

## Performance Characteristics of Laser-induced Fluorescence Imaging Lidar for Vegetation Monitoring

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### 1 Introduction

Recent rapid increases of artificial pollutants and natural hazards possibly simulate functional disease in plants. To understand their living status and to make prompt and quick treatment, a monitoring method capable of detecting their abnormality at as early a stage as possible is required. Green leaves emit a fluorescence in response to laser irradiation and the fluorescence may surely contain some biochemical and physiological information about the plant's insides. It is anticipated that fluorescence monitoring technique using a lidar system may offer remote and nondestructive monitoring of the plants health. In this paper, we demonstrate the performance characteristics of our developed vegetation laser-induced fluorescence (LIF) imaging lidar and discuss its feasibility.

### 2 Method and System

Figure 1 shows the schematic of the LIF imaging lidar system developed at our university. We used a CCD camera as a detector to get an image for covering a certain area such as a whole tree, forests and a part of mountains. As it seemed that the fluorescence from long distance was very weak, the CCD camera was operated together with an image intensifier. The image intensifier has a multi-channel plate (MCP) in the inside for the purpose of amplification of the fluorescence signal. Although usage of the amplification is very efficient to detect the weak fluorescence, the image intensifier with the MCP is not usually operated under daytime sunlight conditions. To overcome this problem, gate mode operation was tested in a way that the MCP gate opened after a certain delay time synchronized to the laser pulse. Usage of a camera lens with a small diameter made the system easy to handle and more practical. Two band-pass filters were inserted alternately in front of the lens. The centerwavelength of each filter was 685 nm and 740 nm that were the peaks of LIF spectra of green leaves. Laser beam of a

Q-switched pulsed Nd:YAG laser was magnified in angle to 150 mrad by a negative lens to be able to irradiate and cover the target tree. The tree was a ginkgo tree growing outside in natural conditions. It was located at a range of about 60 m from the system.

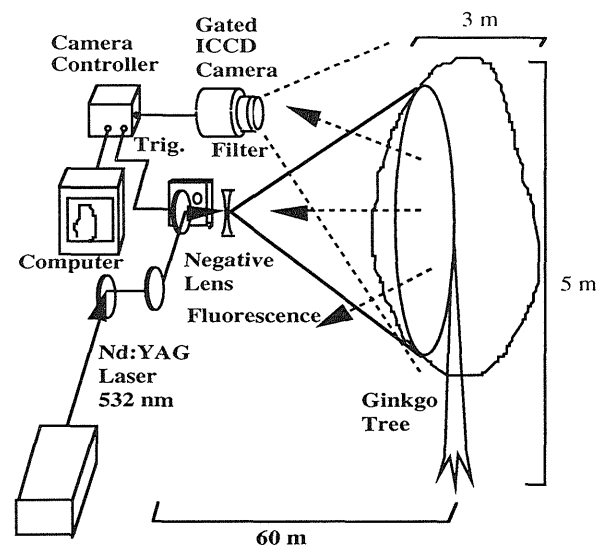


Fig. 1 LIF imaging lidar system and experimental configuration

Table 1 Specification of the system.

Transmitter	
Nd:YAG laser : Wavelength 532 nm, Energy 10 mJ, Pulse Duration 10 ns, Repetition Rate 10 Hz	
Receiver	
Lens: Diameter 42 mm, F 1.2, Focal Length 200 mm	
CCD Camera: 510 pixels (H) x 492 pixel (V)	
Image Intensifier: Gate Time 100-500 ns variable	
Filter: Center Wavelength 685 nm, 740 nm, Spectral Width 20 nm, Transmittance 80%	
Signal Processing	
Personal computer	

### 3 Results and Discussion

LIF images obtained at night and in the daytime are shown in Fig. 2. Subtraction of background image (without laser irradiation) from the fluorescence image were made, but not for nighttime results. The operation conditions of the CCD camera was a delay time of 380 ns, gate time width of 100 ns, and integration time of 180 s. The delay time and the gate time width corresponded to a lidar detection range of 57 m and a range width of 15 m, respectively. This range extent covered the location of the ginkgo tree. The combination of a nanosecond laser and gated operation of a CCD camera with a short time duration made it possible to detect the LIF signal as an image not only at night but also during the daytime.

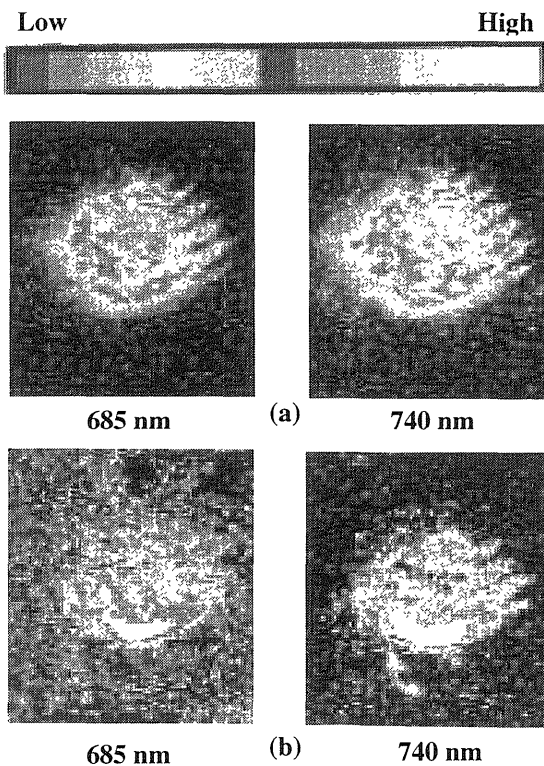


Fig.2 Examples of LIF image obtained in (a) night and (b) daytime (14:00) on July 21, 1997.

To estimate chlorophyll concentration in leaves, we introduced Lichtenthaler's idea<sup>1)</sup> to the nighttime image data. The idea is that the ratio of peak intensities at 685 nm and 740 nm (LIF spectra ratio;  $F_{685}/F_{740}$ ) is strongly correlated to the chlorophyll concentration and may be taken as an indicator of the plants' stress. In our case the inverse value ( $F_{740}/F_{685}$ ) was used. The ratio of the intensity of the 740-nm LIF image to the 685-nm LIF image

(LIF image ratio) was calculated for every pixel and the average value of the LIF image ratio is shown in Fig. 3. For comparison, in Fig. 3 the LIF spectra ratio measured by using the sampled ginkgo leaves with a spectrometer in laboratory experiments and chlorophyll concentration measured with a High Performance Liquid Chromatography (HPLC) are also shown in the figure.<sup>2)</sup> As evident in the figure, the monthly variation of the LIF spectra ratio coincided with that of the chlorophyll concentration, and the LIF image ratio also followed the variations of these values.

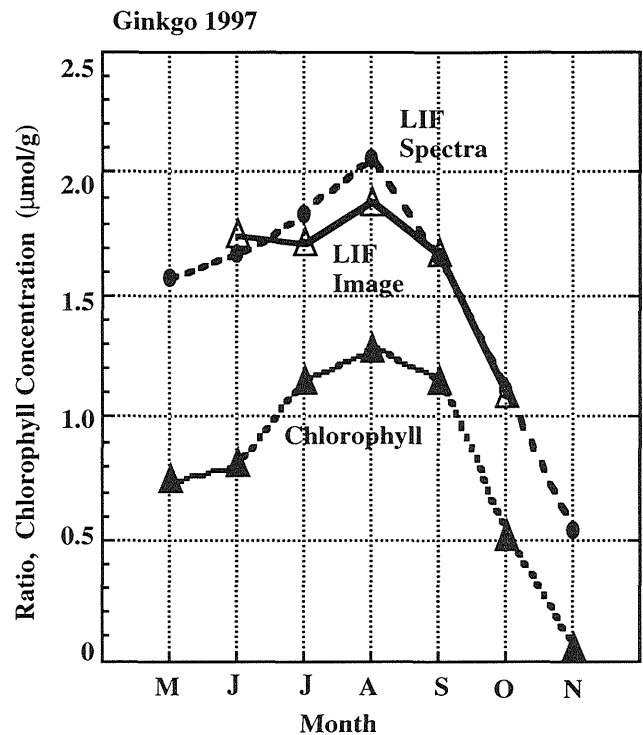


Fig.3 Comparison of ginkgo tree LIF image ratio, LIF spectra ratio and chlorophyll concentration for the different months observed.

### 4 Conclusion

Through the outdoor and laboratory experiments, it was confirmed that the developed laser-induced fluorescence imaging lidar has the potential for macro scale monitoring of trees and leaf foliage remotely and nondestructively.

### References

- 1) H.K.Lichtenthaler et al., IGARSS Vol. 3, pp. 1913-1918 (1987).
- 2) Y.Saito. et al., Optical Review 6, pp. 155-159 (1999).