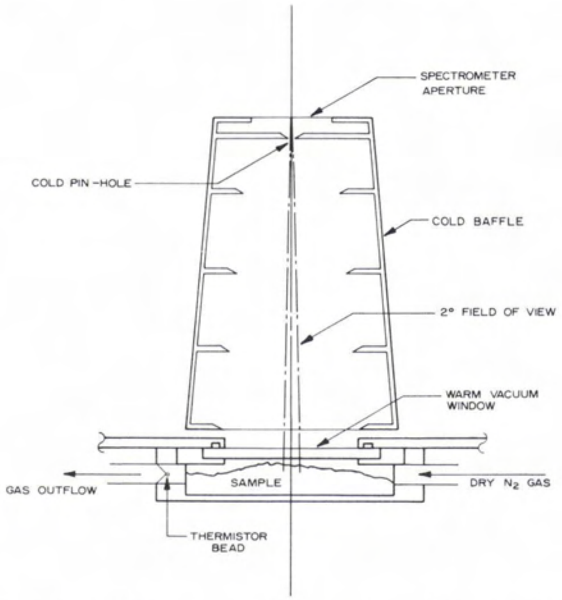

FIG. 3. Optical schematic cross section of the sample chamber and baffle used for emissivity measurements with a CVF spectrometer.

A temperature of 45°C was used because that is the lowest temperature for which the commercial source can be operated under temperature control. Because the main objective of this investigation was to examine the presence of any wavelength dependent features in the emission spectra, use of a slightly different temperature than 45°C should not affect those features significantly. The data were digitized by direct analog to digital conversion.

METHOD FOR MEASURING REFLECTANCE OF SAMPLES

The hemispherical reflectance spectral signatures of the samples in the 0.3- to 2.6-μm band were obtained using a recording Beckman Model DK-2A ratio spectrophotometer. The effects of polarization, associated with reflectance, were minimized through the use of an integrating sphere attachment and by mounting the sample within the holder in random orientation patterns.

Figure 4 is a schematic illustrating the instrument assembly used in the measurement. The integrating sphere has two sample viewports: one for a 100 percent reflectance reference standard and the other for the test sample. The samples were mounted in a vertical plane and, initially, glue was used to support loose substances such as the sand and soil samples. However, the glue spectra corrupted the measurements. Therefore, instead of using glue, the sample holder was fitted with a thin glass window. The effect of the glass window was determined by measuring the reflectance of an identical 100 percent reference standard mounted behind the window. The only effect of the window is a scale change of the 100 percent deflection of the graphic recording. The spectra obtained with the window were corrected by dividing by the indicated reflectance of the 100 percent standard.

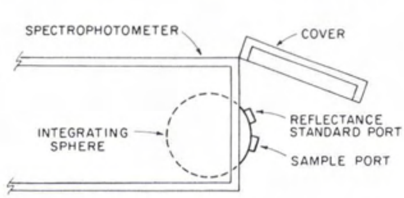

FIG. 4. Spectrophotometer assembly used for the reflectance measurements.

The Beckman DK-2A obtains the spectra in two segments: The first utilized a multiplier phototube for the range 0.3 to 0.8 μm, and the second a lead-sulphide detector for the range of 0.5 to 2.6 μm. These data were corrected for the window, where appropriate, and replotted to produce the composite spectra reported in the next section.

RESULTS

The methods for spectral characterization were used in a study involving remote detection of deer. It is believed that a winter deer range offers the best environmental conditions for the remote detection of deer. This is because the deer tend to be in open meadows in the winter and are, therefore, less apt to be under a vegetative canopy and also because the snow tends to help the detection task by providing a cold and uniform background. The samples used in the spectral characterization study were obtained from a winter range in northern Utah.

EMISSIVITY MEASUREMENTS

The emissivity measurements for both the SWIR and the LWIR bands are presented in Figure 5. The emissivity spectral signatures for certain minerals, especially silica, were matched against those reported elsewhere in the literature (Lyon, 1965; Brown *et al.*, 1975), and the validity of the measurements was confirmed. The data were plotted after the style of Lyon (1965), to conserve space, as a composite illustration. These curves are vertically displaced to facilitate comparisons between spectral signatures of various samples.

It is estimated that the emissivity uncertainty is about 10 percent in the spectra of Figure 5 because of the uncertainty in the sample temperature. The measured ranges for the high and low values of emissivity for the respective samples are given in Table 1.

The original data were taken over the range of 6.75 to 13.0 μm; however, a troublesome joint in the circular variable filter occurs at about 10.0 μm, blocking out the range 9.7 to 10.3 μm. Preliminary

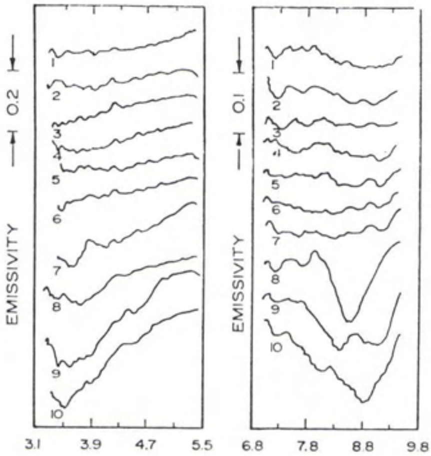

FIG. 5. Emissivity as a function of a wavelengths for (1) deerhide, (2) sagebrush, (3) juniper, (4) rabbitbrush, (5) maple leaf, (6) log, (7) soil, (8) gypsum sand, (9) feldspar sand, and (10) silica sand. Note that curves have been vertically displaced to facilitate comparisons.

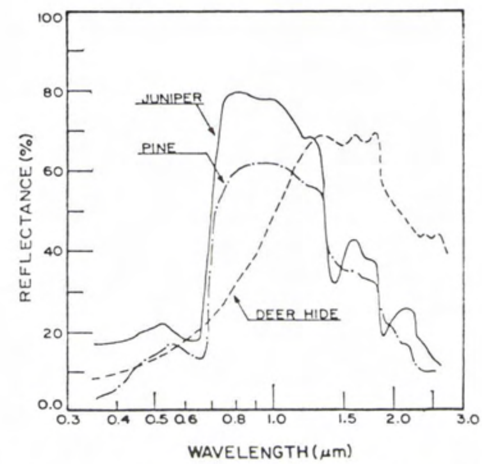

FIG. 6. Reflectance spectra for deerhide, juniper, and pine. The chlorophyll absorption at 0.68 μm is significant.

examination of the data from 10.3 to 13 μm revealed no significant features for the samples of interest.

The data illustrated in Figure 5 show that the biological samples exhibit no significant wavelength dependant features. The radiation has the general appearance of a graybody. Thus, the only information associated with the thermal emission bands, for the biological samples, appears to be effective radiant temperature contrast.

REFLECTANCE MEASUREMENTS

The results of the reflectance measurements reveal considerable unique spectra, as illustrated in Figures 6, 7, and 8. Figure 6 contrasts the deer hide sample with a number of fresh samples that exhibit the typical chlorophyll absorption spectra. These spectra appear to provide a means to discriminate between deer and plant life that exhibits chlorophyll absorption in the region of 0.6 to 0.7 μm and high reflectance in the 0.7 to 1.4 μm region. Note that the integrating sphere attachment reduces the effects of polarization. Further reduction in the polarization effects were achieved by mounting the samples in a random orientation patterns. This is particularly important for pine and juniper samples.

TABLE 1. RANGES OF MEASURED EMISSIVITY VALUES OF SAMPLES

Sample	3.5 to 5 μm emission band	7.5 to 10 μm emission band
Deerhide	0.62–0.70	0.90–0.93
Sagebrush	0.79–0.81	0.90–0.93
Juniper	0.72–0.80	0.89–0.92
Rabbitbrush*	0.60–0.70	—
Maple leaf	0.65–0.70	0.92–0.95
Log	0.65–0.72	0.90–0.94
Soil	0.46–0.62	0.86–0.90
Gypsum sand	0.45–0.65	0.72–0.88
Feldspar sand	0.35–0.68	0.75–0.85
Silica sand	0.30–0.68	0.75–0.88

* During the LWIR emissivity measurement for the rabbitbrush sample the cold baffle temperature was warming up, and therefore accurate range for absolute emissivity values could not be determined.

Figure 7 contrasts deer hide with a sample of soil and dry log. These spectra are less encouraging because of the similarities with the deer hide.

Figure 8 contrasts deer hide with new and old snow and shows distinctive spectra. These spectra indicate that snow provides a very high contrast with the deer.

DISCUSSION

An optical sensor that provides simultaneous measurements in several wavelength regions can provide data useful in a general multivariate classification technique wherein each measurement is considered as an *n*-dimensional vector in the measurement space (Fu *et al.*, 1969). The underlying hypothesis is that the measurement vectors corresponding to a particular class tend to cluster together in the measurement space.

In the past, several attempts to apply remote sensing techniques to the problems of wildlife detection have focused upon the thermal infrared region (Croon *et al.*, 1968; McCullough *et al.*, 1969; Parker, 1972; Best *et al.*, 1982). The thermal scanner is suggested as a possible tool for the animal census. This corresponds to decision making in one-dimensional measurement space where it is seen from the above results that the spectral signatures of the targets of interest do not exhibit appreciable variations as a function of wavelength. In this case,

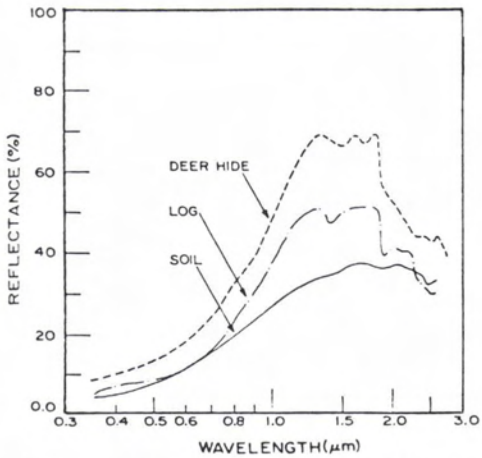

FIG. 7. Reflectance spectra for deerhide, soil, and dry log.

the only discriminatory information present is in the form of thermal contrast magnitude.

Experimental attempts to detect deer in natural habitat have had "limited success" (Colwell, 1983, p. 2369). Few cases (Croon *et al.*, 1968) reported unusual successes in detecting deer under near ideal conditions for temperature differential between the deer and background; however, regarding the thermal scanner's utility in general operational environment was not made. Wyatt *et al.* (1980) have statistically evaluated the effective radiant temperature (ERT) data of deer, snow, and brush (the ERT is defined as the temperature of a blackbody that would produce the same sensor response as did the target). The results of this study indicate that a thermal scanner can successfully detect deer against a snow covered background, but that large errors would occur when the probability of snow-free objects is greater than the probability of deer. This is because background objects in the

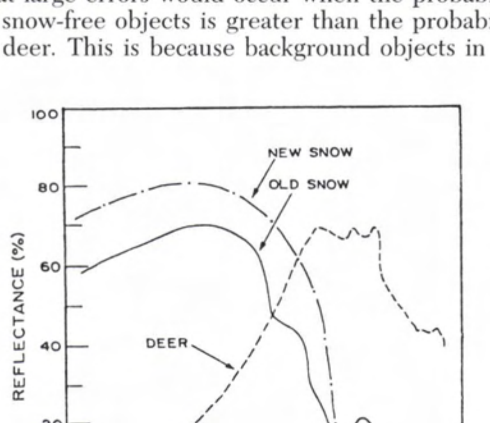

FIG. 8. Reflectance data for deerhide, and new and old snow (after Dirmhirn, 1968).

scene often exhibit higher temperatures than the deer. A similar conclusion was also reported by McCullough *et al.* (1969) where snow background, air temperature below freezing, and a high overcast were suggested as optimum conditions for thermal detection of deer. The spectral characterization study reported in this section provides an explanation for the difficulty encountered in the approaches based on thermal IR scanning.

Development of a remote detection system for any project requires identification of the most suitable spectral band for sensing the electromagnetic radiation. The results reported above help in the determination of such a band from primarily the spectral information content point of view. It is discovered that for deer detection the visible-near IR, 0.35- to 2.6-μm reflection band offers substantially more spectral information than the two thermal emission bands of 3.5 to 5.4 μm and 7.5 to 10.0 μm. This observation can be further amplified by using the concept of contrast.

The contrast can be defined as the ratio of the difference between the deer signal and the background signal to that of the background signal at a given wavelength. Human interpreters are believed to detect, at best, 20 shades of gray in a monochrome image; thus, a contrast of 5 percent is required for detectability. If the data are recorded and analyzed digitally, this criterion is not so important.

Using the above definition, the mean contrast for Parker's (1972) thermal data is about 3 percent (based upon a reported mean difference temperature of 7°K at 250°K). On the other hand, the reflectance data reported in the above measurements show the deer to snow contrast greater than 70 percent at 0.6 μm (see Figure 8). The contrast of deer to the green vegetation is greater than 40 percent at 0.8 μm (see Figure 6). Examination of the deer spectral signatures indicates that most of the commonly occurring background samples exhibit at least 5 percent spectral contrast in the visible, 0.35- to 0.70-μm band. Samples of backgrounds such as snow and green vegetation have as much as approximately 90 percent contrast with that of deer at some wavelength in the reflection bands. Thermal contrasts, on the other hand, between deer and most biological samples were much less significant. A secondary advantage derived by using the reflection bands is the relatively less complex hardware than that required in the cryogenically cooled thermal radiation sensors.

Note that investigation of spectral signatures of deer and their background for discriminatory information has taken precedence over considerations such as deployment method, utilization of information from other domains, sensitivity, etc. By showing that deer and their background possess unique spectral signatures, a necessary, but not sufficient, condition for developing a multispectral approach has been satisfied.

The data reported upon in this study indicate that reflectance spectra in the NIR bands may be useful for remote detection of deer. In order to develop a multispectral classification approach based upon these bands, extensive field studies were conducted to assess the robustness of the spectral signatures (Trivedi, 1979). The reflectance data obtained in a typical winter deer range helped to demonstrate the feasibility of four-color system for the deer detection problem (Trivedi *et al.*, 1982).

Further studies (Trivedi *et al.*, 1984) have addressed the problem of an efficient algorithm that is capable of real-time implementation. A prototype system, thus designed, offered promising results in preliminary field tests.

Future studies should concentrate upon the effects of pixel registration, the stability of detection criteria with environmental conditions, the application of spatial criteria, and, finally, the statistical estimation of total populations from sample survey data.

Conclusions

In this paper techniques for the acquisition of the spectral characterization of objects of interest for a remote sensing study are described. The methodology developed is applied to a case study involving remote detection of deer. The thermal emission spectra were measured in the 3.5- to 5.0-μm and 7.5- to 10.0-μm bands using cryogenic CVF spectrometer systems. The reflectance measurements were acquired in the 0.3- to 2.6-μm band using a laboratory spectrometer with an integrating sphere attachment. The emissivity measurements indicate that most biological samples exhibit emissivity values that do not vary appreciably with wavelength, whereas the reflectance measurements show the presence of unique signatures for deer and some more frequently occurring background objects. This study forms the basis for a multispectral approach that was recently suggested by Trivedi *et al.* (1982) for the remote detection of deer. The methodology reported in this study should have utility in conducting spectral signature studies for similar remote sensing projects, and the results of the case study should be relevant to remote sensing studies involving soil, snow, and other biological scene components.

Acknowledgments

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