Phyton (Austria) Special issue: "APGC 2004"	**Vol. 45**	Fasc. 4	(511)-(516)	1.10.2005

The Development of a Hyper Spectral Imager for Forest Monitoring

By

H. OGUMA[1] & Y. FUJINUMA[1]

Key words: Hyperspectral PRI, NDVI, Tomakomai Flux research site.

Summary

OGUMA H. & FUJINUMA Y. 2005. The development of a hyper spectral imager for forest monitoring. - Phyton (Horn, Austria) 45 (4): (511)-(516).

The hyper-spectral reflectance factor over the forest canopy is expected to obtain the information, related to the health condition, leaf biochemical contents ratio and photosynthetic activity. A hyper spectral imaging system was developed in order to take the hyper-spectral images of the forest canopy in the daytime automatically. This paper describes the outline of this imaging system and initial result of acquired images of Tomakomai Flux research site. A spectroscope and the 2-dimensional CCD camera constitute this imager and cover the wavelength range from approximately 500nm to 980nm with a spectral resolution of 5nm. This imager has been installed at the top of the CO_2 flux measurement tower of the 25m heights which was built in the forest of Japanese larch (Larix Kaempferi). The perpendicular viewing angle is 25 degrees, and the horizontal scan is performed by rotation of the computer-controlled stage. The maximum horizontal rotation angle is 340 degrees. The data acquisition is carried out from 8 a.m. to 6 p.m. in the 2-hour interval. In 2003, the observation was carried out between June to the end of November. In advance observation period, this imager was calibrated by using standard lamp and integrating sphere to transform the observed value of each pixel into radiance or reflectance. By using these images, narrow waveband NDVI (normalized difference vegetation index) which has correlation in the vegetation biomass and PRI (photochemical reflectance index)are calculated. When seasonal change of NDVI was obtained according to the individual trees, having a different seasonal change pattern was observed with larch, the broadleaf trees, and the grass of a background. Furthermore, PRI of larch canopy changes with the photosysthetically photon flux density (PPFD) was found

Introduction

In the Kyoto Protocol, the amount of absorption of the greenhouse gas caused

[1] Center for Global Environmantal Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, Japan, e-mail: oguma@nies.go.jp

by a forest will be accepted as a part of the amount of greenhouse gas reduction. Furthermore, in order to understand the cyclic process of the greenhouse gas in a global scale, development of the method for measuring the amount of absorbed or fixed carbon to the land vegetation is required. From such a background, observation of the biomass and photosynthesis activities of forest vegetation are expected by using the remote-sensing from satellite. So far, a lot of researches have been carried out as the trial which observes vegetation photosynthesis activities by using passive remote sensing , such as photochemical reflectance index (GAMON & al. 1992, 1997) and water index (PEÑUELAS & al. 1997) or hyper spectral analysis observing in the range of visible to short wave infrared region to estimate biochemistry inner leaf (e.g. DAWSON & 1998). However, the earth observation satellite which can acquire a hyper spectrum image is limited only to EO-1 at present, and observation aiming at the monitoring of time series change of vegetation is very difficult. Therefore, the hyper-spectrum camera which acquires automatically the continuation spectrum image of a forest tree canopy was developed. The camera was equipped at the 25m height tower in the flux research site where National Institute for Environmental Studies manages this in Tomakomai, Hokkaido (42°44'N, 141°31'E), and acquisition of the spectrum image on a larch (*Larix kaempferi* Sarg.) canopy is started on September 2, 2001.

This paper describes development of this camera system and acquisition data.

Material and Methods

System configuration

This system consists of a spectrum camera mounted by the rotation stage installed at the top of a tower and the computer for stage control and image data store installed on the ground base. The outline of a system is shown in Fig.1. and the Sensor specification from the version only in 2001, and 2003 to the present was summarized in Table 1. The visible near-infrared spectrum camera was installed to the waterproof housing, and it is mounted on the rotation stage which has tilting and horizontal rotating mechanism. The spectrum camera is constituted by an object lens, an imaging spectroscope, and the 2-dimensional CCD camera. ImspectorV10(Specim, FINLAND) is used as a spectroscope, and when equipped with a 2/3 inch CCD camera, it covers spectral range from 400nm to 1000nm with the spectral resolution is about 5nm (TIMO & al. 1998). The 9.5mm lens was used for the object lens and obtained the 25-degree observation angle perpendicularly. KP-F2A (Hitachi, JAPAN)was adopted as a CCD camera combined with a spectroscope, in 2001, the number of available pixel is 480x640 pixels, and has 10-bit resolution. Since a CCD camera generates an image at a video rate (30 frames per second), a 25-degree spectrum image will be perpendicularly to earth surface obtained at a video rate, and by movement to the horizontal direction of a rotation stage, it will perform a push bloom scan and can obtain the two dimension spectrum image over the forest canopy. The horizontal scan of a camera is performed by rotation of a stage and 340-degree rotation is carried out about 60 seconds. Operation of a camera or a rotation stage is controlled by PC for control and the data recording under the tower. The output of a spectrum camera is transmitted via 5C-2V cable to PC under the tower, and A/D conversion of the signal is carried out as a 10-bit digital signal with the video capture board (PULSAR, MATROX, USA) installed in PC, then the signal is recorded on a hard disk. When carrying A/D conversion, for compression of data size, and improvement signal-noise ratio, only the wavelength direction carries binning for 5 pixels, makes image size for one frame 480 pixel (V:space axis) x128 pixel (H:wavelength axis), and is recorded on the hard disk. From the observation start time in 2003, the CCD camera was upgraded from KP-F2A to MC-781PF (TEXAS INSTRUMENTS, USA). The feature of this camera is having an A/D converter in the inside of a camera unit, and outputting an acquisition image as a 12bit digital signal. Therefore, it is available to carry signal transmission from a camera to the data server placed under the tower with an optical fiber cable, preventing degradation of a signal and mixing of a noise are expected.

Table 1. Sensor specification from the version only in 2001, and 2003 to the present

	2001	2003～
· Spectroscope	Imspector-V10	Imspector-V10
· Spectral range	520-850nm	400-1000nm
· Spectral resolution/pixel	7nm	7nm
· Image sensor	KP-F2A (Hitachi)	MC-781(TEXAS INSTRUMENTS)
· Image size	480x640	754×484
· Quantization	10bit	12bit

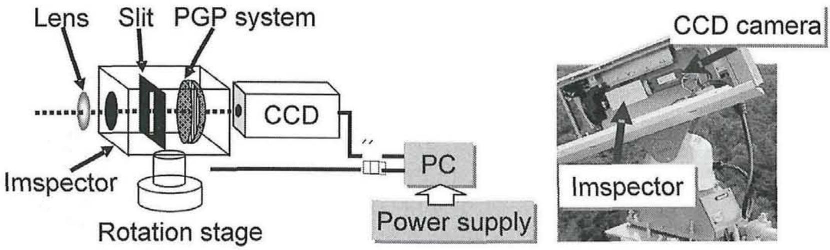

Fig. 1. Illustration of the method for measuring the hyper spectral radiation image and photograph of this system installed top of the 25m height tower in the larch forest.

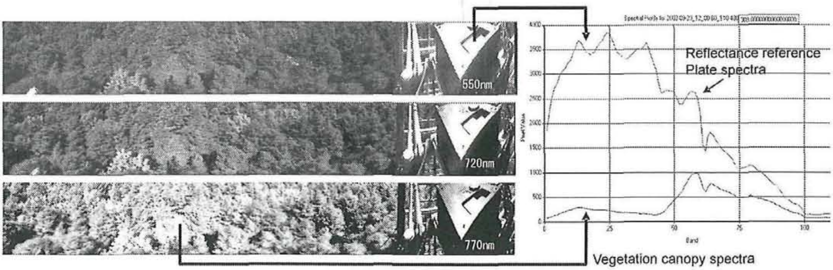

Fig. 2. The canopy image of three wavelengths acquired at 12:00 on September 23, 2003 and the spectrum response curve of a standard reflectance plate and the larch canopy produced by single pixel value. The box on the right side of these images is a housing box of a standard reflectance plate.

Sensor calibration

In advance of the sensor installation to a tower, the sensor was characterized by the laboratory experiment in the optical calibration room of National Institute for Environmental Studies. As for evaluation of linearity, the spatial uniformity of image brightness and gain-offset characterize of each CCD pixels were carried using the 20 inch integrating sphere (Labsphere, USA). In evaluation of linearity, the sensor was set to the aperture of an integrating sphere, and the data was acquired changing the light volume of a lamp. Simultaneously, radiance was measured using field spec by an ADS company as a standard, and comparison with the digital count value of a sensor and radiance measured by field spec was carried. When a digital count value was less than 100, linearity was falling, but in the range used for 100 or more count regions, that is, the usual operation, it is confirmed having high linearity (not shown). Since a CCD camera has a sensitivity difference for every element, it needs to calculate a correction coefficient for every element. Furthermore, the heterogeneity of incidence light occurs by the optical window of housing, the object lens, and iris diaphragm. Therefore, data acquisition of an integrating sphere was carried for the sensor in the condition at the time of observation (together with an optical window, an object lens, and an iris diaphragm), and the coefficient, which corrects heterogeneity, was obtained. With this coefficient, the deviation between pixels was able to be reduced to 0.5% or less.

Results and Discussion

Acquisition of the spectrum image of a larch wood was started from September, 2001. Image acquisition is carried 7 times at 2 hours intervals from 6:00 a.m. till 6:00 p.m. Fig. 2 is the image example acquired on September 23, 2003, 12:00. In order to make an image conspicuous, it magnifies by 2 times horizontally and histogram emphasis is given to all pixels. By acquiring the spectrum data of forest continuously, the relation between the spectrum characteristic and the diurnal and seasonal change of LAI or the photosynthesis activities will become clear, and making it develop into the method development to estimation of a large area and scale-up by remote sensing is expected. Fig. 3 is the seasonal variation of the spectrum reflectance obtained from the larch of one individual of the center in a Fig. 2 image. About 100-pixel value extracted from the tree crown portion is averaged by using the observational data of 12:00 acquired at the time of the fine weather of the autumn of 2001, and spectrum reflectance is calculated on the basis of the standard reflectance plate (Labsphere, USA) in the same image. While the reflectance of a near-infrared region is decreasing at the beginning of the month in October from the middle of September, change of the reflectance of a visible region is very slight. Absorption by the chlorophyll of a red region decreases, and reflectance is increasing to the whole visible region on 26, October. The seasonal variation beginning of September to fallen-leaves stage) of NDVI and PRI were obtained as follows;

$$\mathrm{PRI} = (R_{\lambda 531} - R_{\lambda 570}) \; / \; (R_{\lambda 531} + R_{\lambda 570}) \qquad [1]$$

$$\mathrm{NDVI} = (R_{\lambda 770} - R_{\lambda 680}) \; / \; (R_{\lambda 770} + R_{\lambda 680}) \qquad [2]$$

For calculation of both indices, 100 pixel values were averaged from the surface of about 40 individuals, and it used for calculation. The result shown in Fig. 4. Only a few change of NDVI until the fallen leaves of a larch started, while decrease of PRI had started in the middle of September.

It is reported by previous research, PRI has negative correlation to incidence photosysthetically photon flux density (NAKAJI al. 2003), and we investigated the correlation between PRI and incidence photosysthetically photon flux density (PPFD) on September 26, which were fine weather all through the day (Fig.

5). Furthermore, PRI and PPFD at 12:00 of only the fine day were extracted, and the seasonal change was compared Fig. 6).

According to Fig. 6 although negative correlation existed in PRI and PPFD in September, it was proven that it changes to positive correlation in October.

In the research plan, the causality by which the correlation of PPFD and PRI made it change from negative to a positive relation during autumnal leaves to the fallen-leaves stage, is due to be investigated from the relation between change of air temperature and the leaf biochemistry ingredient, the photosynthesis activities of a needle scale, etc.

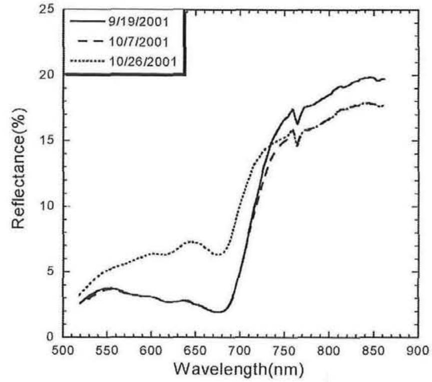

Fig. 3. The seasonal variation of the spectrum reflectance from autumnal leaves to fallen leaves. Each reflectance value obtained from the larch of one individual of the middle in a Fig. 2. 100 pixel values were averaged extracted from the tree crown portion.

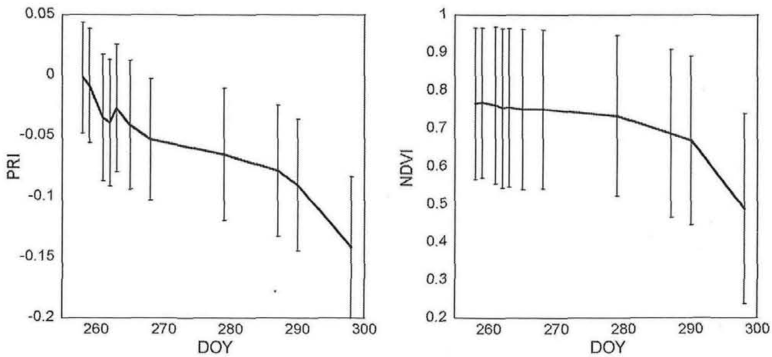

Fig. 4. The seasonal variation (beginning of September to fallen-leaves stage) of NDVI and PRI. Each value is the mean (±S.D.) of 100 pixels extracted from 40 individuals.

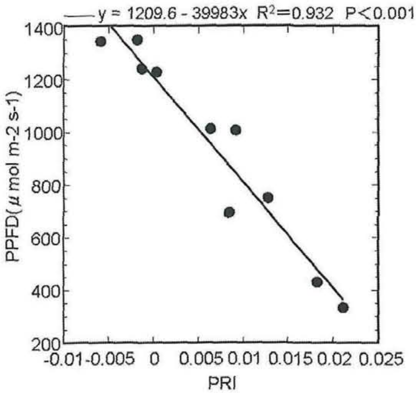

Fig. 5. The relationship between PRI and PPFD in 26, Sep. 2001.The data acquired with one hour interval from 7:00 on the 26th to 16:00 was plotted.

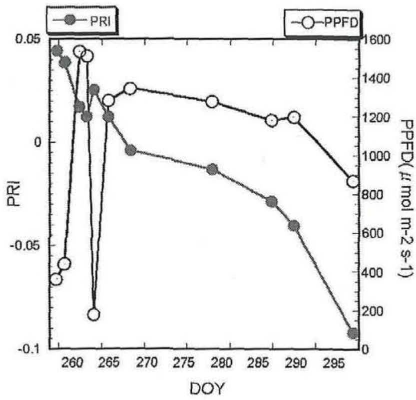

Fig. 6. Daily change of PPFD and PRI of the larch canopy from the middle of September to the end of October 2001.

Acknowledgements

I would like to thank Mr. MORIYA who collaborated to development of this system. We acknowledge the Hokkaido Regional Office of the Forestory Agency for allowing the use of the larch forest.

References

DAWSON T. P, CURRAN P. J. & PLUMMER S. E. 1998. LIBERTY-modeling the effects on leaf biochimical concentration on reflectance spectra. - Remote Sens. Env. 65: 50-60.

GAMON J.A., PEÑUELAS J. & FIELD C.B. 1992. A narrow-waveband spectral index that tracks diurnal changes in photosynthetic efficiency. - Remote Sens. Environ. 41: 35-44.

— , SERRANO L. & SURFUS J.S. 1997. The photochemical reflectance index: an optical indicator of photosynsthetic radiation use efficiency across species, functional types, and nutrient levels. - Oecologia 112: 492-501.

NAKAJI T., TAKEDA T., MUKAI Y., KOIKE T., OGUMA H. & FUJINUMA Y. 2003. Relationships between photosynthetic pigment concentration and photosynthetic activity to reflectance-based indices in Japanese larch needles. - J. Jpn. For. Soc. 85: 205-213

PEÑUELAS J. PINOL J., OGAYA R. & FILELLA I. 1997. Estimation of plant water concentration by the reflectance water index WI (R900/R970). - International Journal of Remote Sensing 18 (13): 2869-2875.

TIMO H., ESKO H. & ALBERT D. 1988. Direct sight imaging spectrograph: a unique add-on component brings Spectral imaging to industrial applications. - Presented at 1998 IS&T/SPIE's symposium on Electronic Imaging.