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APPLICATION OF HIGH RESOLUTION DIGITAL IMAGERY TO FORESTRY STUDIES

Cody A. Benkelman, Positive Systems, Inc., P.O. Box 1551, Kalispell, Montana, 59903

Dr. Dave Verbyla, Department of Forest Resources, University of Idaho, Moscow, Idaho, 83843

Dr. Warren Cohen, Research Forester, Pacific Northwest Forestry Sciences Laboratory, 3200 Jefferson, Corvallis, Oregon, 97331

ABSTRACT

This paper discusses forestry applications of high resolution (1/3 to 1 meter per pixel) digital data obtained with a new 4 band imaging system.

In the University of Idaho Experimental Forest, early-morning images were collected to map stressed vs. non-stressed conifers. Two cases were examined: man-made stress (a chain saw was used to band the trees) and stress in sites known to be infected with root rot. Four-band images were collected in the green, red, and two different near-infrared spectral bands.

Another project involved collection of images in conifer forests in Oregon and Washington. The high resolution imagery are being used to characterize proportions of various scene components, and thus facilitate more accurate modeling of forest canopy reflectance. In addition, the data are being used to observe patterns of riparian canopy disturbance to evaluate changes in stream channel conditions. Spectral bands approximating those of the first four Landsat TM bands were used.

INTRODUCTION

In two separate projects, a new four-band multispectral imaging system was used to collect digital images of forest research sites at pixel resolutions ranging from 1/3 meter to 1 meter. This paper provides a brief description of the imaging system and a progress report on the two projects.

THE ADAR SYSTEM 5000

A. System Overview.
The Airborne Data Acquisition and Registration (ADAR) System 5000 is a lightweight multispectral imaging system developed for commercial use (Benkelman ét al. 1990). The System 5000 was designed to serve the GIS/image processing user with a need for rapidly available

multispectral image data with high spatial resolution. The following paragraphs provide a brief description of the system and its features.

1. CCD Cameras. The System 5000 uses four charge coupled device (CCD) cameras, sensitive to wavelengths ranging from 200 to 1000 nanometers, providing full coverage of the visible spectrum as well as portions of the near UV and near IR. Figure 1 shows the spectral response of the CCD sensor. Due to the inability of the optics to transmit UV radiation, the sensors are effectively limited to the 400 to 1000 nm range.

2. Image Capture and Storage. The System 5000 records images directly in digital format with an 8 bit per pixel grey scale. System memory allows up to four digital images to be stored at any moment. Image data are stored on high speed digital tape, with storage capacity of several gigabytes on a single tape.

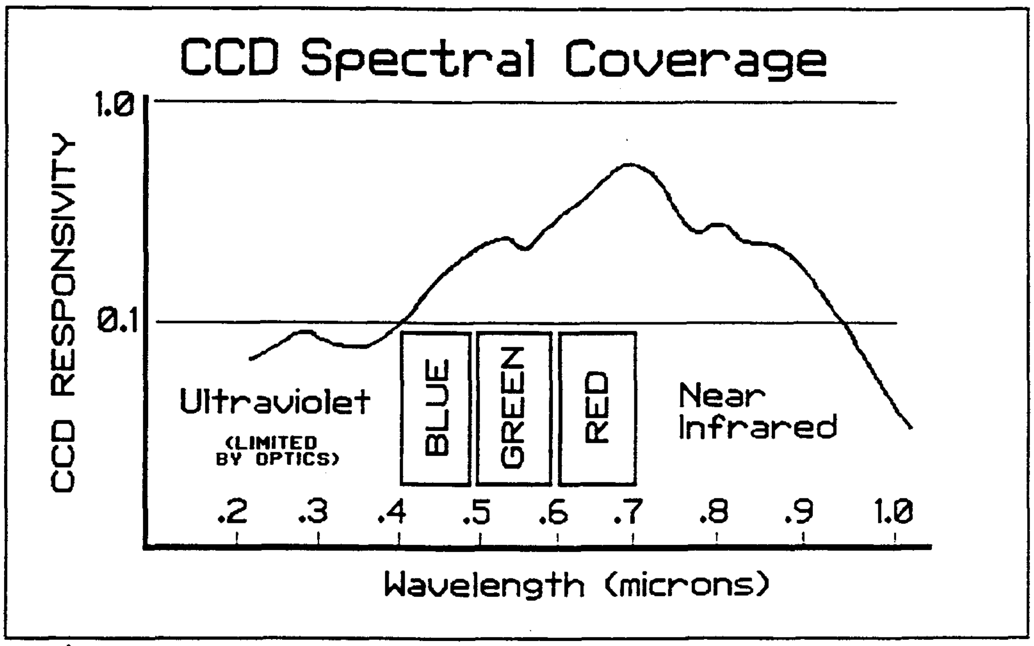

Figure 1. Spectral coverage of the ADAR System 5000

3. Global Positioning System (GPS). The System 5000 continually monitors a GPS receiver, providing latitude, longitude, and elevation data to reference the location of the host aircraft at the time each image is acquired. Images from the System 5000 are thus referenced to lat/long but not registered; image registration must be finalized through post processing, as described below.

B. System Performance.

1. Spatial Resolution. Through use of different focal length lenses, the sensor's instantaneous field of view (IFOV) can range from .2 to 2.3 milliradians (mrad). For comparison, the IFOV of the human eye is approximately .2 mrad, and the IFOV of the LANDSAT Thematic Mapper (TM) is

.04 mrad. Final image resolution may be controlled either through modification of the lens FOV or variation of the flight altitude, with an effective range of approximately 1/3 meter to 3 meters per pixel.

2. Spectral Resolution. Spectral resolution of the System 5000 sensors is adjustable within the spectral range shown in Figure 1, with spectral bandwidths from 12 to 300 nanometers (nm), allowing each individual project to obtain images specially configured for the spectral coverage desired.

3. Rapid Availability of Data. Data generated by the ADAR System 5000 are typically available within 72 hours of the imaging flight for post-flight image processing and interpretation. If demanded by the application, the user can begin processing image data as soon as the host airplane has completed the flight.

C. Data Correction and Image Registration.
For some applications, geometric and radiometric corrections must be applied to the raw data collected by the ADAR System 5000. Geometric distortions result from features inherent in the imaging geometry as well as scale distortions due to ground relief and variations in aircraft altitude and orientation. Radiometric corrections may be necessary because of the nonuniform nature of the sensor response and filter passband as well as external factors such as changes in illumination and ground reflectance. Some of these corrections can be applied automatically based on standard system calibration; other corrections (for ground relief, for example) will require comparison with additional data such as digital elevation model (DEM) files.

After appropriate image corrections have been applied, the raster images may need to be registered to latitude and longitude. GPS data provides coarse registration, with accuracy of +/- 100 meters providing adequate accuracy for some applications. Final registration will typically be accomplished through overlay with an existing registered data file, in some cases assisted by ground control points.

D. Imaging Platforms.
For the projects described here, the System 5000 was installed and flown in a single engine, fixed wing aircraft (Cessna 206). For special applications requiring low level or low speed flights or for imaging subjects other than standard terrain, the System 5000 can be adapted to other platforms including helicopters, boats, and land vehicles.

E. Image Data Format.
Image data collected by the ADAR System 5000 are recorded in a proprietary format. "Positive Format Translator (PFT)" software is used to convert the images into common data formats accepted by leading GIS and image processing systems.

POTENTIAL APPLICATION FOR FOREST HEALTH RESEARCH

The ADAR System 5000 has potential for mapping trees that are dead or dying from insects, disease, air pollution or other stress agents. The University of Idaho Department of Forest Resources is currently testing this application by analyzing ADAR imagery acquired during the summer of 1991 at the University of Idaho Experimental Forest.

A. Project Description. During June of 1991, trees were stressed by severing sapwood with a chainsaw. Three plots, composed of sawtimber-sized grand fir and Douglas fir, were chosen. In addition, two plots within a plantation of sapling-sized ponderosa pine trees were chosen for treatment. Each plot was approximately 10 meters by 10 meters in size. The corners of the plots were marked with a 2 meter by 2 meter white cardboard target. Since saplings typically have no heartwood for structural support, the saplings were cut 1 meter above the ground and tied to sapling stumps to maintain the upright position of the saplings.

On August 13, 1991 ADAR imagery was acquired of the study area with four spectral bands (see Table 1). The spectral regions selected were based in part on research of the effects of bark beetle stress on the foliar reflectance of lodgepole pine (Ahern 1988).

Table 1.
Spectral bands used for ADAR System 5000 flight at the University of Idaho Experimental Forest (8/13/91)

Band	Bandwidth (nm)	Band Center (nm)	Spectral Region
Band 1	80	550	Green
Band 2	12	690	Red edge
Band 3	40	700	Red/Near Infrared
Band 4	40	750	Near Infrared

At the time of image acquisition, the saplings in one plot had yellowed and were starting to brown; the saplings in the other plot were just starting to yellow. There was no visible indication of stress in any sawtimber plots. The imagery was flown at an altitude of 2000 and 3800 feet above ground level, resulting in pixel size of 0.33 and .67 meters. Images were recorded on the ADAR System 5000 during the flight and later transferred to a 486 microcomputer. PC ERDAS is being used for image rectification and analysis.

Since the ADAR System 5000 uses four parallel CCD cameras, imperfect boresighting results in spectral bands which are not perfectly coregistered in a multispectral scene. However, the cameras are rigidly mounted at a fixed distance away from each other, so coregistration can usually be accomplished by using a linear affine transformation. One problem at extremely high resolutions (< 1 meter pixels) is that the accurate delineation of control points is difficult. Typically control points selected for coregistration were artificial objects such as posts, painted lines along a highway, the corners of a building, etc.

At the time of this writing, ADAR images have been coregistered and are being analyzed using image processing and statistical software. Analysis of variance and signature divergence values are being used to determine the optimal band combination for comparing stressed sapling plot versus control sapling plots. This information will then be used for band selection in supervised classification of dead and dying sawtimber sized conifers.

Images were also collected of sites known to be infected with root rot; as of this writing, imagery from those sites has not been processed.

B. Recommendations. Since this was a new experience with high spatial resolution imagery (pixel size < 1 m) for mapping stressed conifers, several recommendations are offered for future users.

1. Ground Control. Because of radial displacement, many of the white cardboard targets were not apparent on some images of sawtimber stands. Therefore, future plots within forest stands should be delineated with a continuous perimeter of white material or another material which provides high contrast with the predominant features (vegetation, soil, or minerals) in the immediate vicinity. In addition, the placement of white targets within canopy gaps are very helpful for band registration.

2. Girdling of Trees. Many of the sawtimber trees were not measurably stressed by cutting through the sapwood two months before the imagery was acquired. The girdling was done with a chainsaw, with cuts at least four inches deep through the sapwood. Since there was no visible difference between the girdled and non-girdled sawtimber stands, a pressure chamber (Ritchie and Hinckley 1975) was used to measure the water potential in a sample of these trees. There was no significant difference in predawn xylem pressure potential between sampled girdled and non-girdled grand fir and Douglas fir trees. Apparently, the sapwood was not completely severed by the chainsaw girdling and enough water was being transpired through the sapwood to prevent moisture stress. Riggs and Running (1991) state that if only 10 percent of the sapwood remains functional, water stress may not be observed. Therefore it is crucial to monitor "stressed" trees with a pressure chamber to determine that the trees are water stressed prior to imaging.

3. Image Scale. One problem with large scale imagery of forested stands is that it is very difficult to determine where the imaged trees are located within the forest. One ADAR image at 0.67 meter pixels corresponds to an area of approximately 3 cm wide by 2 cm high on a

medium scale 1:15,840 aerial photograph. Therefore, the use of medium scale aerial photographs and maps is limited in determining the location of these high resolution images. A better solution would be to image the study area at several altitudes. Smaller scaled ADAR imagery taken at the same date as high resolution imagery would be very useful for locating stands or plots within a forested landscape.

OREGON AND WASHINGTON SITES

On the western slopes of the Cascade Mountains in Oregon and Washington, ADAR data are being used in a variety of ways. These include characterizations of forest structure and mapping of small-scale disturbances in stream channels. ADAR System 5000 imagery was obtained over the H.J. Andrews Experimental Forest in Oregon and the Wind River Experimental Forest in Washington. All ADAR imagery for this project was collected on September 23, 1991, at spatial resolutions of 1 and 2 meters per pixel. Spectral bands were matched as closely as possible to the first four bands of the Landsat Thematic Mapper (TM), as indicated in Table 2.

Table 2.
Spectral bands used for ADAR System 5000 flights in Oregon and Washington (9/23/91)

Band	Bandwidth (nm)	Band Center (nm)	Spectral Region
Band 1	80	550	Green
Band 2	80	450	Blue
Band 3	80	850	Near Infrared
Band 4	80	650	Red

A. Characterizations of Forest Structure

This usage of ADAR data is an extension of the work of Cohen et al. (1990) and Cohen and Spies (1992), in which the objective is to characterize forest structural attributes with satellite imagery in Douglas-fir/western hemlock forests. In those studies, the spatial properties of SPOT 10m panchromatic High Resolution Visible (HRV) imagery were found to be highly correlated with a variety of stand-level structural attributes, whereas similar properties of LANDSAT 30m Thematic Mapper (TM) imagery were not. However, a spectral feature of the TM Tasseled Cap was found to be highly correlated with stand structure.

A next step in this analysis is to determine the optimum ground resolution cell size for characterizations of stand structure using image spatial properties. To accomplish this objective, the ADAR data will be spatially degraded to 5m, 10m, 15m, and 20m prior to analyses. Results of this study will have implications relative to the type of satellite imagery chosen for similar analyses at a regional scale. The next LANDSAT satellite will carry a 15m panchromatic channel registered to the 30m multispectral channels. If 15m data are useful for spatial analyses in the forest conditions of interest, then LANDSAT 6 TM data will be a powerful tool permitting both the spectral and spatial domains of image data to be used in unison to extract forest structure information. If the spatial properties of 20m data are useful, then HRV multispectral imagery may provide this opportunity. The value of using high spatial resolution ADAR data for this study is that we have the ability to determine the change in spatial information content of image data as it is spatially degraded from very fine to relatively coarse pixel sizes.

An additional direction for research of forest structure with satellite imagery is to use canopy reflectance models (Li and Strahler 1985; Smith et al. 1990). For this study ADAR data are being used to characterize the proportions of various scene components (e.g., sunlit and shaded tree canopy and sunlit and shaded background) typically found under a variety of stand structural conditions. This information will help us to calibrate our models for use with 30m TM imagery, where these individual scene components are not resolvable. With the multispectral properties of the ADAR System 5000 we can determine the spectral properties of the individual scene components relative to the TM bands 1 through 4.

For retrospective studies using LANDSAT Multispectral Scanner (MSS) data, ADAR System spectral channels can be matched to MSS channels. Again, knowing the proportions of scene components and the spectral properties of those components can be very useful when relating satellite image spectral properties to stand structure properties. ADAR imagery is being used in this way for a study of land use effects on carbon storage by forests of the Pacific Northwest from 1972 to 1992 (Wallin et al. 1992).

B. Mapping of Stream Channel Disturbances

The RAPID (riparian aerial photographic inventory of disturbance) technique was developed as a method for using measurements made from aerial photos of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time, and to link those changes to their upstream causes (Grant 1988). The ADAR data provide an opportunity to extend this technique to digital image data and thus make the technique amenable to computerization. As a pilot study we are using ADAR data for this purpose along the Lookout Creek drainage in the H.J. Andrews Experimental forests where recurring flood-related disturbances are common.

In a related study, ADAR data are being used to characterize riparian vegetation conditions and to locate streamside forest gaps. The objective is to determine how dissimilar forest fragmentation along stream corridors is from fragmentation up slope. Results of this study have significant implications on issues related to global and regional biodiversity.

SUMMARY

This paper presents work in progress using high resolution four-band image data in a variety of forestry applications. Since this work has not been completed, final results cannot be presented, but initial results are promising for forestry studies using multispectral images with resolution of 1 meter per pixel or higher.

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