J-1.1.1 Measurements of Ecosystem Structures using Optical Sensors

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Abstract: In order to evaluate the role of terrestrial ecosystems in the global environment, we developed methods for measuring vegetation types, structural parameters, biomass, spectral reflectance characteristics and temporal changes using satellite images. First for the measurement of forest structural parameters, we developed a method for measuring forest tree heights using an airborne laser scanner. Secondly as an advanced processing method of satellite imagery, we studied a method for estimating ratios of sub-pixel categories in a pixel. Thirdly as a way to obtain ground-truth spectral data, we developed an imaging spectrometer capable of measuring spectral reflectance at each point in an image.

Key Words : vegetation, airborne laser scanner, structural parameters, tree height, biomass, remote sensing, sub-pixel category, spectral reflectance, imaging spectrometer

1. Introduction

To cope with global environmental problems, such as global warming, deforestation, desertification, a number of international research programs, e.g. IGBP, have been initiated under the cooperation of international research communities. One of the important research themes is the investigation of the function of terrestrial ecosystems in the global environment.

It is realized that satellite remote sensing techniques are effective tools for observing current states and changes of ground surface conditions in large areas. By using satellite imagery, we can regularly collect data concerning ground surface conditions and can really see currently occurring changes. Moreover if we use satellite data as input or verification data for a global biogeochemical process model, we can predict future changes of the environment with higher accuracy.

In this sub-project we have developed methods for measuring vegetation types, structural parameters, biomass, spectral reflectance characteristics and temporal changes using optical satellite sensors. The followings are the research items we have conducted during three years

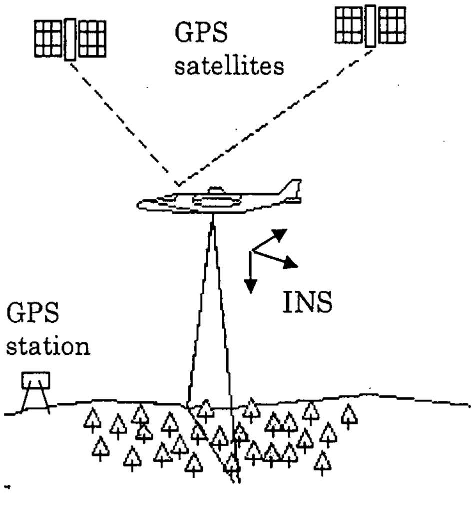


Fig. 1. Airborne laser scanner.

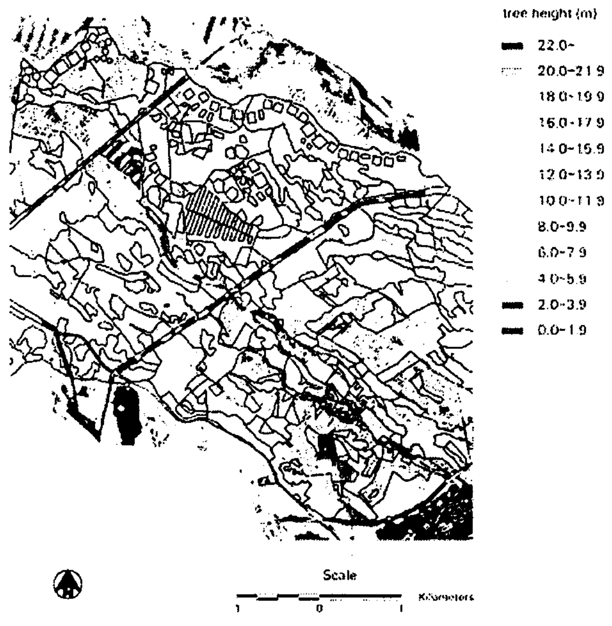


Fig. 3. Canopy height distribution Measured by the laser scanner.

Fig. 2. Aerial photograph of the tower for measuring canopy heights.

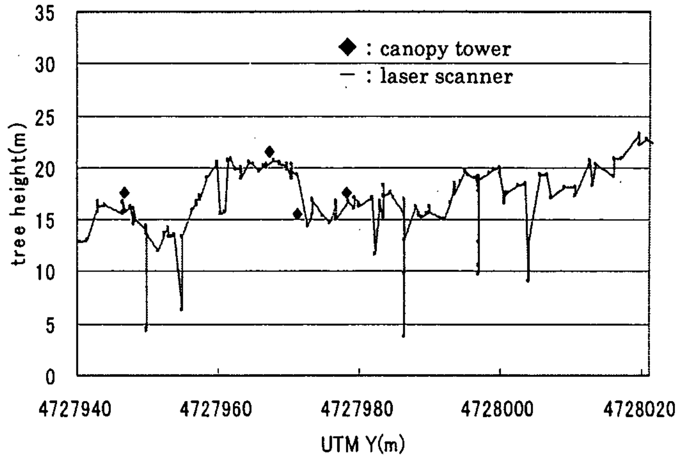


Fig. 4. Comparison between laser scanner data and canopy tower data.

of research period.

(1) Development of a method for measuring forest tree heights using an airborne laser scanner

(2) Examination of a method for estimating sub-pixel category contents

(3) Development of an imaging spectrometer for ground measurements

The following sections explain outlines of these items.

2. Measurements of forest canopy height using an airborne laser scanner

Forest canopy height is one of the fundamental structural parameters for estimating forest biomass and evaluating forest carbon balance. We used an airborne laser scanner for measuring tree canopy heights at the Tomakomai experimental forest of Hokkaido university.

2.1 Airborne laser scanner

The airborne laser scanner measures three-dimensional terrain or canopy profiles using a system composed of a laser range finder, a GPS receiver and an INS (Inertial Navigation System). Figure 1 is a schematic illustration of a laser scanner.

2.2 Measurements of forest canopy heights

Tomakomai experimental forest is located on a flat plateau of volcanic ash, 25 % of which is covered by afforested coniferous forest, and the rest of which is dominated by broad leaf trees such as *Quercus crispula* and *Phellodendron amurense*. A 25m-high canopy tower has been constructed in the experimental forest for measuring tree canopy heights within the radius of 40m from the tower (Figure 2). The tree height data obtained by this canopy tower are used for the verification of the laser scanner measurements.

Laser scanner experiments were conducted in November 1998 and July 1999. In the first experiment terrain profiles were mainly measured; in the second experiment canopy profiles were mainly measured. Canopy heights were obtained by subtracting the terrain profiles from the canopy profiles. Figure 3 shows the canopy height distribution in the experimental forest. These laser scanner data were compared with the ground measurement data obtained by the canopy tower. Figure 4 shows an example of comparison between the laser scanner data along a transect and canopy tower data; the line shows the laser scanner data and the diamond symbols show the canopy tower data. We compared both data along 19 transects (10 from north to south and 9 from east to west), including 89 canopy tower data points. The differences between both data were less than 1m for 67 points (75 %) out of 89. We hence can say that the airborne laser scanner can measure tree canopy heights with accuracy practically usable.

3. Estimation of sub-pixel category contents

Conventional classification techniques such as the maximum likelihood method or the minimum distance method generally perform well for classifying large homogeneous categories in remotely sensed multispectral imagery. But they are not very successful in classifying sub-pixel categories or identifying proportions of categories in a pixel. There have been several sub-pixel classification methods that can estimate the proportions of sub-pixel categories. But they assume that spectral reflectance characteristics of all the categories existing in an image are known. We have studied a sub-pixel classification method[1)] that can detect the proportion of a target category in each pixel of an image without the knowledge of spectral characteristics of background categories.

3.1 Method

This method is based on the following two assumptions:

(1) An observed spectral vector of a pixel in an image can be expressed as a linear combination of the spectral vector of a target category and those of background categories.

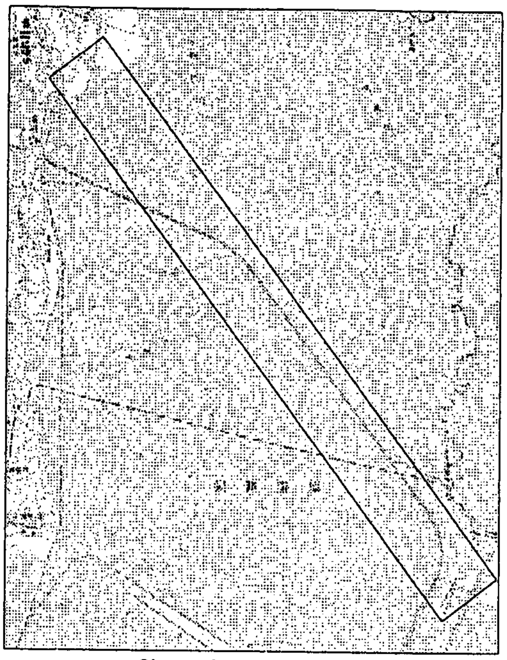


Fig. 5. Observed area (black outlined area)

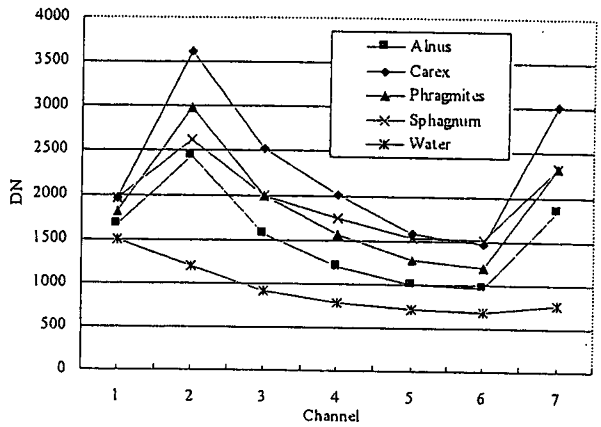


Fig. 6. Spectral profiles of each category

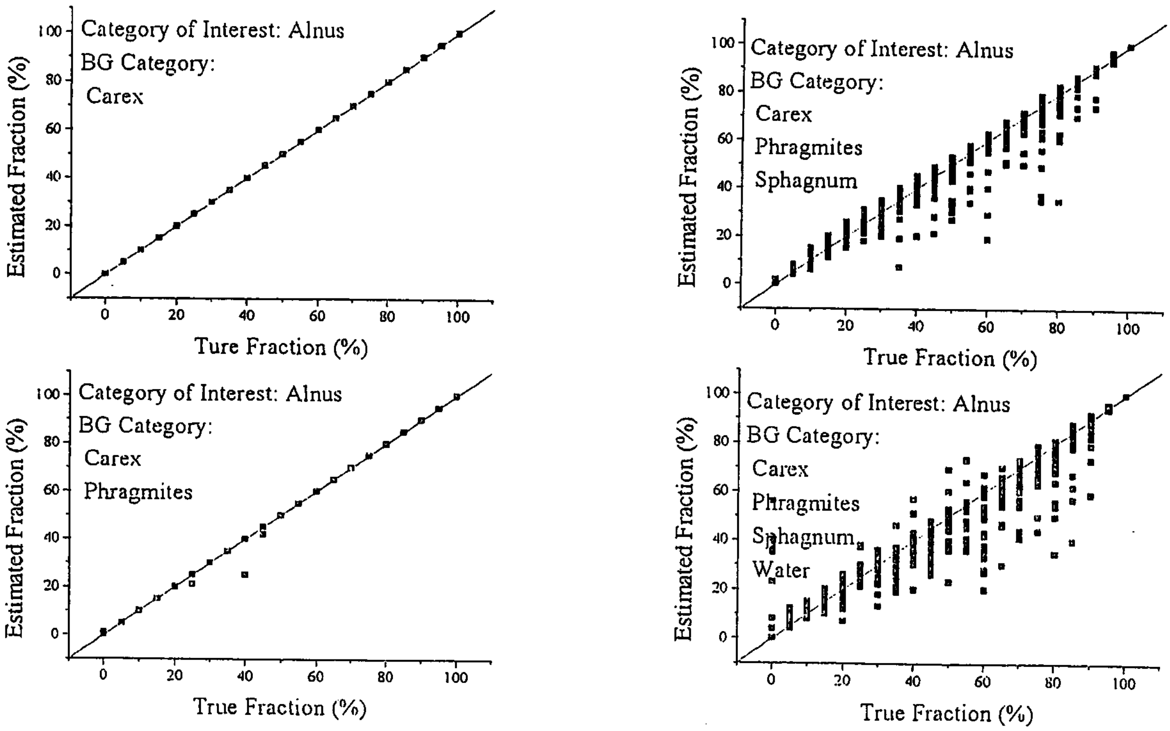


Fig. 7. Estimated fraction vs. true fraction.

(2) The spectral vector of aggregated background components can be expressed by the linear combination of spectral vectors of other pixels in the same image.

Let us express an observed spectral vector of a pixel as V_o. First a proportion k_b of background categories in a currently chosen pixel is assumed. Secondly a candidate of a background spectral vector V_b is selected from an arbitrary pixel in an image and the product of k_b and V_b

is subtracted from V_o to yield a resultant spectral vector $\boldsymbol{R}$. We then calculate similarity fs between the target spectral vector V_t and $\boldsymbol{R}$. Repeating this process for different values k_b's and different V_b's, we finally obtain the pair of k_b and V_b which maximizes the value of fs. We take this best value of k_b as an estimated proportion of the target category.

3.2 Results and discussion

We artificially composed four test images using spectral information extracted from a CASI (Compact Airborne Spectral Imager) image obtained over the Kushiro Mire. There we find alders, sedges, reeds and mosses as representative plants. Figure 5 shows the observation area. We can find five main categories in this image. (Four types of plants above and water surface.) Figure 6 shows spectral profiles of each category. We selected alders as the target category. Using the spectral profiles we artificially composed four test images; (a) one background category, sedges, (b) two background categories, sedges and reeds, (c) three background categories, sedges, reeds and mosses, and (d) four background categories, sedges, reeds, mosses and water.

The method was applied to these four images to estimate the proportion of alders. Figure 7 shows the results for each image. We see that the estimation accuracy of the method decreases as the number of background categories increases. The accuracy is fairly good when the number of background categories is less than three; but it degrades in other cases. This is ascribed to the breakdown of the assumption (2) caused by the increased diversity of background components. Detailed examination on this assumption is necessary to improve the accuracy of the method.

4. Development of an imaging spectrometer for ground measurements

An imaging spectrometer[2)] is a device that can acquire multispectral images of an observation object at a number of wavelength. An ordinary spectrometer used for acquiring ground-truth data for remote sensing can only obtain spectral information averaged over its field of view; but an imaging spectrometer can measure both spatial and spectral profiles at the same time. We have developed an imaging spectrometer by combining an AOTF (Acousto-Optic Tunable Filter) device and a CCD camera.

4.1 Imaging spectrometer

Figure 8 shows the block diagram of the imaging spectrometer. An AOTF device decomposes incident light from an observation target into spectral components, and a CCD camera receives the spectrally decomposed images. The resultant multispectral images are then stored in a personal computer. An AOTF is an element that works as a band-pass filter utilizing the interference between light and ultrasonic waves propagating in a solid element. As the passing wavelength of light is determined by the frequency of an ultrasonic wave, we can choose the extracted light wavelength by changing the ultrasonic frequency. The entire function of the imaging spectrometer is controlled by the computer and the data acquisition is

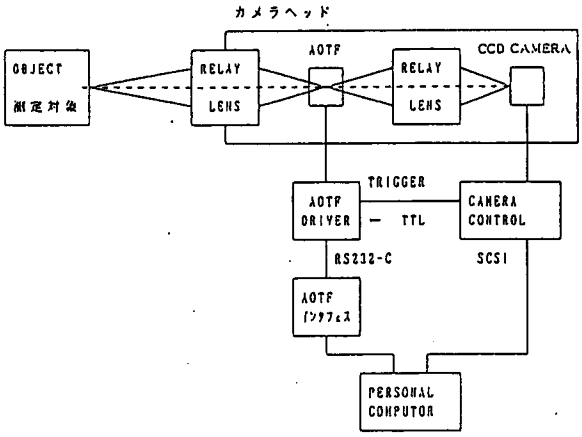


Fig. 8. Block diagram of the imaging spectrometer.

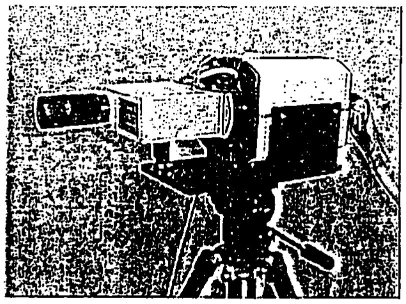


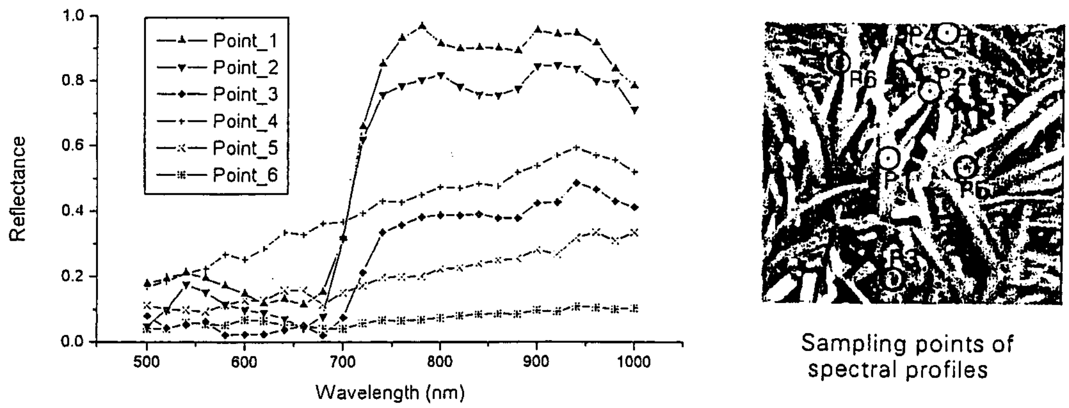
Fig. 9. External appearance of the camera head.

Table 1 Specifications of the imaging spectrometer

Wavelength range	400～1,000 nm
Spectral resolution	5.2nm @ 830nm
Measurement distance	0.98～∞ m
CCD pixel size	1,317 x 1,035

(a) 680 nm (b) 700 nm (c) 720 nm

Fig. 10. Measured multispectral images.



(a) Spectral profiles (b) Sampling points

Fig. 11. Spectral profiles (a) at the sampling points shown in figure (b).

automatically conducted. Figure 9 shows the external view of the camera head and Table 1 shows the specifications of this imaging spectrometer.

4.2 Experimental results

Figure 10 shows spectral images of grass obtained at (a) 680nm, (b) 700nm, and (c) 720nm. Figure 11 (a) shows spectral reflectance curves at several points in the image (b). Points 1 to 3 are located on the vegetation surface; a specularly shining point, an oblique incident point and a shadowed point respectively. Points 4 to 6 are located on the soil surface; shining point, an average colored point and a shadowed point respectively. By using this imaging spectrometer, we can obtain detailed information on the spectral reflectance properties of each component in an observation area.

4. References

1) Huguenin, R. L., Karaska, M. A., Van Blaricom, D., and Jensen J. R., Subpixel Classification of Bald Cypress and Tupelo Gum Tree in Thematic Mapper Imagery, Photogrammetric Engineering & Remote Sensing, Vol.63, No.6, pp.717-725, 1997.

2) Elachi, C., *Introduction to the Physics and Techniques of Remote Sensing,* Wiley Interscience, 1987.