AN OPTIMAL AIRBORNE FOREST INVENTORY SYSTEM

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ABSTRACT

The development and application of an optimal multi-sensor forest inventory system is described. Following review of state-of-the-art approaches to airborne forest inventory techniques, it was concluded that the combination of a multi-spectral imaging sensor to provide planar information on forest characteristics with a laser profilometer to provide vertical sectional information constituted an optimal combination. The two sensors have been utilized in unison, coordinated through a digital computer, to provide a unified three-dimensional description of the forest. The description includes principal forest characteristics such as species composition, forest condition, crown density, and secondary characteristics in the horizontal plane, combined with vertical sectional properties including tree height, vertical stratification, and foliage density. These characteristics may then be used to determine economic parameters such as biomass and timber volume. The system described, consisting of a multispectral camera and laser profilometer connected to a digital data acquisition system, has been developed up to the operational phase through a series of activities including system integration, hardware acquisition and testing, extensive real time and post-acquisition data processing software development, and pilot survey execution. The latter, which included comparison with ground truth data, showed excellent agreement in the primary geometric property measurements of the forest and good agreement in the areas of secondary property evaluation. The system has been found to provide an economical and efficient technique for obtaining forest information ranging from pre-inventory surveillance to detailed inventories and forest change monitoring for a range of conditions in both temperate and tropical climates.

INTRODUCTION

The purpose of the work described herein was to develop an airborne data collection and analysis facility which would be useful for forest assessment either as a stand-alone system or in combination with other airborne and ground based acquisition systems. Current technologies used for assessments of large areas include analysis of aerial photographs and satellite imagery (Ahern and Leckie, 1987). These approaches depend heavily on ground truth data for volume estimations and tree heights can only be estimated. These results are then integrated into Geographic Information Systems (GIS). Also large scale photography is used to obtain tree heights from airborne platforms (Spencer, 1987). However, the technique is costly and time-consuming due to the manual analysis required for each photo pair. Previous investigations have demonstrated the utility of the laser rangefinder for tree height measurements in an airborne configuration (Nelson et al., 1984; Aldred and Bonnor, 1985; Bercha et al., 1987). By pairing the rangefinder with a second sensor capable of obtaining images of the forest canopy, and analyzing the data as an integrated set, a system which could generate a three-dimensional representation of a forest canopy in digital format was predicated.

Prior to this work the laser systems were often operated in conjunction with a video camera in order to recover the aircraft flight line in post mission processing. These two sensors are complementary in the sense that their operational envelopes overlap (flying height, speed, etc.). Additionally, laser measures in the vertical plane and video produces a horizontal image resulting in two very different data sets. Unfortunately, conventional video imagery is not easily interpreted using the analytical techniques which are required for forest assessments. By using a multispectral video camera, the same image data may be separated into several discrete images representing the scene reflectance at a variety of wavelengths. These images can be captured using a video digitizer and analyzed in a manner analogous to the digital analysis of satellite imagery.

STUDY AREA

Testing of this integrated system was performed in Alberta near Drayton Valley and in the Bow Crow Forest Management Unit (FMU) west of Calgary. These areas offer a variety of single species and mixed forest stands located on gently rolling to hilly terrain. A total of 26 km^2 was surveyed.

AIRBORNE SYSTEM DESCRIPTION

The Forest Inventory Reconnaissance System (FIRS) is constructed from low-cost components using a central data acquisition computer to ensure system integrity and to provide timing control. The main sensors are a laser rangefinder and a multispectral video camera. Facilities for film cameras and other alternative sensors are included in the data acquisition package.

The laser rangefinder is a gallium-arsenide (GaAs) diode laser capable of pulsing at rates of up to 4000 times per second. The laser pulses are in the near infrared at a wavelength of 902 nm. Reflections of the narrow pulses are captured by a sensitive photodetector and the two way travel time is converted to distance using the constant speed of light. Special circuitry is provided to allow discrimination between multiple targets and allow the laser system to report either the shortest or longest range as selected by the data acquisition computer.

While shorter ranges to the treetops are reliably obtained, the longer ranges to the ground are not always available due to obstruction of the laser beam by heavy foliage. To maximize the frequency of ground ranges, the laser is pulsed at a rate which provides a 90% overlap between pulses. The data is filtered in real time so as to give a concise data set consisting of ground ranges and tree heights. A statistical summary of the number of ranges intercepted by the foliage is recorded to allow estimation of crown closure along the profile.

The multispectral video camera is based on a conventional charge coupled device (CCD) sensor which is scanned at the North American standard of 60 fields per second (NTSC). The sensor resolution is 384 pixels by 292 lines spatially, while the spectral response is from 0.4 to 1.1 μm (Frost, 1985). The sensor is located behind a rotating shutter which contains six, user-selectable, narrow band spectral filters. The shutter speed is synchronized with the scan frequency of the video circuitry in such a way that each field of the video imagery is acquired through a different filter. This provides continuous six band coverage at a rate of ten image sets per second.

In order to relate the video imagery with the laser profiles in post-mission processing, a digital time code is inserted into the video signal prior to recording. These time are readable by a computer controlled video playback unit.

LASER RANGEFINDER DATA

Reduction of the laser data is a two step process. The first requirement is to determine the range from the aircraft to the ground. This involves filtering out the ranges which are intercepted by the foliage so that the remaining range measurements indicate the ground surface. These ground ranges are considered an intermediate result for scaling the video images.

Once the ground trace is defined, the second step is to subtract the short ranges to give the tree heights. A considerable amount of research has been devoted to determining how well the laser actually detects the top of the tree crown (Aldred and Bonnor, 1985). The factors which come into play here are the sensitivity of the laser to the small branches at the top of deciduous trees and the difficulty in determining whether or not the laser has detected the highest point on the crown. Both of these effects will cause a shorter tree height than is actually the case to be measured. Studies with the laser used in the present application have shown that sensitivity to small objects is not a problem as a fairly wide beam dispersion is used and the ranging electronics provide excellent control over the target selection. Thus, for deciduous trees with large flat-topped crowns, the height measured will be fairly accurate. Another consideration is that the laser is not maintained in a constant vertical orientation and therefore will produce height measurements which are slightly longer than the actual tree size. The net effect has been found to be that the raw range data is within 0.5 meters of the control data when averaged over small segments of the flight line.

An important aspect of the laser cross-section is its display of the vertical foliage distribution along the profile as shown in Figure 1. This output is useful for discriminating between tree species during image interpretation and can be also used to locate defoliated crowns which may be due to disease or insect attack.

MULTISPECTRAL VIDEO IMAGERY

The video imagery is captured using a video "frame grabber" board interfaced to a digital image analysis system. This system utilizes high speed analog to digital converters (ADCs) to convert the incoming video signal to a digital raster. Consecutive fields are captured and registered to form a multiband image. The time codes stored in the video signal are also captured and used to correlate the images with the laser determined aircraft height.

One of the main factors affecting the image quality is the inconsistent amount of solar illumination due to shadowing effects. Therefore, each multispectral video image is scaled and then radiometrically enhanced so as to equalize the relative brightness of each band. Images are then registered to a master file to obtain a high resolution image strip of the flightline. The analysis phase objectives are to obtain a general classification of the imagery by delineating stand boundaries. The laser data is used to differentiate between stands with similar appearances but different heights. Recognition and identification of individual trees is possible manually but has not been implemented as an automated process. In mixed stands, separation of deciduous species from coniferous species is sometimes possible but, due to the limited bandwidth of the video sensor, identification of individual species is unreliable.

General classifications are used such as an unsupervised clustering technique or a supervised approach. At this point, the laser data can be used to advantage. Since different tree species present different vertical profiles in terms of leaf and branch distributions, the analyst can identify the various types by comparing the laser data to the video image.

GROUND DATA

Two methods were used to gather ground control data for this study. The first method was designed to establish the relationship among age, height and diameter at breast height (dbh) of several species of trees in the study area. A total of 691 trees were sampled at random and classed

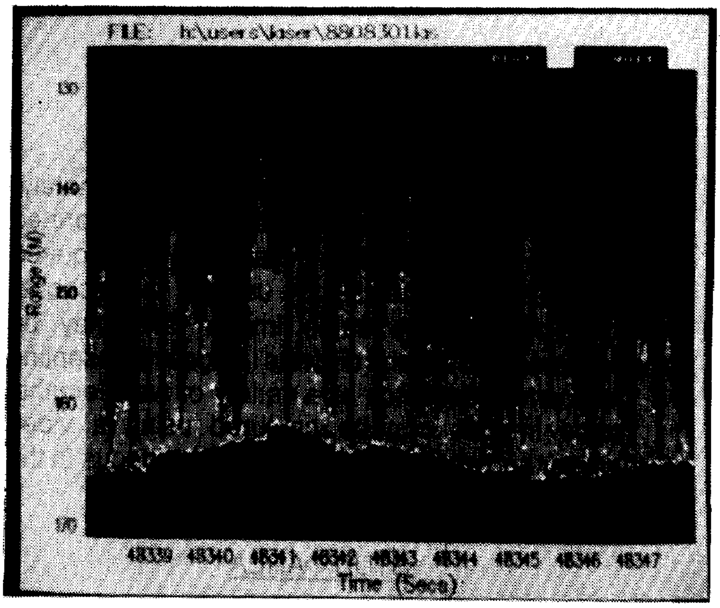

Figure 1 Laser Range Data

by height and species group so as to obtain a significant sample of each species population and to indicate the distribution of age and dbh relative to height. For each species group, five height classes were established and 15 trees in each height class were sampled. The data collected in this manner gave a good indication of growth rates and relative distributions of various tree species in the area.

The second ground data acquisition procedure was designed to specifically test the laser system accuracy. Several flight lines were accurately marked on airphotos of the area at a scale of 1:30,000. At well defined sections of these lines a "strip cruise" was performed covering an area of 10 metres on each side of the line. In the area covered by the strip, each tree was measured for dbh and its species recorded. At 10 metre intervals along the strip, the height of the dominant tree was measured. This data, augmented by the data from the first method, is a clear indication of stem density, species distribution, and canopy height at a location which was also viewed by the aircraft system.

ANALYSIS AND RESULTS

The products of the airborne data interpretation were tabulated to show average stand height, crown closure, and the ratio of deciduous to coniferous species along the strip cruise areas. These parameters were compared to the measurements acquired during the ground truth data acquisition phase.

The average tree heights measured over the profile lines were within 0.5 metres of the ground values. The determination of crown closure was better in single species coniferous stands than in mixed or deciduous areas mainly because of the difficulty in differentiating the low lying ground foliage from the deciduous crowns. Better results in these stands were achieved using the integrated data sets than with the video imagery alone. Similar problems were encountered in determining the ratio of species occurrence.

CONCLUSIONS

The processing of data obtained from airborne laser rangefinder integrated with a multispectral video camera was described. The results of the flight tests of this system were compared with the data obtained by field cruising techniques. The sensor package described has the advantages of relatively low cost while providing a direct measurement of tree height and thematic inventory data which can be easily processed by semi-automated means.

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