092465

Paper presented at 30th Semi-Annual Convention of the American Society of Photogrammetry, Sheraton-Dayton Hotel, Dayton, Ohio, September 24, 1965.

POTENTIAL APPLICATIONS OF REMOTE MULTISPECTRAL SENSING IN AGRICULTURE *

Roger M. Hoffer
Department of Botany and Plant Pathology
Purdue University

Lee D. Miller
Infrared and Optical Sensor Laboratory
Institute of Science and Technology
University of Michigan

INTRODUCTION

Millions of dollars are expended annually for agricultural surveys. Many of these surveys involve statistical sampling based on questionnaires and personal contact with farmers. The application of remote multispectral sensing techniques to such surveys offers considerable economic benefits through improved accuracy of the agricultural surveys and the supplanting of many costly ground surveys.

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* The research reported upon in this paper is a joint program between the Botany and Plant Pathology Department, Purdue University, and the Infrared Laboratory, Institute of Science and Technology, The University of Michigan, and is sponsored by the Manned Space Science Program, Office of Space Science and Applications, National Aeronautics & Space Administration, and the Economic Research Service, U. S. Department of Agriculture. Equipment and Aircraft were provided on loan by the Institute of Science and Technology's "Project MICHIGAN", under the sponsorship of the U. S. Army Electronic Command.

Spectrophotometric curves on plant and soil samples exhibit characteristic spectral shapes which are physically related to the crop or soil. As Colwell and many others have pointed out, multispectral sensing equipment can be used to remotely sample the spectrally dependent electromagnetic radiation which is reflected or emitted from plants and soils. Comparison of the pictorial imagery generated by this equipment in several discrete spectral bands approximates spectrophotometric data. It is thus reasonable to expect that different agricultural crops and crop conditions exhibit characteristic signatures in remote multispectral imagery.

The information content of a scene imaged in any single spectral band is limited, but additional information about this scene may be obtained from additional spectral bands. Interpretation of many individual spectral bands is difficult, and is facilitated by their combination in some manner into a common format capable of easier interpretation. One familiar photographic method is the combination of several spectral bands in color and infrared color (or camoflage detection) film, as demonstrated in Figure 1. The panchromatic film in the broad .4 - .7μ wavelength band is divided into three smaller wavelength band images, each of which is color-coded, and the combination of which results in the color photograph. A similar process between .4 - 9μ wavelength results in the camoflage detection film. In this case, however, the infrared wavelengths in the .7 - .9μ region just beyond the visible spectrum and where healthy green vegetation is so highly reflective, are color coded with cyan, creating the bright red colors on the C.D. film. This color coding of several wavelength bands of imagery results in a picture that is usually much easier to interpret than the grey tones of a single band black and white image.

Another method of utilizing several spectral bands is through the simultaneous gathering of numerous, discrete spectral band images, and evaluating the tonal qualities of specific areas as they appear on the various images. Such tonal qualities are capable of being reduced to electronic signals, and with adequate background knowledge, there exists a potential for an automatic survey capability. We are now in the initial phases of gethering the basic knowledge required to devise such a survey system.

Cameras with different film-filter combinations as well as optical-mechanical scanners utilizing various filters and detectors are presently being used from aircraft altitudes to simultaneously record electromagnetic radiation in up to twenty spectral bands between 0.3 and 14 microns. Interpretation of a portion of this imagery has verified that the detection of several agricultural situations is enhanced by using simultaneous multispectral imagery, in lieu of any single band.

Considerable effort is presently being made to compare quantitatively the photographic tones of images from the various available sensors in order to establish meaningful interrelationships among these tones. Because this capability has yet to be perfected, present interpretation techniques are limited. However, significance can be attached to marked differences or equality in the tone of two areas appearing on the same photo. Such differences or similarity in tone were used in designing the following slides.

It is the purpose of this paper to show examples of some of the potential uses and limitations of remote multispectral sensing in agriculture. The various aspects of the agricultural scene considered are grouped into four general categories, namely; soils and soil moisture conditions, agricultural practices, crop conditions, and finally, species differentiation. Each of these aspects must be considered separately as well as collectively before many of the applications of remote multispectral sensing in agriculture can be fully understood and realized.

DISCUSSION

Soil Type and Condition

Soil type and its condition is extremely important in agriculture, thus necessitating careful consideration of its effect on multispectral imagery. The upper photo in Figure 2 shows a small test irrigation area of bare soil. The aerial photograph in the lower image represents all of the spectral bands listed. The tick mark to the left of a particular spectral band, in this case the .85 - .89μ band, indicates the spectral band of the image shown. Thus, the recently irrigated area has a lower "response" or is darker toned than the drier surrounding soil in all spectral bands examined. The term "response" (which refers to the relative energy levels represented in an image) is more meaningful than image tone, reflectance, emittance, etc. when describing a combination of several spectral images which can be motivated by either reflective or thermal properties or both, and we have found that use of this term prevents confusion when dealing with tonal differences on both positive and negative films.

Dramatic spectral differences in the detection of a silty clay loam soil compared to a silt loam soil have been found. In the ultraviolet, visible, and reflective infrared wavelength bands, the silty clay loam, being dark colored, is darker in tone than the lighter colored silt loam, as one would expect. However, in the thermal infrared bands, the tonal difference, or response, is reversed -- the dark colored silty clay loam having a high response whereas the silt loam has a low response.

This points toward the potential use of multispectral imagery to differentiate between a wet soil and a dark colored soil. Both the wet soil and the dark colored soil appear low in response, or dark toned in visible wavelength bands but only the dark colored soil is of opposite response in the thermal wavelength bands. The dark colored soil absorbs more of the incoming radiation, thus reaching a higher surface temperature than the lighter colored soil. Due to the effects of higher evaporation, however, a wet soil will remain relatively cool in surface temperature as compared to a dry soil, even though both may be dark in color. Thus, when comparing two areas of bare soil, a reversal in response between the reflective wavelength bands and the thermal bands indicated a dark colored versus a light colored soil, whereas a lack of reversal in response indicates a wet versus a dry soil.

Another method of identifying areas of high soil moisture is shown in Figure 3. The .55 - .64 μ image obtained at 0840 hours shows several dark areas representing lowlying, moist soil in a bare field, four days after a 1-1/4" rainfall. That same day at 1630 hours these areas of high moisture have almost completely disappeared due to evaporation and some soil drainage. As pointed out in the previous figure, this condition of high soil moisture is recorded in a similar manner in all spectral bands available. However, in this case, we have valuable temporal as well as spectral data to aid in the identification of the darker areas.

The detection of an artificial drainage system in an area can be facilitated by remote multispectral sensing. The imagery represented in Figure 4 was also obtained four days after the 1-1/4" rainfall previously mentioned. The soil just above the drainage tile dried out much faster than the areas between the tiles. The light toned vertical lines in the bare fileds thus map the artificial drainage system.

The detection of the effects of drainage tile is not restricted to bare soil areas. Figure 5 shows that the effects of the drainage tile system were detectable in a field of 30" tall wheat. The difference in available soil moisture due to the underlying drainage tile were reflected in the crop condition (density, height, and maturity). Thus, in the irregularly shaped wheat field in the center of the image, the horizontal light toned bands indicate the presence of a drainage tile system. Numerous examples of this phenomenon have been found, indicating a marked effect of soil drainage on wheat.

Agricultural Practices

The remote detection of various agricultural practices will be of considerable value in land use studies. Various types of practices can be detected in remote multispectral imagery, dependent upon the season and locale.

The boundary between harvested and unharvested alfalfa shown in Figure 6 is a striking illustration of how the contrast in tone between two areas changes in images formed in various wavelength bands. The tonal contrasts seen in the top and bottom images in this figure are similar to those which would normally be obtained with black and white panchromatic and aerographic infrared film, respectively. However, the division of the spectral regions covered by these films, namely; .4 to .7μ and .7 to .9μ into smaller spectral intervals provides heretofore missing information by the equally important lack of contrast in the illustrated .48 - .56μ image.

Figure 7 illustrates the effects of a particular herbicide spray (2,4-D) on alfalfa. Yellowing alfalfa appears as the light toned portion of the test blocks in the .4 - .7μ image on July 30th. The .7 - 9μ image taken on this same date shows no tonal distinction in the same test blocks. By September 30th, the contrast in tone between the two ends of the test block is still present in the .4 - .7μ image and the .7 - .9μ image has acquired a tonal contrast, the sprayed yellow alfalfa being darker in tone than the healthy green alfalfa.

Crop Conditions

There exists the potential of obtaining remote multispectral imagery rapidly over large areas and at frequent intervals, thus obtaining synoptic information previously unavailable with other agricultural techniques. Surveying transient crop conditions such as differences in growth, maturity, and disease represents an important application to agriculture of frequently obtained, large scale, synoptic data.

The two color photos in Figure 8 show the test areas of corn of three different heights which are shown in both images at the left. In the representative .4 - .7μ image, the 1-1/2' high corn masks very little of the soil and is light in tone whereas the 4' high corn effectively masks the light colored soil and is characteristically dark in tone. As can be seen, the 3' high corn in the center of this image is intermediate in tone, In the simultaneous .7 to .9μ image, no tonal effect due to the three different heights is observed, apparently due to the similarity in reflectivity of this bare soil type and the corn in this reflective infrared wavelength band.

Reflectance curves are potentially useful in preliminary investigations of a particular application of remote multispectral sensing. They offer a relatively inexpensive basis for attempting to predict the tonal contrasts which can be found in remote multispectral imagery. For example, crops which are approaching maturity are relatively stable in their leaf geometry, density, height, etc. One property which does exhibit marked change in relation to the degree of maturity, is reflectance. The difference in the spectral dependence of the reflectance curves shown in Figure 9 between .4 and 1.5 μ's indicates that the maturing of corn may be detectable on remote multispectral imagery.

Species Differentiation

Perhaps one of the most important potential uses of multispectral sensing in agriculture is in accurate species identification from a remote position.

Inspection of Figure 10 demonstrates that the tonal contrast between wheat and oats is different in each of three groups of photographic images The .62 - .68μ image shows wheat as lighter in tone than the oats. The .41 - .47μ image shows wheat to be equal in tone to oats and thus, non-differentiable. The .71 - .79μ image shows the wheat as darker in tone than the oats. Since each of the three simultaneous images shown contains a different tonal relationship between the wheat and oats, each of the three images is equally valuable in the multispectral differentiation of wheat from oats. It is thus again evident that in remote multispectral sensing, the equality of tone for two different types of objects in a particular image (such as wheat and oats in the center image shown) is valuable information and must not be ignored. A last point to be noted before leaving this figure, is that while the wheat and oats are equal in tone in the .41 - .47μ image, other surrounding crops significantly differ from them in tone.

Figure 11 is a graphical portrayal of the tonal differences between wheat and oats in twelve different spectral bands. This graphical presentation of the imagery retains the small tonal differences (such as in the .38 - .44μ band) which are not indicated in Figure 10 due to the grouping of similar imagery for representational purposes. The squares in this figure represent the tone of wheat on each available image in relation to the total range of tone on that image, as represented by the yellow background. The circles represent the tone of the oats in the same image. The ordinate indicates that the lightest tones and thus the highest energy response are shown at the top of the graph. The abscissa indicates the discrete spectral bands considered. The spectral nature of the differences between fields of wheat and oats is clearly portrayed.

Figure 12 shows a graph similar to that of Figure 11 except that the crops being compared are corn and soybeans. The notable features of this comparison of representative values for corn and soybeans is that little tonal difference exists between these two crop species in the photographic bands compared to the large tonal differences that do exist in the reflective infrared scanner bands, namely, in 1.5 - 1.7μ, 2.0 - 2.6μ, and 3.0 - 4.1μ imagery. Several fields of both corn and soybeans, appearing on the same photograph, are represented by this graph.

SUMMARY AND CONCLUSIONS

As pointed out in the introduction and demonstrated by the foregoing slides, the detection and differentiation of several agricultural situations is enhanced through the use of simultaneous multispectral imagery. Detection alone is possible through the use of a single, optimum, spectral band. However, the identification of a particular agricultural situation is facilitated by the simultaneous use of several spectral bands, and especially by extending the wavelength bands of imagery used beyond the photographic region into the thermal infrared bands.

It is anticipated that continuing investigation of the applications of remote multispectral sensing will result in a data collection and interpretation technique appropriate for identification of agricultural and many other situations. Such a program, however, will involve studying numerous agricultural conditions, and will involve many instrumentation variables. The handling of the massive quantities of data produced by such a program and the use of many diverse spectral band combinations in any large scale agricultural survey will necessitate an automatic data processing system. It is toward this goal that we are striving.