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A Multispectral Approach to Remote Detection of Deer

Four spectral bands are required for a typical winter scene with snow, evergreens, and green and dried brush as background in order to obtain a deer detection accuracy of about sixty percent.

(Abstract on next page)

INTRODUCTION

A BASIC REQUIREMENT for resource management programs is the availability of reliable estimates of the size of the resource. In the case of wildlife management, an accurate estimate of animal populations is important. Such information is necessary in order to develop population figures as they relate to the spatial and temporal parameters. Generally, animal habitats are in inaccessible locations, which makes acquisition of population estimates a difficult task. Techniques currently employed to acquire animal population information fall into two categories: (1) Direct methods, requiring human observation of animals in their natural habitat, and (2) indirect methods, which include observation of browse consumption and pellet group counts. Both of these techniques suffer serious drawbacks. Direct methods are not very useful because of poor visibility and difficult terrain, whereas indirect methods tend to provide information on animal activity rather than actual animal counts (Parker, 1972). Remote sensing techniques can be used to overcome some of these difficulties.

The study reported here is primarily concerned with the remote detection of mule deer (*Odocoileus hemionus*) on winter ranges of the western United States. In addition to the need for deer population estimates for proper management and ascertaining allowable harvest, there is a need for estimates of numbers in assessing environmental impacts. Wild deer are an important economic, aesthetic, and cultural resource. Rue (1978) suggests that there may be approximately 20 million deer in North America. Deer hunting in 1975 alone represented approximately 2.4 billion dollars to the economy. Hunters annually realize nearly 125 million pounds of boneless meat valued, conservatively, at 135 million dollars. Of course, various aesthetic values are extremely large, but far more difficult to evaluate. The deer population figures available currently are considered to be merely "guesses devoid of reliable, quantified substantiation" (Gill, 1976). More recently, Connolly (1981) has also made a similar remark about unavailability of reliable estimates of deer populations for any entire state or province in North America. A need for new techniques of acquiring reliable population estimates of deer is, therefore, recognized. A successful remote sensing technique for deer and other wildlife detection can be utilized for biological monitoring, environmental impact assessment, and wildlife management and research.

A remote sensing system consists of basically three components: (1) the scene, (2) the sensor, and (3) the information processor. In the present study the scene is composed of the deer and associated natural habitat backgrounds. The sensor has the capability of detecting the reflected electro-optical radiation from the scene, and the sensor response can be used to characterize the scene.

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The information processor implements the classification algorithm.

The objective of this research was to evaluate, by theoretical and experimental methods, the feasibility of developing an airborne system to survey deer populations using the reflectance spectra. This was accomplished as follows: A relatively large statistical sample of spectral reflectance data was obtained of deer and background objects in a controlled outdoor winter setting. A specially designed circular variable filter (CVF) spectrometer system having the spectral range of 0.4 μm to 1.1 μm was used in the study. The field data were utilized to select the wavelengths which provided greatest differentiation of deer from background, and, finally, multispectral classifiers were designed and tested to assess the feasibility of this approach.

ABSTRACT: *The purpose of this research was to evaluate, by theoretical and experimental methods, the feasibility of developing an airborne system to survey deer populations using reflectance spectra. This was accomplished as follows: A relatively large statistical sample of spectral reflectance data were obtained of deer and background objects in a controlled outdoor winter setting using a specially designed circular variable filter spectrometer system with the spectral range of 0.4 μm to 1.1 μm. Field data were utilized to select the wavelengths which provided greatest differentiation of deer from background, and, finally, multispectral classifiers were designed and tested to assess the feasibility. The results of the study were (1) two spectral bands are adequate for almost error-free detection of deer in a snow and/or evergreen tree background; (2) four spectral bands are required for a typical winter scene with snow, evergreens, and green and dried brush as background, in order to obtain a deer detection accuracy of about 60 percent (if only three spectral bands are used the accuracy drops to about 50 percent); and (3) four spectral bands provide an accuracy of about 90 percent when the winter scene does not include dried brush class (if only three bands are used, the accuracy drops to about 80 percent). The wavelengths used for the four-band classifier were 0.672 μm, 0.764 μm, 0.981 μm, and 0.725 μm, whereas, in the three-band classifier, the 0.725 μm wavelength was excluded. These results justify development of a prototype airborne system which would allow additional and more realistic testing.*

BACKGROUND

REMOTE SENSING OF WILDLIFE BY THERMAL SCANNERS

Most previous studies concerning remote sensing of animals were conducted in the thermal infrared (IR) bands of 3 to 5, 3 to 14, and 8 to 14 micrometres. These include tests by Croon *et al.* (1968), McCullough *et al.* (1969), Graves *et al.* (1972), Parker and Driscoll (1972), Isakson *et al.* (1975), and Wride and Baker (1977). A brief review of these studies does not indicate any conclusive results to support utilization of thermal IR scanners as remote detection tools in animal surveys. Recently, a detailed study conducted by Wyatt *et al.* (1980) analyzed the thermal IR data collected by Parker (1972). In this a Bayesian decision model was used to assess the feasibility of deer detection by thermal contrast. The conclusion of the study was that deer can be successfully detected against a snow background, but a thermal scanner exhibits large errors in detecting deer when the occurrence of snow-free objects is much greater than that of deer. Thermal contrast by itself, therefore, is of limited value in deer census applications.

DATA ACQUISITION

Laboratory studies by Pate (1979) demonstrated that deer and winter-time samples of foliage, brush, and snow exhibit spectral reflectance in the visible-near IR region which are characteristic of the species in general categories. The thermal IR regions do not uniquely characterize the species. Also, statistical evaluation of the thermal IR data indicates that the thermal contrast, by itself, does not provide sufficient discriminatory information for the detection of deer (Wyatt *et al.*, 1980). The study reported in this paper was, therefore, based upon the visible-near IR spectrum of 0.45 μm to 1.1 μm, and utilizes reflected energy of the scene as the primary data source. The feasibility of developing an operational remote detection system for a deer census was evaluated by utilizing the spectral signatures acquired in a specifically designed field experiment. Such an experiment was conducted in an environment closely resembling the actual conditions that would be encountered in the use of an operational system. A circular variable filter (CVF) spectrometer system was used to acquire the data.

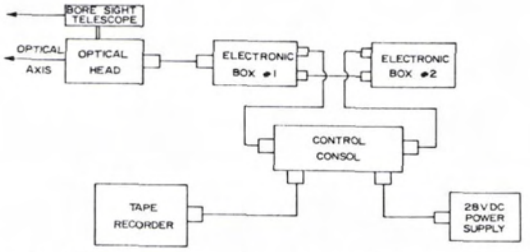

FIG. 1. The circular variable filter spectrometer system.

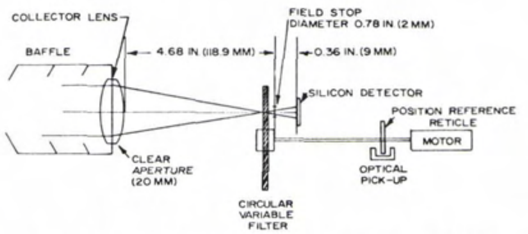

FIG. 2. Schematic diagram of the optical head in the CVF spectrometer.

CIRCULAR VARIABLE FILTER SPECTROMETER SYSTEM

The spectral signatures of deer and various objects under study were collected using a CVF spectrometer system. This spectrometer was designed for the study at the Electro-Dynamics Laboratories of the Utah State University. The block diagram for the CVF spectrometer system is presented in Figure 1. It consists of a boresighted optical head, the signal conditioning and amplification electronics pack, control console, an oscilloscope, and a four channel FM tape recorder. The schematic diagram for the optical head is presented in Figure 2. The field of view is established by the collector lens and field stop. The filter was located directly above the field stop which serves as the spectrometer slit. The detector output provided a representation of the spectrum as the motor driven CVF moves over the slit-field stop. The position reference reticle and optical pick-up produces a filter position reference signal that was used to define the wavelength at any instant of time. The CVF consists of two 180° segments. The first segment covers the spectral range of 0.45 μm to 0.72 μm and the second segment covers the range 0.68 μm to 1.1 μm as masked in the system. The spectrometer completes a scan with each revolution of the filter in approximately one-half a second.

The signal conditioning system was a DC reset design in which the output is forced to zero while the zero-degree mask covers the detector on each filter rotation. This was accomplished through the use of a sample and hold integrator circuit which feeds a correction voltage into the input and holds it until the next reset condition is encountered (Wyatt and Baker, 1975). Thus, the system functions as a DC system while taking data, so that there can be no sag; but, so far as drift was concerned, it behaves as though it were AC coupled. The DC reset system was relatively simple in design compared to the symmetrical chopping approach. The major advantage over the high frequency chopping method was that in the DC reset system the detector-preamplifier frequency response need be no higher than that of the final low pass filter. Also, this system had better signal-to-noise ratio than the symmetrical chopping method. The spectrometer output was available on three separate gain settings in order to provide an extended dynamic range with linear outputs. Trivedi (1979) has presented the detailed calibration data for the CVF spectrometer.

FIELD EXPERIMENT

The controlled field experiment to collect the reflectance measurements of deer and other background objects was conducted in a typical winter deer range setting. The study was performed between 20 January and 28 February, 1978. The reasons for selecting the winter season for study were (1) it was observed that during winter, concentrated deer populations tend to browse in open meadows which are free from overhead canopy on south facing slopes on the ranges; and (2) the winter scene is most favorable for a deer survey because snow cover tends to be a major background which exhibits distinct spectral signature.

In order to provide general applicability to this study, it is desirable to consider a *typical generalized scene* which can be representative of any wintertime scene. For this research the scene was modeled as one which included deer, trees, and brush with a background of snow. The evergreens exhibit significant chlorophyll absorption in its spectral response. Juniper (*Juniperus osteosperma*) was used to typify evergreens. Sagebrush (*Artemisia tridentata*), a major deer browse which is a dominant shrub on many winter ranges and exhibits minor chlorophyll absorption, was also included in the model. To represent partially defoiliated dormant brush with little chlorophyll, rabbitbrush (*Chrysothamnus nauseosus*) class was included. Deer, snow, juniper, sagebrush, and rabbitbrush classes made a total of five classes in the typical generalized model. Figure 3 illustrates an aerial photograph of winter deer range which is basically composed of the four background classes.

The spectral signatures of deer and background objects were collected using CVF spectrometer system mounted on a 15-ft high tower. As shown in Figure 4, the tower provided a nearly overhead angle of elevation for the spectral measurements

FIG. 3. An aerial photograph of a typical winter deer range.

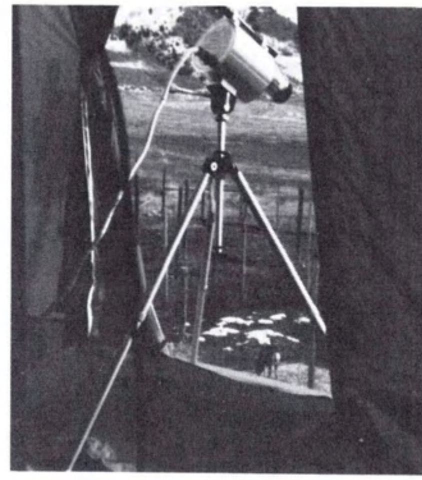

FIG. 4. The CVF spectrometer system mounted on the tower for the field experiment.

so that the data would be representative of that obtained by an airborne platform. The spectrometer was aimed at a particular object with a four-power telescopic rifle sight attached on the optical head. The field of view of the spectrometer covered only the object of interest, and any averaging of target and background was avoided because the airborne scanner will not "see" individual orientations of surfaces within a pixel but an average effect of many orientations. The data were collected so that the pixel size, at approximately 30 feet, was about the same as that for an airborne system at 1200 feet. Such a precaution is necessary due to the considerations of the bidirectional reflectance distribution function. Each measurement run consisted of spectral reflectance measurements from deer and from the other four background classes. All measurements in a particular run were obtained within a duration of approximately one minute, and for every object about six to seven complete scans were recorded. During the course of the complete experiment about 200 spectral scans were obtained for the classes under study.

The main consideration in the field experiment was to collect data which would correspond well to those acquired by the actual airborne deer detection system. Practically, such a system would be operated in conditions of (1) variable insolation, relating to the variations in the overhead illumination; and (2) variable directionality, which relates to the different orientations of individual species, leaves, trees, or terrain. Because of these considerations the data were collected under conditions that varied from bright overhead sunshine to cloudy twilight. Thus, the measurements correspond to a wide spectrum of insolation and directionality conditions. In order to provide for the possibility of examining the effects of the environmental parameters, the conditions associated with each measurement were recorded. Also, the potential problems due to shadows in a scene, if at all serious, might be reduced by restricting the operation of the detection system to the days of diffuse overhead illumination. In the field study, however, shadows are considered to be part of normal scene, and their effect can be examined by limiting the analysis to the data collected during diffused overhead illumination conditions.

Subsequently, the analog spectral reflectance data recorded during the field study were digitized. Calibration information of the spectrometer was used to define each measurement in 50 discrete spectral bands. The first band was centered on 0.457 μm and the fiftieth on 1.139 μm. The bandwidth of these spectral bands was approximately 0.015 μm, making detailed definition of spectral signatures available for the data analysis task.

DATA ANALYSIS: METHODS AND RESULTS

CLASSIFICATION APPROACH

Detection of deer immersed in a background of competing objects such as snow, trees, and brushes can be viewed as a problem of detection of signal in a noisy background. Statistical pattern classification techniques were used to approach the deer detection problem. The objective of a classification procedure was to classify the spectral measurements as either deer or one of the non-deer objects such as snow, green vegetation, or brush. It is desirable to perform such classification as accurately as possible. The Bayesian classification procedure allowed the investigators to classify the data so that the overall probability of error was minimized (Duda and Hart, 1973). A brief description of the classification procedure is presented below.

Let

$$\mathbf{X} = (x_1,x_2, \ldots ,x_d)$$

represent a d-dimensional measurement vector, where x_i corresponds to the spectral measurement in the i^{th} band. Also, let $P(\omega|\mathbf{X})$ represent a posterior probability that a given measurement vector $\mathbf{X}$ belongs to class ω_i. The Bayes decision rule can be stated as, assign $\mathbf{X}$ to class ω_j if and only if

$$P(\omega_j|\mathbf{X}) = \text{Max}\left\{P(\omega_i|\mathbf{X})\right\}, i = 1, \ldots, c$$

where c is the total number of classes in the scene. Thus, the rule simply assigns the measurement vector to the class which is most likely to provide the measured spectral values. By applying the Bayes rule (Anderson, 1958), the above rule can be rewritten as, assign $\mathbf{X}$ to class ω_j if and only if,

$$P(\mathbf{X}|\omega_j)\, P(\omega_j) = \text{Max}\left\{p(\mathbf{X}|\omega_i)\, P(\omega_i)\right\}, i = 1, \ldots, c$$

where $P(\omega_i)$ is the a priori probability of class ω_i and $p(\mathbf{X}|\omega_i)$ is the class conditional probability density function for $\mathbf{X}$ given that it belongs to class ω_i. The expression $p(\mathbf{X}|\omega_i)\, P(\omega_i)$ is called the i^{th} decision function. The measurement vectors are randomly distributed, a multivariate normal distribution is assumed, and, therefore, the class conditional densities can be evaluated as follows:

$$p(\mathbf{X}|\omega_i) = \frac{1}{(2\pi)^{d/2}|\hat{\mathbf{\Sigma}}_i|^{1/2}} \cdot \exp\left[-\tfrac{1}{2}(\mathbf{X} - \hat{\boldsymbol{\mu}}_i)^t \hat{\mathbf{\Sigma}}^{-1} (\mathbf{X} - \hat{\boldsymbol{\mu}}_i)\right]$$

where

- d = dimensionality of the feature space,
- $\hat{\boldsymbol{\mu}}_i$ = estimate of the mean vector for class ω_i, and
- $\hat{\mathbf{\Sigma}}_i$ = estimate of the covariance matrix for class ω_i

The maximum likelihood estimates for mean vectors and covariance matrices can be evaluated as (Duda and Hart, 1973).

$$\hat{\boldsymbol{\mu}}_i = \frac{1}{N_i} \sum_{j=1}^{N_i} \mathbf{X}_j, \text{ and}$$

$$\hat{\mathbf{\Sigma}}_i = \frac{1}{N_i} \sum_{k=1}^{N_i} (\mathbf{X}_k - \hat{\boldsymbol{\mu}}_i)(\mathbf{X}_k - \hat{\boldsymbol{\mu}}_i)^t.$$

where

N_i = number of samples in class ω_i.

In summary, multiclass Bayesian classification with normality assumption requires an evaluation of the maximum likelihood estimates for mean vectors and covariance matrices; also required is the estimate for a priori probabilities. This constitutes the training phase for the classifier. Later on, when an unknown measurement vector is presented to the classifier, the decision functions for all the classes are computed and the vector is assigned to the class with the largest decision function value.

CHARACTERIZATION OF THE SCENE

In order to ensure a consistent performance of the classifier under a variety of ambient conditions, the measurement vector should reflect characteristics of the species of interest rather than of the ambient conditions. In order to describe various methods utilized in the study, a few mathematical notations are presented below.

As mentioned earlier, each scan acquired consists of spectral measurements corresponding to 50 discrete bands. For mathematical convenience, such a scan can be represented by a vector in a 50-dimensional space; i.e.,

$$\mathbf{X} = (x_1, x_2, \ldots, x_{50})$$

where x_k denotes the value of spectrometer reading in the i^{th} band. It is possible to generate a normalized measurement vector as follows:

$$\mathbf{Y} = (y_1, y_2, \ldots, y_{50})$$

where

$$y_i = \frac{x_i}{\|\mathbf{X}\|}, i = 1, \ldots, 50$$

and

$$\|\mathbf{X}\| = (x_1^2 + x_2^2 + \ldots + x_{50}^2)^{1/2}.$$

It should be noted that y_i corresponds to the i^{th} direction cosine of $\mathbf{X}$, i.e., it describes the angle between $\mathbf{X}$ and the i^{th} coordinate axis. Vector $\mathbf{Y}$, therefore, basically represents the angular specification of $\mathbf{X}$; and it also can be interpreted as the normalized reflectance characteristics of the species.

A signature stability study was performed in order to investigate the variations in the normalized and unnormalized forms of the measurement vectors. The study consisted of the evaluation of coefficients of variations for each component of the vectors, based on the entire data set which included a wide spectrum of environmental conditions. If the coefficients of variations were relatively small, it would indicate a particular characterization as quite stable as far as the ambient variations were concerned. The results of this study, for deer class, are presented in Figure 5. The magnitude components of the vector (unnormalized) showed relatively large coefficients of variations: typically between 70 and 110 percent for different environmental conditions. Thus, magnitude can be viewed as more representative of the ambient illumination, and, therefore, it cannot be considered a good characterization of the classes in the scene. The direction cosines, on the other hand, were relatively stable with coefficients of variations between 2 and 20 percent. Consequently, such representation can be considered as charac-

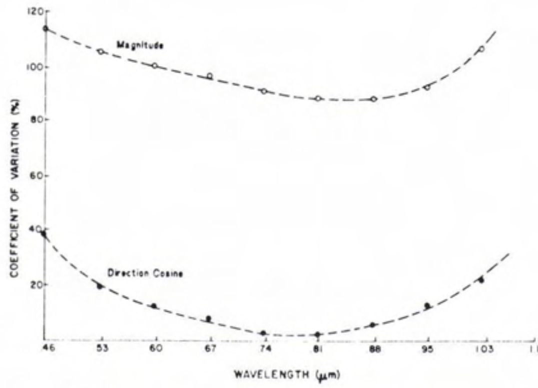

FIG. 5. Results of the stability study for deer class.

teristics of the classes in the scene. The classification studies reported below used the angular characterization of the scene classes. It should be noted that such a characterization allows for the design of a detector system which can operate in a variety of ambient conditions. The mean direction cosines for the deer, snow, juniper, sagebrush, and rabbitbrush classes of the typical generalized scene are presented in Figure 6.

FEATURE SELECTION

Feature selection deals with the concept of selecting a subset of features from the set containing all available features in such a fashion that the performance of the classifier does not deteriorate to an unacceptable level. The problem of feature selection was addressed in two parts.

In the first part, an attempt was made to identify the spectral bands which were best for the representation of a class. This was accomplished by using the signature stability study. It was observed that direction cosines for three spectral bands consistently indicated very large coefficients of variation. These bands were considered to be *noisy* and were unsuitable for the characterization of the classes in the scene. Elimination of these bands from further considerations reduced tbe spread in the coefficients of variation from about 1 to 264 percent to 1 to 20 percent in the remaining 47 bands.

The second part of feature selection dealt with the identification of spectral bands which were best suited for the discrimination between deer and other classes of the typical generalized scene. Detailed description of the development of the technique is presented by Trivedi (1979) and Trivedi *et al.* (1979). Only a brief summary of this technique is presented below. The procedure utilized the mean normalized reflectance characteristics of the classes (Figure 6). The feature selection was performed for four separate pairwise problems, each having deer as one class and one of the four background classes as the other. The spectral bands were represented as vectors in a two-dimensional weighted space where the coordinate axes correspond to the classes considered. This type of representation assured that the magnitudes of the vectors correspond to the discriminatory power of a spectral band and that the distance between two vectors corresponds to the similarity between those spectral bands. Hierarchical cluster analysis was subsequently performed so that the spectral bands with least discriminatory power were eliminated first and the two bands which offered similar discriminatory information were replaced by one of the two. The procedure resulted in a ranking of spectral bands for the four pairwise problems. The final selection of spectral bands was based on the results of several classification studies involving all classes.

RESULTS

The multispectral data were analyzed using the Bayesian classification procedure described earlier. The analysis was limited to four major background classes as specified in the typical generalized scene: snow, juniper, sagebrush, and rabbitbrush. The classifier performance was evaluated by two different methods which are commonly used in pattern recognition studies. The first method, known as the *Resubstitution* method (R-method), employed the same samples for training as well as for testing. The second method, called *Rotation* method (π-method), can be described as follows. Initially, the classifier was trained with four-fifths of the samples (training set) and was tested with the remaining one-fifth of the samples (test set). This was repeated five times with mutually exclusive sets and an average performance index was evaluated. The π-method is similar to the "jackknifing" procedures, which reduce the bias of the estimates of the parameters used in the classifier design (Toussaint, 1974).

Detailed results for the two- and three-class scenes are not presented here for the sake of brevity; however, interested readers are referred to Trivedi (1979) for those details. These results indicate that deer can be detected in a snow and/or juniper background with essentially zero error by use of only two spectral bands. These empirically evaluated errors were in agreement with the analytically evaluated errors in a similar case studied by Wyatt *et al.* (1978).

Results of the classification studies in a five-class typical generalized scene are presented in Table 1. The overall probability of correct classification was computed by dividing the number of samples correctly classified by the total number of samples. For the computation of the probability of correct deer classification, the error was ignored when samples of a "not-deer" class were misclas-

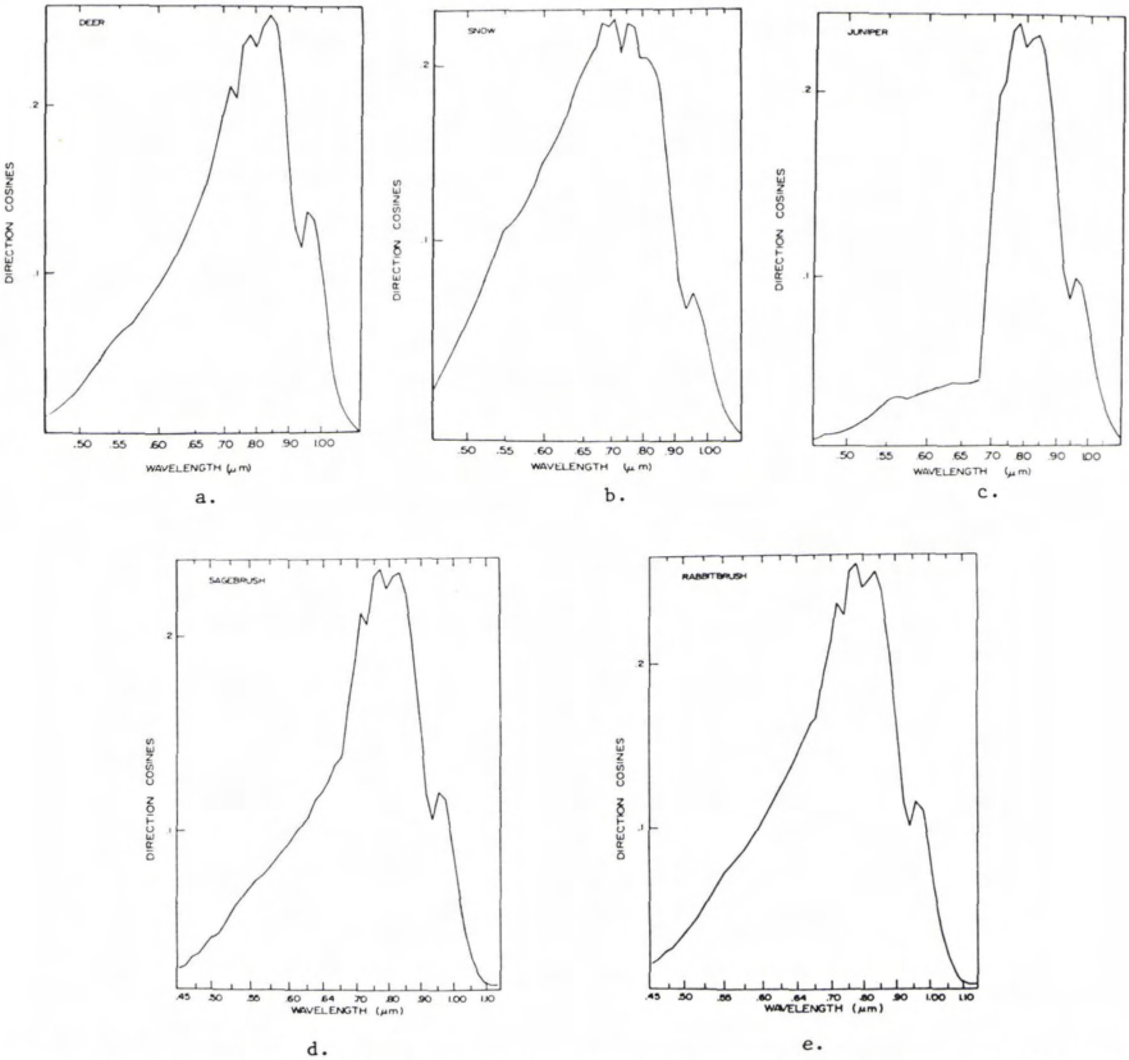

FIG. 6. Mean normalized reflectance plots for (a) deer, (b) snow, (c) juniper, (d) sagebrush, and (e) rabbitbrush classes.

sified into another "not-deer" class. Note the improvement of the classifier performance in a four-feature case. The four spectral bands utilized corresponded to 0.672 μm, 0.764 μm, 0.981 μm, and 0.725 μm. The classifier had the most difficulty in making the discrimination between deer and the dried brush class, which was represented by rabbitbrush. In a scene where the dormant dried brush was not present (which will be the case just after snowfall over winter ranges), the results would be those indicated in Table 2. There was an improvement in number of deer correctly classified. Also, as in the case of the five-class scene, the fourth feature helped to improve the performance.

The statistical classification approach utilized in the study required an estimate of the a priori probabilities for various classes. These probabilities would naturally vary from one habitat to another. It was, therefore, very important to study the effects of the variations in the a priori probabilities on the classifier performance. This was accomplished by performing classification studies, where the ratio of the a priori probability for "not-deer" class to the deer class, $P(ND)/P(D)$, was varied. Note that the "not-deer" class is formed by combining all background classes. In the ratio considered, the range of variations was from 10^2 to an extreme of 10^7, which correspond to a scene with one deer to every ten million occurrences of other objects. The results of such studies are presented in Figures 7 and 8 for the five-class and four-class scenes, respectively. The probability of correct deer detection is computed by dividing the

TABLE 1. PERFORMANCE OF THREE- AND FOUR-FEATURE CLASSIFIERS IN A FIVE-CLASS SCENE. THE A PRIORI PROBABILITIES ARE SUCH THAT $\frac{P(\text{Snow})}{P(\text{Deer})} = 5000$, $\frac{P(\text{Juniper})}{P(\text{Deer})} = \frac{P(\text{Sagebrush})}{P(\text{Deer})} = 2000$, $\frac{P(\text{Rabbitbrush})}{P(\text{Deer})} = 1000$, and $\frac{P(ND)}{P(D)} \simeq 10^4$.

Features (μm)	Class (total # of samples)	Classified As: Deer	Snow	Juniper	Sage-brush	Rabbit-brush	Overall probability of correct classification (R-method) %	Average performance by class (R-method) %	Probability of correct deer classification (R-method) * %	Probability of correct deer classification (π-method) * %
0.672,	Deer (107)	53	0	0	12	42				
0.784,	Snow (107)	0	107	0	0	0				
0.981	Juniper (109)	0	0	109	0	0	84.3%	84.2%	90.0%	90.1%
	Sagebrush (108)	0	0	0	98	10				
	Rabbitbrush (109)	0	0	0	21	88				
0.672,	Deer (107)	61	0	0	5	41				
0.725,	Snow (107)	0	107	0	0	0				
0.784,	Juniper (109)	0	0	109	0	0	86.3%	86.2%	91.5%	91.4%
0.981	Sagebrush (108)	0	0	0	99	9				
	Rabbitbrush (109)	0	0	0	19	90				

* Not counting misclassification of not deer into nondeer categories.

TABLE 2. PERFORMANCE OF THREE- AND FOUR-FEATURE CLASSIFIERS IN A FOUR-CLASS SCENE. THE A PRIORI PROBABILITIES ARE SUCH THAT

$$\frac{P(\text{Snow})}{P(\text{Deer})} = 5000, \frac{P(\text{Juniper})}{P(\text{Deer})} = \frac{P(\text{Sagebrush})}{P(\text{Deer})} = 2500, \text{ and } \frac{P(ND)}{P(D)} \simeq 10^4.$$

Features (μm)	Class (total # of samples)	Classified as: Deer	Snow	Juniper	Sage-brush	Overall probability of correct classification (R-method) %	Average performance by class (R-method) %	Overall probability of correct classification (π-method) %
0.672, 0.784, 0.981	Deer (107)	81	0	0	26	94.0%	93.9%	93.3%
	Snow (107)	0	107	0	0			
	Juniper (109)	0	0	109	0			
	Sagebrush (108)	0	0	0	108			
0.672, 0.725, 0.784, 0.981	Deer (107)	90	0	0	17	96.1%	96.0%	95.6%
	Snow (107)	0	107	0	0			
	Juniper (109)	0	0	109	0			
	Sagebrush (108)	0	0	0	108			

number of deer correctly classified by the total number of deer samples. A steady degradation in performance of the classifier was observed as the relative occurrence of deer with respect to other objects decreases. Also, it was discovered that the classifier never misclassified a not-deer object as a deer whenever the ratio, $P(ND)/P(D)$, exceeded 10^4. This result is quite important, because it indicates that, if one designs a classifier for a scene in which a deer occurs for every ten thousand other objects, then the errors encountered will only be of the nature where a deer would be incorrectly called not-deer. A "false-alarm" of a not-deer being called a deer would never happen. If the classifier is designed with $P(ND)/P(D)$ of less than 10^4, false alarm errors are probable. Thus, in the five-class scene it should be expected that 60 percent of deer would be correctly classified, and for the four-class scene 90 percent of the deer would be correctly classified with no false alarm errors.

It should be noted that the false alarm type errors should be weighted more than the miss errors, because the a priori probability of not-deer objects will be much greater than that of deer. For example, if two false alarms for every one thousand not-deer objects are allowed, then it translates to two thousand false alarms for a million not-deer objects, certainly an unacceptable figure.

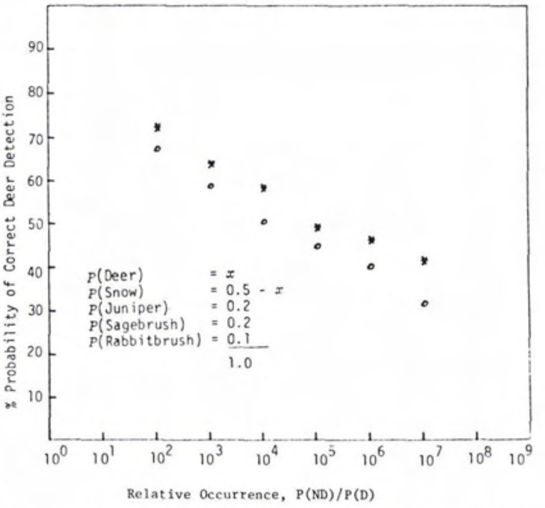

FIG. 7. Plot showing the effect of a priori probability variations on deer detection in a five-class scene. Four-feature classification is denoted by * and three-feature with o.

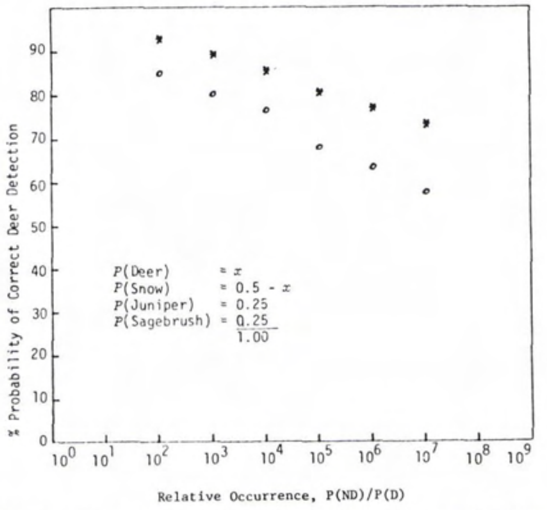

FIG. 8. Plot showing the effect of a priori probability variations on deer detection in a four-class scene. Four-feature classification is denoted by * and three-feature by o.

Discussion

Development of an operational deer detection system is a fairly involved task. The research described in this paper should be considered as only one out of a series of important studies. In this section few remarks about the implications of the work are presented.

It is anticipated that the system developed would be operated during the winter season on the designated deer ranges. These areas are generally open meadows, free from overhead canopy on the south facing slopes. It is commonly believed that about 85 to 95 percent of the total deer population tend to concentrate on these deer ranges. To obtain the overall inventory of deer population using the individual deer counts, a strip transect sampling approach seems to be applicable (Jolly and Watson, 1979). The deer sheltered under trees will not be detected by the system, but it is believed that only a small percentage of the total population will be missed on this account.

During this study, an attempt was made to develop data processing and analysis methods with general applicability. Normalization of spectral reflectance data was performed basically due to such a desire for generality. It may be possible to arrive at somewhat better results by not normalizing the data but limiting the operation of the system to preselected conditions of specific insolation and directionality. Such studies can be performed using the already collected data. However, the results of the study suggest that reasonable deer detection accuracies are possible without such restrictions.

Another important issue is concerned with the speed at which the classification can be performed. Because the aircraft sensor is expected to view a new pixel every few microseconds and also because the size of pixels is extremely small, storage of the data for later processing seems infeasible. Recently, Trivedi (1981) has suggested a multistage classification procedure which would enable near real time processing of the data. Such an approach would satisfy the operational system's timing requirements. It should be noted that for the analysis only spectral properties are utilized, and it is recommended that studies incorporating the spatial information for improving detection accuracies should be considered. Such studies can utilize the data acquired with a prototype system designed on the basis of this research. The spatial features may also have utility in resolving the problem of classifying the mixed pixels, i.e., those regions which are composed of two or more objects. Future studies will address this issue.

Conclusions

In this paper a feasibility study for developing an airborne remote sensing system for deer detection has been presented. The classification studies of multispectral data in a variety of idealized scenes led to the following conclusions:

- Two spectral bands were adequate for error-free detection of deer in a snow and/or evergreen (juniper) background.
- Four spectral bands are required for the five-class typical generalized scene in order to obtain a deer detection accuracy at about 60 percent. If only three bands are used, the accuracy drops to about 50 percent.
- Four spectral bands will provide an accuracy of about 90 percent when the scene is free of dry brush. If only three bands are used, the accuracy drops to about 80 percent. These conditions could be realized if the survey is conducted after a fresh snow-fall.

The classifier performance specified above was obtained by considering the a priori probability of not-deer objects sufficiently high to essentially eliminate the false alarm errors, because of misclassification of not-deer into the deer class.

A three- or four-feature classifier designed to carry out a census of deer appears promising. Such a classifier would make use of reflected ambient energy. The four spectral bands to be used correspond to the 0.672 μm, 0.725 μm, 0.784 μm, and 0.981 μm wavelengths. The three-feature set excludes the 0.725 μm wavelength.

It can be concluded that these results justify development of a prototype system that would allow additional and more realistic testing and verification. In order to improve on the performance of the system, it is recommended that studies involving spatial domain information, along with spectral information, should be undertaken.

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