IDENTIFYING STRESSED AND POTENTIALLY UNSTABLE TREES BY AERIAL PHOTOGRAPHY ON OHIO'S HIGHWAYS[1][2]

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[2] The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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1. Objective

Trees are valuable assets and potential liabilities in a man dominated situations such as along Ohio's highways. While trees are often long-lived, they must decline and die like any other living thing. Decline may be nearly instantaneous as in a lightning strike but a major tree normally declines over one to two decades. The key is to identify declining trees and prune, maintain, or remove them before public safety is compromised.

The primary objective of this study was to begin the process to identify stressed or declining trees using aerial photography. After stressed or declining trees were identified, cost effective means of automating the process could be developed.

Theoretically, stressed or declining trees can be recognized automatically in multispectral/hyperspectral imagery by analyzing the spectral signatures. This study aimed at obtaining multispectral imagery and to test the feasibility of identifying declining trees in a known area (the Shade Tree Evaluation Plot in Wooster, OH).

2. Background

The spectral signature of biological materials is a good health indicator. One of the major objectives in remotely sensing biological materials is to study their dynamic behavior through a growing cycle and to monitor their health. The presence of chlorophyll in vegetation leads to strong absorption at wavelengths shorter than 0.7 micrometers. In the near infrared region, there is a strong reflectance caused by the discontinuity of the refractive index between air and leaf cell. In the region between 1.3 and 2.5 micrometer, the spectral reflectance curve of leaf is the same as that of pure water. Fig. 1 shows the spectral reflectance of a variety of foliages.

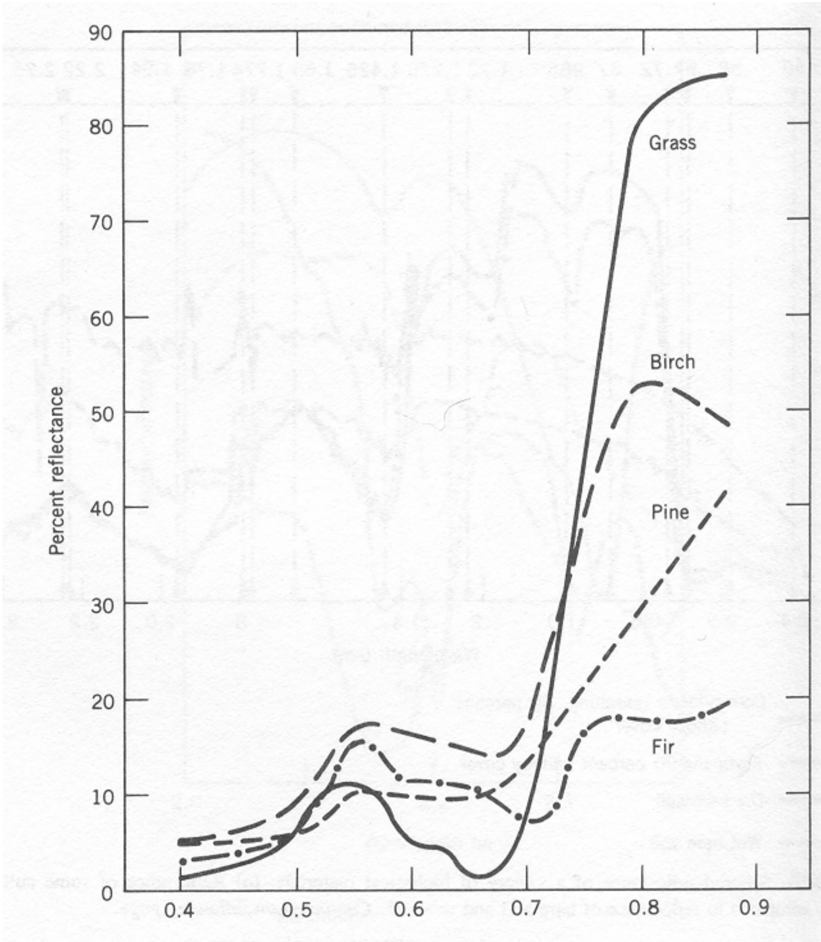

Fig. 1: Reflectance curves of various types of foliage in the visible and near infrared region of the spectrum.

In monitoring the health of trees it is of particular importance to analyze the variations in their spectral signatures. Fig. 2 shows several signatures of the same sycamore tree at different times. The differences are caused by different leaf moisture content. This in turn can be assessed by comparing the reflectances near 0.8, 1.6, and 2.2 micrometers.

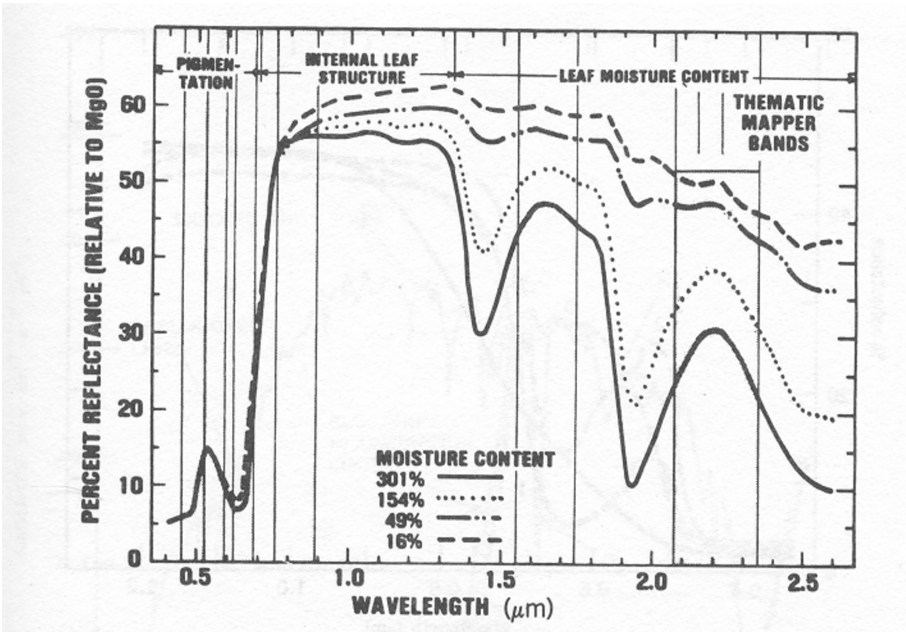

Fig. 2: Spectral response of a sycamore leaf with varying moisture content.

Fig. 3 is another example of the changes that occur in the spectral signature of a beach leaf through its growing cycle, affecting its chlorophyll concentration. The figure also illustrates the red edge, that is, the position and the slope of the rise in the transition visible to near infrared. The changes in the red edge correspond to the transition of a leaf from active photosynthesis to total senescence.

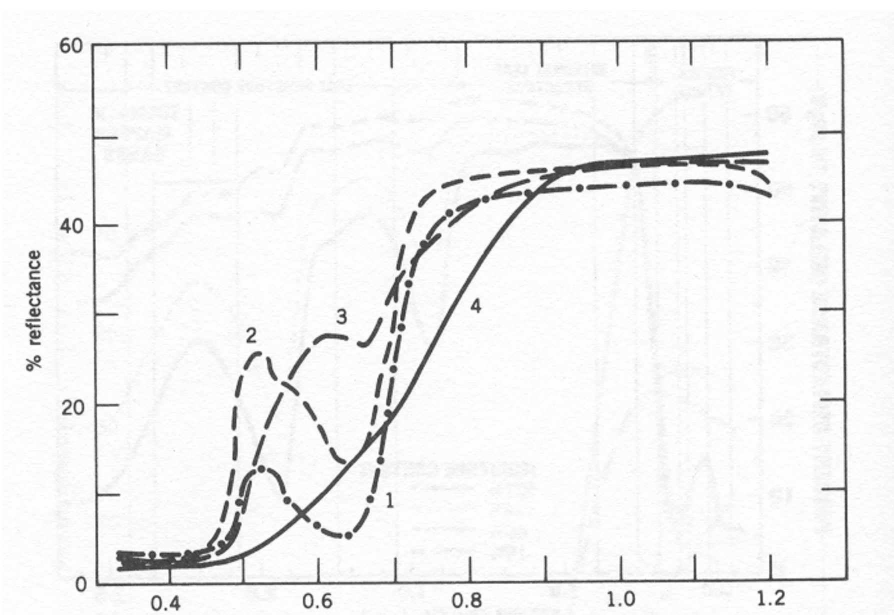

Fig. 3: Reflectance spectra for a beech leaf. Curve (1) shows a healthy leaf, while curves (2-4) show leaves at various stages senescence.

3. Field Work

The Shade Tree Evaluation Project (STEP) on the Ohio Agricultural Research and Development Center contained more than 1000 trees representing more than 100 species and cultivars of trees. Eight trees of each taxon were originally planted. Plant condition for each tree was evaluated in September 1994 before the initiation of the project and again on September 14, 1995; May 3, 1996; and September 18, 1996. Trees were rated from 1 = excellent to 5 = unacceptable based on the level of stress or decline evident. September is normally the best time of year to assess overall vigor although some problems are best seen in the spring as the tree begins to leaf out.

4. Data Acquisition

4.1. Aerial Photography

ODOT flew the plot in September 7,1994 using color IR film. One conclusion was that the trees in the STEP were too close together to reliably separate the trees since the crowns on some plants had begun to coalesce by 1995. The trees in the STEP were spaced out in 2002 to insure that each of the remaining tree crowns is separate from the others.

4.2 Multispectral Imagery

The National Geodetic Survey (NGS) has flown several lines with the Daedalus Multispectral Scanner on September 25, 1996 over the STEP site in Wooster, Ohio. The first flight was around 11 am, approximately 3000 feet above ground. The imagery had numerous cloud shadows. Therefore, the area was reflown later in the day in the hopes that the clouds would dissipate. Unfortunately, a near total overcast condition existed, but the imagery is uniform with respect to ambient solar energy. However, the imagery is a bit mushy due to the video gain necessary to compensate for the lack of light. In the subsequent experiments, we used the data flown at about 5 pm.

The Daedalus 1260 MSS was design to record 12 separate bands (channels) of imagery. As electromagnetic radiation is reflected from the Earth’s surface, it strikes the Daedalus 1260’s rotating scan mirror which directs the energy to a parabolic mirror where it is likewise reflected to a dichroic beam splitter. This filter reflects the thermal infrared energy (bands 11 & 12) to its sensor, while simultaneously transmitting ultraviolet/visible energy to its sensor (bands 1 through 10). Due to the photovoltaic silicon photodiode 10-element array used in the UV/Visible sensor head, the energy detected is 3 to 5 times greater in the visible and near IR region compared to the ultraviolet region. Thus, band 1 is much noisier than the other bands. The array detection breaks down as follows:

band	spectrum	name
1	0.38 – 0.42	ultra violet (uv)
2	0.42 – 0.45	blue
3	0.45 – 0.50	blue
4	0.50 – 0.55	green
5	0.55 – 0.60	green
6	0.60 – 0.65	red
7	0.65 – 0.70	red
8	0.70 – 0.80	near infrared (near ir)
9	0.80 – 0.90	infrared
10	0.92 – 1.10	infrared
11		thermal infrared
12		same as band 11

There is an additional band 13 that is used to record the GPS time as it is outputted from the Trimble SSI GPS receiver every second.

5. Data Processing and Analysis

The major data processing task was to read the Daedalus Multispectral Scanner data and to convert it to a format suitable for further processing and analysis. For every scan line, each band is 750 bytes long and contains housekeeping data and video data. For all 12 spectral bands, the video data is 716 bytes long, leaving 24 bytes for header information and 10 bytes as a trailer. The header contains information such as line count, line number and date (entered by the operator through a thumbwheel), and calibration data.

The elementary data processing was performed with VI2, a program made available by NGS. This program is useful for a quick check to verify if the data is useable. We have developed a small interface program that takes the output of VI2 and converts it to ERDAS Imaging where image processing and image analysis is performed.

The first image-processing step is concerned with visualizing the data. Here, we have experimented with different band combinations with the goal to provide the analyst with the most suitable representation. The following figure is an example of these experiments. It shows the combination of bands 10, 6 and 4 in a RGB representation.

The highlighted area is shown in Fig. 5 approximately 4 times enlarged. Here we can see the individual pixels. One pixel corresponds approximately to a square on the ground, size 1.2 m by 1.2 m. From Fig. 5 we realize that larger trees have a diameter of approximately 6 pixels. This should be sufficient to perform classification.

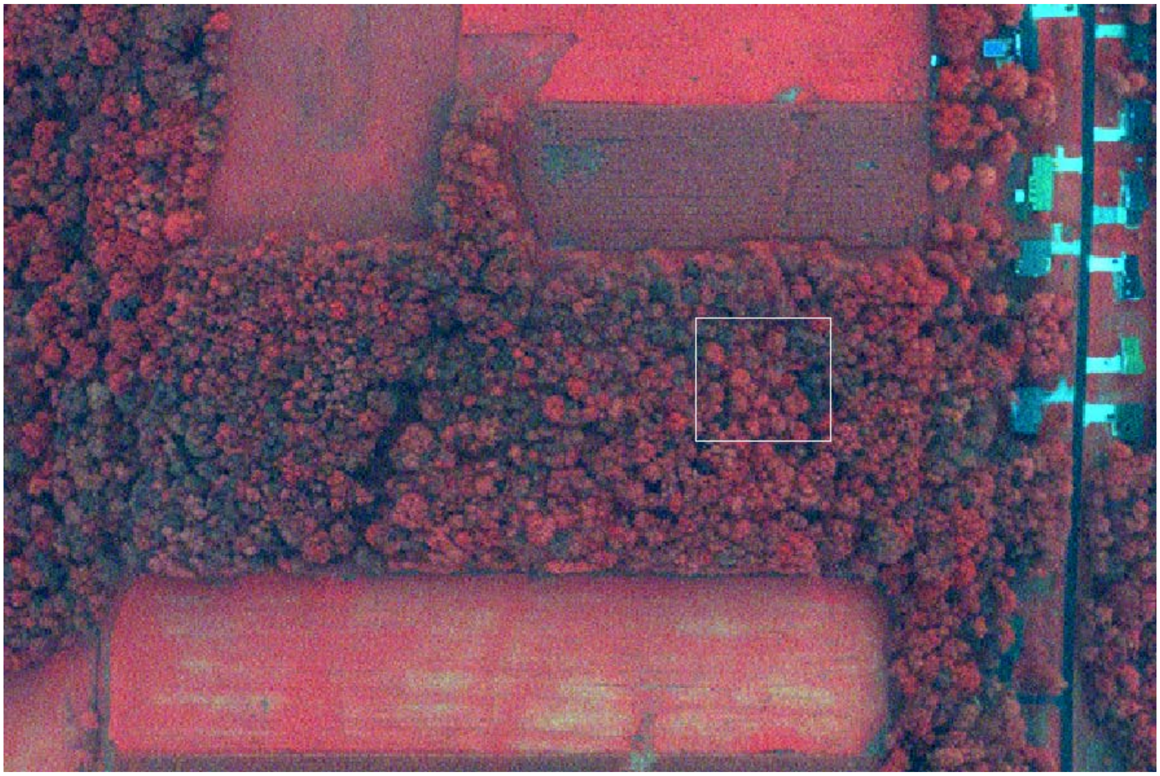

Fig. 4: Shade Tree Evaluation Plot, Wooster, OH: RGB image with bands 4,6, and 10 of the Daedalus Multispectral Scanner (data acquired 9/25/96).

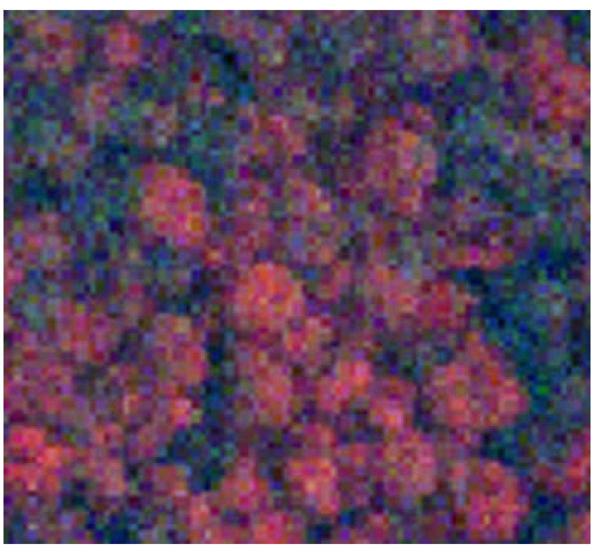

Fig. 5: The highlighted area in Fig. 4 is shown here with a magnification of approx. 4 times. The larger trees have a diameter of approx. 6 pixels. One pixel corresponds to approx. area of 1.2 m x 1.2 m on the ground.

In order to analyze the multispectral images, we computed vegetation indexes, in particular the Normalized Difference Vegetation Index (NDVI). This is an extraction technique that is based on the calculation of multispectral ratios. The advantage of determining ratios is the fact that they can suppress topographic shading if a bias correction is performed first.

The various vegetation indexes used for biomass computations are defined in terms of surface reflectances. This requires the calibration of the multispectral data for solar irradiance, atmospheric transmittance and scatter, and sensor gain and offset. We have not calibrated the data, however, due the lack of ground spectrometer. Multispectral ratios between infrared and visible bands can enhance the difference in radiance between soil and vegetation. For example, ratios larger than one correspond to vegetation and further analysis may lead to the discrimination of the health of vegetation.

The normalized difference vegetation index, NDVI, is the modulation ratio for near infrared and red bands, and is defined as

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

The NDVI is used extensively to monitor vegetation. Its disadvantage is that it is a poor indicator of biomass if the ground cover is low. To cope with this situation, the soil-adjusted vegetation index (SAVI) is superior. It is defined by

$$SAVI = \left(\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red} + L} \right)(1 + L)$$

We have computed the NDVI and SAVI ratios and compared the results with the field assessment of the health of the trees in the test area. Although there was general agreement between the numbers and the field assessment, several discrepancies could not be resolved. Possible reasons include non-calibrated multispectral data and a marginal spatial resolution for smaller trees. We also would expect an improvement by using hyperspectral data with in increase in spectral resolution of more than an order of magnitude.

6. Conclusions and Recommendations

Stressed and declining trees pose a potential hazard in man dominated situations such as along Ohio’s highways. Thus, monitoring the health of trees, possibly automatically, is highly desirable. This study showed that it is feasible to monitor the health of trees in a time series by comparing the biomass. The decline of a tree is manifest in a change of the biomass, and in particular by a change of the position and slope of the red edge (transition of visible to near infrared).

Our limited experiments suggest using higher resolution data, both in geometry and radiometry. It is desirable to have a ground pixel size of less than one meter in order to monitor small trees and differentiate trees in cluttered environment where the crowns of neighboring trees often interfere with each other. A higher radiometric resolution would permit a much more precise location of the red edge. This, in turn, would allow detecting changes in the biomass earlier.

Several important questions could not be addressed within the scope of this research. For example, should monitoring of trees by remote sensing techniques be repeated every year or is a larger time span still acceptable? Another issue is related to the calibration of multispectral/hyperspectral data and the impact of the quality of calibration on the computation of the biomass.