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Marine Pollution Detection Using a Compact Imaging Lidar

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1. Introduction

Oil and bulk liquid chemicals are regularly transported at sea there remains a risk of serious spill. Besides ship accidents, the sea can also be polluted by dumping from ships. The possibility of a fluorescence lidar for remote-sensing the marine pollution has been studied over the last decades.(Fantajia 1971) Its capability to positively identify oils during day and night operation is promising.(Measures 1977, Sato 1978) Laboratory studies have shown that oils emit fluorescence enough to be detected by a laser fluorescence sensor and that their spectra allow classification of oils. Their time decay characteristics also give more precise information of oils.(Camagni 1991) However, most of systems were installed on a large airplane, (O'Neil 1980, Brown 1995) they were rarely used as an operational tool for the clean up operation.

The research has started to develop a compact size fluorescence lidar that could be mounted on a small airplane or a ship and is capable of operation in full daylight and could give real time images.(Yamagishi 1998)

In this paper, we describe a prototype of compact size fluorescence lidar whose feasibility test was carried out at sea, the time-resolved measurements of fluorescence characteristics of chemical substances in the laboratory and in-situ measurement of the extinction coefficient of water was demonstrated.

2. Fluorescence Lidar

Induced fluorescence is observed by a receiver that consists of CCD camera with gated image intensifier. The specifications of components are shown in Table 1. The gain of the receiver can be varied by the high voltage of the intensifier from 0 to 1000 in digital steps. The range gated system is capable of measuring the distance to the target and detecting the relatively weak signals by receiving a small number of background photons. Effective range of the system is estimated to be 350m in full daylight, from the ratio of the signal to the solar radiation. The CCD camera observe a wide view of a scean including a spot of fluorescence excited by the laser so we can easily obtain a relative position of fluorescent target. For each laser shot, a digitized image is obtained and passed to the data acquisition system, which also notes the time and ancillary data. The data acquisition system also contains an interface to GPS positioning system. All this information is displayed on a monitor in a appropriate format tracing a cruse route.

3. Pollutant Characterization

Time-resolved data of LIF/Raman spectra excited by third harmonics of generator of the YAG laser are measured by a streak scope system in the laboratory. The spectral range was covered from 350 to 575 nm with a resolution of 50ps in the temporal range of 0 to 500 ns. An example is shown in Fig.1, where the measured data are plotted in the two dimensional map of time and wavelength. Emission of fluorescence of each substance shows own structural profile; the light oil has a broad peak around 350-400nm, the A-heavy fuel oil 400-450nm, the C-heavy fuel oil 450-500nm, Benzene 400-500nm. Ethanol and Ethylene Glycol has a sharp peak at 400nm. The fluorescence of oils is due to a mixture of poly-aromatic hydrocarbons, each has different lifetime. A measured decay time profile is a convolution of F(t) with the instrument function and the excitation laser time profile, where F (t) is the fluorescence decay function assumed to be composed of two exponential terms. In this case, the full width at half maximum (FWHM) of the excitation laser was about 7ns, the lifetime shorter than that was greatly influenced by the laser time profile. So the other longer term was considered as a typical value of the sample. The measured lifetime varies according to wavelength; the lifetime of the light oil is about 10nsec between 330nm and 400nm and is 25nsec between 450 and 560nm. The profile of A-heavy fuel oil seems to consist of more than two parts, and a lifetime of C-heavy fuel oil is about 17 ns shorter than that of others.

4. Measurement of Extinction Coefficients

The oil layer on the water surface absorbs the laser light, preventing photons from penetrating through the oil to be Raman-scattered by the underlying water. The presence of the oil is indicated by a suppression of the water Raman scattering of the laser light.

According to Hoge's discussion (Hoge 1980) the oil thickness may be written by Equation (1),

Eq. 1 $$d = -\frac{1}{ke + kr} \ln(R'/R) \qquad (1)$$

where, d is the thickness of the oil film, ke , kr are the extinction coefficients of the oil film at laser wavelength, and at the water Raman wavelength, respectively. R' is the water Raman component through the oil film, R is the water Raman component without the oil film. R' should be a net emission of the water Raman scattering from which the fluorescence contribution of oil film and background are subtracted. The single scattering extinction coefficient for a collimated beam is expressed by the sum of the absorption coefficient and the scattering coefficient. But the effective water attenuation may vary with depth, because of changes in angular distribution of laser light as it is multiply scattered and deflected from collimated light at the surface to relatively diffuse light several attenuation lengths underwater.(Browell 1977) And also the scattering coefficient of the medium is greatly affected by the ambient conditions, therefore in-situ measurements are necessary.

An light trajectory in the CCD passive image is convenient to measure the extinction coefficient of the medium where the light passes. Figure 2 shows the surface image with the optical band pass filter of 405 ± 5 nm, passing the Stokes Raman scattering of the water(406.9nm), where the water Raman signal to the bottom and at the surface the fluorescence signal induced by the reflected laser beam can be identified. The temporal gate width was set at 13ns. Figure 3 shows the profile of the Raman signal along the laser beam, with a known oil thickness. The signal at 350 in position includes the fluorescence of the oil film..

5. Sea trial

A sea trial of the system was carried out over the Seto-naikai inland sea in order to verify the performance of the fluorescence lidar in full daytime. (Fig. 4) The fluorescence pulse measured at the onboard detector could be distorted by a complex wave motion. The importance of wave motion is dependent on the fluorescence lifetime of the oil. Considering that the speed of light(30cm/ns) and path difference to the surface and back , our measurements show that decay time of oils are almost less than 30 ns, therefore longer wavelengths are considered important. And the amount of light absorbed on the surface will depend on the angle of incidence. However, at normal condition, it has been shown that the sea state will have a negligible effect on fluorosensor operation. (Rayner 1978) To reduce the background noise the gate operation and narrow band filters were effectively used. An example of the response is shown in Fig.5. This shows that a signal was obtained even in a foamy zone near a side of a ship.

6. Summary

A compact imaging lidar system providing real-time images was designed and its prototype model was tested by on board sea trial.

In order to interpret the data obtained in the field, the time-resolved fluorescence characteristics of chemical substances were measured with a streak scope in the laboratory between the wavelength of 350 to 575 nm and with decay time 0 to 500 ns. The time-resolved fluorescence characteristics of the oil show that the fluorescing organics in oil may be resolved into components according to fluorescence lifetimes.

In-situ measurements of the extinction coefficients were demonstrated using image data of the trajectory of the water Raman scattering,.

A sea trial of the system was carried out over the Seto-naikai inland sea to verify the performance of the fluorescence lidar in full daytime. Background suppression by gate operation and narrow band filters were effectively used to suppress background noise.

7. Acknowledgement

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8. References

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Table 1 Specification of component

Laser	Type	Nd -YAG THG(355nm)
	Pulse energy	11mJ/pulse(4-6nsec)
	Repetition	15Hz
	Weight	19.0kg
CCD	Sensible area	6.52x4.89mm
	Pixel	659x489
	Sensitivity	3.0 lx(F1.4, γ =0.45, with IR cut filter)
Image Intensifier		
	Gate	3ns-DC
	Sensitivity	150μA/lm
	Quantum efficiency	13%(400nm)
	Gain	$7x10^3$

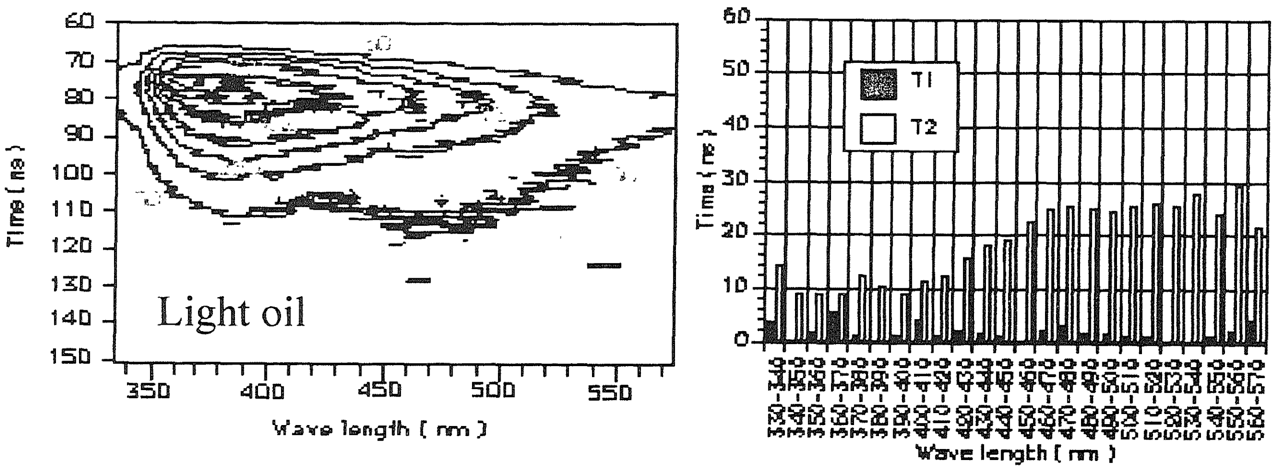

Fig. 1 Time -resolved fluorescence spectrum of the light oil(left) and decay times deduced from left data are shown for wavelength(right). The short term T1 is influenced by temporal profile of the excited laser, T2 is considered a typical value.

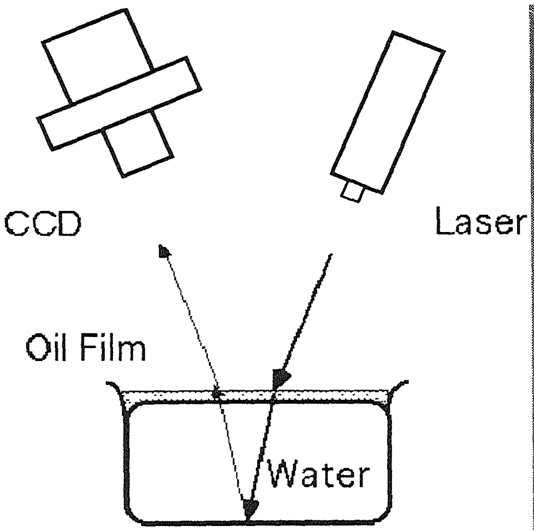

Fig.2(a) Experiment of extinction.

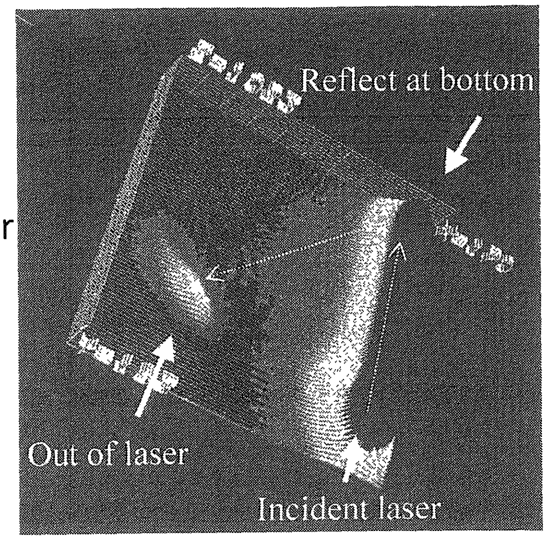

Fig2(b) Obtained image of the light trajectory

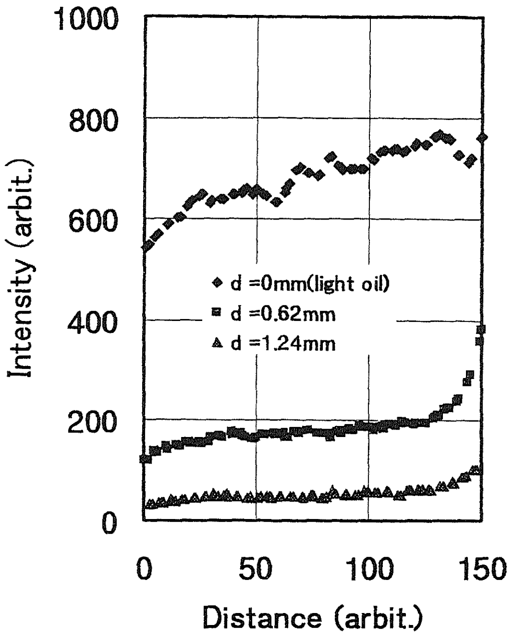

Fig.3 Suppression of Raman scattering of water by oil film.

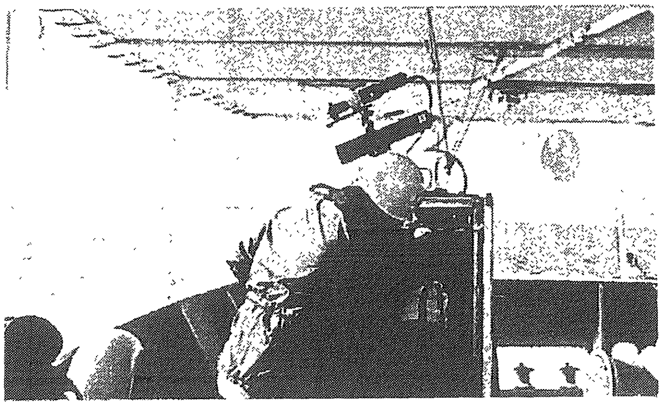

Fig. 4 Onboard sea trial

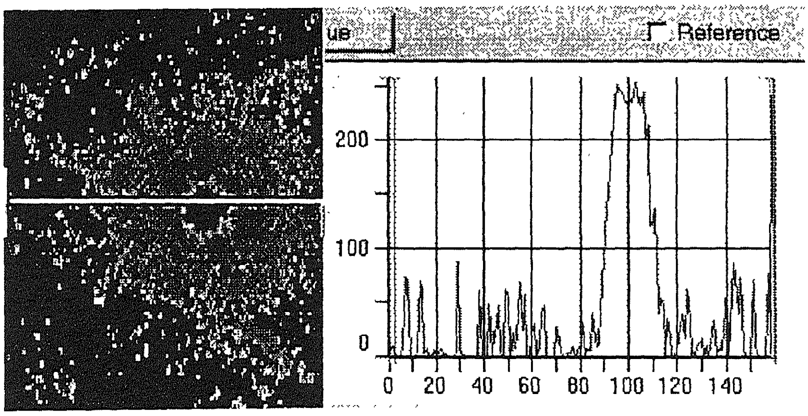

Fig. 5 Image measured in full daytime with temporal gate width of 190ns and signal intensity profile .