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CROP CHARACTERISTIC RESEARCH:
GROWTH AND REFLECTANCE ANALYSIS

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Justification, Goals, and Objectives

Much of the early research in remote sensing follows along developing "spectral signatures" of cover types. It was, however, found that a signature from an unknown cover class could not be matched to a catalog value of known cover class. This approach was abandoned and "supervised classification" schemes followed. These were not efficient and required extensive training. It has been patently clear that data acquired at a single time could not separate cover types.

A large portion of the proposed research has concentrated on modeling the temporal behavior of agricultural crops and on removing the need for any training data in remote sensing surveys--the key to which is the solution of the so-called "signature extension" problem.

A clear need to develop spectral estimaters of crop ontogenic stages and yield has existed even though various correlations have been developed. Considerable effort in developing techniques to estimate these variables was devoted to this work.

The need to accurately evaluate existing canopy reflectance model(s), improve these models, use them to understand the "crop signatures," and estimate leaf area index was the third objective of the proposed work.

The next section gives a synposis of this research effort.

Technical Approach

The technical approach consisted of first developing an accurate model that would describe the temporal development of various spectral transforms with time, henceforth called a profile, that would depend primarily on crop characteristics. It would thus permit features to be extracted from real spectral data that describes a specific crop and would not depend on external variables such as row direction, sun zenith angle, the atmospheric state, etc. Having extracted a very small set of features use the canopy reflectance model(s) to gain (a) better understanding and limitations of existing canopy models, (b) use the model(s) to accure a deeper physical understanding of why these features permit crop separation and develop method(s) of deciding, a priori, what features would permit crop separation, and (c) explorate the applicability of these models to natural forest communities.

Results

The current research effort has shown that the Kauth-Thomas (K-T) greenness, in the spectral space of both the multispectral spectral scanner or the thematic mapper, can be described by a model of the form,

$$\rho(t) = \rho_0 + (\rho_m - \rho_0) \left(\frac{2\beta e}{\alpha} \right)^{\alpha/2} (t - t_0)^\alpha \, Exp \, [-\beta(t - t_0)^2] \quad (1)$$

where $\rho(t)$ the K-T greenness as a function of time, ρ_m, the maximum value of greenness reached at time of peak greenness

$$t_p - t_0 = \sqrt{\frac{\alpha}{2\beta}},$$

ρ_0 the value of soil greenness at times at and before emergence, t_0, and α and β are two crop and condition specifics constant. These two constant are related to the inflection points of the profile

$$t_1 - t_0 = \left[\frac{(2\alpha + 1) - \sqrt{8\alpha + 1}}{4\beta} \right]^{1/2}$$

$$t_2 - t_0 = \left[\frac{(2\alpha + 1) + \sqrt{8\alpha + 1}}{4\beta} \right]^{1/2}$$

This research effort has established that the peak greenness above the soil line, $G_{max} \equiv \rho_m - \rho_0$, the separation

$$\sigma \equiv t_2 - t_1 = \left\{ \frac{1}{2\beta} + \frac{\alpha}{2\beta} \left[1 - (1 - \frac{1}{\alpha})^{1/2} \right] \right\}^{1/2}$$

and the time of peak greenness, t_p, are three characteristics or features that carry 95% of all information (Fisher information criteria) available in both spectral and temporal data and has led to a drastic reduction in the number of variables and a simplification of classifier design.

Figure 1 shows the power of these features in separating two summer crops, corn/soybeans, based on data extracted from the thematic mapper. The axis out of the plane of paper is the number of pixels, the other two axes being G_{max} and σ in days. The distributions are more or less gaussian and provide excellent separability. Not only has it been shown that these features (G_{max}, σ, and t_p) are applicable to different sensor systems but are truly "signature extendable" over vast areas in the United States and, for the first time ever in remote sensing, to areas in Argentina. In particular. it has been found that, (i) G_{max} (soybeans) > G_{max} (corn), (ii) σ (soybeans) < σ (corn), and (iii) t_p (soybeans) > t_p (corn).

It has been shown that the cardinal points t_1, t_p, and t_2 are related to three specific ontogenetic stages of a crop. This has been shown to be case for wheat, barley, corn, and soybeans and appears to be true for rice also. This, then permits, a priori, calculation of these stages from an agrometeorological model and in complete automation of crop classification.

It has also been shown that integral,

$$\int_{t_1}^{t_2} \rho(t)dt,$$

which acts in a manner very similar to the leaf area duration, is strongly correlated to yield in the case of both corn and soybeans. More research in this direction is called for; however, the potential of a true integrated, automatic, and objective crop production system applicable to global corn and soybeans areas seem within grasp.

In order to understand the reasoning behind why G_{max} (soybeans) > G_{max} (corn) almost universely, the existing canopy reflectance models were used. Figure 2, shows a two dimensional histogram of the G_{max} and leaf area index, calculated using the SAIL model. The distribution for each crop was obtained by varying soil types (12 covering the world soil reflectances) and fourteen different leaf angle distribution for a total of 168 different calculations in each distribution. These calculations show that if the leaf area index of these crops is greater than about 4, the primary reason of their separability is because corn is C_4 plant and soybeans is C_3 plant and their leaf reflectance and transmittance are intrinsically different. Differences in soil type and leaf angle distribution simply require a somewhat larger difference in the two leaf area indices to get the same separation. These results have also established that if the input to the canopy model such as leaf optical properties, soil reflectance, etc. for two crops is known, a transform and optimum observation period to provide a given level of separability can be calculated, a priori.

The existing canopy reflectance models had not been subjected to a good test, particularly for off-nadir view angle. In order to acquire a degree of confidence in the models and their predictions, the homogenous SUITS, SAIL, and CUPID canopy reflectance models were very carefully evaluated for canopies of corn and soybeans. All of these models captured the salient features of the canopy reflectance, with the SAIL model showing the best overall performance. However, it was found that it is necessary to include the specular directional characteristics of leaves into these models. Figure 3 shows the performance of the SAIL model before and after the inclusion of leaf specular reflectance systematic angular deficiencies of this model are substantially removed. This should improve the usefulness of these models, to evaluate key biophysical parameters, such as leaf area index. Considerable effort has been devoted in evaluating these models for coniferous canopies such as Black Spruce, Jack Pine, Red Pine, White Pine, and Ponderosa Pine with little success, partly due to lack of input data on key input parameters; however, their performance on Aspen and Birch canopies appear to be much better. We have also found that the temporal profile of an Aspen canopy can be adequately represented by an equation of the form (1). The meaning of the t_1, t_p, and σ would of course be very different.

Significance

(1) For the first time in remote sensing, crop features have been found that are truly "signature extendable." In case of corn and soybeans they have been shown to be applicable to vast geographic regions of the United States for four years 1978, 1979, 1980, and 1982 and are extendable to Argentina. Based on SAIL canopy reflectance model, the reasons for this applicability have been understood.

(2) It has been shown that critical ontogenetic crop stages can be estimated from spectral data. Based on this work and more detailed work, it is suggested that it may be more accurate to estimate crop phenology using spectral data than current methods.

(3) Preliminary evidence suggests that the area of greenness profile from t_1 (when new leaf development stops) to t_2 (dent) is strongly correlated to yield.

The above three results have made it possible to seriously consider an automatic and objective crop production system.

(4) An improved canopy reflectance model has been developed that includes the leaf specular component.

(5) The effectiveness of these models in estimation of leaf area index of wheat, corn, and soybeans and recently in study of forest species separation and aspen leaf area estimation has been demonstrated.

Future

Most of the current work on feature extraction, ontogenetic stage and yield has been done on corn and soybean. Some start was made on wheat, barley, and oats. The work on spring grains should be intensified. Currently, no technique exists to separate the three crops. Additional work on ontogenetic stage and yield of corn and soybeans still needs to be done.

The performance of existing canopy models on forest canopies has been found to be sadly lacking, much more so for coniferous forest than for decidous forest. Major improvements in these models are called for and a corresponding adequate input data set must be collected. Techniques to estimate leaf area index or phytomass of vegetation cannot be developed realiably without such an effort.
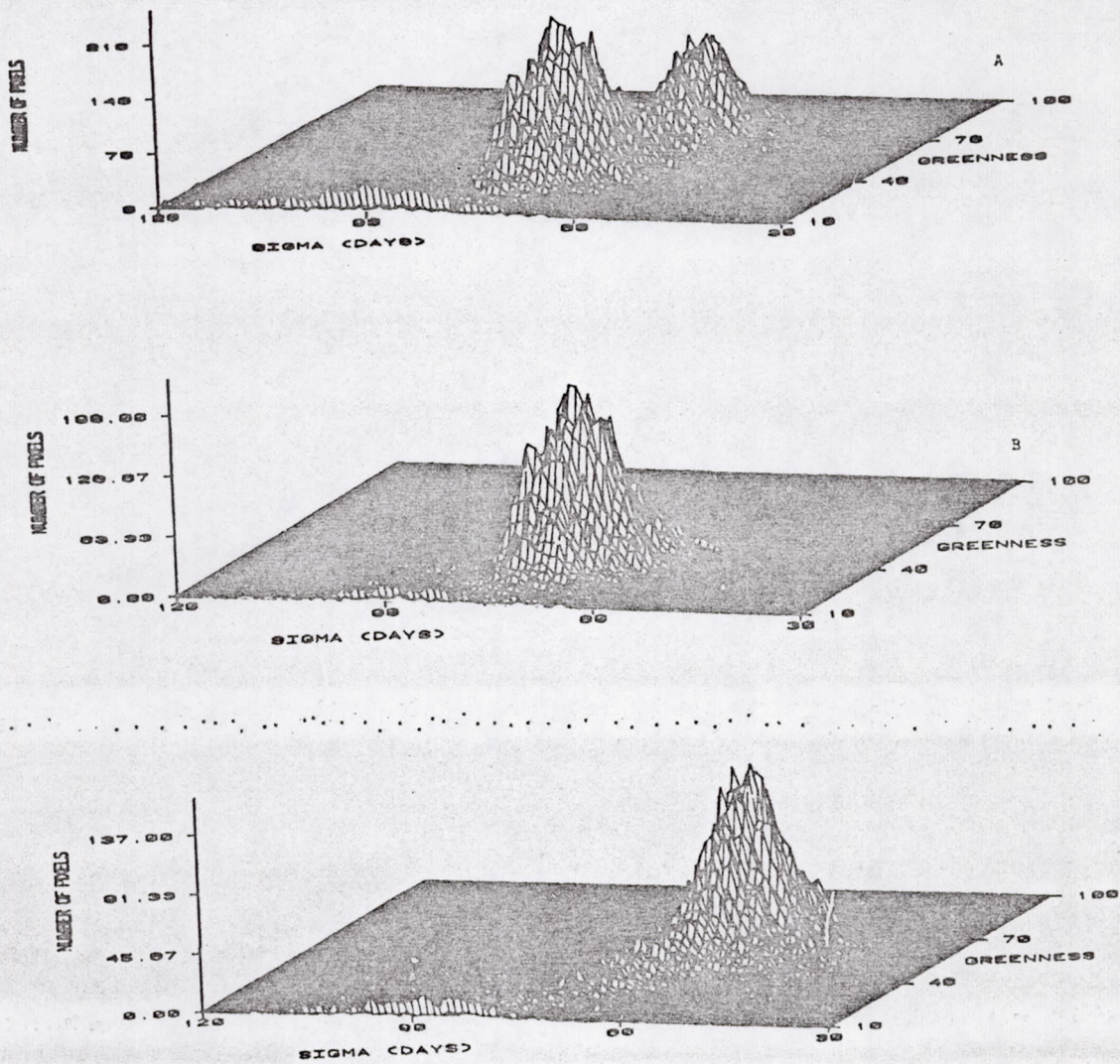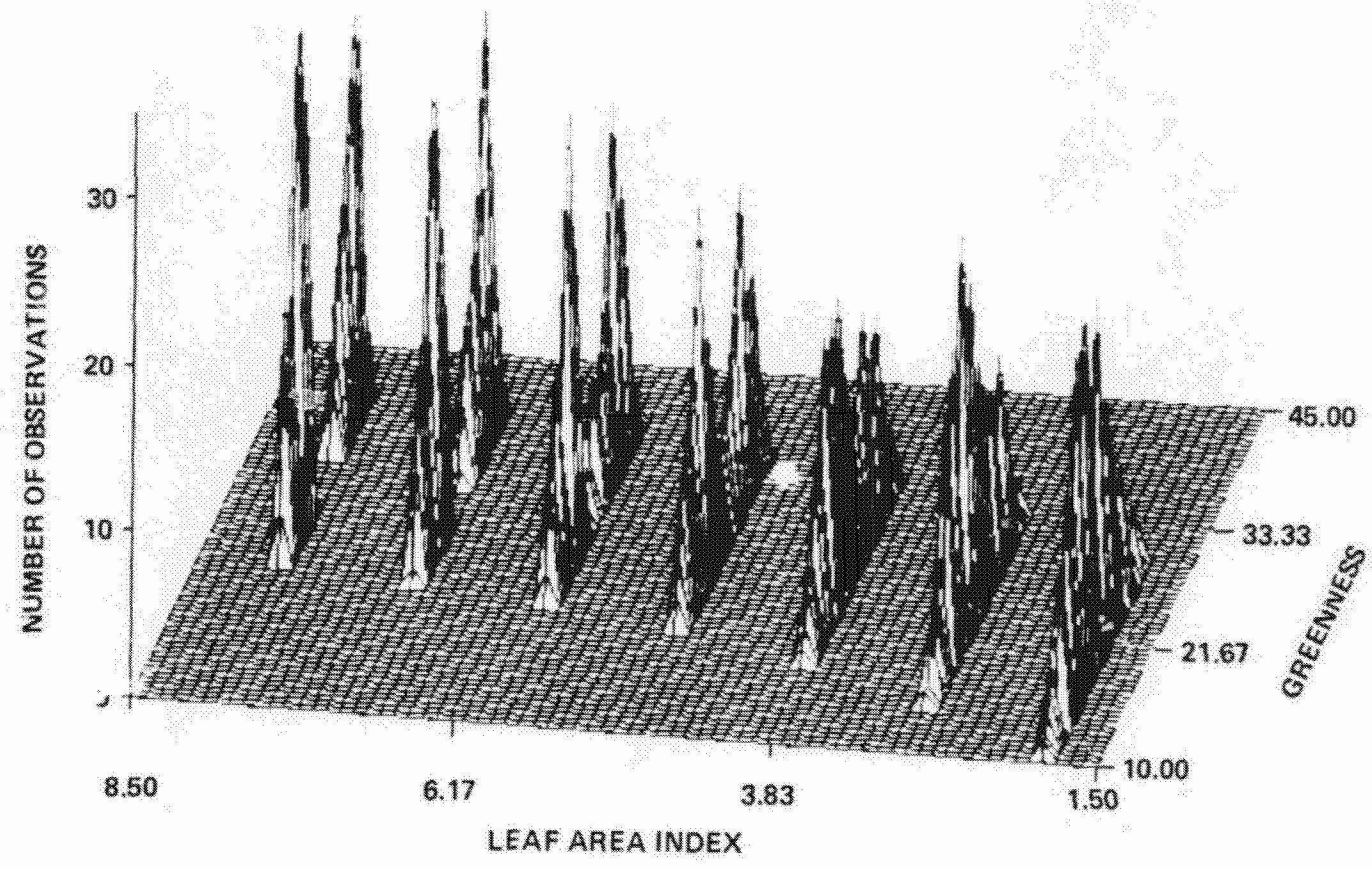
Figure 1

Figure 2

FIGURE 3